MOON BASE
XORS
DESIGNED BY INNSPACE TEAM

1 Idea

This is not the first mission to the Moon, but it is definitely unique. This time we're going to stay. Innspace Group is proud to present the **Xors Moon Base Project**. Our concept is based on the assumption of the cooperation of many States to create an independent Institute on the moon and ensure peaceful exploration. In principle, the base is a temporary place where astronauts stay for a specified period of time - 3, 6 or 9 months and focused on conducting research in specific areas. It consists of **4 modules**, each of which has one laboratory and space **for 4 astronauts**. The modules are connected, but for security reasons they are **self-sufficient and independent** of the others.

The project was prepared by the Innspace team. It is a group of space enthusiasts from over a dozen cities in Poland, from architects, through constructors, programmers, biologists, to lawyers and doctors who carry out space-related projects. The Xors Moon Base Project was designed by Justyna Pelc, Piotr Torchała, Magdalena Łabowska, Beata Suścicka, Łukasz Sokołowski, Małgorzata Popiel, Hubert Gross, Arkadiusz Kołodziej, Ewa Borowska, Aleksandra Wilczyńska, Michał Garus, Cyrus Sidor, and Marcin Zieliński.

2 Location

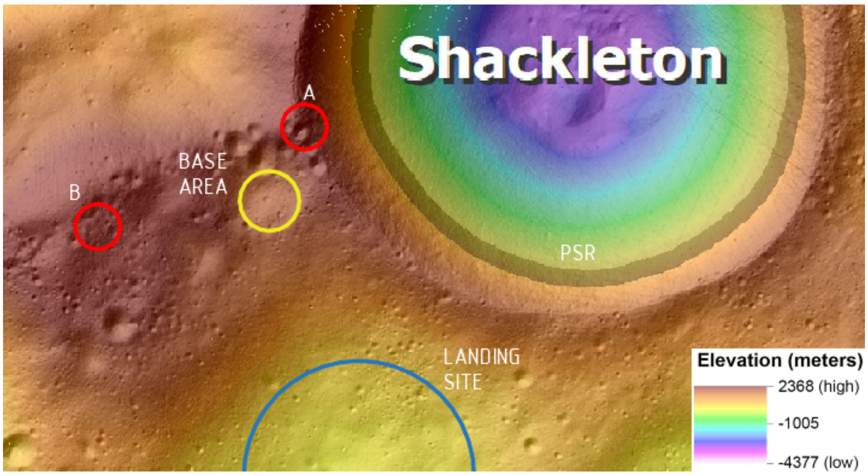


Figure 1: Selected areas with the greatest illumination (points A and B), base area, landing site and PSR (Permanent Shaded Region) near Shackleton Crater [1]

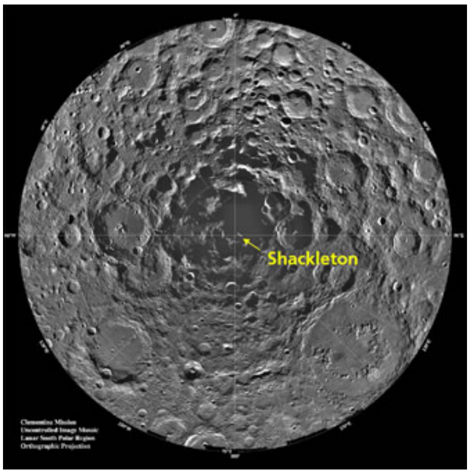


Figure 2: South pole of Moon [2]

The base area is **South Pole, near to Shackleton crater** (fig. 2). It was chosen because of the proximity of two extremes: the areas **illuminated most of the time** (points A and B) and **Permanent Shaded Regions (PSR)** (fig. 1), which have never been exposed to sunlight. The time of the base's exposure plays a key role in the acquisition of solar energy and allows to reduce the number of additional accumulators, which the base must have for the time of lunar night. These are the points (A and B on fig. 1) illuminated together for 8 continuous months and for more than 94% of the time. During 2020 point A had an annual mean illumination of 81% and point B for 82% [3]. These areas are also characterized by direct-to-Earth communication availability of 51% [4].

PSR allows to study the geological past of the Moon and its components not illuminated by the Sun and provide future residents with water, which is trapped there in the form of **water ice on the surface and below** [5]. It is estimated that there is at least 600 million metric tons of water ice at the poles of the moon [6]. **The base is located on a gentle hill**, separated by a slope from the area that can be hit by lunar dust during the landing of rockets and landers.

2.1 Roadmap

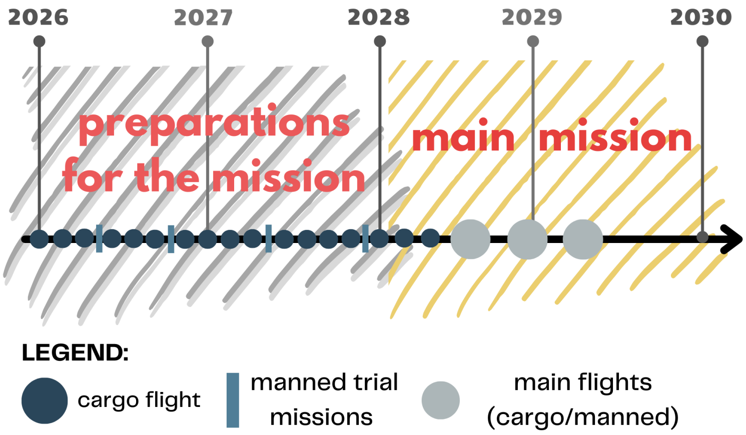


Figure 3: Roadmap of building of Xors Moon base

We spread our mission in the years **2026-2030**. We divided it into two main stages: preparatory mission 2026-2028 and main mission 2028-2030. The individual flights are marked on the timeline and they take place at different intervals (fig. 3). We assume that the last flight will take place in early 2029. In this way, we leave spare time for a possible delay. The preparatory mission consists of **17 cargo flights** carrying prototypes and materials needed for the success of the entire mission (they take place approximately every 1.5 - 2 months) and **short crewed flights**, lasting from 1 to 2 weeks (they take place independently of cargo flights, at intervals of 5 months) (tab. 1). They are designed to get acquainted with the conditions on the Moon. During these missions, the prototype of our base module will also be tested. The main mission begins in 2028 and consists of **three crewed and transport flights**. These flights take: connector module, H_2O tank field, Bigelow Aerospace basic modules, connector modules and crew.

To think about the creation of a lunar base in the next decade, we must think about delivering hundreds of tons of equipment to its surface needed to build the base, maintain it, and meet the basic needs of astronauts. After considering all options, we chose **SpaceX vehicle - Starship**. The cargo version is able to deliver **over 100** *tons*, has 1100 m^3 of hold capacity, 9 m in diameter and 18 m in height (fig. 4). Thanks to the possibility of refueling in orbit, it is possible to use the maximum payload. Currently, Starship is in the developing phase and the first flight to the Moon is scheduled for 2022. It is a reusable rocket, so the costs of the entire mission will be significantly reduced. We considered other options, such as SLS (tab. 2) or the Artemis Human Landing System, but they are not sufficient to build a base within 10 years.

Table 1: The order of sending the most important the cargo from Earth to the Moon

Rocket no.	1-12	13	14	15
Payload	1188t Water 44t MgO	Equipment for regolith extraction Equipment for 3D printing	1 Bigelow Aerospace basic module 4 Interface Heat Exchanger 24 Radiator Beam Valve Module 4 Pump Module 4 Ammonia Tank Assembly 4 Nitrogen Tank Assembly 4 Thermal Radiator Rotary Joint 6 Kilopower	1 Bigelow Aerospace basic module 12 Radiator 24 Battery package 2 Kilopower
16	17	18	19	20
1 Bigelow Aerospace basic module 16 Kilopower	1 Bigelow Aerospace basic module 1 Connector module 2 N_2 tank 3 O_2 tank 160m^2 Solar panels	2 Connector module 2 H_2O tank 2 RP15 with Honeybee PVEx Drill	1 Bigelow Aerospace basic module 1 Connector module 1 Airbus ROXY system	1 Bigelow Aerospace basic module 1 Connector module (stowed position) 1 Airbus ROXY system

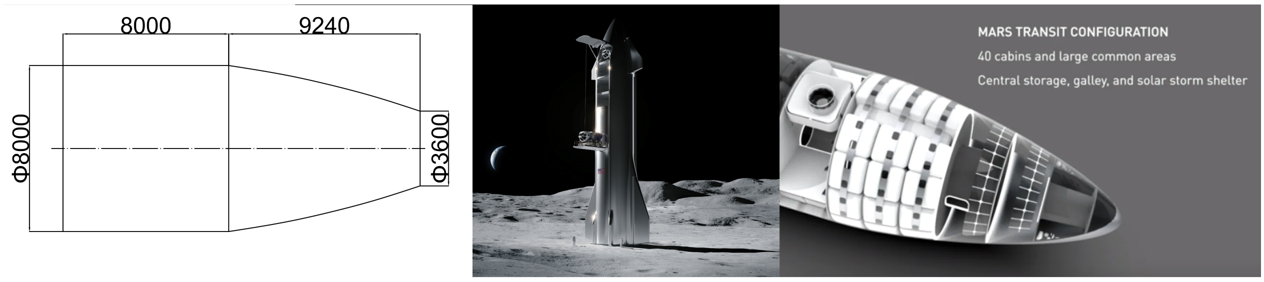


Figure 4: Starship - cargo bay; lunar version of Starship; Crew module [7]

Table 2: Rocket comparison

	Vulcan Centaur [8] [9]	Falcon Heavy [10] [11]	Starship [12] [13]	Atlas V 541 [14] [15]	SLS [16]	Long March 8 [17]
Diameter	5.4 m	3.7m core stage	9 m	5.4 m	8.4 m core stage	3.35 m
Weight	NA	1 420 t	5 000 t	590 t	2 600 t	356 t
No. of stages	2	2	2	2	2	2
No. of bosters	6	0	0	4	2	2
Fuel	different	liquid oxygen and kerosene (RP-1)	Subcooled methane and liquid oxygen CH4/ LOX	Liquid Oxygen/ Liquid Kerosene	liquid oxygen and liquid hydrogen LH2/LOX	liquid oxygen and kerosene (RP-1)
Maximum thrust	∼8 000kN	24 681 kN	72 000 kN	10 600 kN	39 140 kN Block 1/ 52 930 kN Block 2	NA
TLI payload	12 100 kg	∼20 000 kg	100 000+ kg	NA (LEO 17 410 kg)	40 000 kg (Cargo)	NA (LEO 8400 kg)
First flight	Q4 2021	2018	First orbital flight targeted for 2021	2002	Second half of 2021	2020
Coment	To low payload	To low payload	First choose	To low payload	Second choose	To low payload

3 Architecture and design

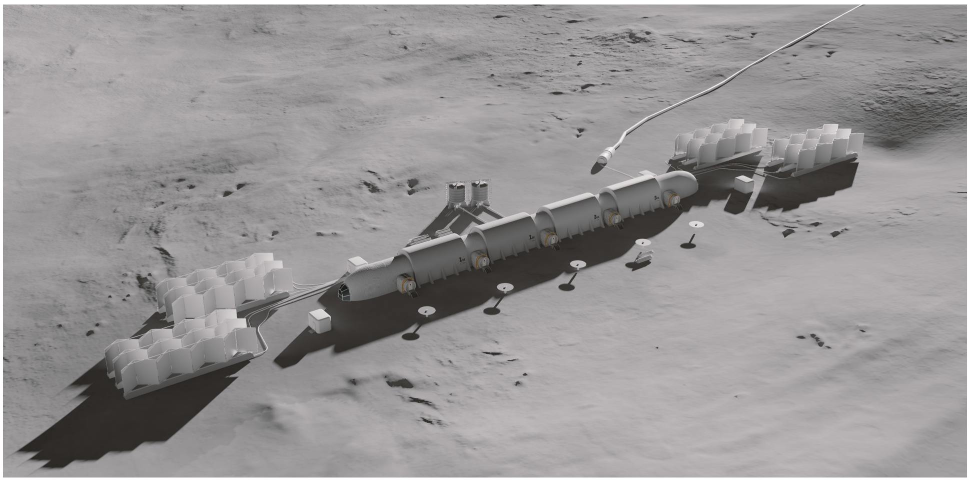


Figure 5: Top view of the Xors base

In the process of selecting the technology, we analyzed the available technologies in terms of their current TRL state, the difficulty of using them on the Moon, the possibility of transporting materials for the construction of the base to the Moon, costs and time of building the base. When designing the habitat, we adopted a human-centered approach to **prioritize the safety and well-being of crew** above the lunar surface. As the main module, we used **Bigelow Aerospace**, which has been encased with regolith to protect against radiation. Our base presents feasible design innovations in 3D printing used in missions to the Moon. Moon base Xors uses an evidence-based design process to outline the design and the possibility of building a future habitat for a crew of four who will live and work on the Moon for three months on Earth. The base was designed from 4 main residential and scientific modules with **internal dimensions of 8 m x 16 m** and 2 smaller ones, which include a garage and a greenhouse with dimensions of 4 m x 8 m (fig. 5). Each residential module is designed for 4 people and is completely **self-sufficient**. In total, the habitat will be inhabited by **16 people**. In addition, another module serving as a hotel was located in the area.

3.1 Base construction and radiation shielding

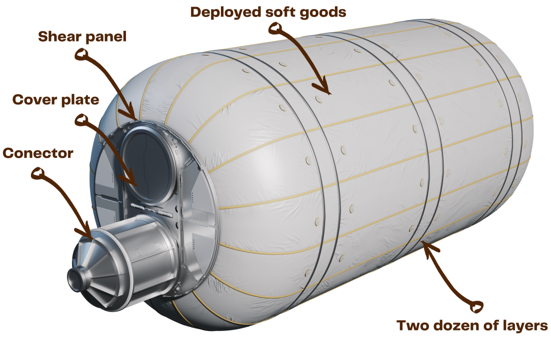


Figure 6: Bigelow module

Xors is intended to be a pioneering environment that uses preexisting lunar infrastructure components critical to mission success, but also introduces a ready-made module brought from Earth to diversify the design measures and scalability methods of the habitat design. The base structure is based on **inflatable modules**. We decided to use Bigelow Aerospace's modules (fig. 6) because their solutions **have been tested in space**, as well as they are able to produce the module we need in the assumed time. These modules consist of two compartments, an **aluminum structure and two dozen layers** with spacing between. The layers consist of, among others, flexible Kevlar, soft sponge, etc. Thanks to this, protection against radiation and micrometeor impacts was achieved. According to our assumptions, the ideal module should be 17 m in length and 9 m in diameter. The thickness of all layers is about 0.5 m. Such a module (not inflated) could be made up to 10 m in length and 6 m in, which would allow them to be placed in the Starship cargo bay. After they are delivered to the site, they are filled to reach the final size to provide **900 m^3 of living space**. Modules are transported by rovers on special platforms. Mobile platforms are designed to transport modules between the rocket landing site and the target base location. On site, they are placed in designated places, and then unfolded and inflated. Then we **print a 1 meter thick regolith** on the modules (fig. 7). Mobile 3D printers minimize the risks and costs associated with the development of too high a gate system for 3D printing technology. We chose this method of creating the base, maximizing the solution in terms of economy, but also the safety and comfort of residents.

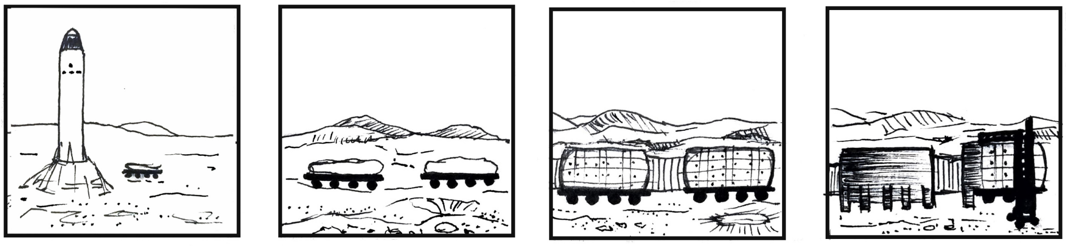

REMOVING THE MODULES
TRANSPORT TO THE SPOT
UNFOLDING AND BLOWING
PRINTING FROM REGOLITH

Figure 7: Building a base

3.1.1 3D Printing

Table 3: Mass of printing component

	Module	Connector	Totals
Volume, m^3	210	50	1090
Mass, t	349	83	1810
Mass of regolith, t	105	25	543
Mass of additional MgO, t	5	1	28
Volume of additional MgO, m^3	8.5	2.0	44
Mass of water, t	229	54	1188

D-shape technology [18] seems to be currently the most advanced and time-efficient large-scale 3D printing technology that can be implemented in lunar environment. It requires a large amount of ink for bonding regolith, but, on the other hand, uses less energy and is much faster. It uses a binder jetting technology to print complex-shape structures with special type of concrete. The principle of printing is to **apply a liquid binder on the powder material of cement-sand mix** (fig. 8). Research [19] shows it is possible to use lunar regolith stimulant for that kind of printing. According to data [19] we estimated amount of materials to be transported from Earth in tab. 3, assuming using lunar regolith. 13 flights are required due to the large amount of water transported. We assume that by 2027 it will not be possible to create a technology capable of extracting enough water to create a mixture, but if we manage to do it, only one flight with MgO is needed. The estimated time to print one module for one printer is about half a year. This time can be accelerated by using more printers.

Printing a layer of regolith on the module provides **additional protection against minimetors**. Our project was designed to use the structure of the Bigelow Aerospace module and the thickness of the regolith wall structure for radiation protection. In addition, the module applies thicker shields to the parts of the habitat where the crew is estimated to spend the most time according to their daily schedule. It also allows you to reduce the stress created in the module after inflation.

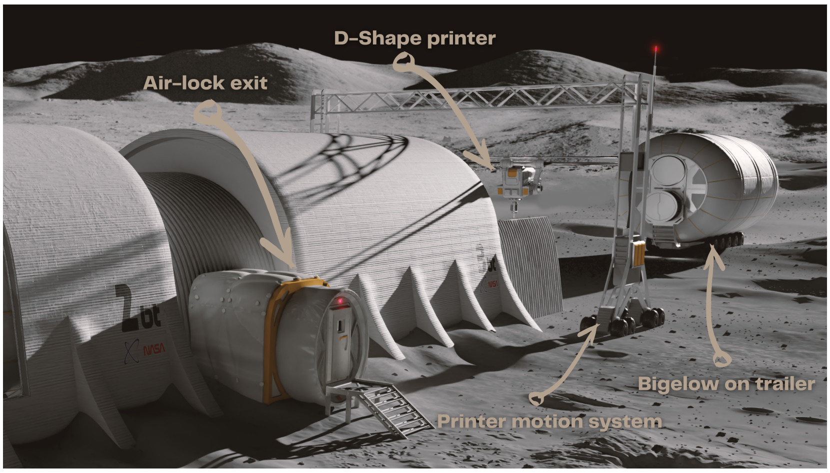
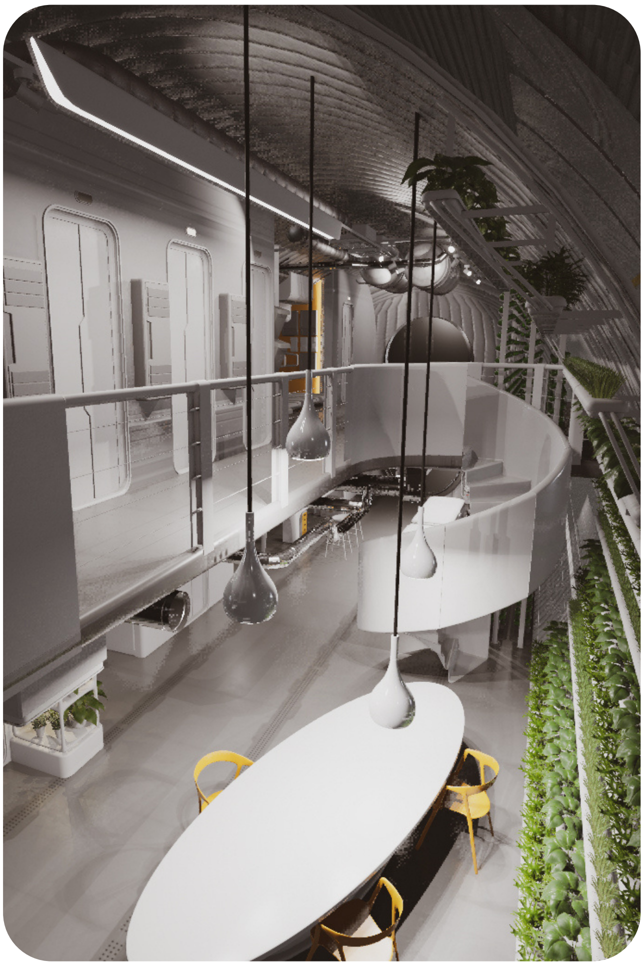
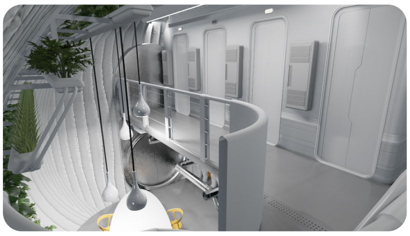


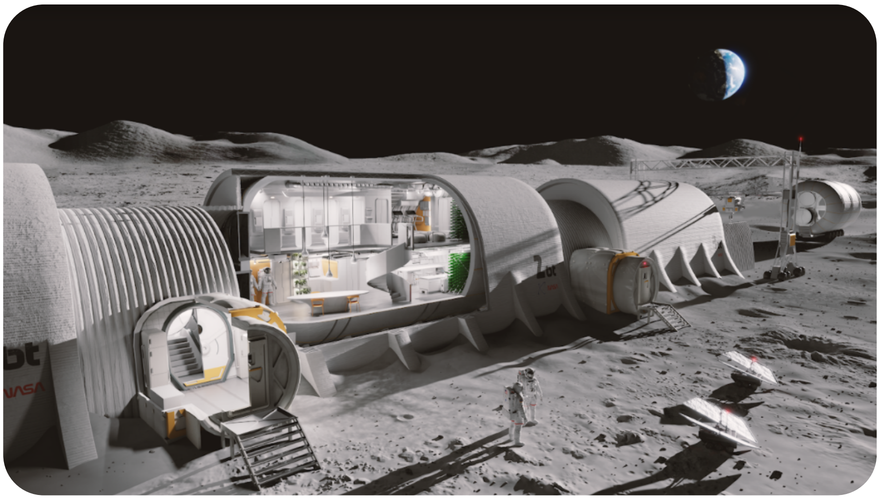
Figure 8: Xors base and 3D printing process

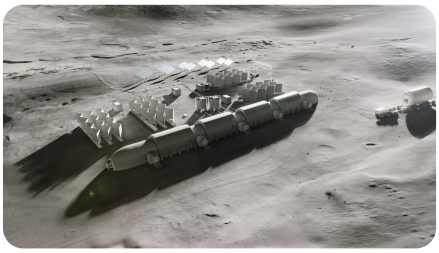
3.2 Organization and evacuation

Access to each module is through the locks on both sides. They enable the module to be **cut off in any emergency case** and the others to be secured. Independent service zones ensure safety in the laboratory areas on the ground floor and the living area on the second floor. Emergency exit from the floor is provided by stairs and a "pipe" that is drained as an addition. It allows a **quick evacuation** from the floor. The types of emergencies that could be encountered by the crew could include fire, a chemical leak, or a microbe that becomes a pathogen in oxygen. The exit paths of travel and the ceiling of high-risk zones are again the main factors influencing habitat design. More about emergency situation and protection is in section 4.6.









3.3 Functions

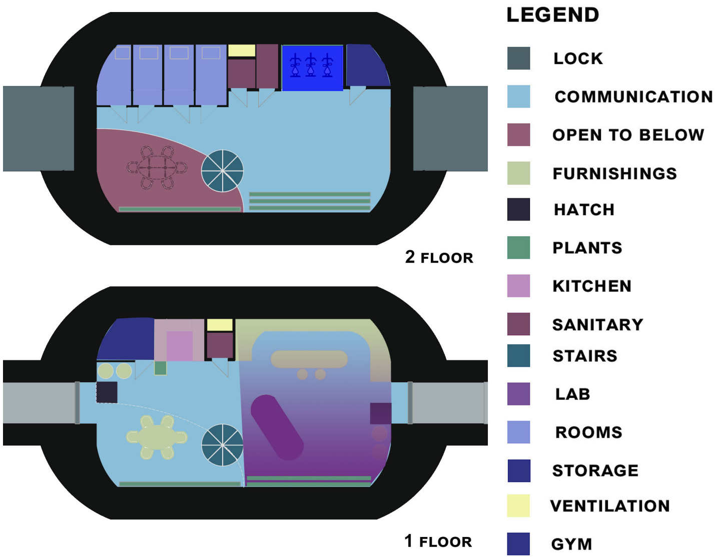


Figure 9: Functional analysis

The **modules are repeatable**, only the laboratory part distinguishes them. The module has two floors, the lower floor is public / semi-private, it can be used by residents of other modules and the upper one is completely private (fig. 9). On the ground floor there is a communication and operation zone which, through the lock, also provides increased access to the **rover's port**. There are suits in front of the lock entrance. We separate here a laboratory zone, a kitchen with storage and a sanitary zone. In the kitchen part, daily meals are prepared for the residents of the module, it has direct access to the food warehouse. The remaining area has a **communication function**. There is a large, multi-functional table, which has been designed to meet the needs of residents to ensure maximum ergonomics of use for dining, work and entertainment. A storage compartment for processing critical items, including food, is located under the floor and is accessible through hatches. We separated the clean lab from other areas and provided there separate and independent ventilation systems. The upper module is private. There are **four rooms**, separate for each resident. They are equipped with a bed, a small desk and a wardrobe. In addition, we separate a sanitary section (shower and toilet) and a gym (each module is equipped with different equipment). The remaining area has been separated into the hall, which serves a communication function and is a place to spend free time, e.g. watching movies or practicing various types of exercises, e.g. yoga or meditation (fig. 10).

3.4 Innovation in design and aesthetics

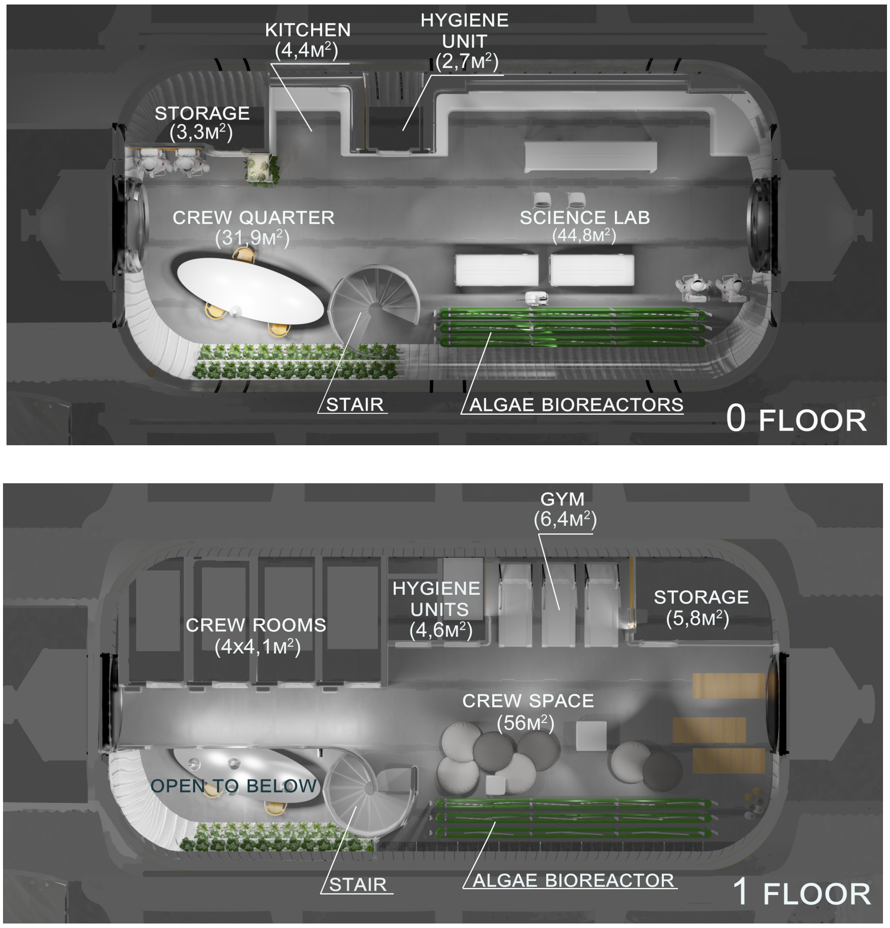


Figure 10: Ground floor and first floor plan

We started the process of designing the habitat with various analyzes. It was crucial for us to study the experiences of users of the International Space Station. The goal of the entire process was to maximize the satisfaction of the base users by improving functionality and usability. We also focused on the attractive appearance of the base from the outside. Interiors are accessible and ergonomic. The entire habitat is designed in line with sustainable development. We have used **ecological solutions** such as a closed water cycle or the use of materials available on the planet's surface. We used lunar regolith printed in the innovative 3D printing technology tailored to our needs.

The interior of the base is extremely important from the psychological point of view, as it directly affects the mood of the habitat's inhabitants. When designing the space, we tried to open it as much as possible to make the module seem large and provide walking surfaces, supporting natural movement. The colours used are neutral and result from the materials used. The main purpose of this decision was to create a space that would be as favourable as possible to work.

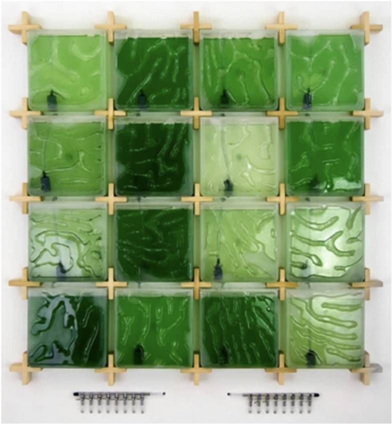


Figure 11: Innovative algae panels [20]

We focused on **growing plants in each module**. This solution creates a naturally dominant, calms and provides oxygen. Further, we are proposing peculiar additional system for air support in every module. Special wall algae system in Corning® culture flasks is shown in fig. 11. Every panel will be a combination of different type of algae for best adjustment to modules' condition and enabling **air purification** in every room. Living in an artificial environment without access to natural solar light has a strong influence on humans. That's why we use lamps designed by QLab company, which **mimics the intensity of sunlight** at different times of the day to regulate astronaut's circadian rhythm. They emit not only visible light, but also the right amount of infrared light as well as UV-A and UV-B light to accurately imitate natural light [21]. Thanks to this solution, the residents have a better mood and they get tired less. At night, they are accompanied by a discrete LED light along the floor, which follows our steps, so we can safely move around the module. We also took care to diversify the space by designing separate building with greenhouses, in which, apart from a varied space, we also have a different temperature and a hotel. Situated on the edge of the crater, the hotel serves as a base for research missions and allows you to change the environment.

3.5 Laboratories

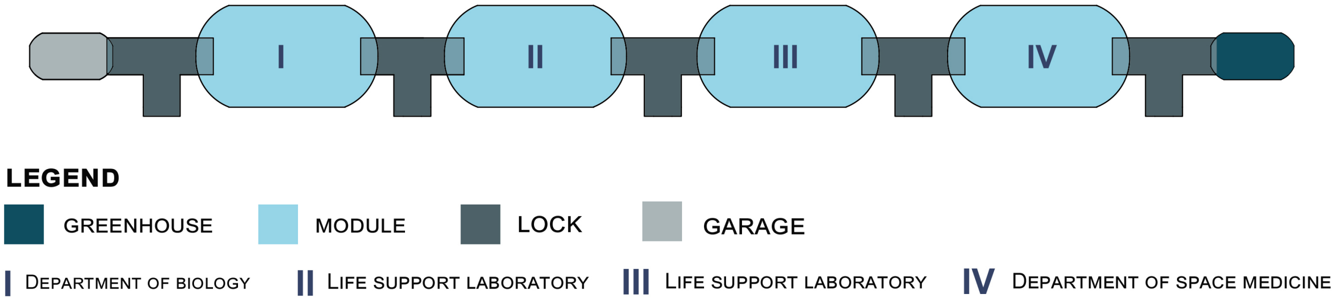


Figure 12: Laboratories

The main purpose of our Moon base is **science development** as our first habitat needs to be focused on adjusting all technologies to lunar environment. As mentioned, the whole laboratory part is divided into few departments, each in different module (fig. 12).

3.6 Department of space medicine

This department combines features of **healthcare facility and space medicine research center**. It will be focused on investigating and mitigating practical problems of space missions that impact astronauts' health. The main objectives of this unit would be:

- understanding space-induced changes in human physiological systems including muscle atrophy, bone demineralization, cardiovascular and metabolic dysfunction, impaired cognitive function and reduced immunological competence and implementing countermeasures to reduce some of these changes,
- understanding spaceflight-induced stresses and related mechanisms and molecular processes as well as countermeasures for psychological, neurosensory, neuroendocrine and stress-sensitive systems of the human body,
- optimizing crew physical and mental health including training, rehabilitation and other preventative treatments,
- enabling future long-duration spaceflight missions.

Scientist working in this unit will also **take care of other members** of the Moon base society. Crew biomedical monitoring may include ECG, pulse rate, temperature, respiratory rate, pulse oximetry, and blood pressure. Behavioral health and performance assessment will be conducted by mental health specialist in base or on Earth by using telemedicine devices. Except for that, department of space medicine has to offer some medical equipment in case of emergency on the Moon. Antibiotics, anticoagulants, painkillers, birth control, laxatives, antidepressants and many more drugs are always available for the members of the lunar community. Defibrillation and cardiac monitoring devices, airway management, suction, and ventilator support instruments, intravenous fluid and medication administration tools and some basic surgical instruments could be used in case of trauma, cardiac arrest or other acute condition.

Portable ultrasound system is excellent in diagnosis of some acute medical conditions within the abdomen and pelvis like kidney stones, but it can be also used in treatment - by releasing ultrasound waves that crush stones it enables them getting out of human body with urine. Compact Magnetic Resolution Imager (MRI) available in this department will be helpful not only in diagnosis of head trauma-related pathologies, but primarily it will be used in neuroscience research of lunar factors impact on neuroanatomy and physiology, sensorimotor and behavioral changes. It could help to understand the **role of gravity** in the development of central nervous system. Other research proposals include study of neuroplasticity, so the adaptive response of CNS to altered gravity and other space conditions. What is more, by using devices such as portable sequencer – Biomolecular Sequencer MiniOn – it would be possible to assess genetic changes that may occur in response to radiation-related mutations in crew genome.

3.7 Department of biology

This department in collaboration with space medicine laboratory will try to address questions about the **impact of lunar factors on biological processes**, cells and whole organisms but in more molecular manner. It has been clearly demonstrated that biological systems exhibit altered function and behavior in different gravity conditions or increased radiation [22]. However, the exact mechanisms and regulatory pathways remain unknown. Conducting research in that field will provide a better understanding of space-related responses and adaptation processes of the living organisms, genetic aberrations, metabolic changes etc. It will enable identification of protective measures for long-term human space missions and improving the design of bioregenerative life support systems. In this department scientists work on **reduction of radiation** sensitivity in live cellular cultures, plants and animals using gene therapy. Scientists also work on extraction of radiation resistant proteins from extremophile bacteria and melanin fungi. Experiments focused on regenerative processes, genetics and ageing mechanisms can be used to identify therapeutic strategies that could be implanted in medicine on Earth.

Scientist working in this unit monitor evolution of microbes in deep space environment. Thanks to microbiology lab they can analyze samples taken from other residents of the base. In case of disease they produce antibodies against new bacteria, fungi, parasites and viruses and assess drugs resistance of those organisms. Some drugs can present shorter lifetime in space conditions, therefore scientist will also work on new technologies for drug production. By using biotechnology and genetically modified organisms they will be able to produce particular medicine if needed. Moreover, growing plants and conducting research on them will be indispensable if we want to grow food in conditions other that terrestrial. **Small greenhouse** present in this unit will be a part of research projects related to that topic.

Research in the field of space radiation will possibly enable scientist to discover a prophylactic protection from its impact. For example, viral vectors with drugs would deliver it to the particular location of an injury associated with space radiation – it will open the way to gene therapy that will cause long-term expression of therapeutic nucleic acid in astronauts' tissues and organs sensitive to radiation. Except for plant, animal and microbial models, there will be a possibility of bioengineering human tissues from induced pluripotent stem cells connected to vascular perfusion and investigating the effects, mechanisms, and protective measures related to cosmic radiation.

3.8 Life support laboratory (BIO-Tech Lab)

Laboratory will be situated in 2 modules, where:

- Module 1. Wastewater and sewage cleaning room supported by bioreactors with varying algae and bacteria (fig. 13). Different type of waste must be sorted first before inclusion into biological cleaning of liquid wastewater and sewage. Further hone of purifying wastewater is planned after first cleaning cycle, based on additional equipment. For instance: medical (biohazardous) waste or laboratory waste (as toxic flammable compounds). Dome bioreactor construction will be built in special transparent PVC-U (polyvinyl chloride) material for tubular photobioreactor what can be used for simple algae production throughout growing on processed wastewater by bacteria [23].
- Module 2. Other technical and biological equipment for processing: cultivation of algae, fungi, and plants. Enrichment of soil will be possible by simple invertebrates as soil worms (Earthworms), bee, ants. Algae and cyanobacteria as a natural source and processed into biomass and biofuel. Fungi and plants (bean family, lettuce and herbs) is planned to be cultivated in special indoor farm system for cover additional fresh food.

BIO-Tech Laboratory will also support canteen for food supply. Mushrooms is planned to be cultivation for additional nutrition components as microelements and vitamins. Moreover OPCOM® Indoor Farm [24] is used in hydroponics planting system. Lamps and air provide not only airing of toxic compounds but also enrich air with additional pure oxygen. Likewise, simplicity of harvesting has a bearing on proper supplementation of vitamins in astronauts' diet. Important issue is bioprinting related to encapsulation in varying types of gels (hydrogels, alginates, which are compatible to human tissues [25], [26], [23]), materials for medical care (like wound dressing including medicaments which can be simply deliver by skin with a right amount of dose).

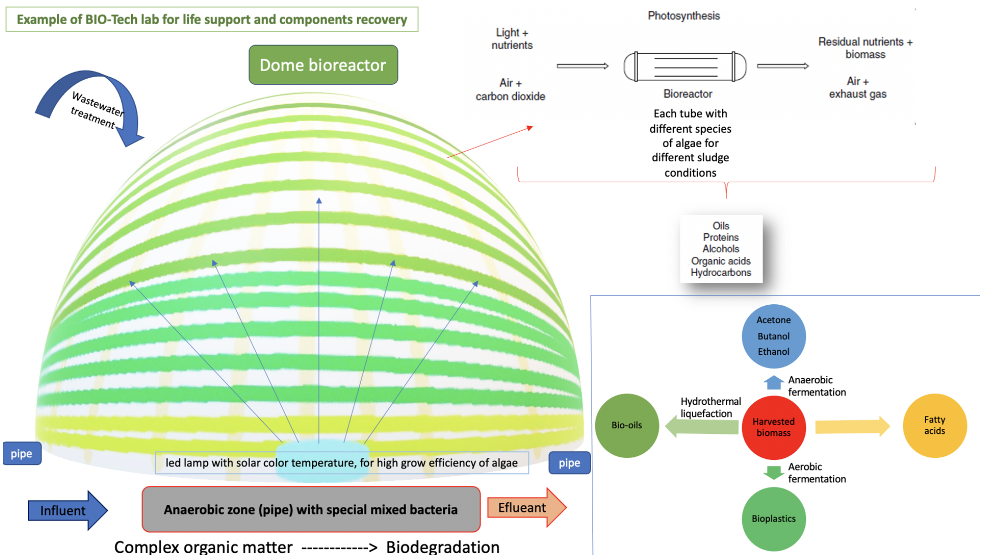


Figure 13: Algae bioreactor placed in modules and its processing products

Both modules will support by **algae and cyanobacteria biomass production**. Why? Efficiency of CO_2 conversion in cell is higher than in plants. As well as fast growing and variety of species which can be freely adapted to different conditions. Algae are more flexible and much easier to cultivate with low demand of nutrients. Additionally, very readily purifying the air from toxins and other chemical compounds (phytoplankton on Earth is a primary and the main oxygen production source) [27]. All processes will be connected to algae and bacteria towards biotransformation and supporting life conditions for humans and culture collections of plants and invertebrates. To major components derived from algae production is planned to be vitamins, oils, fatty acids, proteins, amino acids, dyes, pigments, polysaccharides. These elements can be used in differential fields, in food supplements, cosmetics, feed for other organisms, CO_2 sequestration and biofuels [28]. During develop of the Moon base all systems will be improved and become self-sufficient over time.

4 Systems

4.1 Power generation and distribution system

The required energy starts from at least 13 kWe [29] to 33,9 kWe [30] a 4 person base. ISS requires 70-90 kWe for 6 astronauts [31]. We assumed **70 kWe during the day, 35 kWe during the "night"** and up to 15 kWe in emergency situations (tab. 4). These numbers include transmission losses etc. During the lunar night it is necessary to reduce the energy consumption by about 2 kWe per hour to reduce the impact of the lack of electricity production from the solar panels. Regardless of the use of solar panels, most of the electricity will be produced using a **KiloPower generator** (fig. 14). It is a generator developed by NASA that uses uranium-235 to generate heat that is carried to the Stirling converters with passive sodium heat pipes. Ultimately, one such generator is to produce 10 kWe of energy [32]. To ensure the necessary amount of produced electricity in relation to the needs of the base, an **appropriate degree of redundancy** is provided.

Table 4: Energy demand of per module

Number of Kilopower	6
Number of battery pack	5 + control unit
kWh in battery pack	1320
Power comsumption during the day	75
Power consumption during the night	35
Power consumption during emergency situation	15
Amount of energy produce by KP	60
Amount of energy produce by PV	5

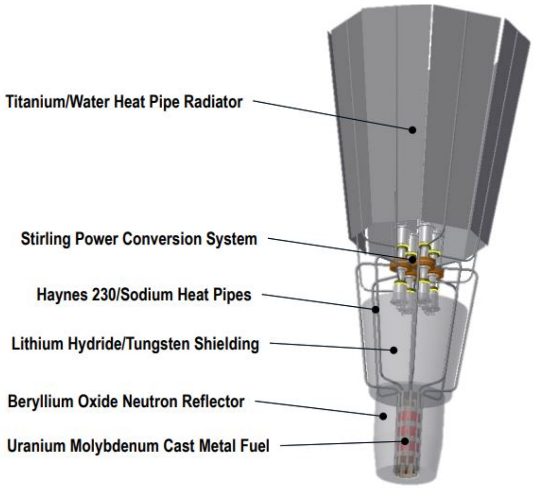


Figure 14: Kilopower [32]

Each module is powered by one group of 6 Kilopowers and these groups are spaced apart from each other. All systems, however, are connected with each other between base modules. Thanks to that other reactors will be able to supply the module, ensuring basic needs such as electricity, ventilation, air purification, water purification in any case. **Halogen cables** is used for power transmission. They are non-flammable and do not emit poisonous substances. Each module must also have its own electrical switchboard, which protects individual circuits against surges, etc.

4.2 Thermal control system

Table 5: Habitat Thermal Control System main elements

Full name	Acronym	Length [cm]	Width [cm]	Height [cm]
Interface Heat Exchanger	IFHX	63,5	53,34	20,32
Pump Module	PM	175,26	127	91
Ammonia Tank Assembly	ATA	200,66	116,84	139,7
Nitrogen Tank Assembly	NTA	162,56	91,44	76,2
Thermal Radiator Rotary Joint	TRRJ	170	140	130
Radiator Beam Valve Module	RBVM	60,96	50,8	13,72
Radiator	—	2330	340	—

The Habitat Thermal Control System (HTCS) is designed to **maintain the temperature of the interior** in the range of human comfort (20-24 ^{o}C) [33]. The main task of this system is to cool the interior to an appropriate temperature, caused by heat emitted from the human body, exhaled air, electrical equipment and especially during the lunar days, when solar radiation additionally heats up the habitat cover made of regolith. HTCS is a modified Active Thermal Control System used on ISS [34]. There are 4 units of this system installed in XORS Moon base. The basic elements of HTCS are shown in the fig. 15 and tab. 5.

The basic function of HTCS is to combine the **water loop** (that receives heat from inside the habitat) with an external **ammonia loop** that rejects it. IFHX as a heat exchanger transfers the heat from the internal loop to the external loop, regulating the temperature in the habitat. The heated ammonia is circulated, pressure regulated and temperature controlled by the Pump Module. PM is combined with Ammonia Tank Assembly and Nitrogen Tank Assembly. ATA is used to regulate the amount of ammonia during expansion and contraction due to temperature changes in the outer loop. NTA provides the necessary pressure to force the ammonia flow from ATA to the loop. Additional heating of the ammonia to avoid freezing during lunar nights is done with spare batteries charged during lunar days. Radiators, Beam Valve Module Radiator and Rotary Joint Thermal Radiator are used to reject heat outside the loop. The radiator consist of two series of flow tubes used to radiate heat. The ammonia transfer in radiator is controlled by the RBVM (one for each series of flow tubes) so that its temperature meets the cooling requirements. TRRJ ensures the transfer of liquid ammonia to the radiator and a controlled rotation of radiator to control cooling. The HTCS can be fully modified by connecting devices requiring additional cooling or by connecting plate heat exchangers to the internal loop to increase the heat absorbing surface.

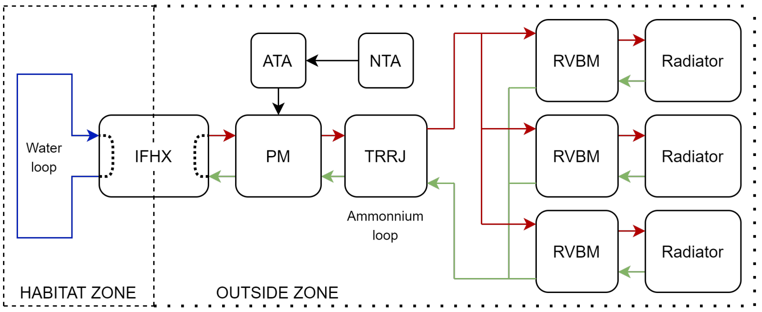


Figure 15: Habitat Thermal Control System Architecture (red line - warm ammonia, green line - cold ammonia)

4.3 Water

The water management system consists of **two circuits** - primary and secondary. In the first, clean water is used for drinking, food preparation, as well as in laboratories and medicine. The second circuit supplies water for hygienic purposes and for watering plants, crops and algae. The main water tank is located outside the base, because it allows for easy distribution of water to each of the modules, as well as to easily fill it with water delivered from Earth. In each module there is a tank that collects water from the main tank. Tanks located in the modules can accommodate a monthly supply of water for 5 people (about 5000 l). Water in the secondary circuit stays in a closed circuit, flowing through treatment systems and filters - it is also replenished with fresh water from the primary circuit (fig. 16. The water for the entire crew was calculated on a monthly basis. The quantities are presented in tab. 6.

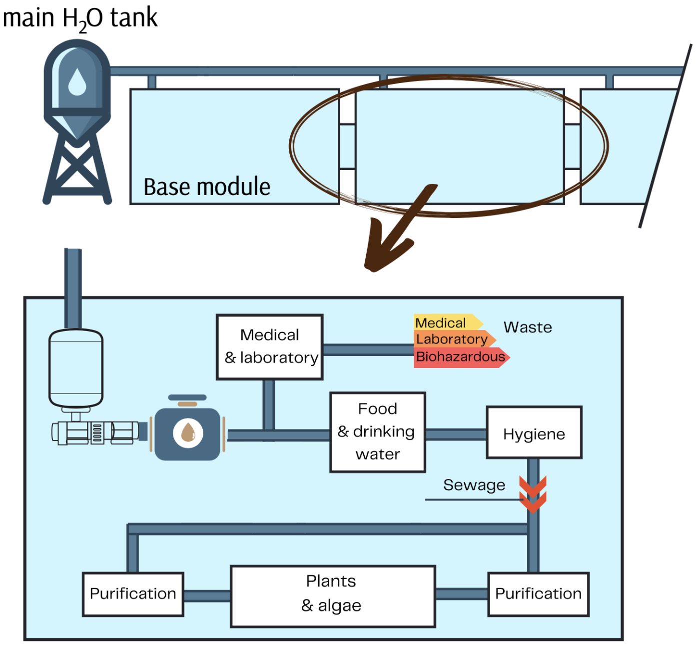


Figure 16: Water management in base

Table 6: Calculation for monthly water supply for a 16-person mission

Drinking water	Food	Hygiene	Medical	Plants and algae	Reserve
1060	500	10000	300	5000	5000

4.4 Air circulation system

Table 7: Average daily amount of oxygen demand and carbon dioxide production per person

Oxygen consumption [kg/d/person]	0.52
Carbon dioxide emission [kg/d/person]	1.04

Air is one of the most important elements necessary for human survival. During breathing, humans produce carbon dioxide, which is exhaled from the lungs along with other metabolic products such as alcohol (tab. 7). In addition, other ingredients, such as methane, are excreted. All the metabolic products are present in small quantities, but in an hermetic module these products can accumulate and become harmful to humans. It is therefore important to remove them during **air purification** and apply appropriate purification filters (e.g. HEPA). Algae, as a universal plant, in addition to water and air purification, produces oxygen. Therefore, each room will have additional relief panels on the walls, that will **produce oxygen and remove carbon dioxide** from the air. Nitrogen generation can be realized using azobacter (decomposing bio-waste), sewage (industrial, municipal - 3600 g/day/all), but first portion is taken form Earth. Calculations for filling the module with air (first time):

- $N_2 = 460$ kg (per module)
- $O_2 = 130$ kg (per module)

Calculation of air demand for 3 days (in case of an accident and waiting for external support e.g. from Earth):

- N_2 - nitrogen is not used up, but it is suggested 100 kg of reserve to make air mixtures
- $O_2 = 65$ kg + 35 kg reserve (supplied)/one module (4 people)

4.5 Water and oxygen in situ extraction

Extracting resources on the Moon or other bodies is one of the milestones of human space exploration. The most important substances concerning further exploration are water and oxygen. These chemicals have critical value in terms of life support as well as producing propellants. During the further development of the base, we suggest using the solutions described below to limit the amount of water and air supplied from Earth.

4.5.1 Oxygen extraction

According to the review research concerning in situ oxygen extraction [36], there are several processes that may be used for production of oxygen at the surface of the Moon:

- Extraction of water and other volatiles from ice,
- Extraction via a reactive gas,
- Reduction via electrolysis,
- Vapour phase pyrolysis.

The most promising (in terms of technological readiness) seems to be process of oxygen extraction via **electrolysis of regolith in molten salt**. This process is used in metallurgy industrial by Metalysis Ltd. and it is called FCC (Fray, Farthing, Chen) process to extract pure metals from ores or metal oxides. The by-product of this process is O_2 or CO/CO_2. It is proven that there is a possibility to translate this process to extraction of oxygen in the Moon environment [37]. The same process is used by Airbus in its Regolith to Oxygen&Metal Conversion Lunar Demonstrator (ROXY), which prototype is currently tested (fig. 17).

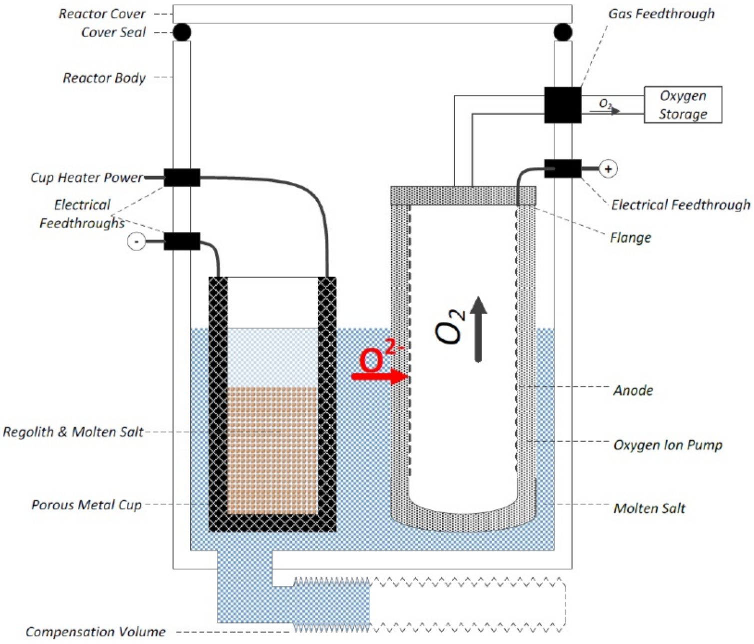


Figure 17: Principle of the ROXY concept[35].

4.5.2 Water Extraction

Water is probably the most desirable substance for space exploration. It is not only required for human beings to live but it is also compound of two elements which we are currently use as fuel for rockets - hydrogen and oxygen. In general, there are two possibilities of extracting water on-site: active extraction (drills, subsurface heating), and passive extraction (excavation of icy regolith, sublimation of ice from regolith) [38]. **Active extraction technologies** are developed by Honeybee Robotics Company in cooperation with NASA and the latest published test seems promising [38] [39] (fig. 18). Passive technologies are at conceptual design level and are developed by Colorado School of Mines [40]. There is also numerical model developed by Florida Space Institute [41].

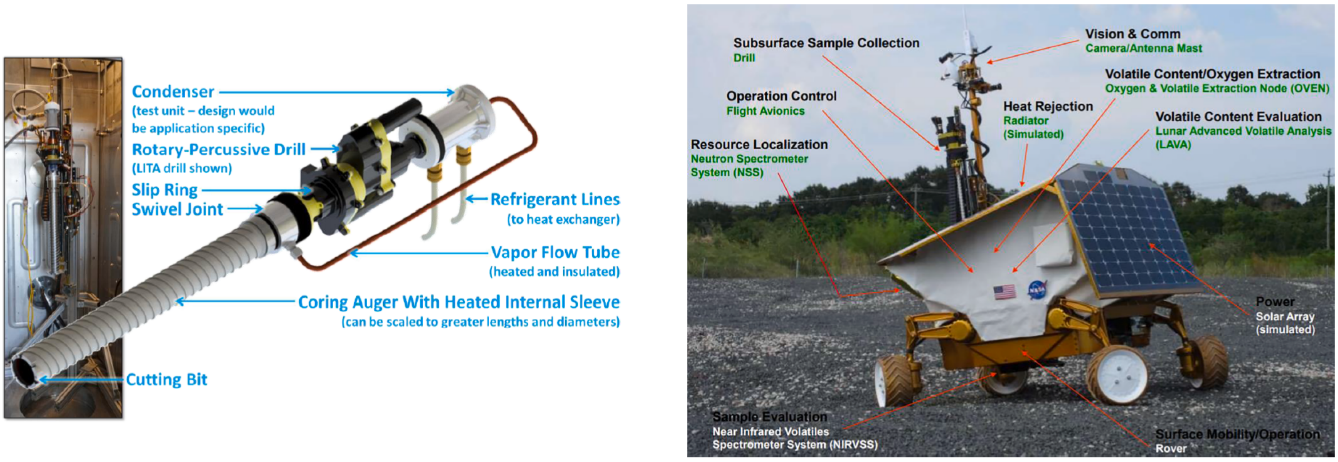


Figure 18: Extracting drill (PVEx) [38] and Lunar Resource Prospector RP15 with Honeybee PVEx Drill [39]

4.6 Fire Extinguishing System

Isolation and fire protection are one of the most important factors in building the base in such conditions, especially when systems must be hermetic to maintain internal stable quality. Hence, isolation systems will be built of **unique composition of aerogel**, enhancement of silica and glass fibres. Their insulations are distinguished by the best thermal conductivity, providing the best thermal protection and acoustic, which can help in harsh wind conditions and minimize noise inside the base. The reinforced aerogel has been classified as a material of the 'A' reaction to fire class, which means that it is completely **non-flammable and resistant to high temperatures**. It retains all its properties up to a temperature of about 500 °*C*, while its melting point is 1200 °*C*. When exposed to fire, it does not emit any toxic substances and does not fall off. Interestingly, aerogel incorporated with glass fibers secures of water and humidity [42]. Its features make it an **ideal protectant of many harmful external factors**.

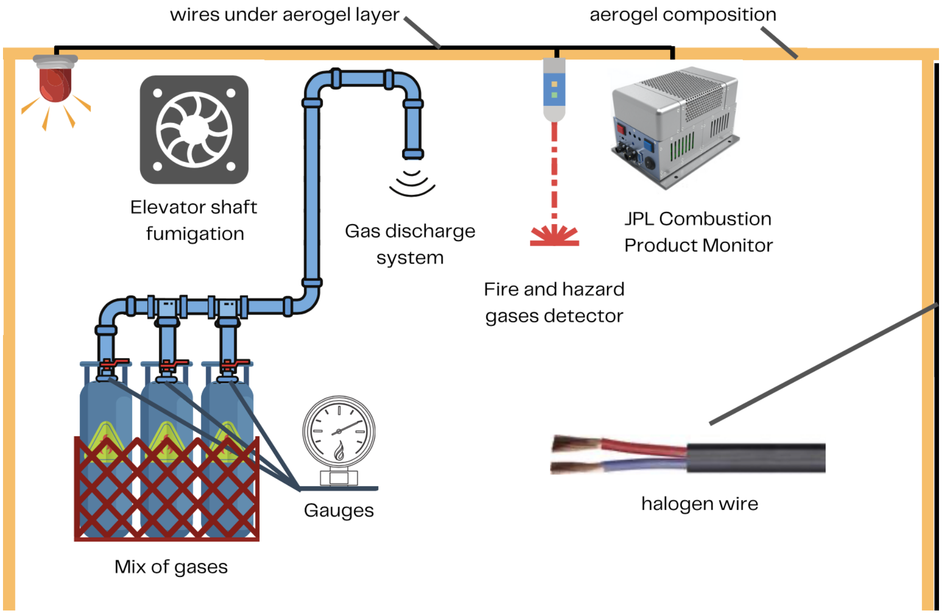
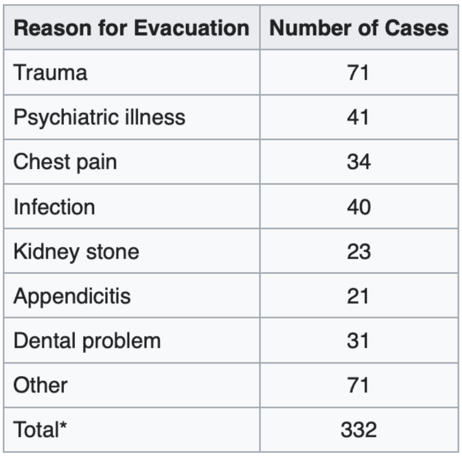


Figure 19: Fire Extinguishing System in each module

To prevent possible fires, we would like to apply "Spacecraft Safety Monitoring System" based on NASA JPL and California Institute of Technology solutions. Combustion Product Monitor (CPM) - tunable laser absorption spectrometer for monitoring CO, HCl, HCN, HF, and CO_2. Additionally, extinguishing agent will prevent of potential fire. It is planned to implementation of chemical clean agent (e.g., FK, FM, HFC) and inert gas fire (inergen, argonite, nitrogen). Furthermore, the system is checked twice a day, using the automatic system (i.e., sensors, gauges, indicators). The elevator shaft ventilator and fumigation (LCS) are utilized for the removal of smoke from modules. In addition, to minimize the risk of fire, halogen cables are used, which are placed under the aerogel composition layer. However, during possible installation burnout, the **risk of emission of toxic substances is minimized** (only water vapour and carbon dioxide are produced), therefore they are safe for people (fig. 19).

4.7 Other emergency systems

It is important to secure the supply of essential components required for the survival of astronauts. In order to minimize the risk, each of our modules has **warehouses for storing basic elements**. Our base have supplies for **at least 3 days in order to repair damaged elements or to be able to wait for supplies from the Earth**. Additionally, in the return rocket, there are supplies sufficient to return the entire base crew to the Earth. However, the modules are interconnected and are able to transfer water, electricity and air among themselves. The entire base is supervised by an automatic irregularity detection system, which controls in real-time the data provided by sensors distributed throughout the base (such as consumption of individual utilities, systems parameters, pressure in the base, the composition of the air mixture, current intensity, supplies in warehouses, the amount of generated energy), all in order to **immediately detect an anomaly** and inform the crew or react. In the event of a leak in one of the modules, it is important to immediately cut it off from the others and to evacuate the crew from the damaged module. All modules are able to function with increased crew in such case. In addition, the crew is required to perform routine tests of individual systems and check them for emergencies. Such routine inspections take place at specified intervals, depending on the system. Emergency systems are tested in every few weeks, e.g. by simulating a power cut or leak detection.



Reason for Evacuation	Number of Cases
Trauma	71
Psychiatric illness	41
Chest pain	34
Infection	40
Kidney stone	23
Appendicitis	21
Dental problem	31
Other	71
Total*	332

Figure 20: Reasons for medical evacuations from all submarines [43]

The Moon base **consist of medical hardware essential** in treatment of acute medical conditions, but patient evacuation procedure should be elaborated. The vehicle and systems used for medical evacuation support presence of at least 3 passengers, among which one could be transported in a supine position. Crew Medical Officer have access to patient at all times and is able to deliver ALS level care while in transit. Critical care equipment is accessible in this spacecraft [44].

During Russian Space Program between 1961 and 1990 four Russian cosmonauts had to be evacuated due to medical conditions and lack of resources to mitigate them in space. So far there has been no medical evacuations from the ISS [44]. However, taking into consideration the factor of isolation from terrestrial resources and lack of medical hardware typical for average clinical hospital – lunar mission can be compared to analogs representing harsh environments such as Antarctic expeditions or submarines. According to data from these analogs the most frequent medical emergencies included intracerebral hemorrhage, stroke, myocardial infarction, appendicitis, and bone fractures as well as cases of cancer and psychiatric illness (tab. 20). However, the **overall rate of serious medical or surgical emergencies was low** [43].

The second most frequent reason for medical evacuation during submarine mission was **psychiatric illness** [43]. Among others depression and anxiety were the two most common psychiatric diagnoses made during submarine missions [45], and they were also frequent among researchers working in Antarctic environment [46]. One of the most dangerous psychiatric conditions that may occur in space is acute psychosis - a medical emergency that may pose danger to the affected patient, other crew members and the success of the mission [47]. Psychotic event can have many causes (fig. 21). In order to diagnose a mental illness other possible causes should be rule out. In order to exclude them full blood count, serology, electrolytes and other laboratory testing are procedured. Additionally, MRI scan would be helpful in excluding physical brain lesions. Due to telemedicine devices the neuropsychiatrist on Earth could be contacted and help in planning medical treatment and potential evacuation of the patient.

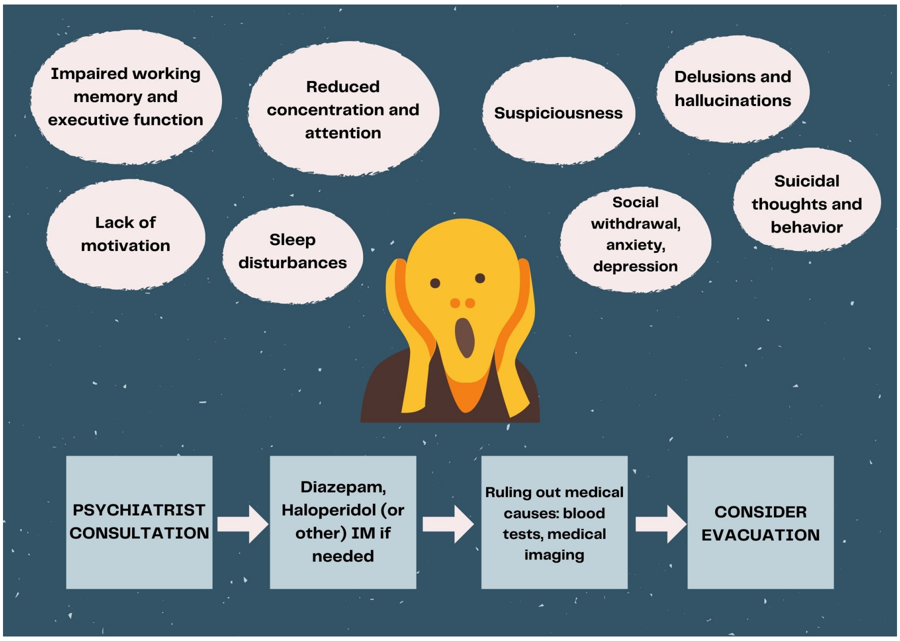


Figure 21: Acute psychotic episode in space

4.8 Communication system

4.8.1 Habitat communication network

Communication network on the surface of the Moon is one of the most important systems that holds the whole base together. System responsibilities are:

- Integrate all kind of sensors and IoT devices inside the hub: environmental sensors, monitoring cameras, computers, smart devices, etc., allowing them to exchange information with each other and with mission control center.
- Provide access to the applications that works as an interface to monitor and control habitat operations.
- Aggregate and exchange crucial data of habitat operations: resources usage, environmental data, medical data, etc.
- Allow exchange of messages and files between the crew via intranet access.

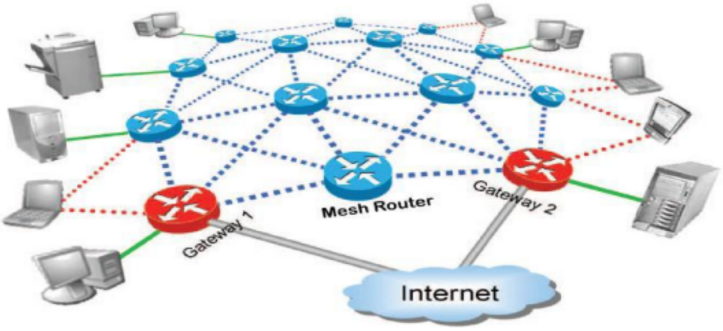


Figure 22: Diagram of the network on the Moon [48]

We used **Wireless Mesh Network (WMN)** (fig. 22) as topology of the communication network because this topology best meets our two main requirements:

- Reliability - there can be no single point of failure in the network. Outage of a single element of a system should have no impact on whole system operability.
- Scalability - adding new system elements and replacing or upgrading existing elements should be fast and easy.

A mesh network consists of 3 kinds of components: **Gateways, Mesh Routers and Endpoints**. Every system component has a direct or indirect connection with all other components.

- Gateways are the backhaul of a system that connects the internal network with the Earth's Internet. The connection between gateways and earth will be described in the next chapter. In case of a single gateway outage, other gateways can instantly take its operations for the cost of decreased bandwidth.
- Routers are backbones of the systems. They move data between endpoints and gateways. They are connected wirelessly with every other router in range to avoid bottlenecks in signal paths, to always find an available path in case of node outages or overload.
- Endpoints are devices like sensors, computers, mobile phones or small servers connected to the routers, wirelessly on 2.4GHz and 5GHz bandwidth according to IEEE 802.11 standard or via Ethernet cable. In our network every endpoint device is in range of at least 2 mesh routers to get rid of a single point of failure and split the data load between nodes.

Applications and websites that build habitat intranet are hosted on small servers and private computers. We decided to not place a big datacenter in the habitat because it's a waste of the resources to power servers and cooling systems. Archive data from sensors are streamed to servers on Earth. Due to security reasons habitat intranet is not reachable from public internet, similar to enterprise networks. On top of that, crucial system elements, like life support systems, are separated from wireless network and connected to private LAN, restricted only to physical access [49].

4.8.2 Communication between Moon and Earth

In order to connect internal habitat network with Earth's Internet, **mesh gateway connect wirelessly with Bases Station**. At the end of 2022 Nokia set up first 4G/LTE station on the Moon. Base Station is a compact, low power device, which is part of Nova-C lander produced by Intuitive Machines Company, which participates in NASA Commercial Lunar Payload Services. When lander sits on the surface of the Moon, the Base Stations starts automatic configuration and convert whole lander into stationary telecommunication tower that cover nearby area with cellular network. Base Stations are points of connection for habitat's Mesh Gateways and for various autonomous vehicles moving around. This solution is easily saleable, to expand the network cell area or to ensure a redundancy company can send another lander that will convert into base station. In the future we can expect that more companies will offer similar solutions, presumably offering also 5G technology. For now, Nokia chose 4G/LTE, because this is well known and reliable technology. The part of communication link on the surface of the Moon use **TCP/IP and UDP transport protocols** to exchange data, just like systems on the Earth, however communication between Moon and Earth need to use more sophisticated protocols like **DTN (Delay/Disruption Tolerant Networking)** for applications that require low latency to handle delays that are result of light speed limitations and disruptions caused by movement of intermediate network nodes (satellites). TCP/IP protocol first find the available path between sender and receiver and exchange a control packet in both ways to establish connection. When connection is set up, data packets will be send one by one, and the next packet will be send only if the previous one has been acknowledged by the receiver, if other way, the previous packet will be retransmitted. In best case scenario every packet need 2.6 sec to beat the road between Earth and Moon, back and forth. This protocol can be used only for applications that does not require low latency, for example emails or file transfer. UDP protocol in opposite to TCP, does not require acknowledgements from receiver, so in practice it can be used only for applications where loss of some packets does not make message unreadable, for example to transfer video and voice, still with minimum 1.3 sec delay due to light speed limitations. Other applications that require reliability and low latency, for example World Wide Web, can use DTN protocol. It works similar to TCP, however acknowledgements are send between adjacent network nodes, instead of between sender and receiver. In result, the next data packet can be send after previous one beat the road back and forth adjacent nodes (satellites), instead of between Moon and Earth. In this solution every network node need to be able to store data packet in the buffer for purpose of retransmitting in case of broken connection.

5 Daily life in Xors base

Our base is divided into few cylindrical buildings, each of which is intended to be a research facility of particular field. Our laboratories specialize in scientific research that cannot be conducted on Earth, nor orbiting stations. This is a **special research center**, where scientist use Moon conditions to perform experiments that would push the boundaries of space exploration, science, and technology once again. They are experts in their fields with wide scientific experience. The process of recruitment is coordinated by space agencies of given countries – the most interesting and necessary research project is chosen, and the candidate can become an astronaut! Every scientist on the Moon live according to **personalized schedule**. They all live and work in their own departments and are lab rats at the same time. One stay in the Moon lab takes 3, 6 or 9 months. The base is open to scientists and tourists, but with a ratio of at least **3:1 (3 scientist, 1 tourist)**.

5.1 Sleep and meals

For the proper functioning of the body, we need an **individually optimized amount of sleep**. Inadequate sleep can cause all-day drowsiness, fatigue, motivational decline or even depression [50]. Bedtime is scheduled as a constant point of the day. The optimal, preferable length of sleep for an adult is between 7 and 9 hours. Sleeping below this value results in weight gain and obesity, high blood pressure, heart disease and depression. What's more, it is also associated with impaired immune function, reduced pain resistance, impaired production and increases the likelihood of making a mistake or causing an accident. The astronauts have the ability to adjust his sleep time individually, however, they set their fixed time to start and end regeneration at the beginning of the mission. They should avoid physical equipment 2-3 hours before bedtime, and limit caffeine and excess sugar during the day [51]. The place of sleep is specially adapted to sleep comfortably. A significant element regulating sleep is sunlight with a systemic cycle. The rooms contain **daylight lamps to regulate the biological clock**. The temperature is in the cooler range [52].

Table 8: Schedule of the day

Time	Activity
7:00 AM	Measurement and morning service
8:00 AM	Breakfast
9:00 AM	Job (scientists), program of stay (tourists)
1:00 PM	Physical activity
2:00 PM	Lunch
4:00 PM	Maintenance of the base / Rest
5:00 PM	Job (scientists), research (tourists)
7:30 PM	Supper
8:00 PM	Evening briefing
8:30 PM	Yoga
9:00 PM	Measurement and Evening toilet
10:00 PM	Free time & Sleep

Regular consumption of meals and a reduced frequency as well as a fixed time of meals bring numerous physiological benefits, such as improved cardiovascular rhythm, increased autophagy and stress resistance, and supports the modulation of the intestinal microflora [53]. Astronauts have **three main meals** planned in their schedule to cover their daily caloric needs (tab. 8).

5.2 Measurements

Each astronaut is equipped with **wristbands to monitor health**. Blood pressure, body temperature, heart rate and pulse oximetry is measured. Every week, the astronaut has a medical consultation with an eye test, bone density measurement and ECG. There are conducted blood and urine tests, balance and spatial orientation tests, and lung function measurements as well. Astronauts have a weekly **consultation with a mental health professional**.

5.3 Work

The optimal working time for a human being is 6 *hours* a day [54]. The scientists' **work schedule has been specially adapted to their natural circadian rhythm**. Humans generally have a well-defined internal clock that shapes our energy levels throughout the day [55]. Most of the work is concentrated in the four hours of the morning when our brain is most productive. Then there is a lunch break when the brain activity drops significantly. It is also time for physical activity. Scientists return to work at 5 PM when the next peak of the body's efficiency occurs, and they work for the next two hours [54].

5.4 Physical activities

In conditions of microgravity, bones and muscles have to do less work to support the astronaut's weight [56]. Prolonged stay in space causes deconditioning of the neuromuscular and cardiovascular systems, leading to a decline in physical fitness. In such environment, reduced physical performance (e.g. aerobic performance, muscle strength and endurance) can compromise the performance of the human body, which can affect the success of the mission and the safety of the crew [57]. We do not really know the long term effects of lunar gravity upon human body. We do know that so far, physical activity is the most effective way to counteract the adverse effects of reduced gravity on the human body. **Physical exercise** is therefore an essential part of daily routine in the base [56]. Astronauts have a schedule of 2 hours of physical activity a day, focusing mainly on strength and aerobic exercises [58]. At the end of the day, **relaxation yoga** is planned for the entire crew. Research shows that performing yoga is beneficial for sleep efficiency and quality [59].

5.5 Evening briefing

During the briefing, the activities undertaken that day are summarized. Residents have the opportunity to express their opinions, what introduces an atmosphere of comfort and professionalism. An additional important point of briefing is **the planning and distribution of tasks** for the next day and **setting specific individual goals** to be achieved by each resident. Thanks to this, the actions of each astronaut will be systematized and supported by motivation.

5.6 Entertainment

We have planned a number of entertainment for the residents of the base. In the table 9 we have described just a few of them along with a description of the space used and the necessary equipment for their implementation.

Table 9: Few examples of entertainment activities

Activity	Space	Demand
Yoga	Area of about 20 m^2	Mats, tutorial screen
Cinema	Cinema hall	Projector, screen
Board games	Room	A wardrobe with board games, tables and chairs
Golf	A playing field near the base	Golf clubs and balls, mobile holes and golf obstacles
Bar, karaoke and darts	Corridors and common space	Bar, bar stools, darts, karaoke equipment, foldable billard table
VR Games	VR game station	VR game set, seat belts, protective foams
Bowling	An extendable bowling alley	An extendable bowling alley, bowling pins and balls
Trip to the second base (hotel)	Hotel	Conveyance
Build mini rovers + mini rovers racing	Workshop for the construction of rovers	Ready-made models of rovers for assembly, tools.
Breaking the lunar records	-	Each tourist will have the opportunity to break the "Moon Record" and do something on the Moon as the first person in the world. The record will be individually set before the mission. After breaking the record, a commemorative plaque will be placed.

6 Organization and management

An important issue for the base is how to manage it. Since the inhabitants of the base will be there periodically, and their number is about 16 people at a time, there are no arguments that could indicate that the base has its own state, legal or administrative structures. So, in terms of management, the base will be completely **dependent on Earth**. The base will be of a research and scientific nature, and its primary goal will be the development of humanity. Therefore, it is worth making this initiative an international project, as is the case with the International Space Station.

6.1 The basis for the base

Even the temporary occupation of the Moon by humans is associated with a breakthrough, but also with enormous socio-political threats. The creation of a base on Moon will be a success, but the consequences of the low coordination of the base may be critical for humanity. In order to prevent this, it is first needed to remember the principles in the **Treaty on the Principles of the Activities of States in the Study and Use of Outer Space** [60].

- Research into the use of outer space with the Moon is in the interest and good of all humanity, regardless of countries. In pursuit of scientific purposes, it must not restrict access to space to individual countries. States shall facilitate and encourage international cooperation in such research.
- The Moon is not subject to state appropriation, neither through the declaration of sovereignty, nor through use or occupation, nor in any other way.
- Activities in exploration and use of outer space, including the Moon, are conducted in the interests of maintaining international peace and security and the development of cooperation and understanding between nations.

It must be emphasized that the current international space law is not sufficient for an expedition to the Moon. However, it is a set of rules and principles that protect space against its expansion, and against using it for military.

6.2 Independent Moon Organization

Xors is an international project involving the countries concerned. In addition, it completely depends on the Earth. Therefore, we want to delegate its management to an independent unit called **Independent Moon Organization**. The member states associate themselves in the IMO Council and have a democratic influence on the strategy of the base on the Moon, but the organization organizes the work and managing the base. In the future, when creating more bases on other objects, it will be possible to expand this unit and change its name to the Independent Space Organization. Member States may join the project after paying a membership fee for the construction and development of the base. In addition, in order to send their own research mission, they have to finance all related costs. Only persons approved by the Council may be members of the board of the Independent Moon Organization, provided that no two persons of the same nationality may be in its composition. Among the employees of the organization itself, there can be only 15% of the same nationality, with the proviso that there may be only 25% of citizens of the European Union.

The premise itself is based on the commonalities in establishing the ISS. The states sign an **international agreement**, i.e. a treaty establishing an organization and a base on the Moon. The space agencies of the founding countries and the European Union sign contracts that detail the functions and responsibilities of each agency in the design, development and use of the stations [61].

Any mission taking place in Xors base must be approved by the Independent Moon Organization. To obtain such consent, the state must prepare a research project. The research project must contain information such as: the type and purpose of the research, proposed specialists, the cost of research, the need for equipment and the individual stages of the research mission together with the stages of preparation for it. The organization approves or rejects the application in the form of a decision. The reasons for the rejection of the application may only be due to the fear that the mission may violate the security of humanity, violate peace, have military targets or may be dangerous to the health and life of the base inhabitants. Only after receiving consent, the state pays the cost of living.

7 International relationships and law

Astronauts who will live in the designed institute cannot be exempt from the laws and obligations imposed on people on Earth. Unfortunately, however, there is no international space law that would exhaust the structure of a base on the Moon. Here it is again worth referring to the success of the ISS, where the principle is that "each partner shall retain jurisdiction and control over the elements it registers and over personnel in or on the Space Station who are its nationals" [61]. At the Xors base, the partner can rent a module. **Jurisdiction** will continue to be based on the extended principle of territoriality, but will be limited in time. In the event that one country rents a module for a specified period, the laws of that country will apply to that module for that period. When an international team is responsible for the research in a given module, the countries that donate funds for this research will sign an agreement among themselves about the applicable law within the module. In the case of an invention or work within the meaning of **intellectual property** rights, the work in question will belong to the country on whose territory it was created. When sharing a module, countries will include an **IPR clause** in the cooperation agreement. It will be different in the case of court jurisdiction. It will depend on citizenship, not place. In the event of a shared space, the law established by the Independent Moon Organization will govern. Every year, the law of a different country is in force, with the proviso that base members cannot be subject to capital punishments, physical penalties and penalties related to financial liability.

8 Costs and revenues

Table 10: Cost of building Xors base

System	Subsystem	Pcs	Pcs cost	Total cost
Rocket launch	-	20	60 M +20 x 60 M	3600 M
	Other costs (R&D, human work, reserve)	-	-	6000 M
Modules	Bigelow modules	4+2	300 M	1800 M
	Connecting modules	5	100 M	500 M
	Regolith collectors	6	70 M	420 M
	3D printer	4	37.5 M	150 M
	Printer's additional equipment	10	8 M	80 M
	General module equipment	7	150 M	1050 M
	Laboratory equipment	4	200 M	800 M
	Communication devices			4 M
	Positioning devices			0.5 M
	Other costs (R&D, human work)			4000 M
Energy	Kilopower	24	5 M	120 M
	Solar panels	124	100 k	12,4 M
	Cables + safety systems	1	5 M	5 M
	Battery packs	24	0.5 M	12 M
	Other costs (R&D, human work)	1	300 M	300 M
Water systems	Tanks		0.5 M	3 M
	Treatment system	5	1 M	5 M
	Filters			1 M
	Valves, seals			2 M
	Pump	100	10 k	1 M
	Pipes			1 M
	Other costs (R&D, human work)			120 M
Air system	Tanks	20	100 k	2 M
	Compressors			1 M
	Algae panels	20	50 k	2M
	Filters	100	10 k	1<
	Other costs (R&D, human work)			120 M
Thermal system	HTCS	4	225 M	900 M
Misc	Airlocks	15	60 M	900 M
	Safety systems	1	200 M	200 M
	Water extraction prototype	1	350 M	350 M
	Oxygen in-situ generation prototype	1	400 M	400 M
	Rovers	4	150 M	600 M
	Hotel	1	200 M	200 M
	Other R&D activities		1200 M	1200 M
	Organizational costs		10 000 M	10 000M
	Repairs in any cases		7 000 M	7 000 M
	Reserve founds		4 000 M	4 000 M
			Sum	55.7 B

Before we build a base on the Moon, we need to collect the funds. The creation of the Independent Moon Organization, which will manage the entire base and its finances, is going to help with this. This institution brings together the member states that will finance the construction of the base. In return, for the first 10 years, they receive the opportunity to take modules for the missions they plan for a period proportional to the **premium paid**. After 10 years of existence of the base, the members of the organization still have priority to rent a slot, but if a slot remains unspecified, anyone can rent it.

An important element is the need to plan **missions in slots**, i.e. one mission is to hire the entire module (for 4 astronauts) for 3 months or a multiple of this period. If a country or organization wants to send one astronaut, it must either pay for the entire module or form a consortium with other countries and apply together for the rental of the entire module.

States have the opportunity to conduct **international research** both with other Member States and with those that are not members of the organization. In this case, the countries that participate in the mission sign an agreement between themselves and the Independent Moon Organization. In the contract, the states participating in the mission determine how much each state must pay for the contribution and for the maintenance of the mission. The cost of the premium is covered immediately when building the base, and the cost of the mission is covered at a certain interval before completing the mission. They can join Independent Moon organization or buy a slot from another member country. In this case, the buyer covers the cost of maintaining 1/16 for one slot, which he pays directly to the Independent Moon Organization. The price for one slot that the seller can receive from the buyer can be up to 101% of the value of the minimum premium (BCU). The value of the minimum premium is subject to indexation. A condition for resale is obtaining approval from the organization.

8.1 Costs

8.1.1 Building a base

Time span: 2022 - 2030
Total cost: USD 55,7 billion
BCU: USD 348 million

A **Basic Construction Unit (BCU)** is the base amount paid by the Member States at any multiple. It is equal to 1/160 of the total cost of building Xors base. Why 160? We assumed 10 years as the depreciation period for the base. Under the Independent Moon Organization, Member States contribute to the cost of building the base, which is described in tab. 10. In return for covering these costs, they can later rent a base module for their research for a certain number of slots (i.e.

3-month time frames). We have 4 modules in the base and 4 slots a year for 3-months each, which is a total of 16 slots a year. It means, there are 160 of them for 10 years (during assumed depreciation period for the base). A country that pays one BCU (1/160 of the construction cost) can rent one whole module for 3 months. A country that pays 10 BCU can rent any module 10 times for 3 months, etc. In addition to the construction costs, there are also the current maintenance costs described below. The costs are related to the purchase of parts, ready-made elements or systems, R&D works, prototyping and testing, quality control, as well as organizational costs related to the maintenance of infrastructure or human work (tab. 10).

Member States pay a contribution of **at least 1/160 of the base construction and development costs (1 BCU)**. There is no need to use the slots one by one. You can rent each slot at intervals and different modules. You can sign up for a specific date only after paying the fee. Priority to the slot deadline is given to the member state that pays the slot premium in advance. No country can buy more than 20% of all slots, so the maximum amount it can pay is 32/160.

After 10 years, the base is open and anyone can rent the module on a **commercial basis**. The mission cost is then lower, covering the cost of maintaining the base and further investments. Ultimately, it should be self-sufficient, i.e. the funds obtained finance all costs related to the base, and the profit finances further investments (subsequent modules, another base in a different place, other missions).

8.1.2 Maintenance

Time span: 2030 - 2040
Total annual cost: USD 5 billion
BMU: USD 312,5 million

A **Basic Maintenance Unit (BMU)** is the base amount paid by by the country carrying out one mission. One mission is a 3-month stay of 4 astronauts in one module. BMU covers all mission costs and 1/16 of the total cost of annual maintenance of Xors base. Why 1/16? In addition to the cost of construction, each country sending its crew to the slot will have to additionally finance all costs related to the maintenance of the mission, i.e. all variable costs: the cost of the crew, the cost of research, laboratory equipment needed for a specific test, maintenance of the module. It is possible to rent or buy laboratory equipment already on the Moon from another country after signing a rental or purchase agreement with that country. Such an agreement remains without organization interference.

Maintenance is billed on an **annual basis**. There are 4 slots (3 months) in one year, which multiplied by 4 base modules gives 16 slots. The country carrying out the 3-month mission must therefore cover 1/16 of the costs of the current maintenance of the base, which include fixed costs, ongoing repairs and needed supplies. They also pay for all overhead related to the mission, i.e. the cost of Moon-Earth transport, the cost of supplies and the cargo collected and others. The maintenance costs are estimated at 6% of the construction costs per year, or USD 3,3 billion. The cost of all 8 flights is equal USD 480 million and supplies for a year cost about USD 1,2 billion. The total annual cost is USD 5 billion, therefore the BMU is equal to 1/16 of this cost, which is USD 312.5 million.

8.1.3 Further development

Time span: 2040 -
Total annual maintenance cost: USD 3 billion

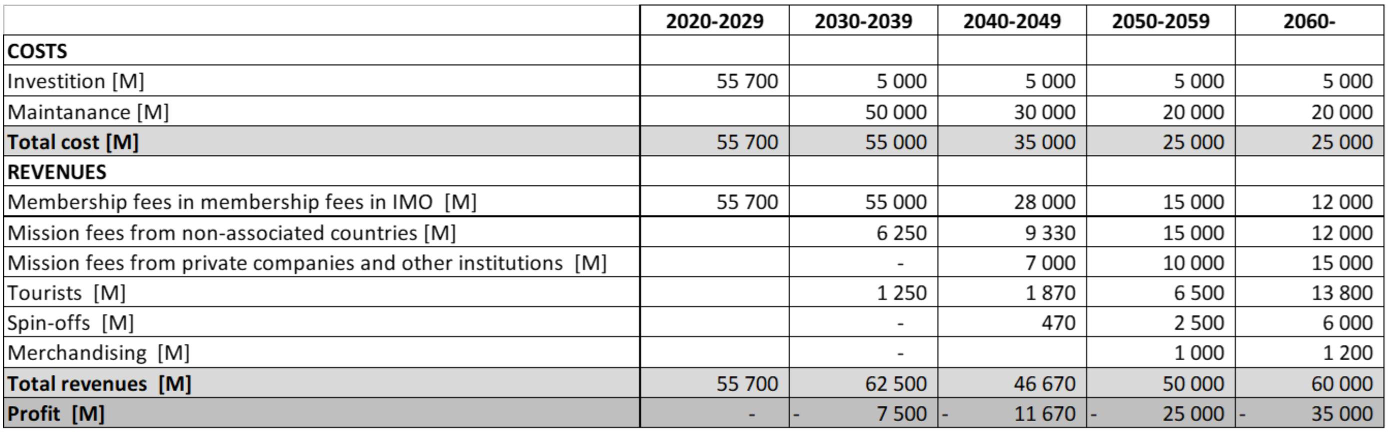
The cost of maintaining the base will **decrease over time**, which is related to the development of technology (e.g. obtaining water on the Moon) and lowering the cost of the flight between the Earth and the Moon. However, it should be remembered that conservation works and new investments will be needed.The system of 4 modules proposed by us is optimal, but not the only one. If the contributions from member states are smaller or larger than assumed, thanks to the modular architecture of our project, the Xors base can have more or less modules. It is also possible to expand the base in further stages.

Building another module is related to the interest of the Member States, external States or other institutions and companies in the next laboratory. If there are people willing to buy slots for such a module and the Independent Moon Organization agrees, a list of interested parties is opened. If all slots are filled for the entire amortization period (i.e. 40 slots - 4 3-month slots per year for 10 years), membership fees are collected and the construction of the next module begins. The time needed to build the next module depends on the type of laboratory and may take from 2 to 5 years.

In addition, the cost of operating the base after the depreciation period is significantly lower, which may allow you to earn money by renting modules. However, these funds may be used to cover maintenance costs (and hence, reduction of membership fees) or investments related to the construction of another module, another base or the implementation of another mission. The allocation of these funds is decided by the Independent Moon Organization.

8.2 Future revenues

The funds obtained from membership fees that will be used to build and maintain the base for the first 10 years have been described in the previous chapter. In this, we will focus on **additional sources of income and the structure of revenues** at various times of the base development.



	2020-2029	2030-2039	2040-2049	2050-2059	2060-
COSTS					
Investition [M]	55 700	5 000	5 000	5 000	5 000
Maintanance [M]		50 000	30 000	20 000	20 000
Total cost [M]	55 700	55 000	35 000	25 000	25 000
REVENUES					
Membership fees in membership fees in IMO [M]	55 700	55 000	28 000	15 000	12 000
Mission fees from non-associated countries [M]		6 250	9 330	15 000	12 000
Mission fees from private companies and other institutions [M]		-	7 000	10 000	15 000
Tourists [M]		1 250	1 870	6 500	13 800
Spin-offs [M]		-	470	2 500	6 000
Merchandising [M]		-		1 000	1 200
Total revenues [M]	55 700	62 500	46 670	50 000	60 000
Profit [M]	-	- 7 500	- 11 670	- 25 000	- 35 000

Figure 23: Costs and revenues

Space exploration is an expensive activity, so striving to reduce costs is an important part of the business. Lower membership fees mean more countries and institutions will be able to join this project. The base cannot make money, i.e. the activity in the base cannot be profitable. Any surplus can be used for one of two purposes - **reducing membership fees** or **further investments** (e.g. building more modules). For simpler calculations, we have not indicated the allocation of the generated funds in tab. 23. Ultimately, we want the base to be **self-sufficient**, i.e. mission fees are related to covering fixed costs (flight and necessary supplies), and other costs are covered from other activities. This is possible especially after the depreciation period. Membership fees should decrease over time and ultimately cover mainly investments in the development of the facility, and current costs should be covered from fees for the mission. The remaining sources of income should in a few decades be able to cover the operating costs of the base and other organizational costs. Over time, the base will start to generate profit that can be spent on further investments or new bases.

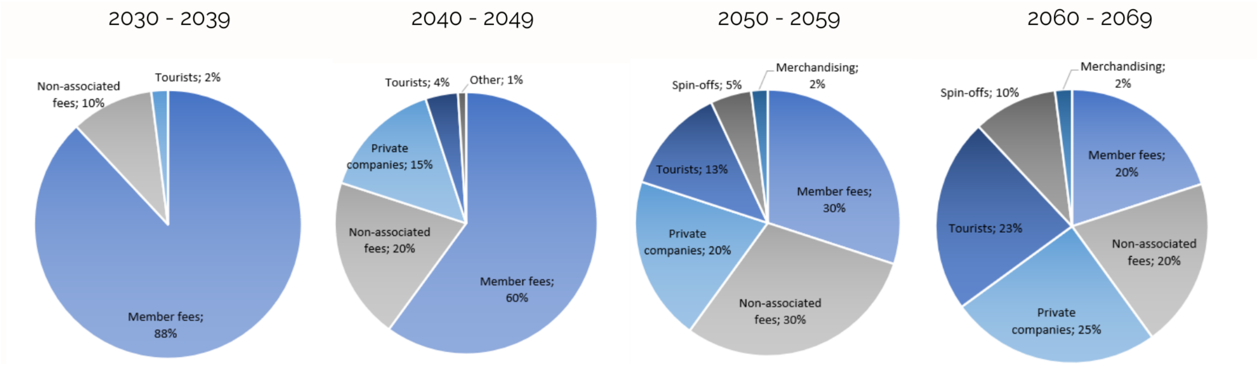


Figure 24: Revenue sources - structure

The Xors base can raise funds from several sources. Lowering the costs of the Earth-Moon flight related to the development of rocket technology will increase the interest in the commercial use of the base, e.g. in the film or tourism industry. During the first 10 years, tourists will be able to fly to the Moon in a mission location as described in the previous chapters in a 3: 1 ratio. We have 4 people in the module, so the country responsible for the mission will be able to resell one place in its module for tourists. It is the state that is responsible for the proper preparation of such a person and for his return trip. After 10 years, the organization will **open a base for tourist purposes** (fig. 24). In order to prepare tourists for the flight, the Independent Moon Organization will open or rent a special training center from a Member State. The organization will also provide transport, meals and entertainment.

Another example of a source of income is the creation of **spin-offs** that will commercialize the technology developed during the implementation of the Xors base. Creating a permanent base on the Moon requires the development of many solutions that can also solve the problems that we also have to deal with on Earth - such as water treatment systems.

The last major source of revenue is the **advertising sector**. Here you can include merchandising, revenues from movies or commercials, and other activities related to sales and promotion.

References

[1] Topography and permanently shaded regions (psrs) of the moon's south pole. *Regional Planetary Image Facility, Lunar and Planetary Institute, Houston, Texas, USA*.

[2] Japan Aerospace Exploration Agency (JAXA). Lack of exposed ice inside lunar south pole shackleton crater published in science express of science magazine.

[3] D.B.J. Bussey, J.A. McGovern, P.D. Spudis, C.D. Neish, H. Noda, Y. Ishihara, and S.A. Sørensen. Illumination conditions of the south pole of the moon derived using kaguya topography. *Icarus*, 2010.

[4] S. Bryant. Lunar pole illumination and communications maps computed from goldstone solar system radar elevation data. *The Interplanetary Network Progress Report, vol. 42-176, p. 1-43*, 2009.

[5] NASA. Ice confirmed at the moon's poles. `https://www.jpl.nasa.gov/news/news.php?feature=7218`, 2018. [access 06.01.2021].

[6] NASA. Nasa radar finds ice deposits at moon's north pole. https://www.nasa.gov/mission_pages/Mini-RF/multimedia/feature_ice_like_deposits.html. [access 30.01.2021].

[7] T. Ong. Elon musk's giant battery is now delivering power to south australia, 2017. `https://www.theverge.com/2017/12/1/16723186/elon-musk-battery-launched-south-australia`.

[8] J. Roulette. Bezos' blue origin to deliver first flight-ready rocket engines next summer - ula ceo, 2020.

[9] United Launch Alliance. Rocket rundown a fleet overview, 2019.

[10] `https://www.spacex.com/media/Capabilities&Services.pdf`.

[11] `https://www.spacex.com/vehicles/falcon-heavy/`.

[12] E. Musk. Making humans a multi-planetary species. *New Space*, 5:46–61, 06 2017.

[13] `https://www.spacex.com/vehicles/starship/`.

[14] `https://www.ulalaunch.com/rockets/delta-iv`.

[15] Delta iv launch services user's guide, Jun 2013.

[16] A. Schorr, K. Robinson, and D. Hitt. Nasa's space launch system: Enabling exploration and discovery. 10 2017.

[17] S. Clark. China's long march 8 rocket successful in debut launch, 2020.

[18] Monolite UK (Dinitech SpA). D-shape - report. `http://3dprintetbyggeri.dk/pdf/bes%C3%B8gsrapporter/D-Shape.pdf`, 2016. [access 06.01.2021].

[19] G. Cesaretti, D. Enrico, X. De Kestelier, V. Colla, and L. Pambaguian. Building components for an outpost on the lunar soil by means of a novel 3d printing technology. *Acta Astronautica*, 93:430–450, 01 2014.

[20] K. Schwab. This kit makes it shockingly easy (and pretty) to farm your own algae at home. `https://www.fastcompany.com/90365320/this-kit-makes-it-shockingly-easy-and-pretty-to-farm-your-own-algae-at-home`, 2019. [access 10.01.2021].

[21] A. Kolodziejczyk, H. Lakk, and L. Orzechowski. Time architecture, 05 2016.

[22] The Science Department of ESA's Human Spaceflight and Exploration Directorate. Roadmaps for future research. 2016.

[23] D. A. Carbone, G. Olivieri, A. Pollio, and M. Melkonian. Comparison of galdieria growth and photosynthetic activity in different culture systems. *AMB Express, 10(1)*, 2020.

[24] OPCOM Farm. `https://www.opcomfarm.com/EU/pagenew`, 2016. [access 06.01.2021].

[25] P. Calvert. 3d printing of gels with living photosynthetic algae. *MRS Advances, 1(36), 2569–2572*, 2016.

[26] I. Michalak and K. Chojnacka. Introduction: Toward algae-based products. *In: Algae Biomass: Characteristics and Applications*, 2018.

[27] C. Formighieri. Solar-to-fuel conversion in algae and cyanobacteria. *In: SpringerBriefs in Environmental Science*, 2015.

[28] A.C. Tyagi. Drainage and environmental sustainability. *In: Irrigation and Drainage (Vol. 66)*, 2017.

[29] G. Broccia. Energy Production in Martian Environment - Powering a Mars Direct based Habitat, 2018.

[30] A. Rucker. Surface Power for Mars, 2016.

[31] STEVE TARANOVICH. International Space Station (ISS) power system, 2014.

[32] L. Mason. Kilopower overview and mission applications, 2018.

[33] F.H. Rohles Jr. Temperature and temperament - a psychologist looks at comfort. *ASHRAE Journal*, 2007.

[34] Boeing. Active thermal control system (atcs) overview. [access 29.12.2020].

[35] M. Kinnersley, A. Seidel, U. Kuebler, U. Pal, and R. Hyers. Roxy: Regolith to oxygen & metal conversion lunar demonstrator.

[36] L. Schlüter and A. Cowley. Review of techniques for in-situ oxygen extraction on the moon. *Planetary and Space Science*, 181:104753, 2020.

[37] B.A. Lomax, M. Conti, N. Khan, N.S. Bennett, A.Y. Ganin, and M.D. Symes. Proving the viability of an electrochemical process for the simultaneous extraction of oxygen and production of metal alloys from lunar regolith. *Planetary and Space Science*, 180:104748, 2020.

[38] D. Kornuta, A. Abbud-Madrid, J. Atkinson, J. Barr, G. Barnhard, D. Bienhoff, B. Blair, V. Clark, J. Cyrus, B. DeWitt, C. Dreyer, and B. Finger. Commercial lunar propellant architecture: A collaborative study of lunar propellant production. *REACH*, 13:100026, 2019.

[39] V. Vendiola, K. Zacny, P. Morrison, A. Wang, B. Yaggi, A. Hattori, and A. Paz. *Testing of the Planetary Volatiles Extractor (PVEx)*, pages 467–480.

[40] G. Sowers. Thermal mining of ices on cold solar system bodies - niac phase i final report, 2020.

[41] J. Brisset, T. Miletich, and P. Metzger. Thermal extraction of water ice from the lunar surface - a 3d numerical model. *Planetary and Space Science*, 193:105082, 2020.

[42] Aerogel: price, properties and use of aerogel in construction. `https://www.mgprojekt.com.pl/blog/aerozel/`, January 2020. [access 20.12.2020].

[43] J.R. Ball and C.J. Evans. *Safe passage : astronaut care for exploration missions*. DC: The National Academies Press, 2001.

[44] C.D. Nowadly, B.D. Trapp, S.K. Robinson, and J.R. Richards. Resuscitation and Evacuation from Low Earth Orbit: A Systematic Review. *Prehospital and Disaster Medicine*, 34(5):521–531, 2019.

[45] W.A. Tansey, J.M. Wilson, and K. Schaefer. Analysis of health data from 10 years of polaris submarine patrols. *Undersea biomedical research*, 6 Suppl:S217–46, 1979.

[46] D.J. Lugg. Antarctic Medicine. *JAMA*, 283(16):2082–2084, 04 2000.

[47] N. Keks and G. Blashki. The acutely psychotic patient: Assessment and initial management. 2006.

[48] M. Sudhakar. Wmns: Efficient scheduling algorithm and classification of routers with multiple gateways. *International Journal of Applied Engineering Research*, 10:17213–17228, 01 2015.

[49] F. Sara and H. Katie. What are the top 10 largest commercial mesh network deployments globally? `https://askwonder.com/research/top-10-largest-commercial-mesh-network-deployments-globally-77uhnkul0`, 2017. [access 06.01.2021].

[50] J.P. Chaput, C. Dutil, and H. Sampasa-Kanyinga. Sleeping hours: What is the ideal number and how does age impact this? *Nature and Science of Sleep*, Volume 10:421–430, 11 2018.

[51] N. Watson, M.S. Badr, G. Belenky, D. Bliwise, O. Buxton, D. Buysse, D. Dinges, J. Gangwisch, M. Grandner, C. Kushida, R. Malhotra, S. Patel, S. Quan, and E. Tasali. Recommended amount of sleep for a healthy adult: A joint consensus statement of the american academy of sleep medicine and sleep research society. *Journal of clinical sleep medicine : JCSM : official publication of the American Academy of Sleep Medicine*, 38, 04 2015.

[52] NHLBI Health Information Center. In brief: Your guide to healthy sleep. `https://www.nhlbi.nih.gov/files/docs/public/sleep/healthysleepfs.pdf`. [access 06.01.2021].

[53] A. Paoli, G. Tinsley, A. Bianco, and T. Moro. The influence of meal frequency and timing on health in humans: The role of fasting. *Nutrients*, 11:719, 04 2019.

[54] C. Fournier. Are shorter working days the secret to a happier, healthier and more productive life? `https://youmatter.world/en/schedules-working-days-productivity/`, 2017. [access 06.01.2021].

[55] C.M. Barnes. The ideal work schedule, as determined by circadian rhythms. `https://hbr.org/2015/01/the-ideal-work-schedule-as-determined-by-circadian-rhythms`, 2017. [access 06.01.2021].

[56] Canadian Space Agency. Physical activity in space. `https://www.asc-csa.gc.ca/eng/astronauts/living-in-space/physical-activity-in-space.asp`. [access 06.01.2021].

[57] K. Hackney, J. Scott, A. Hanson, K. English, M. Downs, and L. Ploutz-Snyder. The astronaut-athlete. *Journal of Strength and Conditioning Research*, 29:1, 09 2015.

[58] N. Petersen, P. Jaekel, and A. Rosenberger. Exercise in space: The european space agency approach to in-flight exercise countermeasures for long-duration missions on iss. *Extreme Physiology & Medicine*, 5, 12 2016.

[59] Ducharme J. This is the best time of day to work out, according to science. `https://time.com/5533388/best-time-to-exercise/`, 2019. [access 06.01.2021].

[60] C.A. Conley. *Outer Space Treaty*, pages 1–1. Springer Berlin Heidelberg, Berlin, Heidelberg, 2014.

[61] International space station legal framework. .