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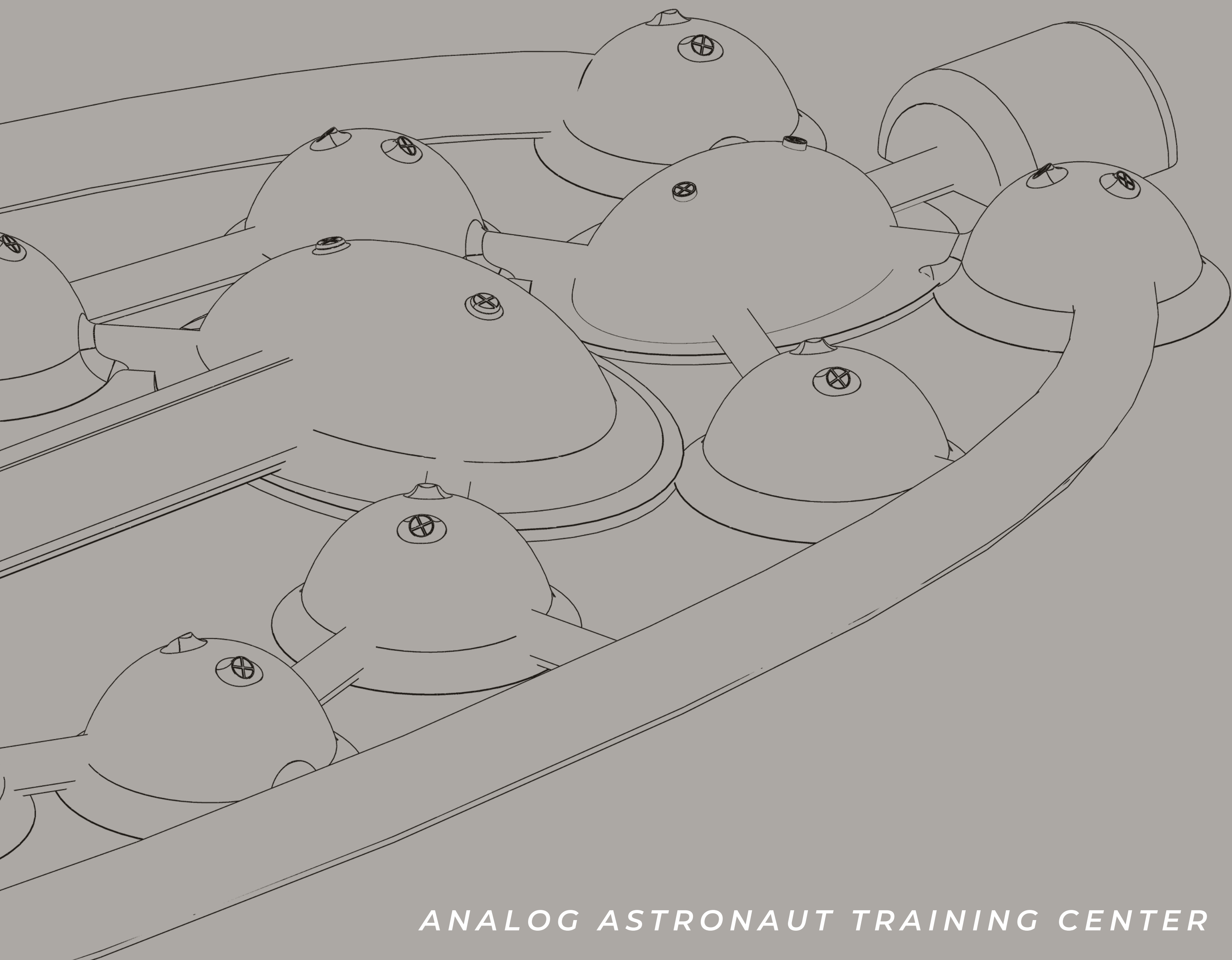
ALLDREAM LUNAR INSTITUTE

HOME ON THE MOON PROJECT



ANALOG ASTRONAUT TRAINING CENTER

Home on the Moon Project

ALLDREAM LUNAR INSTITUTE

Project realized by BRIGHT 1 & 2 analog mission crews
Figure above is our mission logo designed by Sophie Shen

Contents

1 Who we are?

Welcome! A group of eight analog astronauts from Poland would like to present their project of a home on the Moon. We are the crew of the analog mission "BRIGHT I & II". Not long ago we were strangers to each other. The common goal united us during our 6-week mission: we decided to take up the challenge and created our vision of a lunar home.

The creation of the project was based on our common passion and willingness to participate in the exploration of space. We wanted our lunar house to reflect the vision of each of us. We decided that the best way to combine these ideas is to create a lunar hospital, because through this we will combine our passions: medicine and modern technology.

The main purpose of our base is to provide future residents with a place, where they can recover from the accident. The new environment will generate new discomfort factors for the human body. Our base is designed to help adapt to the new conditions. It is also a research facility for space medicine and biology research. It will enable the development of new technologies and research methods in the field of telerobotics and medical automation. Space conditions will allow for extensive research on the treatment of DNA mutations and genetic anomalies.

Figure 1: Our team

1.1 Meet our team

Our team consists of:

- **Justyna "Princess of tuna” Pelc**

  The right women in the right place! Automation and robotics engineer. She thinks that a good project needs good promotion in order to use its potential. That’s why she deals professionally with marketing and PR. She is fascinated with Mars and for several years has been carrying out projects related to this planet. Crewed space exploration is her main pet project. Addicted to coffee and she really doesn’t like yoga. Her guilty pleasure is Netflix. Her answer to the question: "What invention could change the world for the better?”: Sleep in pills. How many things we could do if we didn’t have to sleep!

- **Arkadiusz "Dr Habitat” Kołodziej**

  Arkadiusz is a fifth-grade medical student. Amazing man who wants to do spectacular things! He wants to operate on astronauts’ brains with robots in the future. He doesn’t really know whether he wants to become a doctor or a scientist. He’d surely like to get a Nobel Prize and fly to the ISS. He’s interested in everything and would like to know everything, but he’s afraid he won’t have enough time. His greatest dream is to discover a way to stop the aging process of cells, although he realizes that it could lead to an absolute disaster of human civilization. In his free time he reads literature written by Olga Tokarczuk and Virginia Woolf.

- **Michał "Szeldon" Garus**

  Physics graduate with specialization in optoelectronic and microelectronic. He was working on Optical Atomic Clocks during his previous studies. Now he is in the last grade of Computer Science studies and working at the same time as a backend Software Developer at Fujitsu. His life goal is to contribute to overall progress of humanity, one way or another. He is gadgeteer and electronic engineering hophead, free spirit, daydreamer, stargazer and nerd. Interested with astronomy, sci-fi literature, historical reconstruction of X and XV century and tabletop role-playing games. He is also a proud father of Epiphyllum Oxypetalum, Nepenthes, Drosera, Coffea Arabica and more than twenty other offspring. To make the word a better place he would like to invent an endless cup of always hot and fresh coffee.

- **Maciej "Sniki" Trzaskowski**

  This is a young boy with a plan for life. All the time he dreams about going into space one day and looking at the Earth from a completely different perspective. Maciej is a high school student in the field of automation technician. He starts his final year at this school in September, and when he finishes it, he intends to study astronomy. In addition to his interest in space and astronomy, Maciej would like to be a bartender, he believes that human creativity has no limits, and he can show his own by serving various drinks. Currently, Maciej is trying to become independent and is already looking for a job so that he can move away from his parents, he prefers to live his own life, in his own way, without being stupid.

- **Aleksandra „Rover” Wilczyńska**

  A fresh high school graduate. From October she starts her studies (provided that she gets it) at "Modelling and Data Science". Her main value in life is to change the world for the better in the future, she would like to be involved in the scientific education of children and space exploration. Her main value in life is to change the world for the better. In the future, she would like to be involved in the scientific education of children and space exploration. Her challenges are not terrible. Currently she spends most of her free time scouting and exploring the world. She believes that change starts with small steps and ends with great success. That is why she would like to develop modern ways of learning and absorbing knowledge through quantum technology.

- **Milena „Honey Bunny” Michalska**

  Milena, even though she is at the beginning of her IT studies, is already working as a front-end developer for European Space Agency's contractor. In the future, she would like to specialize in artificial intelligence, become a rocket constructor or own a cat's cafe. She would like to invent a rocket propulsion system with enormous performance. She is particularly passionate about space, and runs a blog that promotes science and programming. She devotes her free time to cycling and drawing.

- **Hubert „Boar” Gross**

  Hubert is in the final stage of his engineering studies "Aviation and Cosmonautics". He is in the process of writing his engineering paper "Design and analysis of solid fuel rocket engine". He works for an automotive company. In the future he would like to work both scientifically and typically as an engineer in a company dealing with the space industry. He is interested in subjects related to widely understood engineering in connection with space. He would like to take up the challenge and lead the Alcubierre drive project.

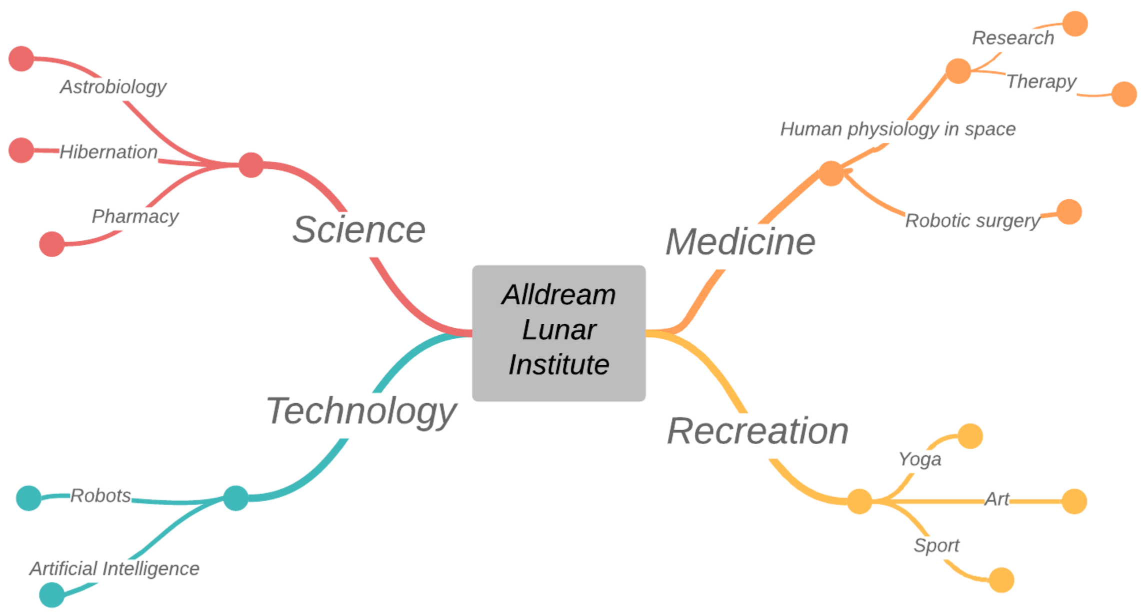
- **Agata „Twarda” Kołodziejczyk**

  She received her PhD in neurobiology from the University of Stockholm. Winner of the FNP Rojszczak Award for combining biology with astronomy. A three-time winner of the first prize in the Global Space Balloon Challenge competition for taking astrobiological experiments to the stratosphere. She worked in Advanced Concepts Team of the European Space Agency as an expert in biomimetics. She is currently organising analogue simulations of space missions and training for future space tourists and commercial astronauts, as well as all those who wish to develop their careers in the space sector. She initiated the creation of the first analogue Lunares base in Piła, currently the founder and co-owner of the Analog Astronaut Training Center in Rzepiennik Strzyżewski. Together with her partner Matt Harasymczuk, she runs the only organisation in Poland dealing with topic of human space flight (https://www.astronaut.center). She created a lamp simulating sunlight to synchronize daily rhythms.

1.2 Get to know our idea!

Alldream Lunar Institute is an ultra modern multi-specialized medical facility with the access to the state-of-the-art equipment. It resembles (in morphology and function), a mitochondrium to highlight the strategy widespread in nature for inhabiting new environments in a symbiotic way. The main function of this unit is to bring safety for living communities on the Moon. It is intended for taking care of emergency medical conditions that may occur among people living on the Moon. But also other discomfort situations relevant to health. It is created for all those, who come to the Moon and who are not necessarily able to cope with the new environment and challenges. Moreover, due to advanced lab and up-to-date devices it acts as a research and experimental institute focused on all deep-space projects, which cannot be done on Earth or on the cis-lunar orbit. Residents that stay in our Home on the Moon can spend time together in specifically arranged set of buildings, where they can develop their interests and skills in multiple activities.

The idea of Alldream Lunar Institute came to our mind, when we started to think about our talents and interests. We are all interested in science, technical advancement and we have a future medical doctor in our team. Taking into consideration the principles of the project we decided to create a place, which would connect healthcare facility, research unit and center of activities and recreation, so every resident of our Institute would feel like home.



It is supposed to be not only a hospital, but also a research facility, because of the need of conducting all the new experiments that cannot be performed on humans anywhere else. Nowadays, Space Biology and Space Medicine are the basis for any space tourism, colonization and journey to the Deep Space and not everything can be done on Earth nor in orbits. Due to our Institute there will be a possibility of development of new technologies and research methods in the field of medical telerobotics and automation. What is more, experiments performed within the Institute will enable the colonization of the Moon and other celestial bodies in space thanks to the new scientific discoveries about the human body and new branches of space medicine. Top-class scientists working in our Institute could make a contribution to the development of a new treatment methods of DNA mutations, genetic anomalies and other diseases that are difficult to treat on Earth. Also, projects conducted within the Institute will provide new workplaces in fields of STEM on the Moon and on Earth. Supposing that people traveled to the Moon and started living there, they would definitely need medical treatment given the conditions on the Moon and factor of isolation from terrestrial resources, which make our Institute an useful element of the future Moon society.

2 How our project should be implemented?

The Alldream Lunar Institute assembly on the Moon will take five years depending on technology readiness levels of incorporated technologies and financial power of contributing partners. The project implementation will consist on six phases. First four phases will be only robotic missions remotely controlled from the Earth and after launching the cis-lunar Operating Platform in phase 2, also from the lunar orbit.

The first phase will be critical for the rest of the assemblage. Several remotely controlled rockets will transport cargo for pre-deployment. Telecommunication antennae, security systems, energy plants and 3D printing reinforcement materials (for radiation shielding and sintering). Cargo will be specially designed to be ready for use just after successful landing on the lunar surface. During the phase 2 a robotic operator devoted specifically for the Alldream assembly will be launched on the cis-lunar orbit. The main function of the orbiter called Cis-lunar Operating Platform will be: (1) observation of the Alldream site; (2) 3D printers control; (3) backup communication from the Moon to Earth and (4) security systems. Phase 3 will launch 3 large robotic combine 3D printers on the Moon. Each 3D printer combine-harvester (harvesting lunar regolith), will be independent, remotely controlled, AI driven vehicle able to print all designed infrastructure. Estimated time for a printing process is three years. When the infrastructure is ready, phase 4 will start with transporting robots and automatic machinery to the Alldream base. Robots and machines will be stored in safe areas, prepared for the further assembly by humans. In the phase 5 there will be the first transport of humans to the Moon based on 100 experts: mainly engineers and a few medical doctors. This large crew will be responsible for all arrangement, testing and final assembly of the Alldream Lunar Institute. At the end, regular flights carrying people to the Moon will initiate the last phase 6.

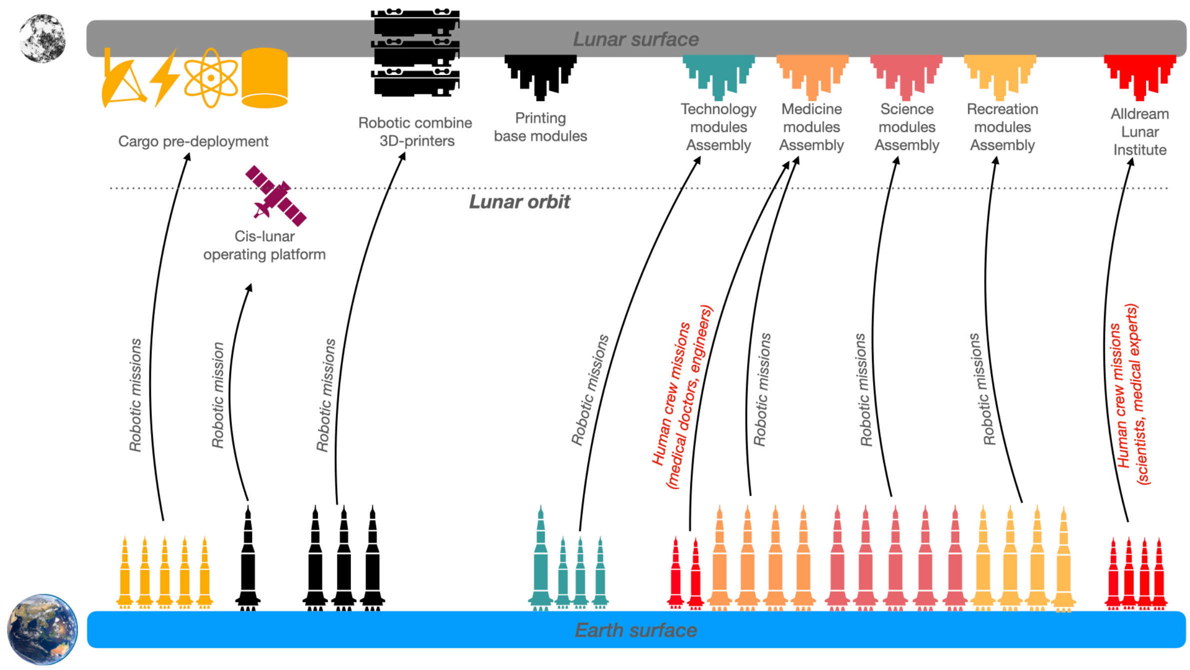


Figure 2: Alldream Lunar Institute roadmap

2.1 How should we start to build our Institute?

The first hospital building necessary for its proper functioning in terms of providing basic health services is the ER / ICU building. Initially, one of the operating rooms was part of this building, thus enabling emergency treatment not only with the use of pharmacological resources but also with the use of modern surgery. In one of the next buildings there had to be a room with a sterilizer, thanks to which it was possible to maintain aseptic conditions and use sterile equipment. The next step in implementing the project was the separation of the building to act as a medical laboratory with the equipment necessary for the analysis of samples taken from patients. Due to this it was possible to control the medical parameters needed to assess the health condition of patients. On the first floors of each of the buildings there were storage rooms for equipment - including those used for imaging diagnostics and bone density analysis, food, medicines and other resources needed for the basic functioning of the first buildings of the Institute.

The more people and resources were transported to the Moon, the more opportunities our Institute gained. The construction of new buildings allowed for the development of the hospital in order to provide more comprehensive assistance in a wider range of clinical cases, and to direct the staff's attention to the need for psychological help, scientific development and recreation.

The possibility of future journey to the deep space and the need for biomedical research, that is associated with it, generate the prospect of further development of the Alldream Lunar Institute.

3 Where it is located?

One of the most important things in choosing a place for a lunar base is to recognize the area before designing and constructing it. The Moon has a complicated topography of the terrain, which makes the task even more difficult. The average surface gravity is 1,62 m/s^2, daytime temperatures near the lunar equator can reach a 120° C (400 K), nighttime temperatures can reach -130° C (140K)[1]. These are conditions that make it impossible to survive without a properly designed base - a home that is designed to provide not only survival, but also comfort of use and potential for development and expansion.

In order to choose the location for the Family Home Outpost our task was to analyze six landing sites of Apollo missions[2]. During the Apollo 11 mission the first step of the man on the Moon was made. The target landing site was Sea of Tranquility. Going further Apollo 12 landed in the southeastern portion of the Ocean of Storms, Apollo 14 in Fra Mauro Highlands, Apollo 15 in Hadley Rille, Apollo 16 in Descartes Highlands and Apollo 17 in Taurus-Littrow region. These sites vary in terrain, geological profile, prevailing temperatures and many other parameters[3].

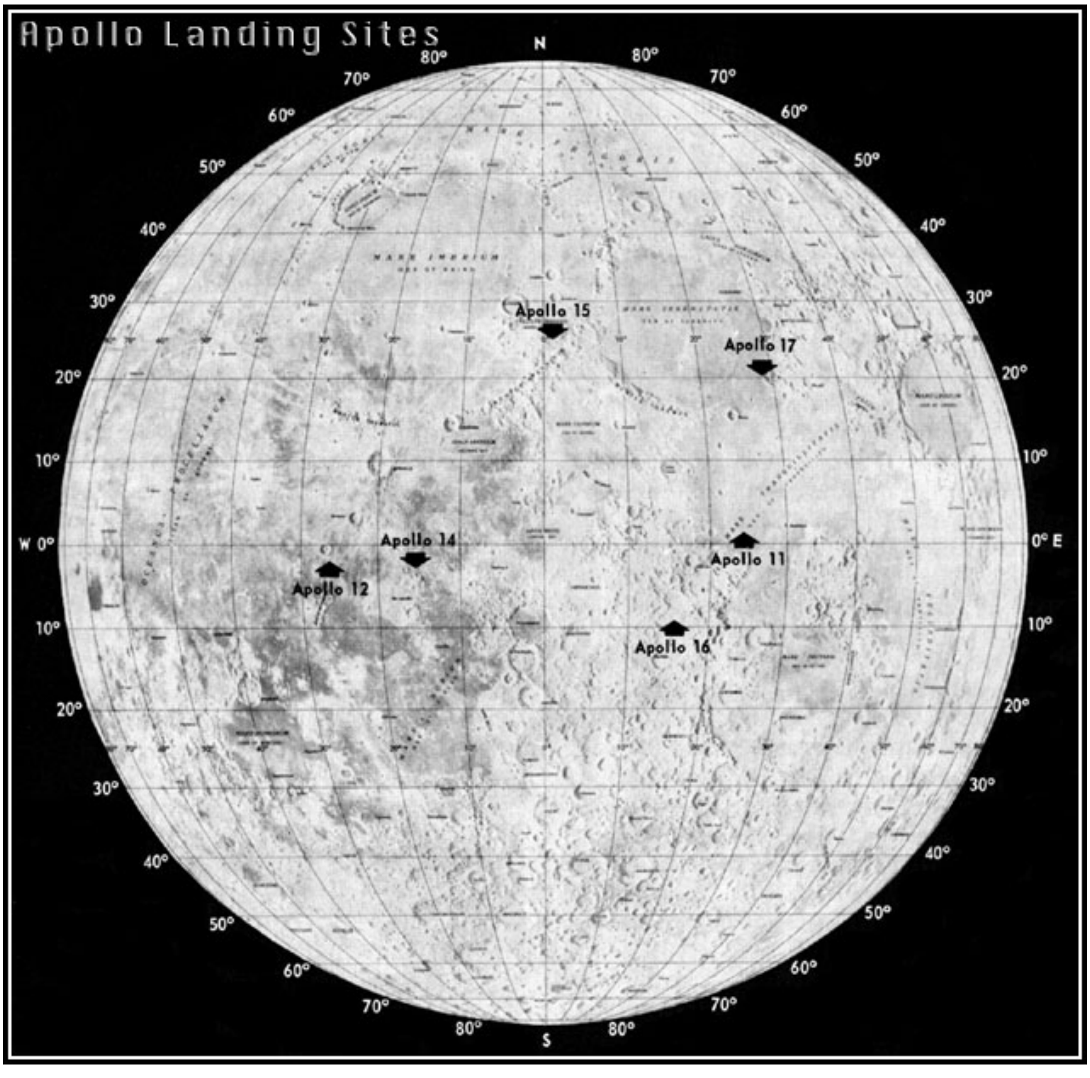


Figure 3: Landing sites[4]

In purpose of choosing one of the six available places to establish Family Home Outpost, basic (defining the location) parameters such as:

- landing site
- range of temperature
- length of day and night
- lunar gravity
- topography

were compared in table below.

Parameter	Apollo 11	Apollo 12	Apollo 14	Apollo 15	Apollo 16	Apollo 17
Degrees N latitude	0,67416	-3,0128	-3,64589	26,13239	-8,9734	20,1911
Degrees E longitude	23,47314	-23,4219	-17,47194	3,6333	15,5011	30,7723
Range of Temperature [$^\circ C$]	-150 to 120	-187 to 115	-193 to 105	not available	not available	-171 to 111
Range of Temperature text [K]	123 to 393	86 to 389	80 to 379	not available	not available	102 to 384
Lenght of Day	14 Earth Days					
Lenght of Night	14 Earth Days					
Lunar Gravity [m/s^2]	1,627	1,625	1,625	1,626	1,621	1,624

Table 1: Comparison of basic parameters [5] [6] [7] [8]

This data set shows that the temperature amplitudes and maximum values achieved may vary depending on the geographical location. The highest temperature amplitude is around the Apollo 12 landing site and is as high as 302 $^\circ C$. This is unfavourable due to the combined highest energy demand for night-time heating and daytime cooling systems. The lowest temperature amplitude was recorded during the Apollo 11 mission. For the landing site, the amplitude is 270 $^\circ C$, which in the case of the lunar base can result in significantly lower energy demand.

Lunar gravity is slightly different for each of the Apollo landing sites. The lower the gravitational acceleration value, the more fuel can be saved to send the rocket to the Collins station and more payload can be taken away. However, these differences are so small that they should have a slight impact on the decision to choose a landing site.

3.1 Apollo 11 Landing Site Topography

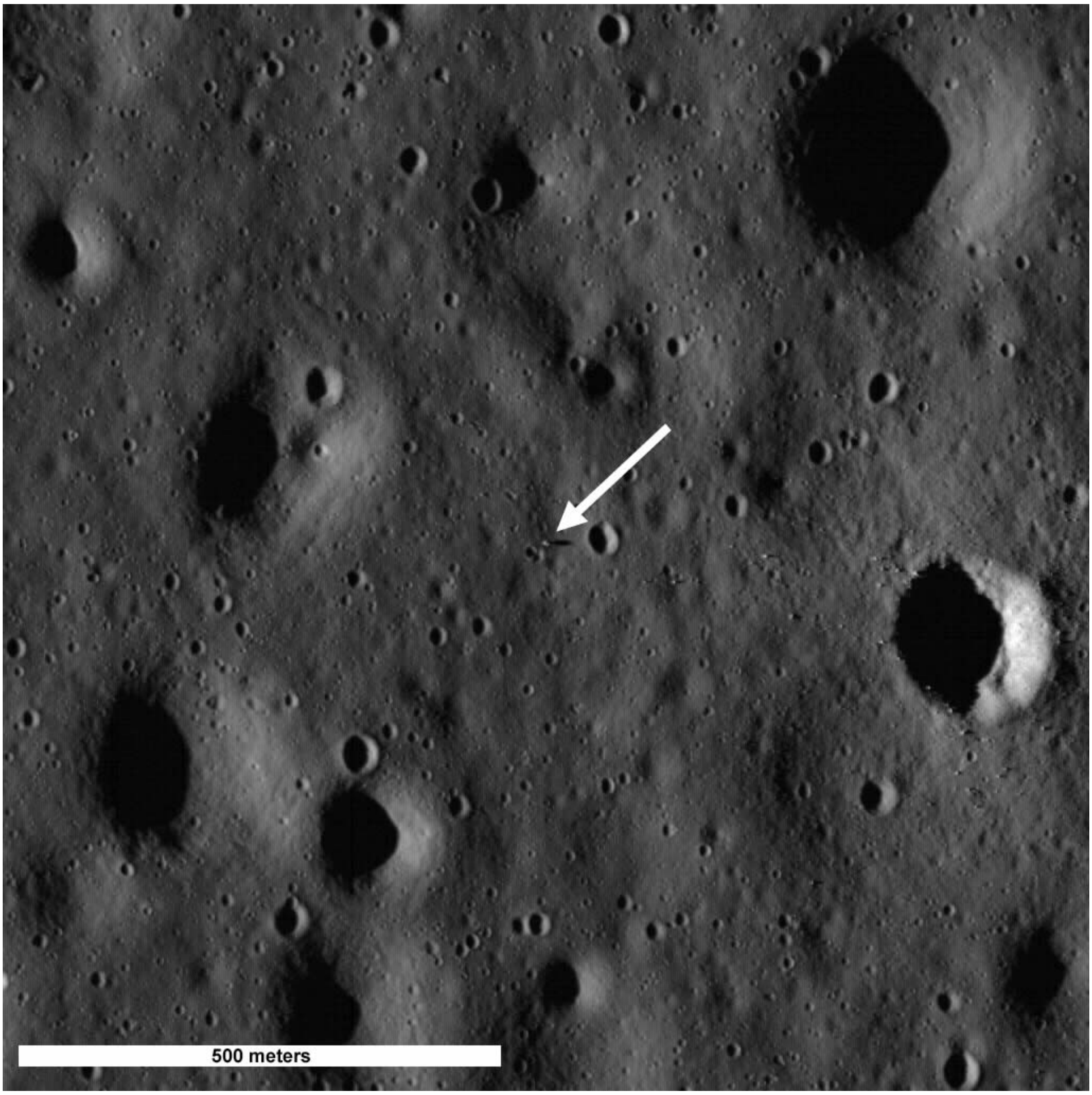


Figure 4: Apollo 11 landing site[9]

The landing point of Apollo 11 was Mare Tranquillitatis (Sea of Tranquility). It is a very large basin with a diameter of 876 *km*[10] (544 *mi*) and consists mainly of basalt. On a larger scale, the Apollo landing site is easily determined by craters in the vicinity. In the west there is a cluster of large craters, including Ritter and Sabine. To the north the craters Aldrin, Collins and Armstrong form a line from west to east, while to the south there is a Moltke crater. On a smaller scale the Apollo landing site is relatively smooth. There are craters in some places, but between them there is a large space for a potential Family Home Outpost. The lack of significant hills and mountains facilitates both the construction of the base as well as land communication and the possibility of potential expansion of the buildings.

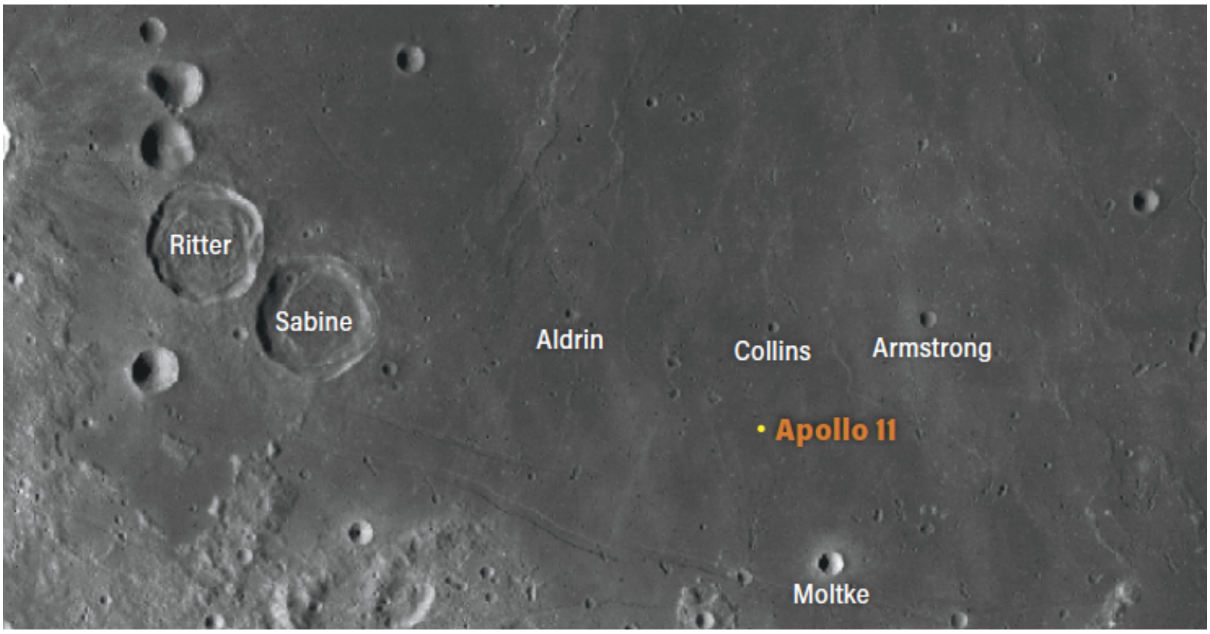


Figure 5: Apollo 11 landing site[11]

3.2 Apollo 12 Landing Site Topography

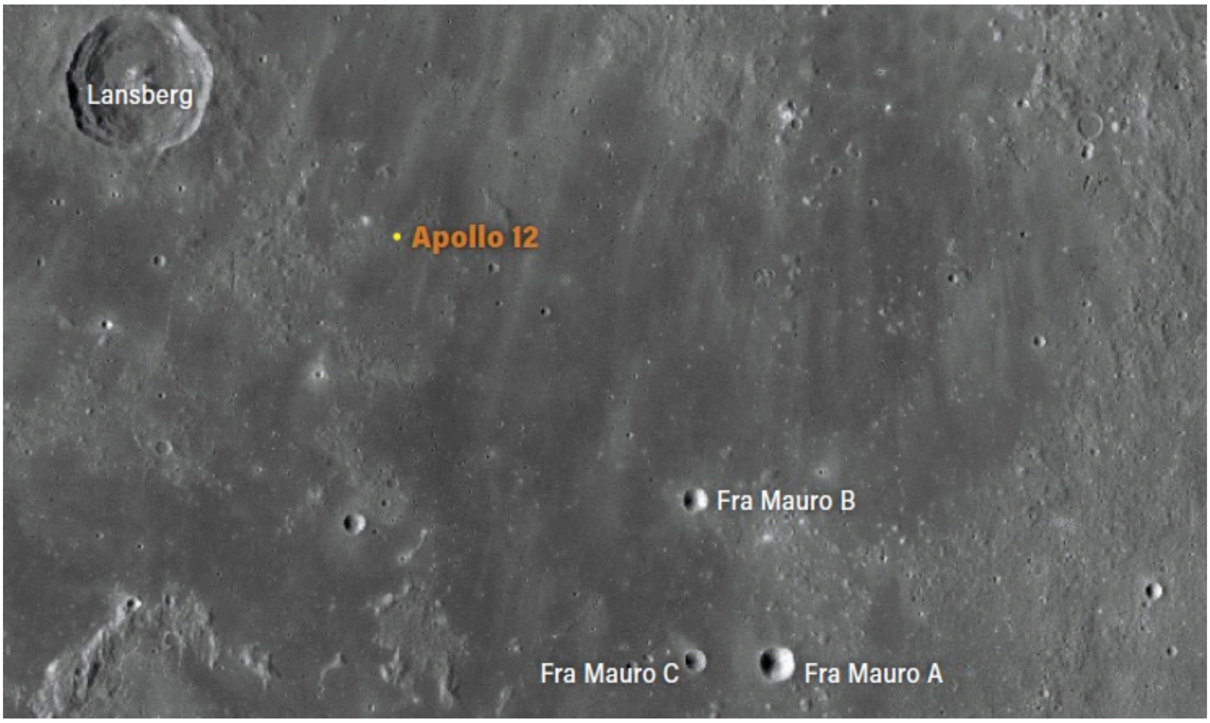


Figure 6: Apollo 12 landing site [11]

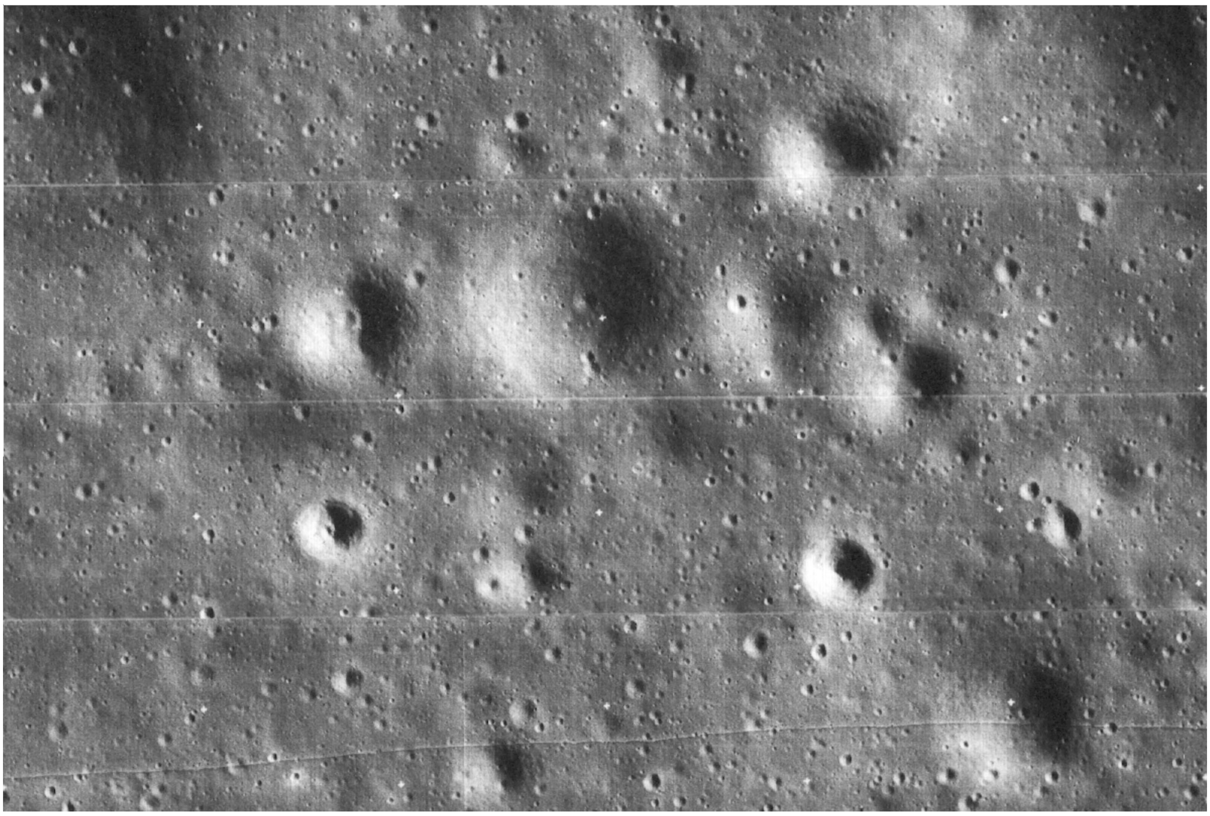


Figure 7: Apollo 12 landing site[12]

The Apollo 12 landing site is placed in the area called Oceanus Procellarum or Ocean of Storms. It's the largest lunar maria (Latin for sea)! That means it lays in a huge, almost plain terrain formed by solidified magma[13].

It's called Ocean of Storms for a reason - even thought Moon lacks atmosphere and Earth-like weather is not possible, there are storms caused by the solar wind. Eruptions from the Sun's surface are emitting electrons and protons, and other highly energetic particles into space and can cause space weather storms. In this type of storm, the solar wind particles are displacing Moon dust and sending it to space. It can also affect electronics, changing bit values or damaging it. The missing surface material is supplemented by rocks from meteor showers, that also occurs frequently in this area. Quite busy site[14]!

There are some soft hills and craters in the neighborhood so there's a place for facilities demanding various temperatures and insulation.

3.3 Apollo 14 Landing Site Topography

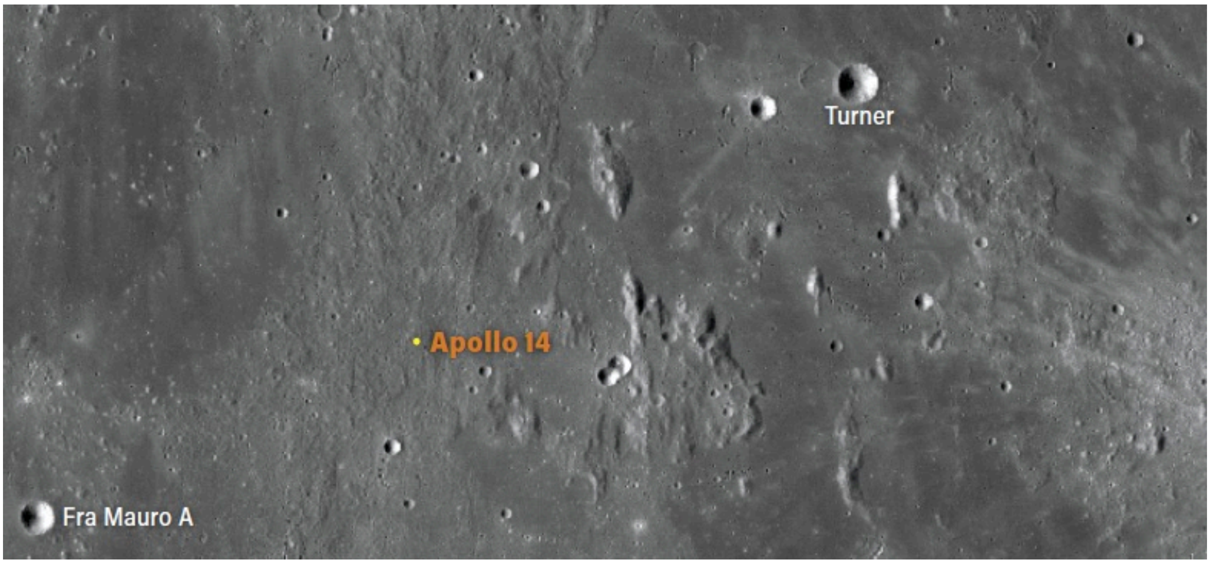


Figure 8: Apollo 14 landing site[11]

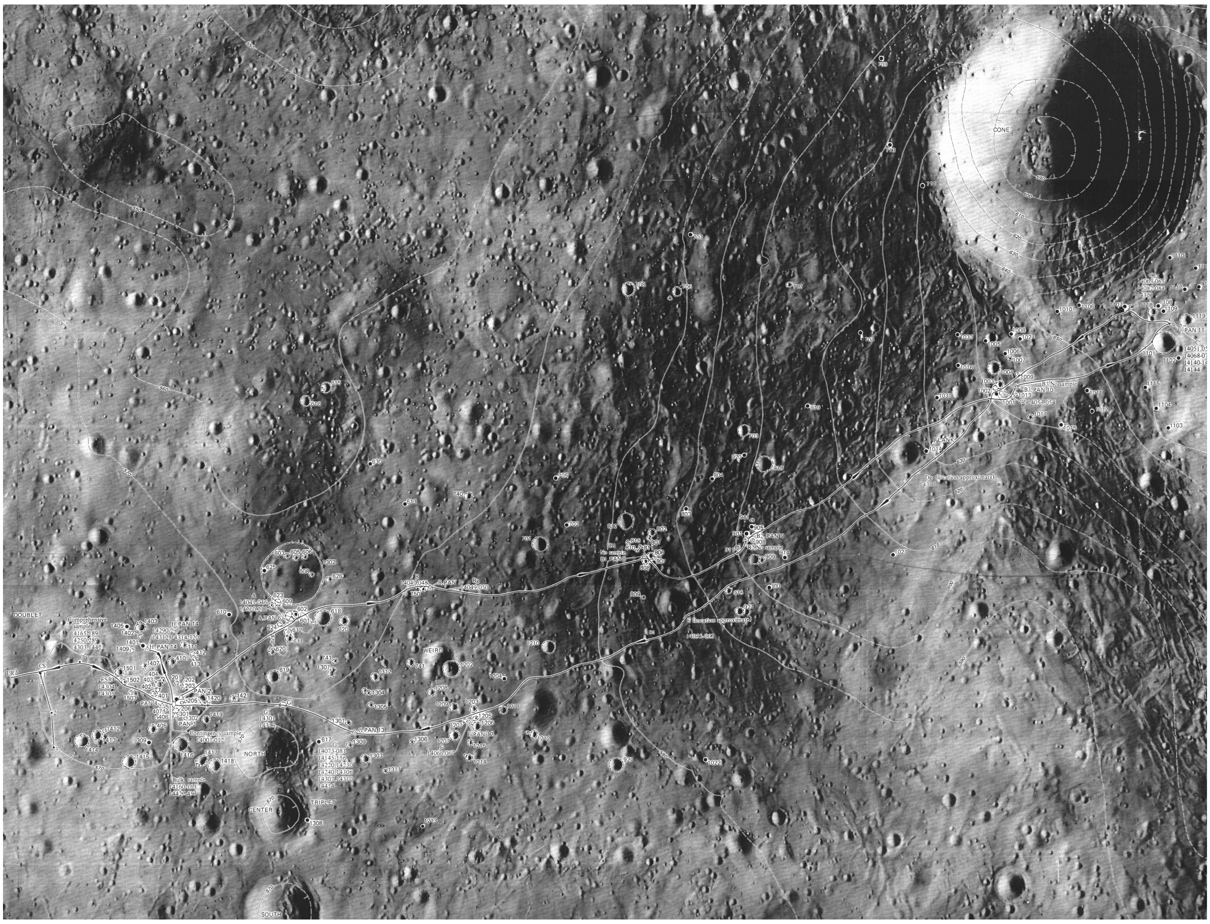


Figure 9: Apollo 14 landing site[15]

Apollo 14 landing site is located in Fra Mauro Highlands, which terrain is probably some kind of ejecta blanket formed by the creation of Mare Imbrium - the largest recognizable impact structure on the Moon. Currently, the ejecta blanket is covered by young rubble, meteoroid impacts and Moonquakes. On a smaller scale Apollo 14 landing site is to the west of the Cone Crater. It is a very difficult area in terms of establishing Family Home Outpost and land transportation. Most of the terrain between Cone and the landing point is covered by all kinds of craters, uneven terrain, and the terrain itself has variable heights in its immediate surroundings. For an astronaut this type of terrain can be very time-consuming, and setting up a base may require a lot of intervention in the surface without a guarantee of success[16].

3.4 Apollo 15 Landing Site Topography

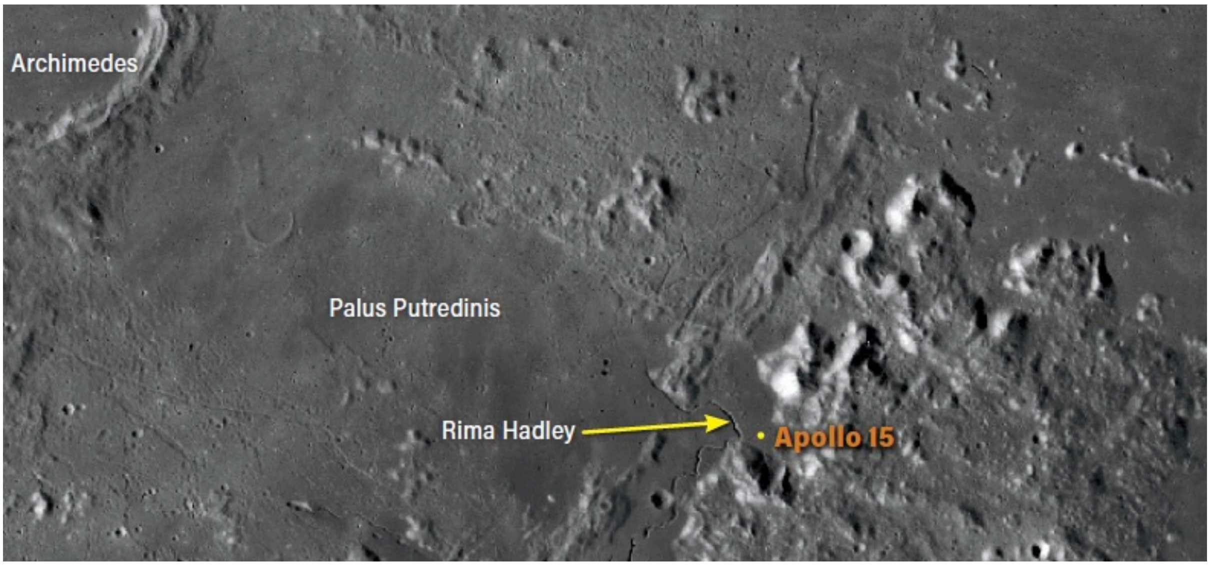


Figure 10: Apollo 15 landing site[11]

The Apollo 15 landing site is located between Montes Apenninus and Rima Hadley, a ditch on the surface of the Moon about 80 *km* long. It separates the landing site from the vast Palus Putredinis. Unfortunately, contact with this part of the area is very difficult due to the depth of the Rima Hadley reaching over 200m. Without building a bridge, it would potentially be possible to cross the ditch with locally less deep places in the north of the ditch. To the east there is the massive Montes Apenninus mountain range, which is extremely difficult, if at all possible, to cross. As far as the local terrain is concerned, there are a large number of relatively shallow craters and the surface is only slightly sloping.

Figure 11: Apollo 15 landing site[15]

3.5 Apollo 16 Landing Site Topography

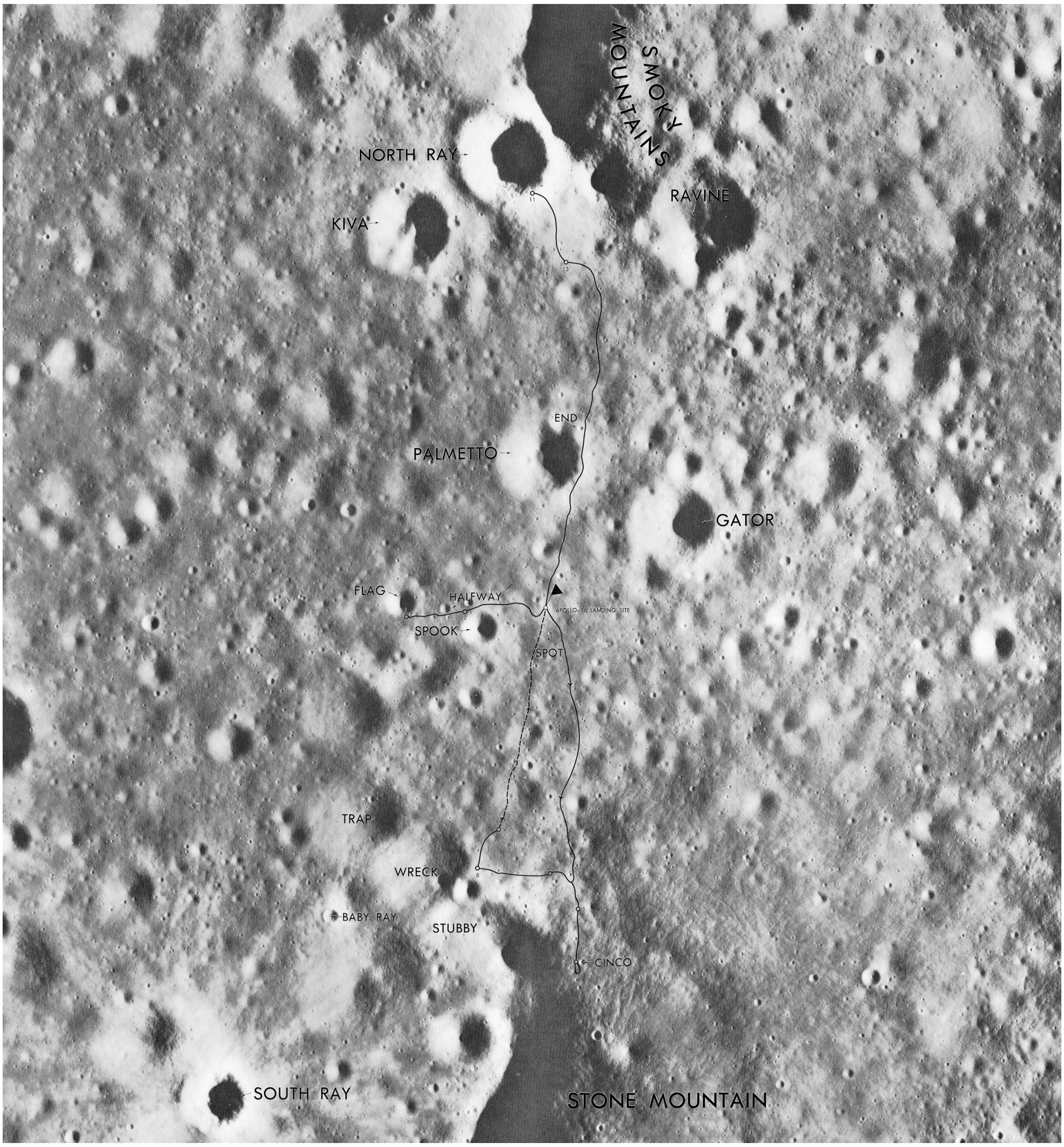


Figure 12: Apollo 16 landing site[15]

Apollo 16 landing site is located in a logistically challenging environment. Both to the north and south of the zone there are mountainous areas. To the north we have the Smoky Mountains, which can be quite difficult to travel. To the east there is a large area of craters and some hills, and to the south there is a large mountainous area that starts with Stone Mountain. These conditions are extremely difficult for conventional machines, rovers and astronauts on foot. The easiest way to get to Apollo 16 landing site is on the west side between North Ray and South Ray. Despite the potentially best route to get there, the area is still difficult both to navigate and to build Family Home Outpost.

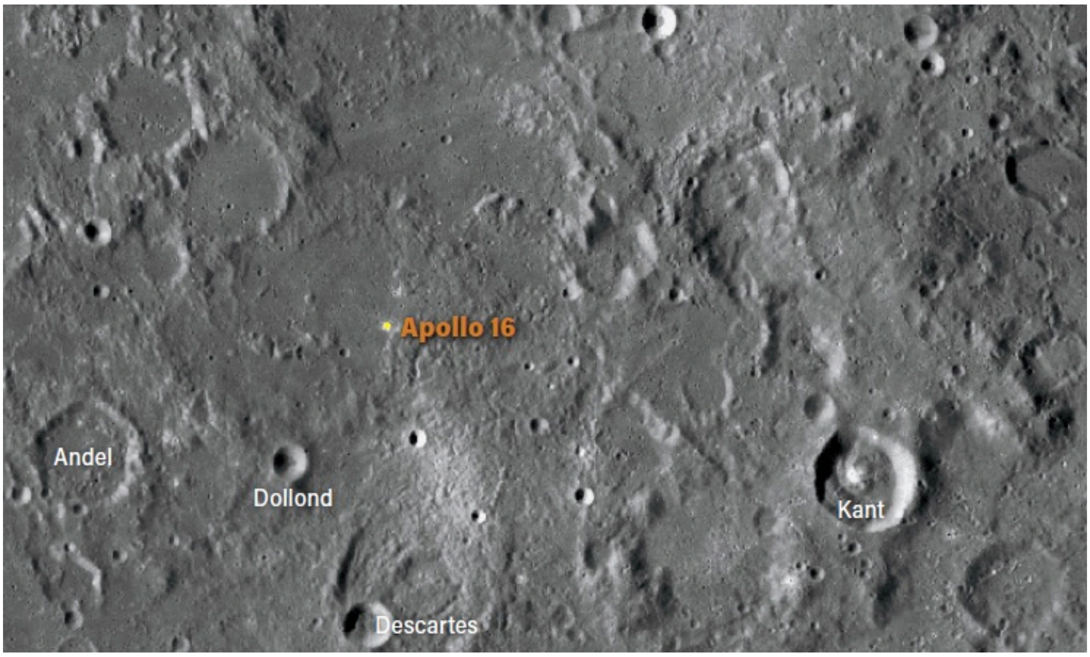


Figure 13: Apollo 16 landing site[11]

3.6 Apollo 17 Landing Site Topography

Apollo 17 landing site is located between three mountain ranges: North Massif, South Massif and Sculptured Hills. In a slightly closer environment, Apollo 17 is surrounded by craters and hills, and the whole area is located on sloping terrain. In order to get to the designated point with the bypassing of the mountain massifs you need to plan a trip between Family Mountain and South Massif. Otherwise, the journey to Family Home Outpost may be time-consuming and inaccessible to conventional rovers or astronauts.

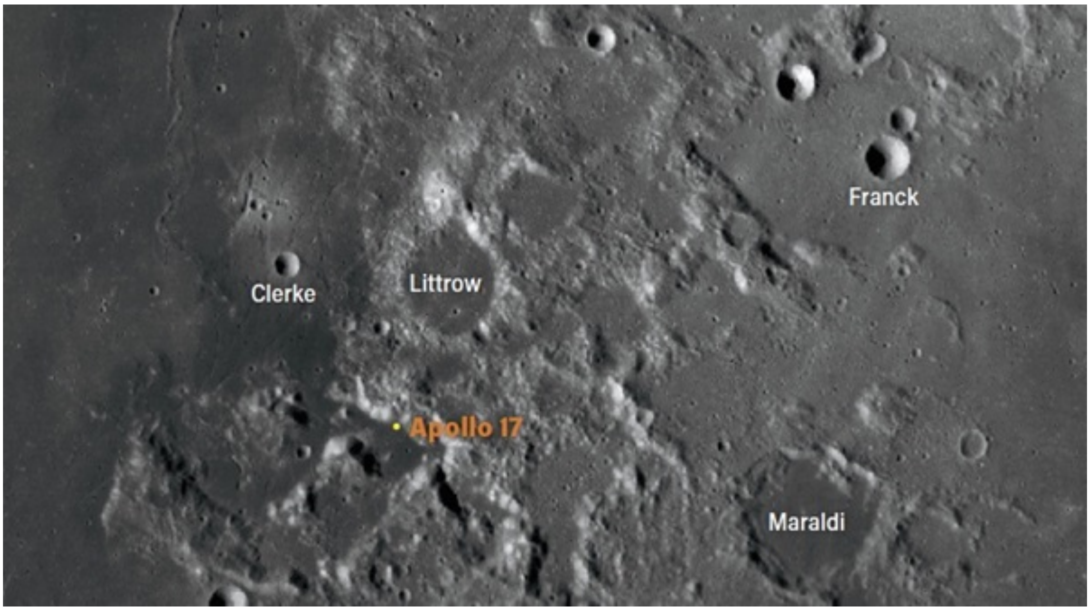


Figure 14: Apollo 17 landing site[11]

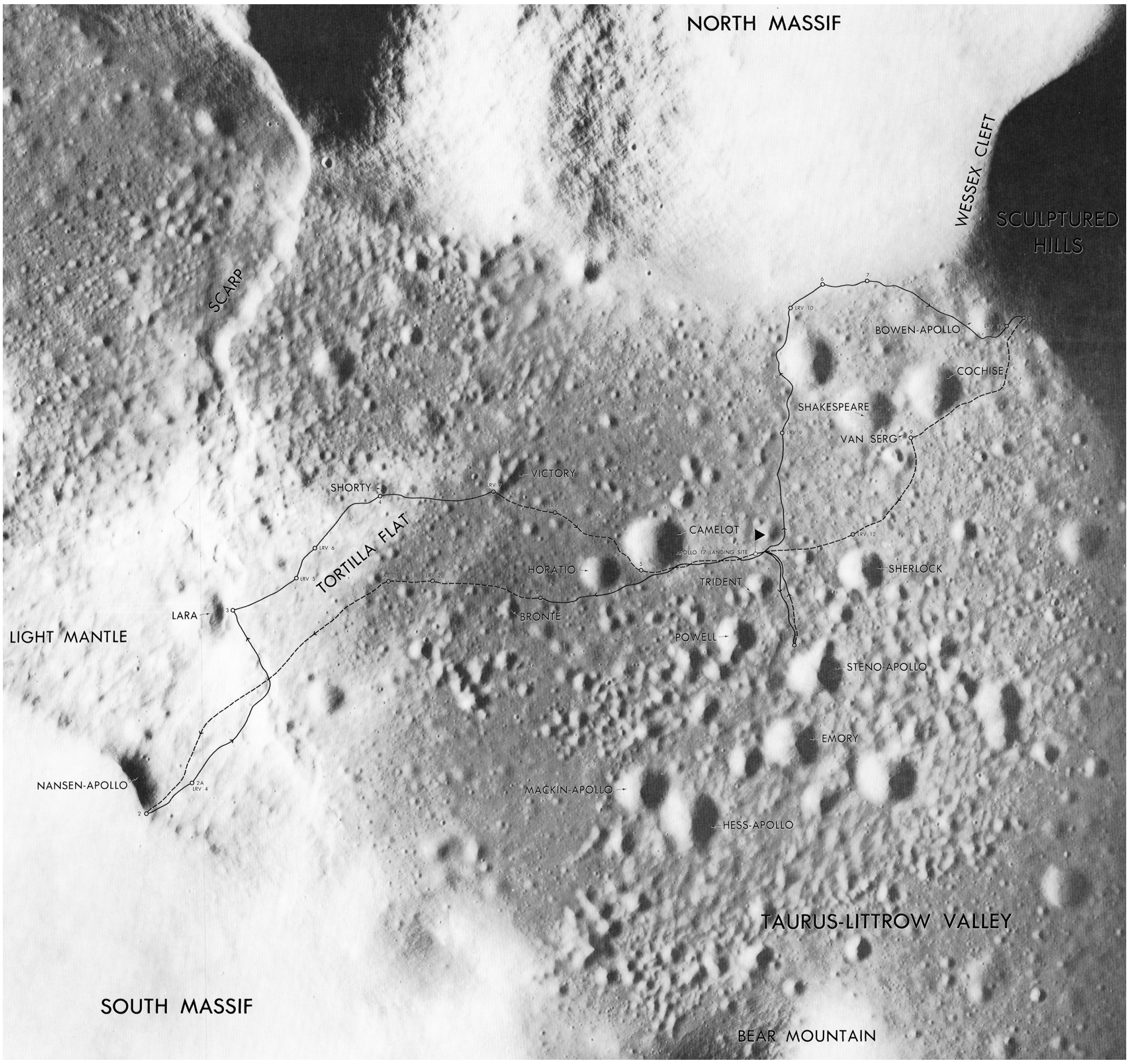


Figure 15: Apollo 17 landing site[15]

3.7 Our choice - Apollo 11 Landing site

The area where people laid foot on the Moon's surface for the first time is not only very important historical place that we want to commemorate. In our opinion it has optimal conditions to place a small colony, and Alldream Lunar Institute can be the heart of it.

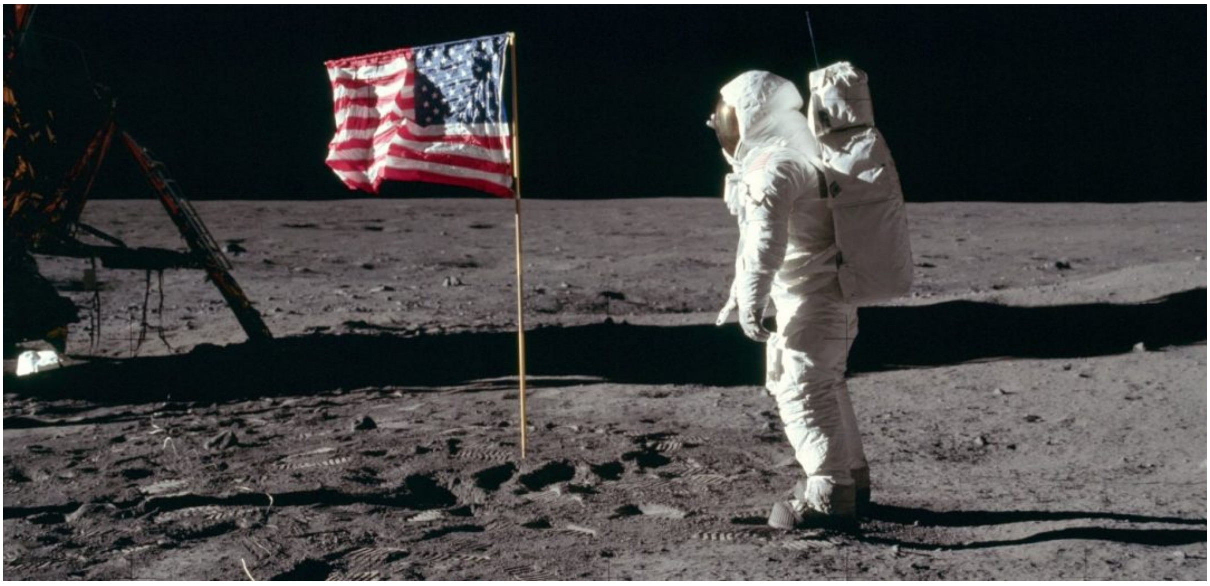


Figure 16: Buzz Aldrin on the Moon - Apollo 11 mission

As you can see in the comparison table at the beginning of location analysis, the landing site of Apollo 11 has the slightest difference in temperatures during the lunar day. Also the lowest temperature there is a little bit higher than lower limit on the other potential places. It's really convenient when it comes to sustaining comfortable temperature inside the base, really energy-efficient as air conditioning and warming is so power demanding.

Geographically the Apollo 11 landing site is very close to the Moon equator, so it's nearly equally distant from each of the pole facilities: The Buzz Aldrin Research Station and The Neil Armstrong Research Station. The Apollo 11 landing area is smooth, less than 2% slope[17], with rock chunks ranging from small stones to 0.8 m in size[18], so that if necessary, the terrain for the base will not be as much of a problem as at other Apollo landing sites. It's really important when we are building such significant institution. We want to help people from all-around the (lunar) globe as fast as it's possible!

To calculate the length of the road and the time needed to get from Family Home Outpost to the Aldrin Research Station in the Shackleton crater, the coordinates of both locations were established and then the necessary data on the Moon and Earth (for comparison) were collected.

Coordinates	Apollo 11	Shackleton crater
Degrees N latitude	0.67416	-89.54
Degrees E longitude	23.47314	0

Table 2: Coordinates of both locations[19]

Parameter	Moon	Earth
Polar Radius [km]	1736.0	6356.8
Equatorial Radius [km]	1738.1	6378.1
Mean Radius [km]	1737.4	6371.0
Ellipticity (Flattening)	0.0012	0.00335

Table 3: Other data of both locations[20]

From the Ellipticity value shown above, it can be assumed with a slight error that the Moon is the ideal sphere. The spherical law of cosines was used to determine the orthodrome between the two points of interest in order to establish the central angle between them:

$$\Delta\sigma = \arccos(\sin\phi_1 sin\phi_2 + cos\phi_1 cos\phi_2 cos(\Delta\lambda))$$

Where:
$\Delta\sigma$ is the central angle between two points
ϕ_1 is the first point latitude
ϕ_2 is the second point latitude
$\Delta\lambda$ is an absolute difference between longitudes of two points

After determining the central angle, a simple formula for the length of the orthodrome was applied:

$$d = r\Delta\sigma$$

Where:
d is the length of the ortodrome
r is the radius of the Moon
$\Delta\sigma$ is the central angle

To determine the time needed to travel between two points, a commonly known formula was used:

$t = \frac{s}{v}$

Where:
t is time
s is length between two points
v is constant velocity of the body

The calculated values are shown in the table below:

Parameter	Calculated Result
ϕ_1	0.67416
ϕ_2	-89.54
λ_1	23.47314
λ_2	0
$\Delta\lambda$	23.47314
$\Delta\sigma[rad]$	1.575198461
$r[km]$	1737.4
$d[km]$	2736.749806
$v[km/h]$	20
$t[h]$	136.8374903
$t[EarthDays]$	5.701562095

Table 4: Calculated values

4 How it is designed?

Healthcare and Research Unit of Alldream Lunar Institute is the most important part of the project. The hospital is planned to take care of the patients that need medical help as a matter of urgency and patients whose problems can be taken care of in the outpatient clinic. The main uniqueness of our hospital is presence of state-of-the-art robotic technology that uses artificial intelligence and smart software. Alldream Services System (ASS) with access via any personal device of every Moon inhabitant would provide the hospital system with medical information about the patients, facilitate the communication and limit the need of transport of the patients who do not need to be hospitalized.

However, patients who do need urgent medical treatment have an access to the newest achievements of medicine and technology. Robotic arms, robotic surgery, robotic nurses... We surely love robots and all the news from robotic and artificial intelligence field give us goose-bumps, that is why we wanted to use those extraordinary inventions in our Institute. Also a telemedicine system will allow us to connect with specialists from Earth which can help us to take care of our patients in case of lack of medical staff on the Moon. Cardiac arrest, shock, stroke, anaphylaxis, intracranial bleeding are just a part of possible medical problems that may occur among Moon residents. Newest technology and presence of top-class medical doctors and scientists make our healthcare facility the place, where every patient would feel in safe custody.

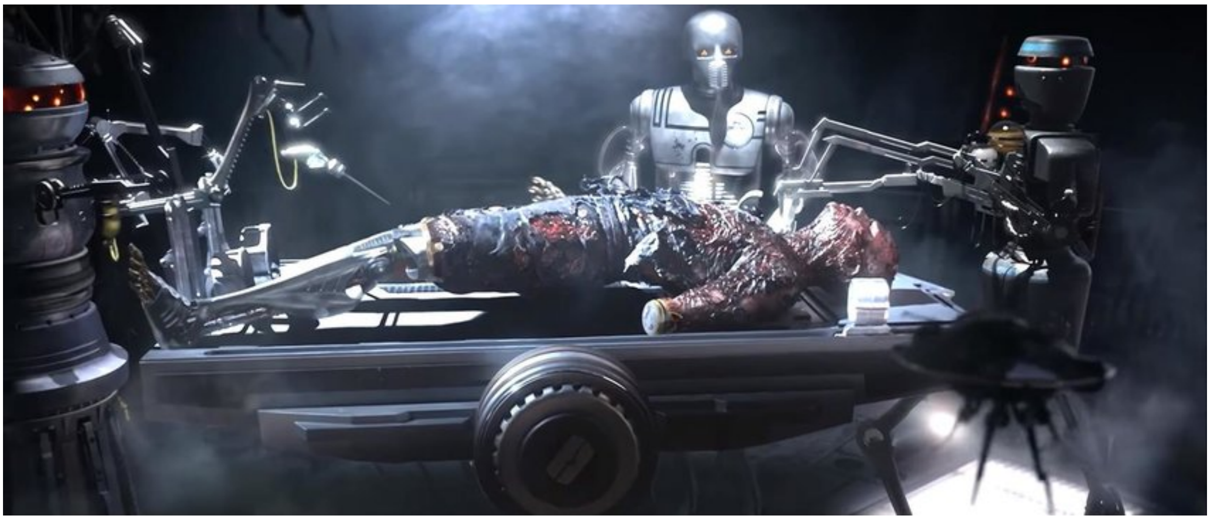


Figure 17: Robotic surgery in Star Wars Episode III: Revenge of the Sith. We hope in your hospital it would look less... invasive?

4.1 Meeting the competition rules

The basic assumptions of our work were determined by the competition requirements. Below is a list of the most important sub-points with a brief reference to how they were met in our project:

- *Three crewed stations have been established to support lunar activities.*

  The Collins Orbital Gateway is located in a high orbit around the Moon and serves primarily as a way-point and depot in traveling from Earth to the Moon and back. People and high value items from Earth arrive at Collins and are repacked for delivery to the lunar surface.

  The Neil Armstrong Research Station is located near the lunar north pole due to the presence of water and lava tubes that simplified the initial construction of the station.

  The Buzz Aldrin Research Station is located at Shackleton Crater at the lunar south pole due to the presence of significant water resources. Aldrin serves as the primary terminal for transportation and supplies to the surface, as well as the supply head for lifting fuel to orbiting spacecraft.

  Our hospital was located at the optimal distance to other places designated by the competition organizers. We have considered two potential solutions at our Institute - one in which the hospital is dependent on The Neil Armstrong Research Station and The Buzz Aldrin Research Station for providing some of the resources necessary for life support (as it is running) and the hospital as a self-sustaining unit due to the high risk and the need to ensure continuous operation. They are presented in the following chapters along with the way of transporting people and goods between them.

- *Construction of the FHOs will be primarily by the use of large-scale additive manufacturing techniques, also referred to as 3-D printers, using the lunar regolith as a base material. Construction will be conducted by partner contractors.*

  Lunar soil is the best raw material for building a base, as we have it in abundance, and the current development of 3D printing from the soil allows us to be calm about the possibility of using this technology on the Moon. Key constructions can be made by 3D regolith printing using printers placed on rovers, machines or robotic arms. The roof surface is rounded in order to reduce sand deposition and thus avoid extra loading conditions.

  Our Institute consists of ready modules which are covered with an appropriate layer of 3D printed regolith. This method will allow to simplify the construction thanks to the possibility of bringing ready-made elements necessary to create the foundation of the building, and on the other hand, will allow for a significant reduction in construction costs, thanks to the use of in-situ materials as well. A thick layer of regolith will fulfill several functions. It will protect against radiation, provide a thermal insulation layer, protect sensitive parts of the hospital from debris, micrometeorites and other elements, and additionally strengthen the building structure, which due to the significant pressure difference will have to be highly durable.

- *Lunar Positioning Satellites (LPS), a system of satellite navigation similar to Earth's GPS, has been established allowing for very accurate robotic operations accessible from every part of the lunar surface.*

  Very high bandwidth electronic communications between and among people at Collins, Armstrong, Aldrin and Family Home Outposts (FHO) locations will be conducted through the data function of the constellation of LPS satellites.

  We presented the architecture of the systems in the base, taking into account not only the communication inside the hospital, but also between the hospital and other homes or research stations on the Moon, as well as direct communication with Earth.

- *A suborbital transportation system has been created that allows for access from Aldrin to any outpost in under three hours. This system is designed primarily for emergency use. Consider it to be similar in function to a Life Flight helicopter.*

  For the standard movement on the Moon, we have planned lunar rovers, also in the version of lunar ambulances. Near the hospital, there is a landing strip for suborbital aircrafts that will enable faster transport between remote locations on the Moon for emergency use. Due to the specific nature of the hospital's operations, it is a very important functionality.

- *A ground-based robotic rover transportation system provides deliveries of high value materials and supplies to each FHO every month. The hub for this system is located at Aldrin Research Station.*

  We assumed the delivery of the necessary materials once a month. Both everyday items and medical equipment have been calculated with the appropriate stock.

- *Power is supplied to each family outpost by solar panels throughout the lunar day and by batteries throughout the lunar night.*

  Taking into account the high risk related to the lack of access to electricity in our hospital, we took into account additional power sources.

- *A human-rated rover vehicle and space suits will be provided for the use of residents and guests for the purpose of local excursions.*

  We have provided the possibility of direct entry to the hospital through two locks for rovers prepared for this purpose, thanks to which the procedure of entering the hospital will be simplified and will not require the use of appropriate suits. It is especially important in cases of immediate health and life threat, when putting suits up may be difficult or impossible. For this reason, we also suggest that every building on the Moon has a similar entrance for rovers.

- *A remotely operated rover capable of autonomous operations will be provided assist in maintaining surveillance of the Apollo landing site.*

  We assumed several rovers located in close proximity to clusters of houses, which will allow us to shorten the travel time to the hospital, by avoiding the need to leave the hospital as a starting point. To enable first aid, these rovers are equipped with basic medical equipment.

- *Robots for the purpose of cleaning, maintenance, etc., will be provided according to your specifications.*

  The main goal of the hospital was to achieve the maximum level of automation and robotization, due to the limited number of available personnel.

- *Travel time from the most remote FHO to Earth under the best possible conditions will be approximately four days.*

  The hospital is supposed to be a response to the need for quick assistance. Returning to Earth may be impossible in most cases of life and health threats due to the travel time and risks associated with it.

4.2 Our assumptions

In addition to the requirements imposed by the competition rules, we also compiled our own assumptions, which helped us design the final concept of our Alldream Lunar Institute.

1. **Short distances**

   We assumed that all FHOs should be built close to the Alldream Lunar Institute as it is the only way to be able to provide needed help to all inhabitants of the Moon in a short-enough period of a time. For safety reasons all buildings should be built in a maximum distance of about 2 *km* to ensure that time from calling for help to be in an emergency room will be less than 45 minutes.

2. **Simplified construction**

   To simplify the structure, the Institute should consist of ready-made modules covered with a thick layer of 3D printed regolith. The modular structure is extremely important, as it ensures safety on the one hand, as all buildings are separated from each other by airlocks, and on the other hand allows for easy continuous development of the Institute.

3. **Emergency exits**

   To ensure safety, all building should have at least 2 exits. This allows for efficient evacuation in any emergency case, avoiding problems with moving around the base and, what's more, allows you to quickly move between any buildings.

4. **Moving to the hospital without spacesuit**

   One of our priority is to simplify the transport between the FHOs and Alldream Lunar Institute. We are proposing two airlocks - entrances for rovers, which allow transport to the hospital without the need of wearing the suit. This is especially important in an emergency case, when there is no time for it and/or it is impossible to wear the appropriate suit. For this reason, all buildings on the Moon should have a similar solution.

5. **Population of the Moon**

   In order to make the appropriate calculations, we assumed a hypothetical number of the Moon's inhabitants of 200 people. Everyday in the Institute there will be minimum 22 members of staff, half of which are medical personnel and the other half of the scientists responsible for research projects.

6. **Medical equipment in every FHO**

   As it can be difficult to provide medical assistance, we suggest also to take into account the basic medical equipment in each home.

7. **Main activities on the ground floor**

   As our project is a hospital and patients can demand special conditions, we wanted to avoid high buildings. For this reason, each building consists of a ground floor, which houses the entire medical and day part, and only one floor, where research is carried out as part of the Exoplanetary Laboratory of Sustainable Life activities.

8. **Multifunctional institution**

   The main goal of the facility is to provide help in emergencies. However, our Institute should be multi-functional and should take care of regular health checks of all residents, as well as conduct research.

9. **Minimizing the amount of personnel**

   Due to limited capacity, a minimum number of personnel must be sufficient in the hospital. All possible activities should be automated. The use of robots is crucial to achieving maximum efficiency and productivity with limited resources.

10. **Redundancy**

    Another requirement is security. This must be achieved through the appropriate design and redundancy of all systems. The institute should be self-sufficient as much as possible.

11. **Comfortable conditions**

    The last important assumption is to adapt the Institute to the needs of employees and patients. The hospital should provide comfortable conditions for work and convalescence, and should also take care of the mental health.

4.3 Risk assessment

In such a project, safety is a priority. We conducted a short analysis that helped us identify the most important problems. Thanks to this, we were able to take into account preventive measures already at the design stage.

Short Name	Description	Likelihood / Severity	Mitigation
Meteorite impact	When a meteorite hits a building wall (made of 3D printing) can be damaged and unsealed.	Unlikely / High	The buildings have been placed partly under the surface of the Moon, which will ensure effective protection of the lower floors against damage. The part of the building protruding above the surface has been covered with a thick layer of regolith, which is supposed to take up most of the impact energy.
Cover leakage	A wall printed in 3D technology can become mechanically damaged, which can lead to air and water leakage.	Unlikely / High	The walls of buildings are regularly inspected by pressure sensors and strain gauges. If a discrepancy is noticed, the room is taken out of use and renovated. In case of sudden leakage, the room is automatically closed and an emergency team is dispatched if residents are present in the room.
Water leakage	Water can leak from the hydraulic system and flood rooms.	Possible / Low	Near the components of the hydraulic system, sensors are installed which cut off the water supply with the shut-off valves if a prolonged leakage of water is detected (a distinction is made between accidental water leakage and serious leakage).
Fire	A fire can occur through damage to electrical equipment, chemical reaction and inadvertent entrapment of fire	Possible / High	In order to avoid risks, fire detectors are installed, which are simultaneously connected to the hydraulic system to extinguish the fire. Flammable substances are kept in a separate insulated room in prepared containers. It is forbidden to bring in devices which may start a fire, e.g. lighter, burner, without special permission. In the event of a fire in the room, after the residents leave it, the safety locks are closed.
Electrical short circuit	When using electrical equipment, an electrical short circuit may occur, which can lead to fire or electric shock to residents.	Possible / Low	In order to eliminate the risk, all electrical equipment must comply with a specially selected standard, which consists of adequate insulation of both the wires and the equipment itself. Protective clothing must be worn in case of repairs.

Short Name	Description	Likelihood/ Severity	Mitigation
Air contamination	The air may be contaminated or its components may be in incorrect proportions.	Possible / Moderate	In order to purify the air in each room there is an air purification system and air quality sensors which regulate the mixture in case of non-compliance with the optimal air composition.
Failure of critical communication systems	In case of failure of communication systems, communication with the station in orbit of the Moon and the command unit on Earth may be lost.	Unlikely / Low	In order to eliminate the threat, the standby communication systems were duplicated. During important operations, both systems will be used, and in case of a complete lack of communication, the rescue team will go to the nearest lunar habitat.
Temperature control system failure	In case of a temperature control failure, hospital residents may die from overheating during the lunar day and freezing during the lunar night.	Unlikely / High	The sensors were duplicated to control the temperature. Insulators such as quartz glass fibers and aerogels were used to avoid overheating. To avoid freezing, a battery pack was used, but if the batteries fail or need to be saved for the first few days, it is possible to heat the rooms with hot water heated during the lunar day.

Table 5: Risk assessment

4.4 Capturing the entire scope of the project

As working with complex projects demands capturing the entire scope of the project. It is important to find the relationships between the product and the functional work allocation.

That's why we prepared basic version of the System Breakdown Structure (SBS), which is a logical decomposition of the system. We considered what we need to include in our project to make it fully capable to perform the designed function. We divided the graphics into 3 parts which present Lunar Hospital, Care and Recreation Unit and Exoplanetary Laboratory of Sustainable Life.

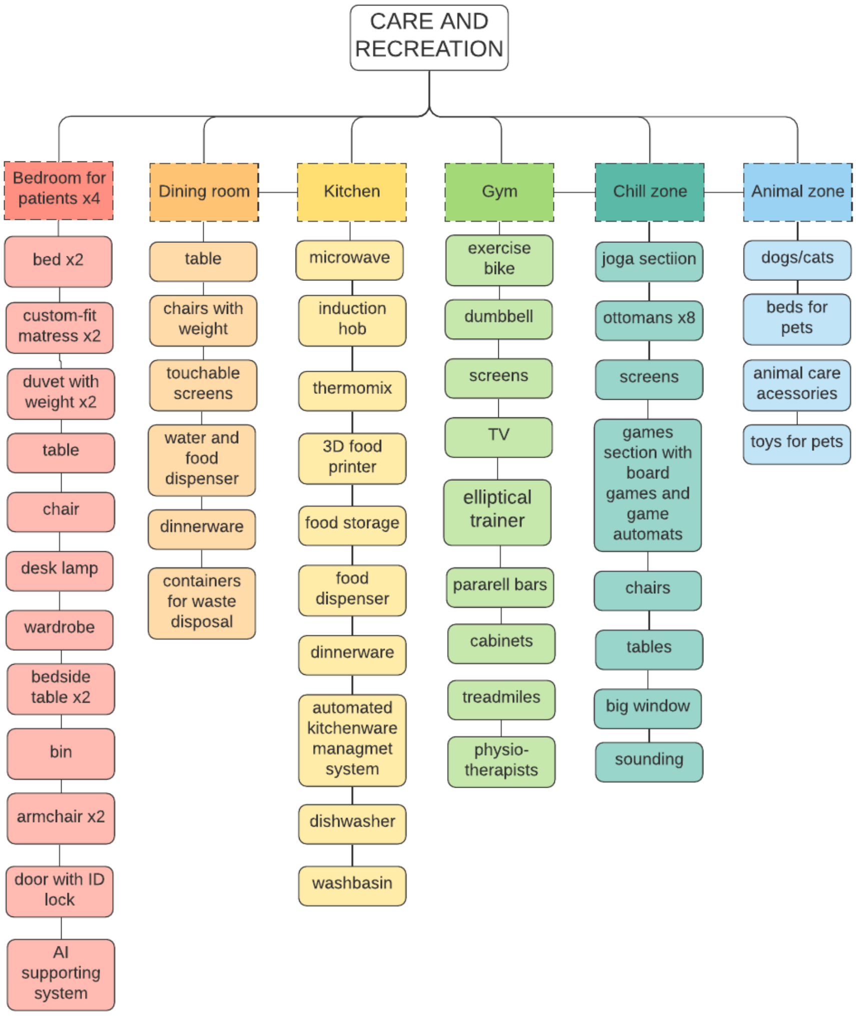


Figure 18: SBS of Care and Recreation Unit

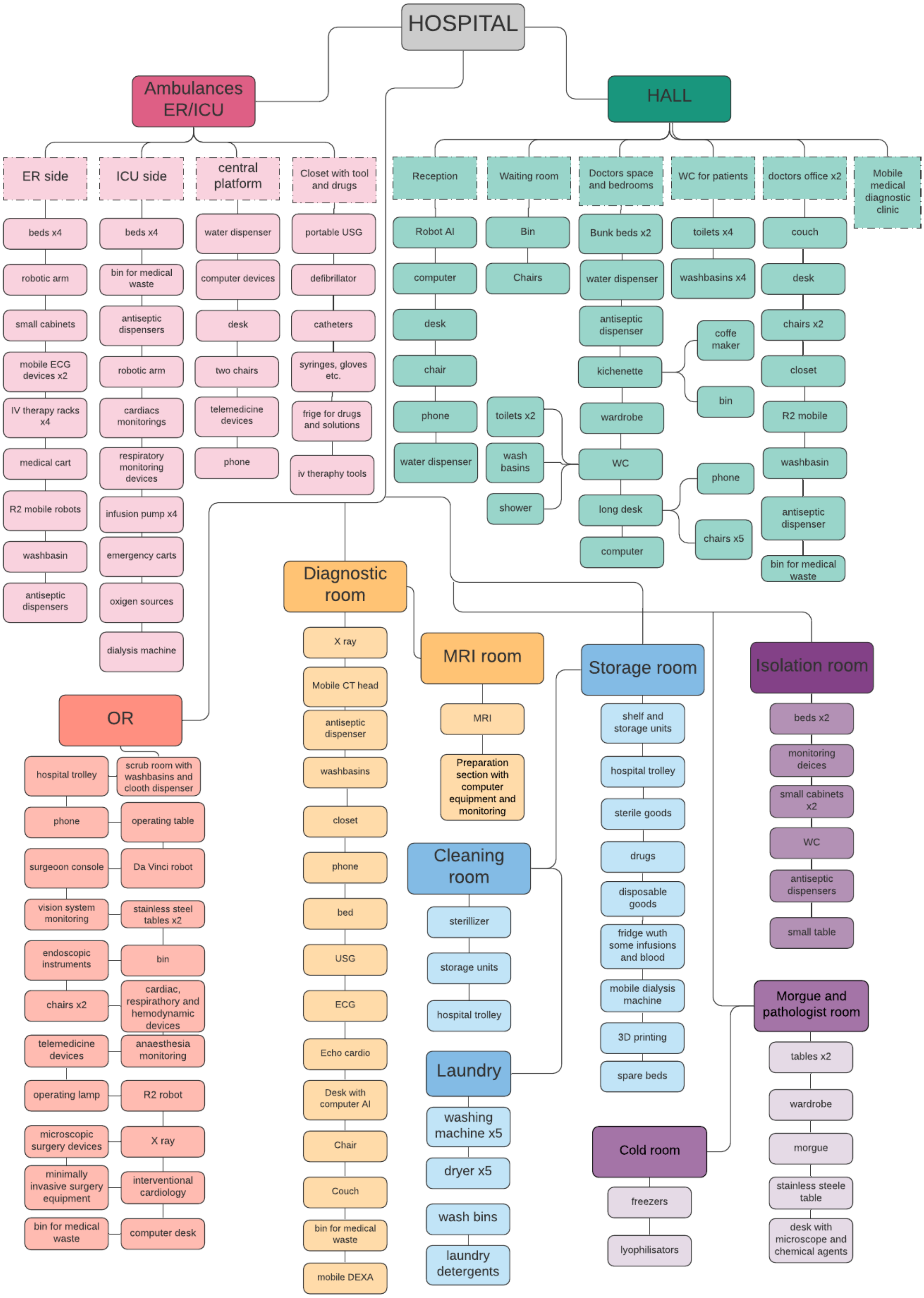


Figure 19: SBS of Lunar Hospital

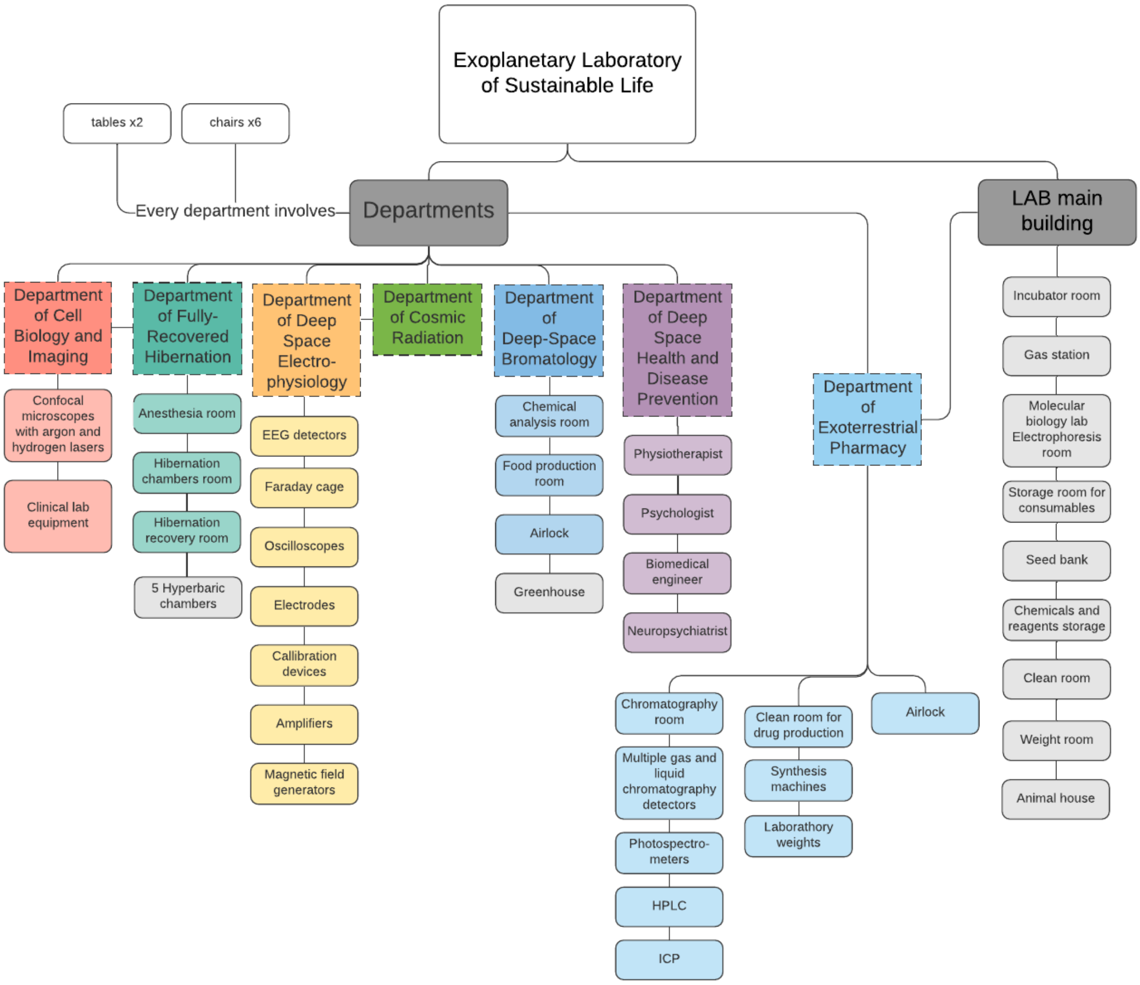


Figure 20: SBS of Exoplanetary Laboratory of Sustainable Life

4.5 How it is built?

Competition rules points that construction of the FHOs should be using of large-scale additive manufacturing techniques, also referred to as 3-D printers, using the lunar regolith.

Lunar soil is the best raw material for building a base, as we have it in abundance, and the current development of 3D printing from the soil allows us to be calm about the possibility of using this technology on the Moon. Key constructions can be made by 3D regolith printing using printers placed on rovers, machines or robotic arms.

Our hospital consists of modules of three sizes, defined by the area of the room on the ground floor. They are connected by overground corridors in such a way that each building has, for safety reasons, at least two exits with airlocks. These modules are covered with an appropriate layer of 3D printed regolith. This method will allow to ensure an appropriate degree of cleanliness in the base and simplify the construction, thanks to the possibility of bringing ready-made elements necessary to create the foundation of the building, and on the other hand, will allow for a significant reduction in construction costs, thanks to the use of in-situ materials for protection against radiation. A thick layer of regolith will fulfill several functions. It will protect against radiation, provide a thermal insulation layer, protect sensitive parts of the hospital from debris, micrometeorites and other elements, and additionally strengthen the building structure, which due to the significant pressure difference will have to be highly durable. The roof surface is rounded in order to reduce sand deposition and thus avoid extra loading conditions.

The presented simplified cross-section shows both floors of the building, a corridor with an airlock, module walls and a layer of 3D printed regolith.

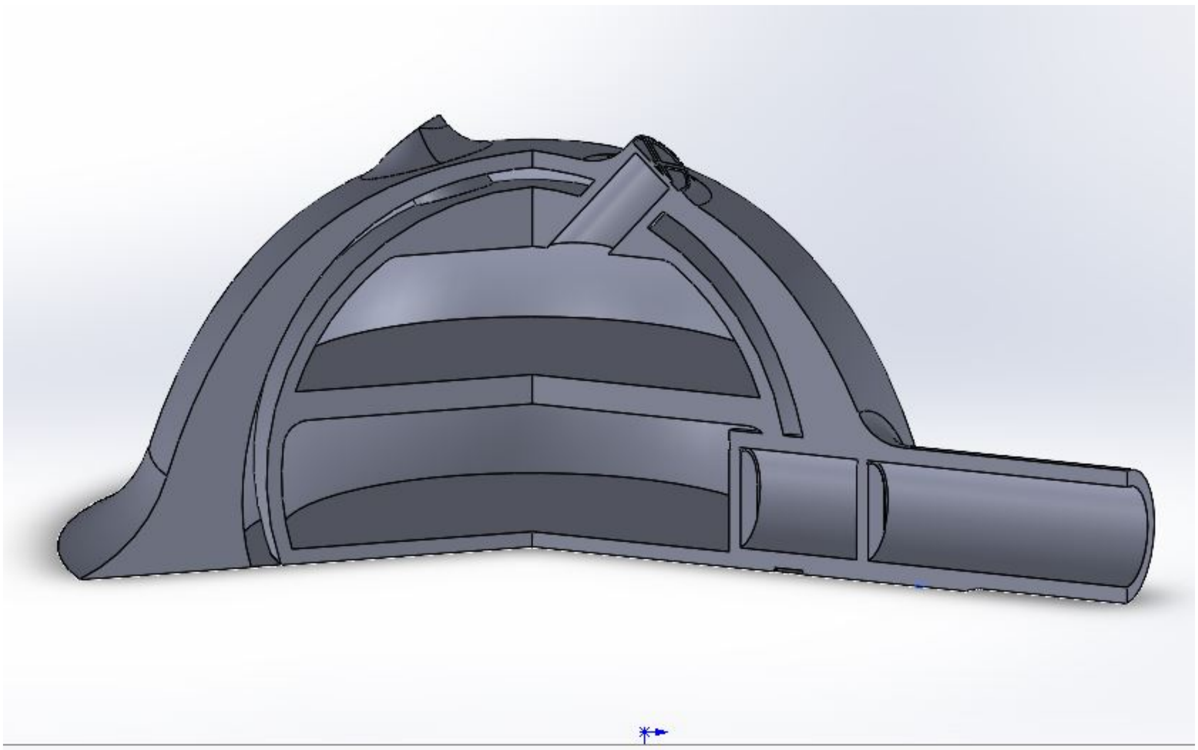


Figure 21: Cross section of a building

4.6 Take a peek inside our project

This is what a simplified 3D model of our hospital looks like. It shows the location of all buildings and communication corridors between them.

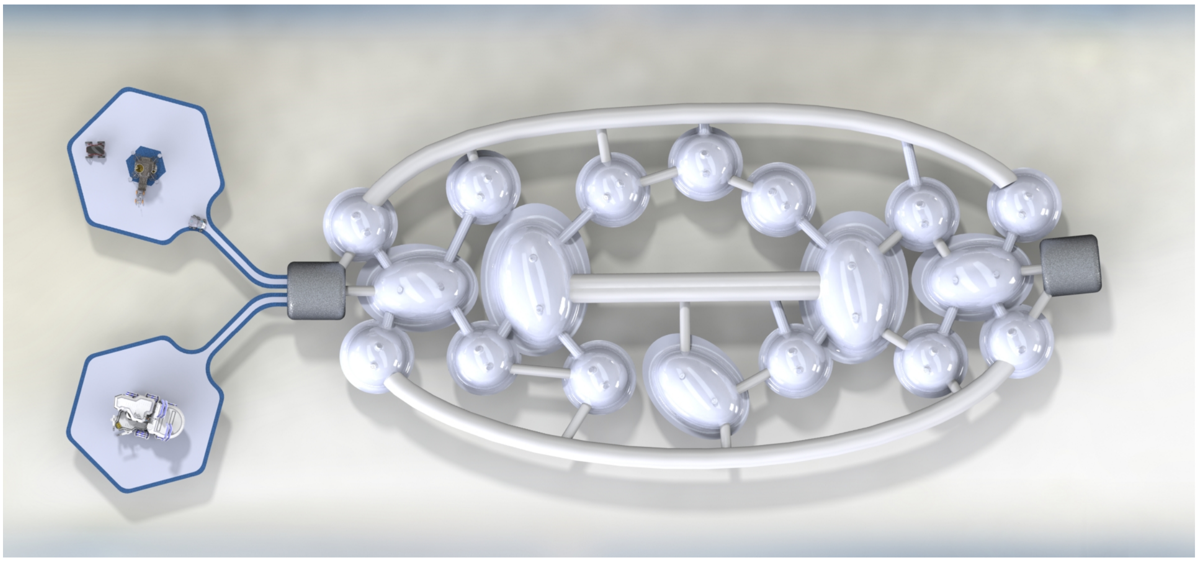


Figure 22: 3D model of Alldream Lunar Institute

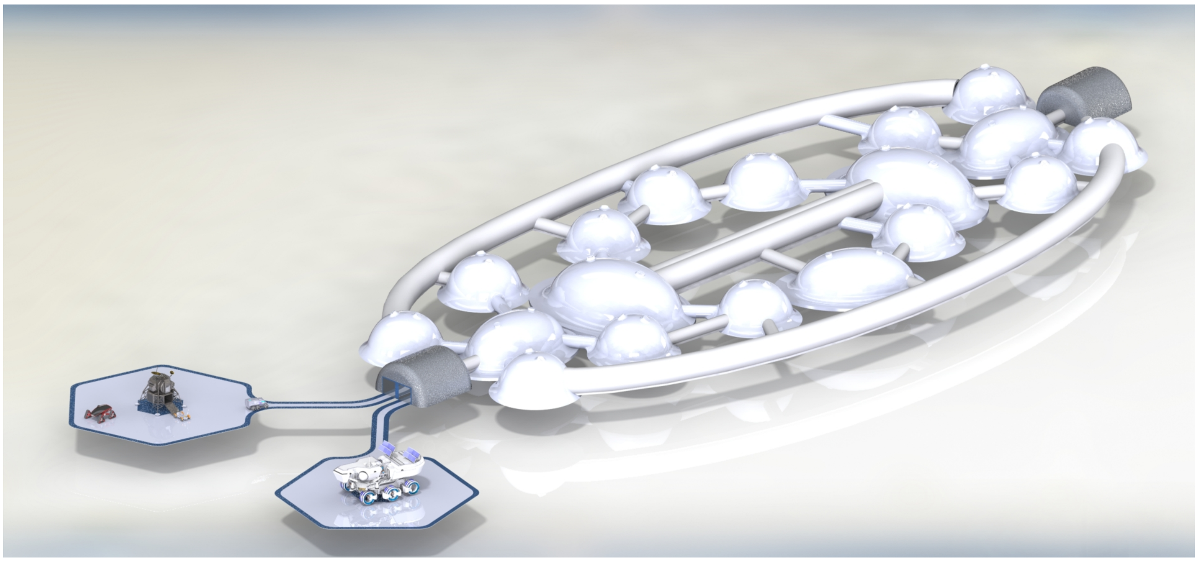


Figure 23: 3D model of Alldream Lunar Institute

Each building consists of 2 parts. The main part, that is medical and day care, is located on the ground floor, laboratories and warehouses on the first floor. Each building has at least two exits, ended with airlocks that allow you to move around the entire complex efficiently and provide additional protection in case of an accident.

Take a look inside!

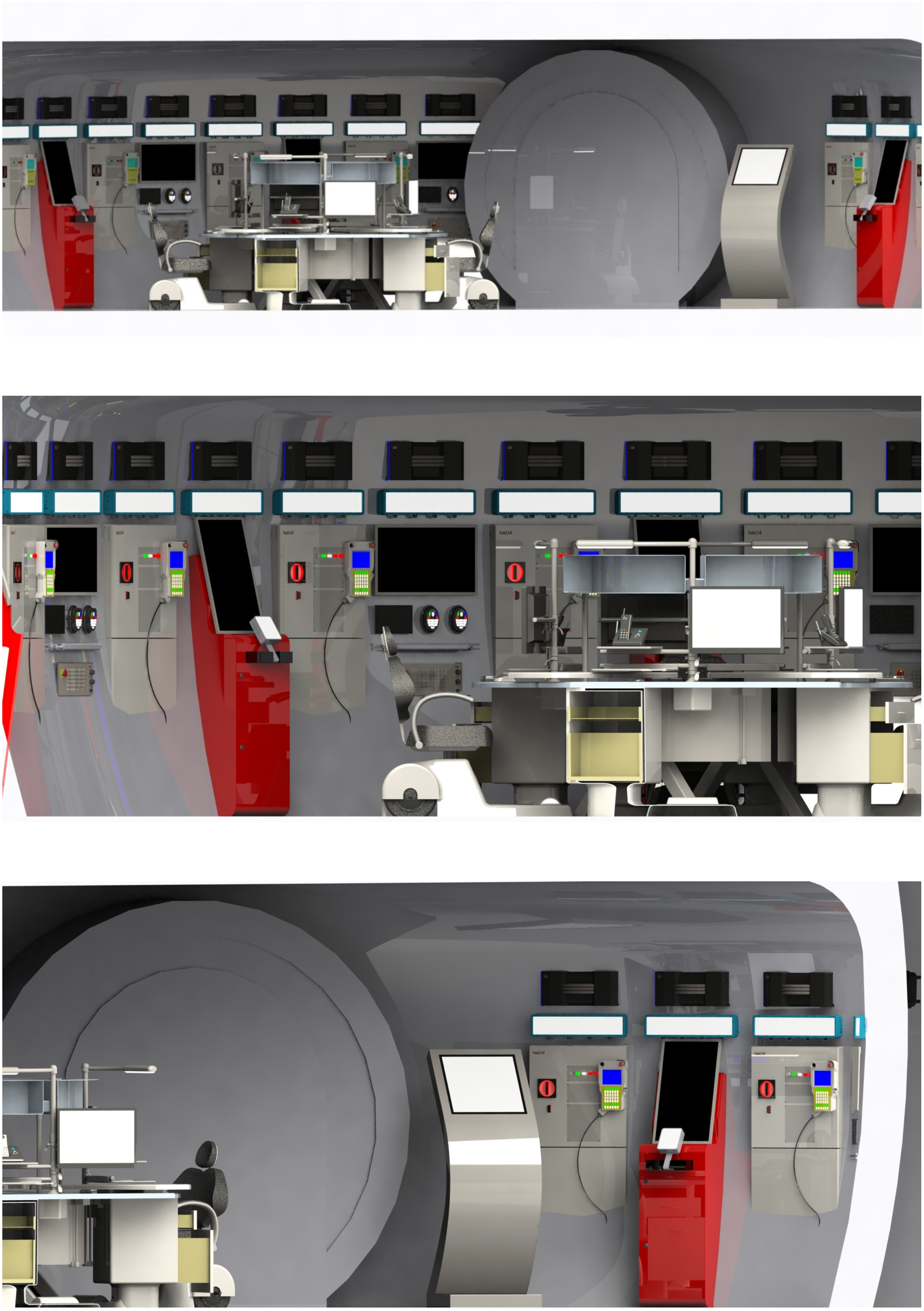


Figure 24: How our Institute looks inside?

4.7 How the Institute is arranged?

The figure below shows the main dimensions of the entire complex. One of the assumptions was modular construction, so we only have three different sizes of buildings.

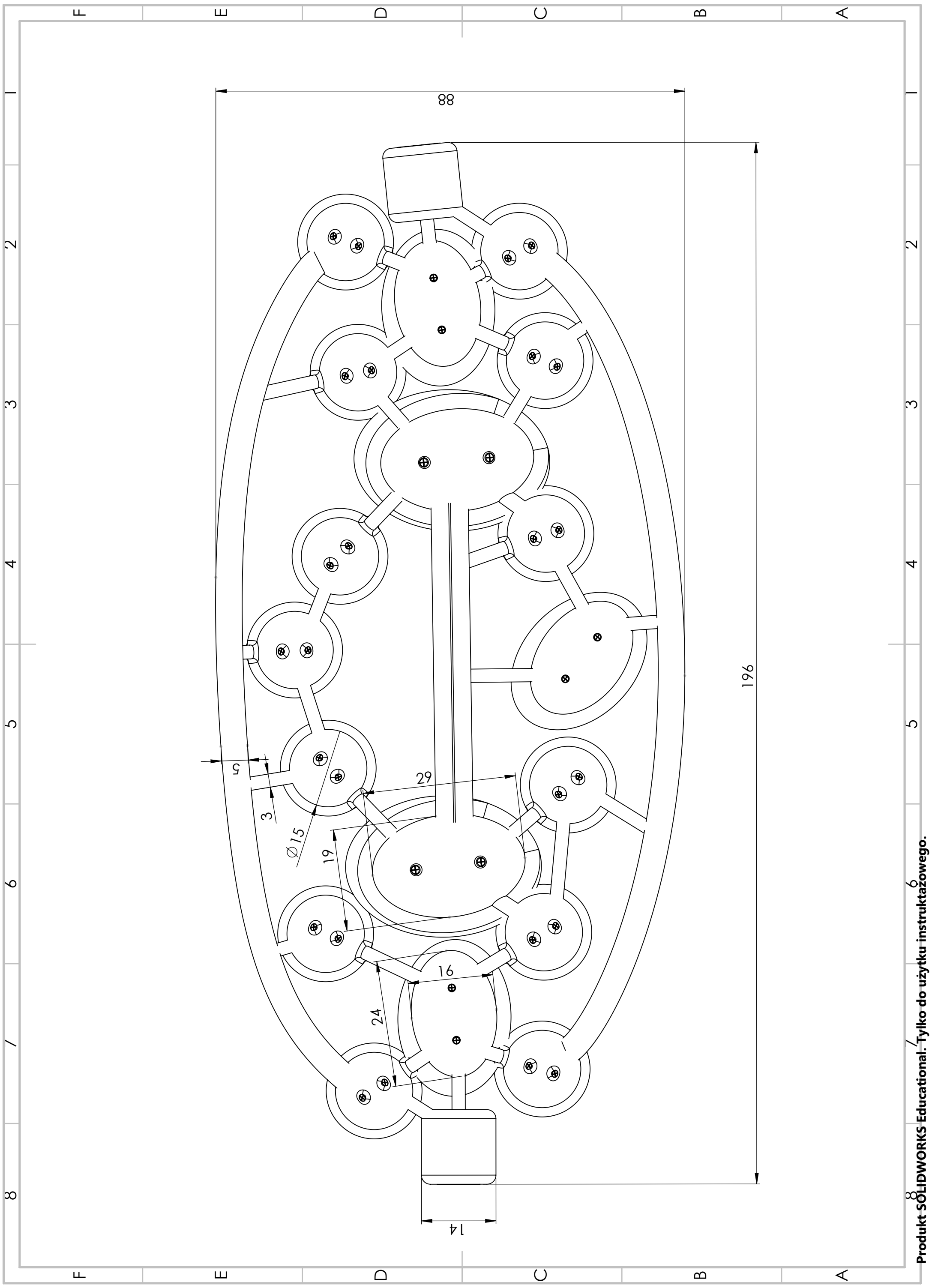


Figure 25: Main dimensions of the entire complex

Description of function of all building can be found on graphics below:

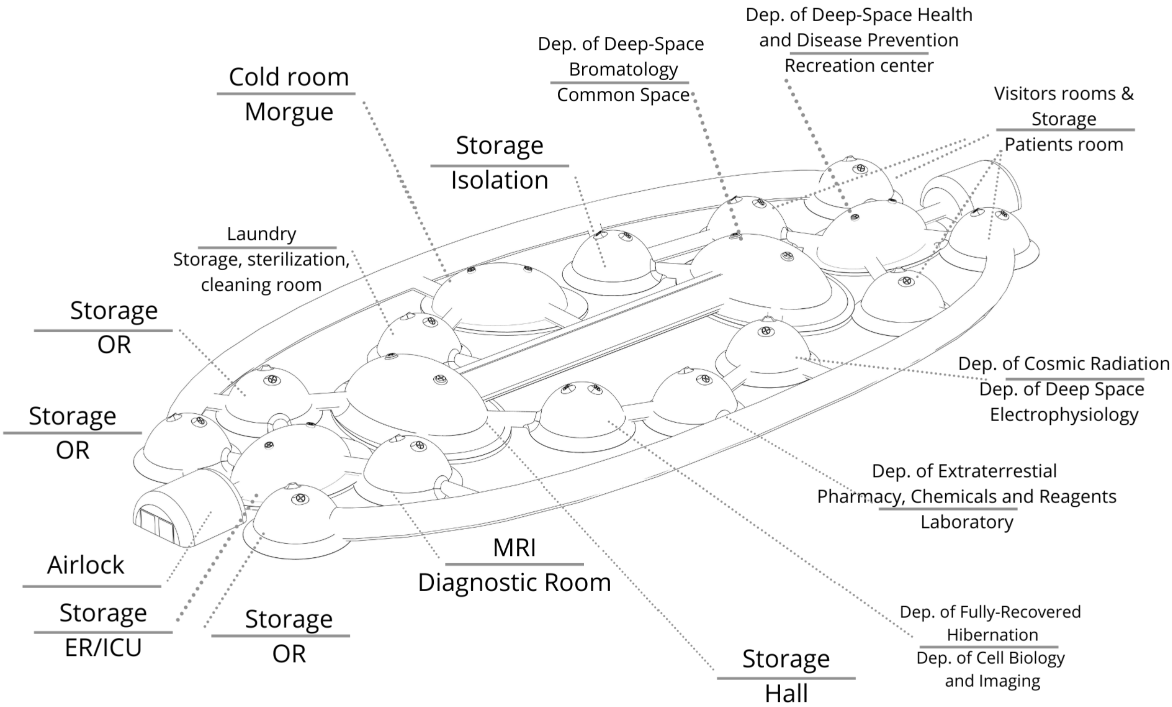


Figure 26: Purpose of buildings (above the line - the purpose of the first floor, below the line - the ground floor)

4.8 How the communication and transport look like?

Rovers will be used for transport between the FHOs and the Alldream Lunar Institute. There are 6 ambulance rovers spread throughout the entire residential complex. Two of them are adapted to the presence of medical personnel and are stationed near the hospital. The remaining 4 are unmanned and located in every quarter of the complex. They are connected to the communication systems of each FHO and allow you to recall them yourself in case you need to go to the Institute in light and medium-serious cases. All rovers can accommodate up to 4 people, including one in a lying position.

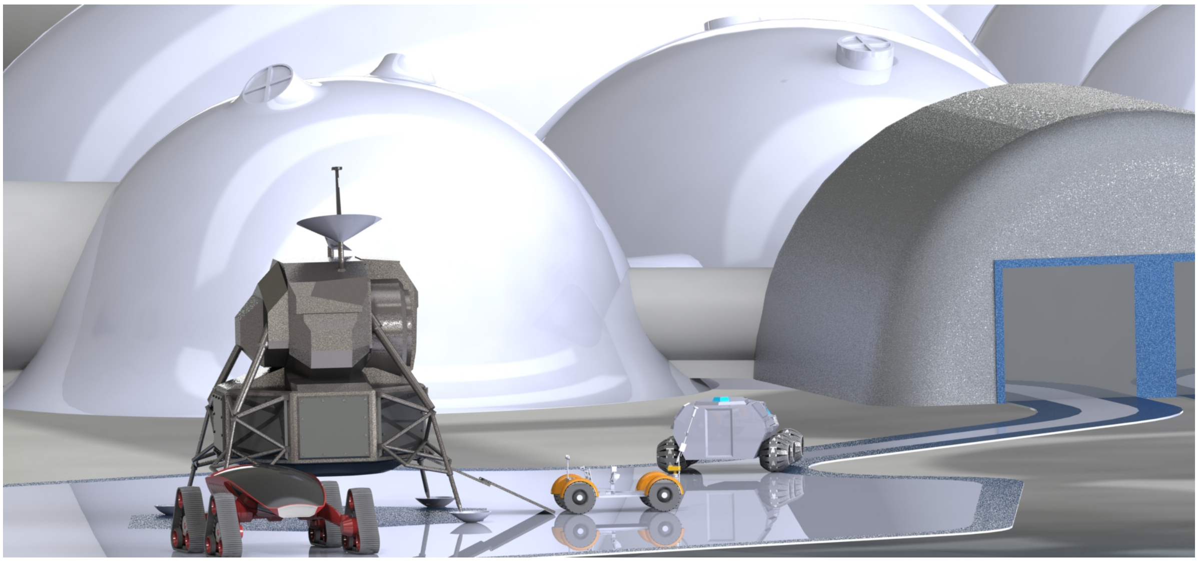


Figure 27: Entrance to the Institute

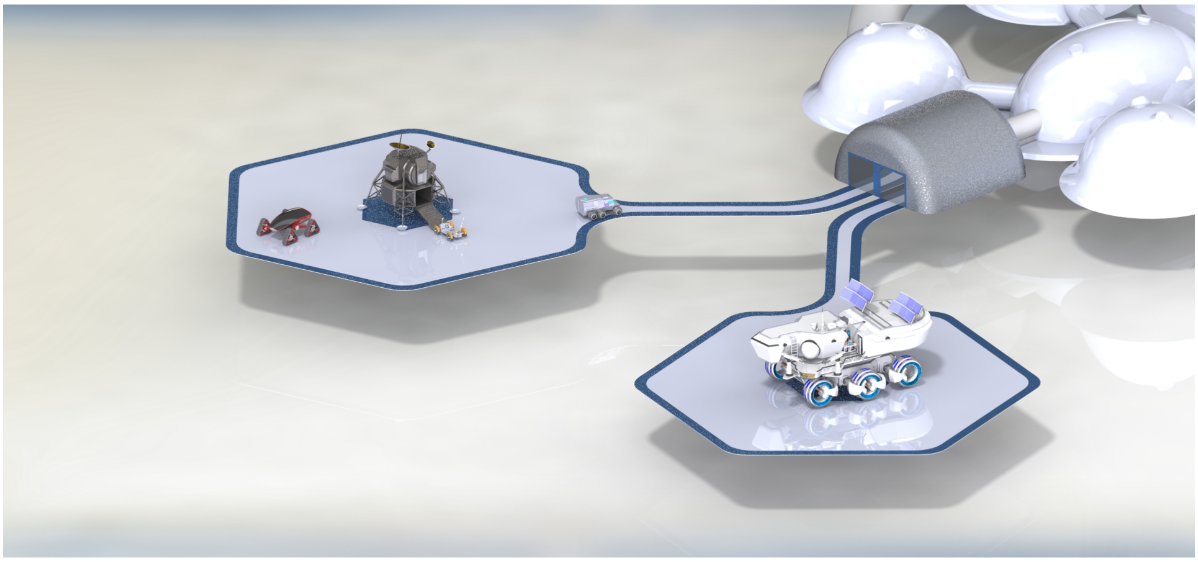


Figure 28: Launch pad near to the Institute and the entrance for rovers

The rover-ambulance could be inspired by the rover designed by Toyota and JAXA.

Figure 29: Rover designed by Toyota/JAXA

Our medical rovers contain equipment and supplies that are necessary in case of emergency in order to bring help in place and transport the patient to the hospital. The medical rover's equipment contains as follows:

- ventilation and airway equipment,
- monitoring and defibrillation,
- immobilization devices,
- bandages,
- communication devices,
- infection control equipment,
- injury prevention equipment,
- vascular access instrumentation,
- medication bag - pre-loaded syringes if available
- and more - depending on the case medical staff can add more equipment that could be necessary in particular clinical situation.

We are proposing in our Institute two airlocks - entrances for rovers, which allow transport to the hospital without the need to wear a suit. This is especially important in an emergency case, when there is no time for it and/or it is impossible to wear the appropriate suit. For this reason, all buildings on the Moon should have a similar solution. This will allow you to shorten the time that passes from the occurrence of an event to maintaining the necessary assistance.

Suborbital aircrafts are used between more distant parts of the Moon - e.g. research stations and a hospital. They allow to travel a distance that using rovers would take several days in a few hours, which is extremely important in the case of the specifics of our Institute's activities - fore example to transport the people or urgent equipment. They are designed for a maximum of 6 people, but the configuration of the internal cabin can be adapted to the needs. The launch pad is located in close proximity to the hospital. Rovers are the second way. They are used to transport basic equipment needed for the normal functioning of the Institute, e.g. food supplies or medicines.

Inside the institute, transportation takes place on foot due to the short distances. It also has additional advantages. Thanks to the use of plants and appropriate lighting, walks around the Institute can have a good effect on mental health, and the reduced gravity requires more exercise to maintain good health.

5 How the treatment of patients looks like?

As mentioned before, the Healthcare and Research Unit of Alldream Lunar Institute is the most complex and challenging part of the project. All of the rooms are planned to be useful and comfortable for the patients and staff members. Expediently connected rooms of the hospital facilitate cooperation between each one of them.

5.1 Intensive care unit

Intensive care unit along with Emergency room is a special room that provides intensive treatment medicine and afford medical help in case of emergency incidents. Common conditions that are treated within ICU include acute respiratory distress syndrome, septic shock and other life-threatening conditions. Patients may be referred directly from an emergency side or from their room if they rapidly deteriorate, or immediately after surgery if the surgery is very invasive and the patient is at high risk of complications.

Emergency side of the room is directly connected to the ambulance entrance, which enable medical staff to take care of critically ill patients immediately. It offers four beds separated by walls. There are small cabinets for patients' personal items and intravenous therapy racks next to each bed. Robotic arm inbuilt within wall make it possible to take care of each patient quickly and precisely. Robonaut 2 (R2) technologies can aid in a variety of medical applications, ranging from telemedicine to handling the logistics of medical procedures. These activities can be done in autonomous mode or in teleoperation mode, where the robot is controlled by a technician or physician. R2's intelligent systems allows the robot to partake in many medical scenarios. Apart from taking care of patients in the ER, R2 can assist a surgeon and the surgical team. The robot has the vision, dexterity, and the ability to perform tasks tirelessly 24 hours a day, seven days a week. R2 can be safely implemented into hospital environment and cooperate with humans[21].

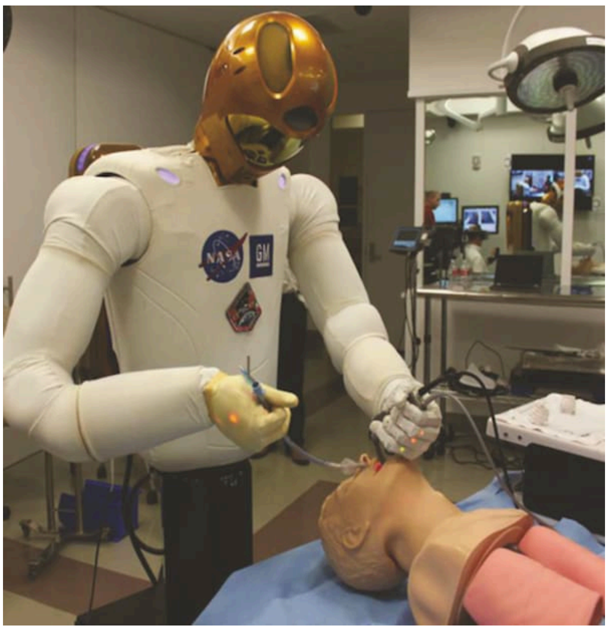


Figure 30: R2 during medical procedures

Medical cart located in the room is useful for human- and robo-medics to transport needed medicament and equipment. Mobile ECG machines enable checking on patients' cardiac rhythm and any disturbances that may occur, such as atrial fibrillation or ventricular tachycardia. Washbasin, antiseptic dispensers and bins for medical waste are essential in hospital environment, because of need of preservation of hygiene and safety.

ICU side of the room offers four beds separated by walls with oxygen source devices next to each one of them. Given the possible medical conditions that may occur among patients on the Moon, the ICU need to guarantee multi-specialized medical help taking advantage of advanced technology. Robotic arm and R2 robot enable rapid reacting in life-threatening conditions. Moreover, high-tech monitoring devices such as cardiac, hemodynamic and respiratory monitoring devices and medical ventilators are essential in vital signs controlling in real time. That is why, they are located next to each bed along with infusion pumps guided by robotic arm. Two emergency carts are necessary to transport needed pharmaceutical drugs and medical accessories. Also, in case of renal failure ICU affords two dialysis machines.

In the middle of the room, there is a central platform with desk and computer devices necessary to control robotic arms. Medical doctor in charge of controlling the robotic arm can decide about quantity and concentration of medicament that the arm will administer to the patients. What is more, telemedicine system enables medical staff to communicate within the hospital and with specialists residing on Earth.

Alongside one of the room's walls there is a big closet with inbuilt fridge and temperature controlling system for holding of medicines, solutions, blood for transfusion, medical devices such as portable USG, defibrillator, Holter ECG, catheters, IV therapy tools, syringes, gloves, endotracheal tubes etc.

Staff: 2 medical doctors, 1 R2 assistant and 2 robotic arms

5.2 Operating rooms

Alldream hospital has three independent operating rooms with state-of-the-art robotic surgery and minimally-invasive equipment. The newest generation da Vinci robot enables surgeons on the Moon and Earth to procedure complicated operations of wide range of specialties.

Figure 31: da Vinci Surgical System

From robotic appendectomy, through cardiac surgery procedures unto intracranial aneurysm treatment - every of these procedures can be performed by using the special console and vision system. Due to telemedicine, terrerstrial surgeons can take part in the operation by controlling some of the robotic arms and discussing complications. Each of the OR has a scrub room with washbasins and sterile clothes dispenser. Hospital trolley and stainless steel tables are used by doctors and R2 robots for holding proper surgical instruments during the procedure and passing them to operating surgeon in the OR. Anaesthetist, sitting next to cardiac, respiratory and hemodynamic devices, monitors vital signs of the patients.

There is an operating light under the ceiling and X-ray lamp machine that allows doctors to perform precise, interventional cardiology procedures due to proper equipment available in the room. Minimally invasive laparoscopic instruments along with microscopic surgery devices are crucial given the lower force of gravity. Thanks to them operation field remains relatively clean, it is easier to take care of the bleeding (it remains in the body and do not float around operating table) and patients come to themselves more quickly than after conventional open surgery procedures.

What is more, spare medical equipment, catheters, gloves, gauze sponges, sutures, etc., remain in the wardrobe with endoscopic instruments, medicament and other goods. Bins for medical wastes are necessary in every OR. Apart from that, there is a desk with computer and chair next to it. It allows hospital staff to pass the information about patients' medical history.

Staff: 2 surgeons, 2 anaesthesiologists, 1 R2 or human assistant

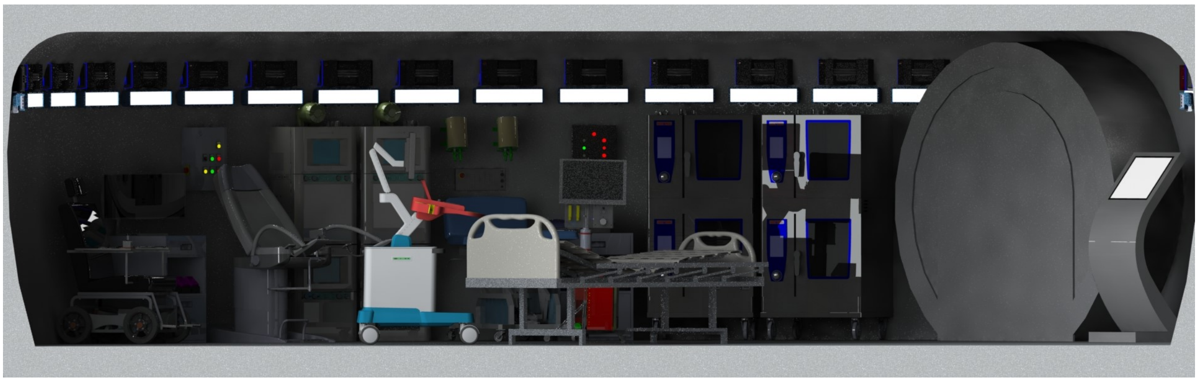


Figure 32: Operating rooms

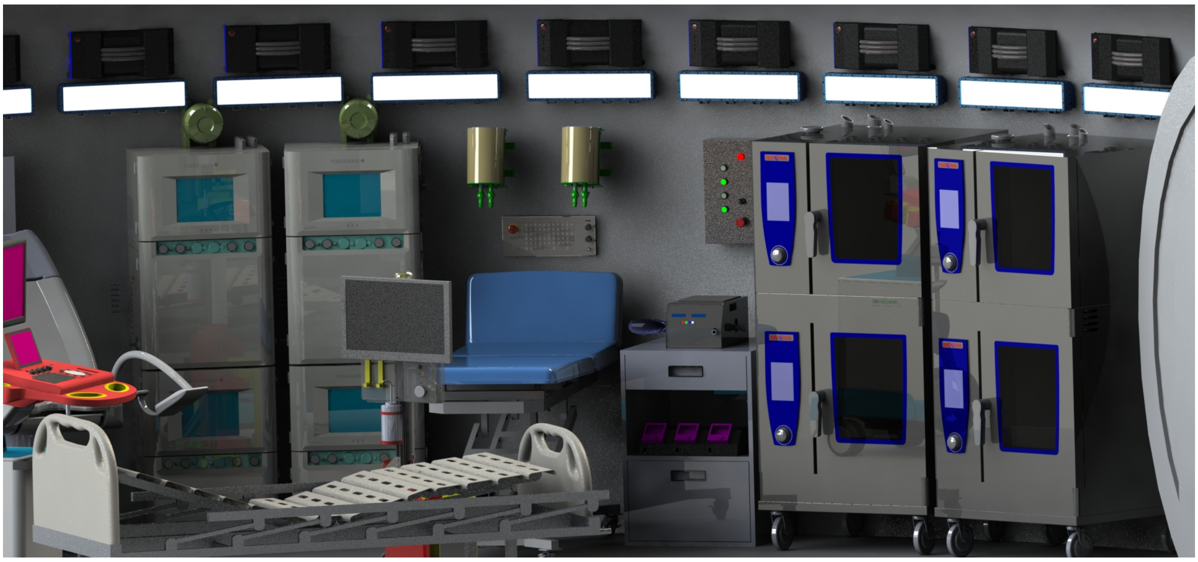


Figure 33: Operating rooms

Figure 34: Operating rooms

Figure 35: Operating rooms

Figure 36: Operating rooms

5.3 Hall

Hall is the central space of the Institute, where patients can gather information and wait for the visit with their doctor. There is a reception desk with robotic assistant that offers help to the visitors and mobile medical diagnostic clinic that can bring diagnostic process forward. Patients that wait in the line can sit on the chairs in the waiting part. There is a WC for the patients - it is gender free, so everyone can feel comfortable and satisfy their physiological needs without gender rules-related stress. Apart from that, there is an Outpatient clinic consisted of two doctors' offices. Physicians have R2 robots at their disposal, so some primary medical procedures like taking blood samples can be performed. There is a desk, two chairs and a couch, so patients can feel comfortable. From the Hall there is an entrance to the Doctors' space, where they can sleep in the bunk beds, when they have to stay the night in the hospital. There are toilets, showers, kitchenette with coffee machine, wardrobe for staff's personal items and long desk with chairs, where doctors can sit and discuss some medical cases and decide what to do with specific patients.

Staff: 1 medical doctor

5.4 Cleaning room and storage

There is a sterilizer with autoclaves, which is crucial in every hospital and allows to remain medical equipment aseptic. Due to that the pathogens can be killed, which prevent spreading diseases among the patients. There is a possibility of culturing drugs-resistant bacteria in the hospital because of wide antibiotic use - that is why every hospital on Earth and on the Moon should take care of proper asepsis of such medical tools like scalpels, retractors or laparoscopic instruments. We perform sterilization using the following methods:

1. Steam under pressure in the range of two temperatures: 121 $°C$, 134 $°C$,
2. Low-temperature formaldehyde sterilization.

Sterilization processes are covered by a monitoring system using chemical and biological tests, charge control, package control and device control. In this room, apart from autoclaves for sterilization with steam under pressure and low-temperature steam-formaldehyde sterilizer there is a lot of shelves and storage units full of medical supplies and spare equipment. There is a hospital trolley full of packed sterile goods ready to take to the OR. Moreover, there are spare beds for patients and mobile dialysis machine in case of need. There is a big fridge full of medicines, fluids, IV infusions, blood for transfusion etc. This room is also a space where 3D printing takes place - in case of lack of medical equipment, some of the instruments necessary in the hospital can be printed and stored here.

It can be crucial taking into consideration that transport of some goods from Earth can take time. The most important things to take into consideration in the context of storage are medicines. Some of them are used less and some more often than others, but it is important to store appropriate quantity of each of drugs in case of medical emergency. Some of them could be produced in our Laboratory by genetically-modified organisms (GMO), but nowadays, it is difficult to assess if producing every drug is possible and on how big scale. The challenge is also prevising the cosmic conditions impact upon drugs' pharmacodynamics and pharmacokinetics and their durability. Apart from meds, the blood substitute is crucial in case of serious blood loss during surgery or following trauma. This can form an important difficulty given the fact that even in the hospitals on Earth sometimes there is no enough blood for transfusions. On the first floor above the cleaning room, there is a laundry with five washing machines and dryers that help to maintain patients' clothes and sheet clean.

Staff: 1 employee or R2 robot

5.5 Diagnostic room and MRI

Diagnostic room is the space for the patients who need extended medical imaging before the surgical procedure or in case of lack of information about the patients and their medical history. Before undergoing any surgery, whether on Earth or in space, diagnosis is always the first step to understand the medical situation. There is a X-ray lamp, USG, ECG and echocardiography devices, mobile CT head, useful for imaging of the internal organs of the patients and mobile DEXA machine (Bone density scanning, also called dual-energy x-ray absorptiometry (DEXA scan) or bone densitometry) that is used to measure bone loss, which is very crucial given lower gravity conditions prevailing on the Moon and associated with them high risk of osteoporosis and bone fractures. Medical exploration can be realized by medical doctors or R2 robots. Due to advanced computer system with artificial intelligence such tests can be analyzed quickly and precisely with minimal probability of mistake. Fractures, kidney and ureteral stones, internal bleeding and even tumors - every of these conditions can be evaluate in this room and thanks to information gathered during imaging medical doctors are able to make decisions about their patients' health.

Staff: 1 medical doctor or technician and 1 R2 assistant

Figure 37: Bone density scanning, also called dual-energy x-ray (DEXA) or bone densitometry

Above this room there is a MRI section on the first floor. To provide a diagnosis device suitable for space a compact Magnetic Resolution Imager (MRI) was developed by researchers at the University of Saskatchewan, Canada. It produces detailed "sliced" images of human bodies, just like a conventional MRI, but whereas the conventional MRI weighs about 11 tons and costs about $2 million, the mass of the compact MRI is less than 1 ton and costs only $200,000, making it much more space- and cost-effective[22]. Magnetic resonance imaging (MRI) is a medical imaging technique used to form pictures of the anatomy and the physiological processes of the body. MRI scanners use strong magnetic fields, magnetic field gradients, and radio waves to generate images of the organs in the body. Conventional scanners require an empty space free of metal objects that can disturb its activity. Since the compact MRI relies on a permanent Halbach magnet, which is much lighter than the traditional superconducting coil, it does not create any detrimental interference with the electronic equipment in the hospital. Our MRI scanner acts quickly and due to sophisticated computer system allows medical staff to create 3D models of the internal part of human bodies, which is helpful before and during surgical procedures. Also, software based on artificial intelligence can assess MRI scans easily and with minimal probability of mistakes.

Staff: 1 medical doctor or technician or R2 assistant

5.6 Isolation rooms

Each of two isolation rooms on two levels consist of two beds, two small cabinets for the patients, vital signs monitoring devices and WC. It is intended for potentially contagious patients in order to isolate them from 'healthy' patients. In front of each room there is a small table with disposable medical protective suits, masks and gloves needed to be wear in contact with contagious patient. The isolation is needed in case of infectious disease occurrence in the hospital setting. For instance, one of the most common cause of hospital-acquired infections is spore-forming bacterium called Clostridioides difficile[23], that can be spread by bacterial spores found within feces[24]. Surfaces may become contaminated via the hands of healthcare workers or other patients. It can cause symptoms ranging from watery diarrhea, fever, nausea and abdominal pain to life-threatening inflammation of the colon. It makes up about 20% of cases of antibiotic-associated diarrhea[24]. Complications may include pseudomembranous colitis, toxic megacolon, perforation of the colon, and sepsis[24]. The patients with such infection should be isolated until eradication of the bacteria to prevent spreading of the disease and maintain health of other patients. Infectious diseases of all types can be a serious problem on the Moon given the small-sized homes and limited-space hospital. People crowded in the small area make up an important risk factor of spreading potentially pathogenic organisms. It can be challenging, but we hope that our hospital will provide Moon inhabitants with proper medical care in such cases.

Staff: on demand

5.7 Morgue

Morgue is the place, where pathologist works. Pathologist assesses deceased patients' bodies with the aim of finding the cause of death - that can be key in case of newly discovered pathogen or other abnormality associated with lunar conditions. There are two tables for the bodies, stainless steel table for necessary instruments, closet and the morgue itself. After proper evaluation the deceased can be transported to Earth. Pathologist can also evaluate biopsy specimen taken from the patients' organs by preparing microscopic slides - which is principal procedure before any excision, when doctors suspect inflammatory or neoplastic pathology. Above the morgue there is a special cold room with -80 $^{\circ}C$ freezers, lyophilisators etc. that is a part of Exoplanetary Laboratory of Sustainable Life.

Staff: 1 pathologist

5.8 Exoplanetary Laboratory of Sustainable Life (ELSL)

Laboratory specialises in scientific experiments unable to be realised on Earth and on orbiting spaceships around Earth or around the Moon (eg. ISS, Gateway). This is unique research center enabling investigations related to exoplanetary life - the only place created by humans, where working scientists are lab rats at the same time. They all live in defined laboratory conditions, following the schedule, performing experiments and monitoring their physical and psychological parameters at the most professional possible levels. Scientists working in the laboratory are experts in their fields. They have a profound experience from scientific methods they are going to use on the Moon. They are also required to provide their publication list strictly related to the proposed topic of the research. Grant proposals are selected by all space agencies yearly competition for a deep space research. After selection of the best and most critical grant proposals, scientists are trained for their mission. The winner is not only a scientist with a great idea, but a scientist with astronaut predispositions and discipline. The other way to work in the lab on the Moon is to be asked on demand of space agencies.

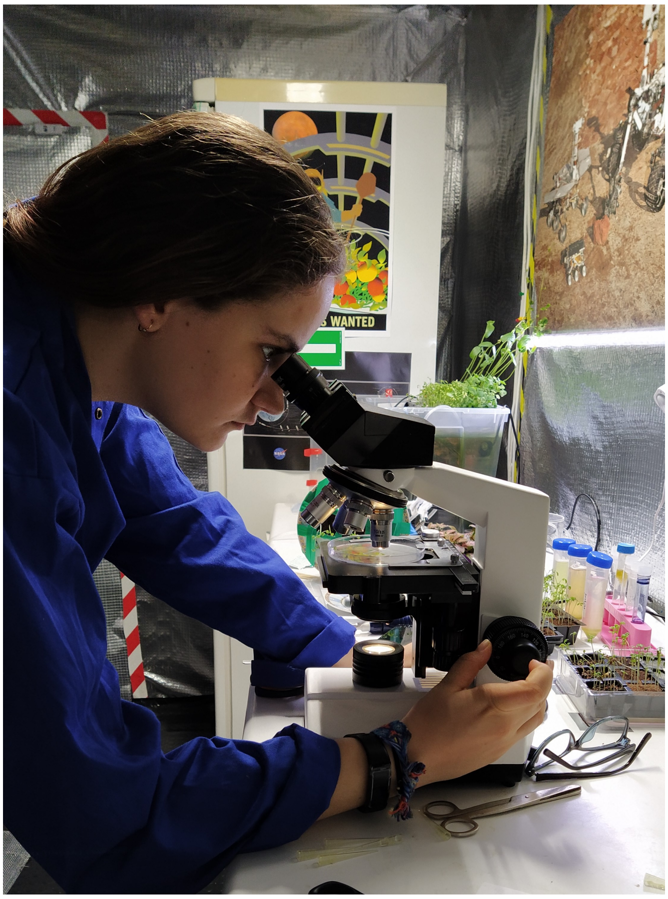


Figure 38: Exoplanetary Laboratory of Sustainable Life

Once selected scientists fly to the Moon, they are accommodated in their small private chambers in one of the homes on the Moon, where they relax and sleep. During the day they have 3 hours of food breaks and 2 hours of physical training. The rest of the time they spend on science in the Institute. Every week, they have to report about their progress during weekly seminars transmitted to Earth. There is possibility to interact and collaborate with scientists on Earth to design a new studies or expanding studies on the Moon by sending back prepared in the laboratory lunar samples to Earth for further analysis (testing recovery of some genetic and morphological processes in living organisms). On demand, scientists have the right to ask for one laboratory assistant and one laboratory technician. Single internship in the lab takes two years without holidays on Earth. There is possibility of extension two year internship, if scientist will pass medical checkup and prove that his/her presence is critical for the ongoing project. Laboratory is equipped with sophisticated equipment impossible to be assembled on board of spaceships and satellites.

Additional rooms common for all research departments are in the Lab building, that is connected with corridors to other, smaller buildings with individual departments that specialize in particular field of study. In order to make use of spare area above some of the rooms we decided to place some of the ELSL segments on the first floors of Hospital and Care and Recreation units.

5.8.1 Department of Cell Biology and Imaging

Figure 39: Department of Cell Biology and Imaging

Confocal microscopes with argon and hydrogen lasers are the main equipment in this laboratory. Microscopes cannot be assembled on spaceships because their total mass with special cold room for lasers exceeds any kind of spaceship mass norms. Also power consumption of this sophisticated equipment is far much higher, not saying about space requirements - min. 2 rooms, each room minimum 3x3 *m*. Confocal microscopes are needed for antibody labeling and live cell imaging with the highest available resolution. In this department scientists are monitoring cellular changes in live cellular cultures. They monitor evolution of microbes in deep space environment. If needed, they produce antibodies against new bacteria, fungi, parasites species and against viruses.

Staff: Min. 1 postdoc, 1 laboratory assistant and 1 laboratory technician on demand or robotic assistant.

5.8.2 Department of Deep Space Electrophysiology

EEG detectors require isolation from electric devices in order to enable correct data recording (this instruments are very sensitive: even switching on a microwave in separated spaceship module can interact with EEG recordings, therefore it is impossible to run relevant EEG studies on board of orbiting spaceships which are fully equipped with electronic devices). A special Faraday cage room (min. 3 *m* x 3 *m*) is needed for such investigation. Additional equipment: oscilloscopes, electrodes, calibration devices, amplifiers, magnetic field generators.

Staff: Min. 1 postdoc, 1 laboratory assistant and 1 laboratory technician or robotic assistant.

5.8.3 Department of Cosmic Radiation

Beside professional monitoring of ionisation radiation in the lab, in the hospital and outside the Alldream Institute, 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. They have large radiation resistant cultures of such organisms and perform several experiments with them searching for a large scale use for sustaining life in deep space conditions. Finally, they work on enhancement of recovery processes after radiation exposure in human body. 2 rooms minimum 3 m x 3 m are required for this laboratory: one for the monitoring - radiation operation room, and one specifically for research.

Staff: Min. 2 postdocs, 2 laboratory assistants and 2 laboratory technicians on demand or robotic assistant.

Figure 40: Department of Cosmic Radiation

5.8.4 Department of Fully-Recovered Hibernation

Hibernation is one of the proposed solutions for a long-term journeys in deep space. It has been proven, that artificial hibernation can be induced in non-hibernating organisms and that hibernation reduces the risk of DNA radiation damage[25].

Experiments with hibernation induced in deep space environment cannot be performed on Earth and on board the spaceship yet, before we don't know what are critical steps, especially during the recovery. Also testing the influence of a long-term deep space environment cannot be tested other way as in the lunar lab. Another experiment is to observe and analyse changes of organism recovery after the hibernation, simulating the situation when astronauts will have to recover after long trips for example to Mars. Will they be ready to perform their mission successfully? The main aim of this department is to investigate the most safe for health hibernation and dehibernation protocols for animals and humans. In this department we need anesthesia room (min. 9 m^2), hibernation chambers room (min. 9 m^2) and hibernation recovery room (min. 9 m^2).

Staff: Min. 1 postdoc, 1 laboratory assistant and 1 laboratory technician on demand or robotic assistant.

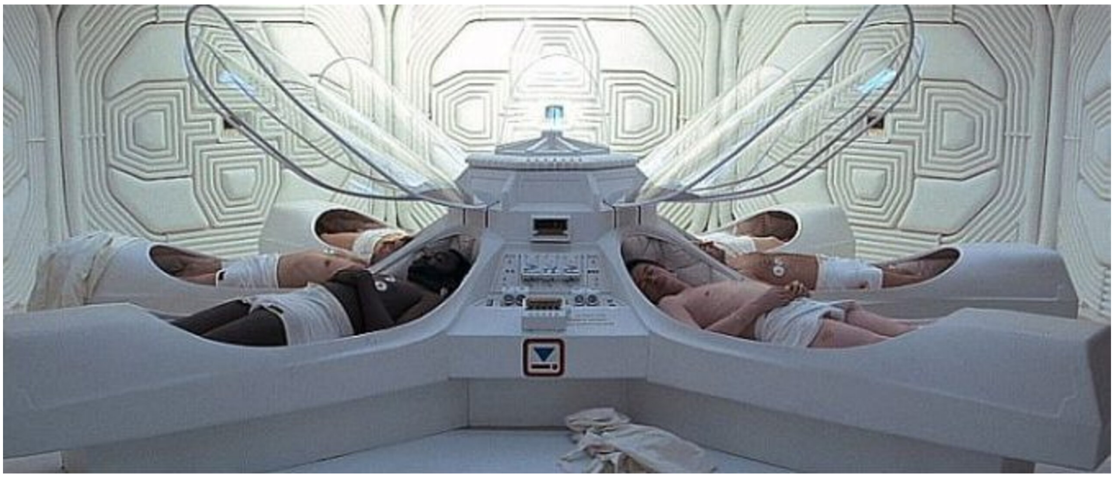


Figure 41: Human hibernation probably will not look like in Aliens movies, but still the concept is extremely interesting and worth studying

5.8.5 Department of Exoterrestrial Pharmacy

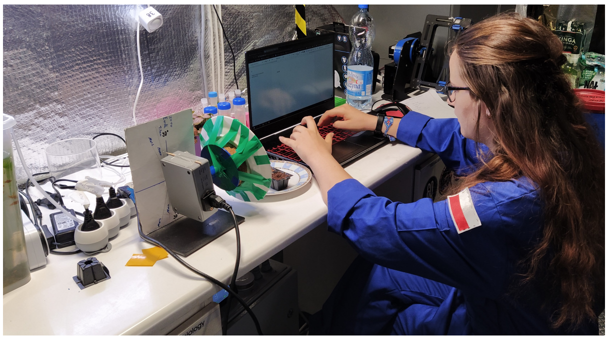


Figure 42: Working on new drugs

Some drugs are very sensitive for space conditions and their life time in such conditions is very short. Special protective shields are designed for space drugs but their effect on human body is not fully understood because of a small number of tests. Therefore there must be a unit of quality control for all drugs located on board of the Moon base. Also reactions to some drugs on Earth might be different to reactions on the Moon and beyond. This department works on a new technologies for a drug production outside Earth and prolonging the life time of drugs in space. For this laboratory we need minimum two rooms: Chromatography room with multiple gas and liquid chromatography detectors, photospectrometers, HPLC and ICP analyzers - minimum 10 m^2, Clean room for drug production with several synthesis machines and laboratory weights: min. 10 m^2 plus airlock - min. 4 m^2.

Staff: Min. 2 postdocs, 2 laboratory assistants and 2 laboratory technicians on demand or robotic assistant.

5.8.6 Department of Deep Space Bromatology

Similarly to drugs, food can be also changed in deep space conditions. Therefore, there is need for a continuous food quality control in the lunar base as well as running research on food digestion and metabolic conversion in such unusual for humans conditions. Functional space devoted for this laboratory will be similar like in case of Pharmacy lab, but with lower hygienic regime. The laboratory will consist on chemical analysis room (min. 10 m^2), food production room (min. 10 m^2) plus airlock (min. 4 m^2). This department is on the first floor above the common kitchen and dining room building.

Staff: Min. 2 postdocs, 2 laboratory assistants and 2 laboratory technicians on demand or robotic assistant.

5.8.7 Department of Deep Space Health and Disease Prevention

Sport is crucial for physical and mental health in stress conditions. The main function of this department is monitoring of the Moon base crew considering health parameters including psychological states. Experts working in this laboratory are: physiotherapist, psychologist, biomedical engineer and neurologist. They all provide support for issues which cannot be solved using telemedicine. Besides monitoring of the lunonaut crew, this team is responsible for design and assembly of a new attractive sport activities, sport equipment and meditation techniques. Staying in the same environment as crew and patients they can understand what is needed and what should be improved. This department is located on the first floor above the building with gym, yoga and relaxation center.

Figure 43: Let me examine you

Staff: Min. 2 experts, 2 laboratory assistants and 2 laboratory technicians on demand or robotic assistant.

5.8.8 Additional rooms

ELSL will additionally inhabit spaces common for all laboratory departments. Most of them are located within Lab main building. These rooms are briefly characterised in the list below:

- Cold room with -80 $^{\circ}C$ freezers, lyophilisators (min. 50 m^2) - morgue - first floor.
- Incubator room with incubators keeping the stable temperature, lighting and humidity conditions (min. 50 m^2) - lab building - ground level
- Gas station (liquid nitrogen, liquid oxygen, compressed air from Earth, liquid helium, liquid nitrogen, CO_2 (min. 50 m^2) - lab building - ground level
- Molecular biology laboratory with four laminar air-flow chambers, four PCR machines and four electrophoresis stages (min. 20 m^2) - lab building - ground level
- Storage room for reusable consumables (min. 30 m^2) - lab building - ground level
- Seed bank (min. 20 m^2) - lab building - ground level
- Chemicals and reagents (buffers, powders, salts, acids, bases, live culture media, animal growth media, drugs, antibiotics, sterilizers) (min. 50 m^2) - lab building - first floor
- Clean room (for microbiology and viruses research) (min. 20 m^2) - lab building - first floor
- Cleaning room (autoclaves, washing machines, dryers, lyophilisators) (min. 20 m^2) - ground level
- Weight room (min. 5 m^2) - lab building - first floor
- Animal house (rat cages, transgenic *Drosophila* culture shelves) (min.50 m^2) - lab building - ground level
- Greenhouse (min. 50 m^2) - common space building
- 5 Hyperbaric chambers, 5 hyperbaric chambers (min. 20 m^2) - within building with Department of Cell Biology and Imaging and Department of Fully-Recovered Hibernation;

6 How the Care and Recreation Unit looks like?

6.1 Bedroom for patients

The patient rooms have been specially designed for effective recovery. Each room can accommodate two people. The room is adapted for people with different types of disabilities, has handrails to support movement and facilities for the blind. Mattresses are equipped with special springs that adapt to our body to provide the best conditions for regeneration. Bedding with weights ensures stabilization of the body during sleep. The room also contains such basic furniture as a table, wardrobes, armchairs or bedside tables.

The functioning of the room is supported by artificial intelligence. For example, doors have a facial recognition function so that they open only for a specific patient or employee. Also thanks to artificial intelligence, the temperature and lighting in the room are adjusted to the current medical needs of the patient.

Above every room there is a place for visitors to sleep and storage room. Thanks to such a solution, family and friends can spend with you time when you need to stay in a hospital longer time.

6.2 Dining room

The canteen is intended for both patients and staff of the institute. In the room there are tables adapted to meals in conditions of reduced gravity. The chairs enable people with disabilities to eat without any obstacles, each of them has special weights. The canteen has modern food and water dispensers. Each person can choose their favourite meal using a special touch screen. The device has a default profile memorization. Thanks to this, meals and their macro-calorie are adjusted to the patients' diet.

In the room there are special containers for waste disposal, not eaten food is processed into compost. This allows us to reduce the amount of waste produced.

The dining room is located in the common space building along with kitchen.

6.3 Kitchen

The kitchen is equipped with modern appliances. Most of the food is produced from freeze-dried products. However, traditional meals are also cooked according to needs, so the kitchen has such facilities as induction hobs, microwaves, dishwashers and thermomixes.

The whole is complemented by a 3D printer adapted to print food. Produced food is put into a special dispenser which transfers it to the canteen. The kitchen has an automated kitchenware management system. The dishes are transferred on a tape to the canteen, and then they return and are automatically loaded into the dishwasher.

6.4 Gym

The gym is located in Recreation Center along with Chill and Animal zones. It serves as a general centre for physical health. It is used by patients for rehabilitation purposes and employees to maintain a good mental and physical condition. The gym is fully equipped for convalescence and body renewal. Also, the gym has a number of facilities for the disabled. There are support railings next to each equipment. Patients can perform both physiotherapeutic and strength exercises. In the gym there will be full-time physiotherapists who will help patients in their training. The gym has such equipment as a treadmill, cross-trainer, training bicycle, dumbbells.

Employees staying at the institute will also need a daily dose of physical exercise. The gym serves as a recreation area. Special screens can imitate, for example, the view of the beach or the forest. The room also has several TVs on which you can play recordings of your training.

6.5 Chill zone

The chill zone, as a part of Recreation Center, is intended for every member and guest of the institute. This place helps to maintain mental comfort and provide a space where people can regenerate. In this zone you will find a section for practicing yoga and playing various types of games, whether computer or board. Special VR/AR googles enable users to play video games of newest generation and have fun during recovery. The chill zone has a specially adapted ottomans for sitting. It is possible to adapt the room to the cinema, the walls have built-in screens. The whole scenery is complemented by a large window with a view of our new home - the Moon.

6.6 Animal Zone

The Animal Zone is an unique space, where patients and guests can take advantage of Animal-assisted therapy (AAT) that is thought to improve a patient's social, emotional, or cognitive functioning and can be useful for educational and motivational effectiveness for participants[26][27].

In this zone, all residents have the opportunity to relax and enjoy therapy in the company of animals. The room has a specially adapted enclosure for dogs and cats. Each animal has its own playpen and bowl. Residents in this zone are supposed to take care of these animals and play with them. The zone has a number of accessories and toys for this purpose.

7 Who works in our Institute?

Figure 44: Best specialist on the Moon

Leading specialists from the world of science work at the Alldream Lunar Institute. The total number of human employees at one time should be at least 22 persons, half of which are medical personnel and the other half of the research staff responsible for research projects conducted at the Institute. In order to minimize the number of staff, some of the duties may be performed by robotic assistants and possible volunteers coming to the hospital from among the inhabitants of the Moon.

At our institute, the staff will change just like the astronauts living in the ISS. Most of all, it relates to scientists who will come to the Moon to carry out their research projects. Some of the medical staff will visit the hospital every day to help new patients and look after patients already staying in the hospital. Depending on their responsibilities and the number of patients, some doctors will be able to stay at home and change with staff present in the hospital within the shift system. In the event of a large accident or a big number of patients, all doctors on the Moon can be called to the hospital.

The scheme presents exemplary staff with medical doctors of desired specialities that can work in the Institute. However, every member of medical crew should have interdisciplinary experience and be ready to learn and train more. Such medical crew will be able to take care of the patients representing various clinical cases. Medical doctors along with scientists will take Moon inhabitants under protection and enable proper treatment and solutions for their problems and discomforts. More detailed information about the staff members and their duties is described in the section dedicated for buildings and rooms of the Institute.

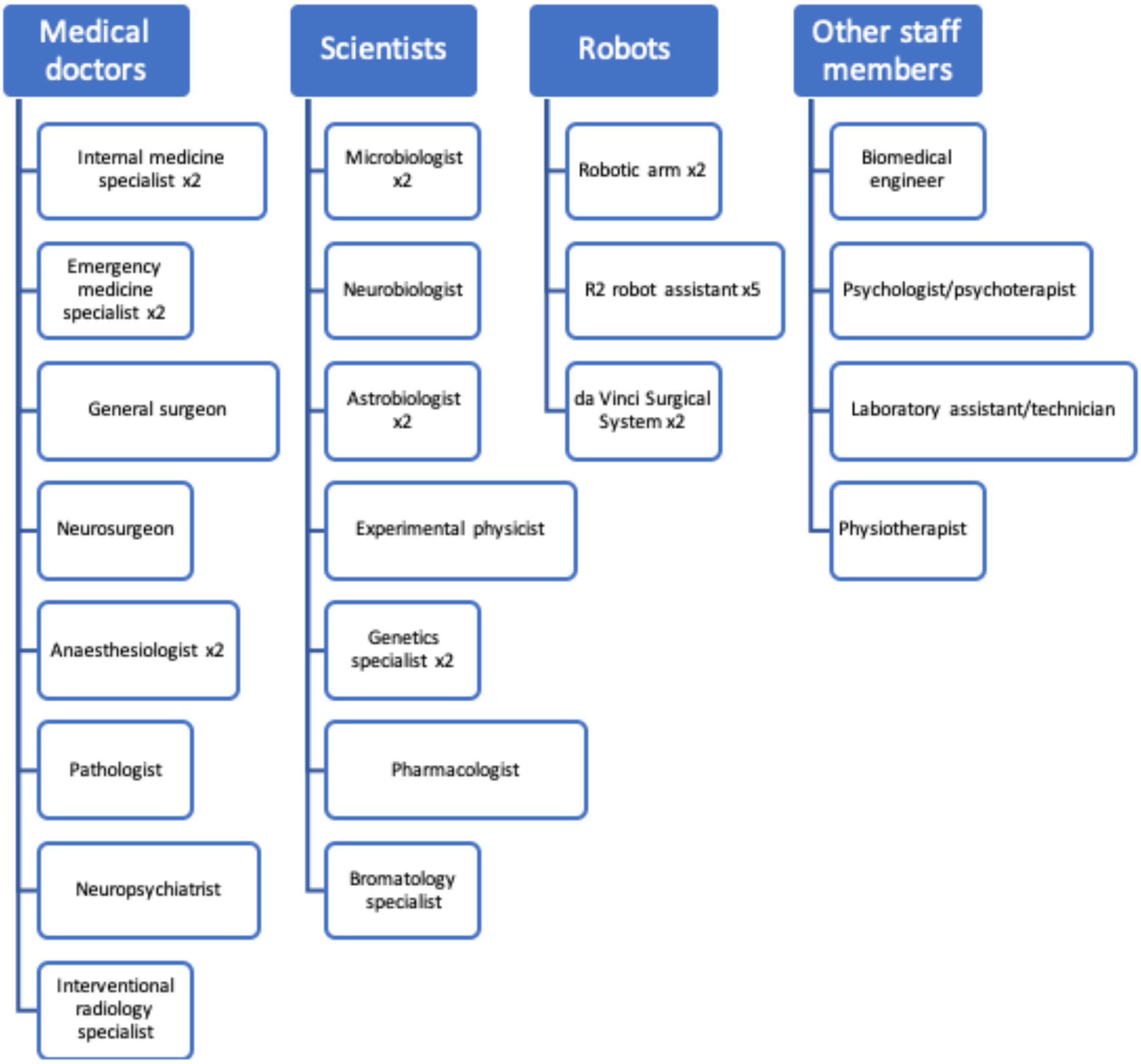


Figure 45: Exemplary staff of Alldream Lunar Institute

8 How all systems work?

We divided the systems in the base into three main parts - life support, base maintenance and broadly understood communication. Following the competition rules we have conducted *research to establish a baseline spreadsheet or chart of consumables your family uses in a week-long period and considered the following: Oxygen, Water, Food and Energy (electricity and gas)* as well as created *a list of items and quantities we must have to survive and explain the source of each item*. We conducted *research to establish a baseline of waste your family produces in a week-long period. and considered the following: Carbon dioxide, Wastewater, Solid waste and Paper*.

As we designed Alldream Lunar Institute, we defined all equipment needed by the hospital to function in a productive and effective way. We described the principle of operation of all systems.

8.1 How life support systems look like?

The key to survival on the Moon will be water. As a facility designers we will rely on highly effective water purification and treatment systems outside the Alldream Lunar Institute. We consider our institution a complementary part of bigger base - other parts like big distillation and catalysis units can provide us a service of wastewater management. Even now water recycling systems used in space, like on International Space Station are amusingly effective, squeezing every last drop of water form wash, pee, sweat or breathed out steam (it's very important because overly humid environment can lead to development of bacteria, fungus and lots of other really nasty things), to use it again.

Technology on ISS, which is not the latest technology (water recycling device was mounted in 2008, 12 years from now!) can restore 90% of collected water to be drinkable again. This and additional water that's already on the Moon (in case of emergency water can be supplied from lunar icebergs in cold areas of some craters or from under the surface reservoirs) makes water a perfect fundamental resource.

Supplies needed for 1 day of Alldream Lunar Institute:

Section of Institute	Name of resource	Unit	Quantity for 1 day
Nursing home & Personnel dormitories	Drinkable Water	l	(2,5 x 100)
	Hygiene Water	l	(5 x 100)
	Cooking water	l	(8 x 100)
	Breathable air	m^3	(525 x 6 + 300 x 2) x 24
	Basic food	kg	(10,3 x 100)
	Fresh/Extra food	kg	(0,043 x 100)
	Electric power	kWh	935,5
Maintenance area	Washwater	m^3	40
	Breathable air	m^3	(175 x 10) x 24
	Electric power	kWh	203,8
Hospital (w/o Lab)	Drinkable Water	l	300
	Washwater	m^3	(5 x 100)
	Breathable air	m^3	(120 x 10 + 4 x 25 x 15 + 90 x 15) x 24
	Electric power	kWh	1340
Lab	Water	l	600
	Breathable air	m^3	(115 x 10) x 24
	Electric power	kWh	505,6

Table 6: Supplies needed for 1 day of Alldream Lunar Institute

Water usage was estimated based on publication by Water, Engineering and Development Centre of Loughborough University, Leicestershire for World Health Organisation (WHO), on how much water is needed in emergencies[28]. Brochure covers amount of drinking water for a person to survive, but also has calculations for running medical center or even garden. Water to prepare dehydrated food is also taken into account.

Our colony (meaning the family houses on the Moon and necessary facilities on Apollo 11 site) will need some initial batch of drinkable and technical water from Earth. As mentioned earlier, we need highly efficient system for collecting all the used water and then transporting it by pipelines and water pumps to the special unit that will purify. This way we can use it again even for drinking purposes just like astronauts and cosmonauts on ISS!

Even when >90% of water would be provided by recycling old water, remaining <10% have to be refilled with external sources. Scientists speculate about water that can be isolated from Moon regolith (based on samples and experiments performed by probes like Japan's Kaguya or India's Chandrayaan-1) and appearance of ice in cooler (with no sunlight) areas of our natural satellite. It's possibe that after some time and on-site research this external water could be provided directly from Moon!

We have to save some room in our maintenance/storage are for emergency water tank, since just like oxygen, water is one of the survival resources for human being. Assuming weekly deliveries from Earth, it's crucial to have resources for minimum one full month.

According to a research article on ventilation systems in airborne infection risk in hospital rooms[29] and air appendix guidelines from Centre of Disease Control and Prevention[30], there are different ventilation requirements for each room in healthcare facility to prevent airborne-contamination from spreading. Values in the table are based on number of air change per hour for every room in Alldream Lunar Institute. Air will be delivered by colony's ventilation system. Just as water, we have to pack in our space explorers' backpack some of oxygen from Earth before going to the Moon, and then try to recycle as much as we can (more about that in *Production and waste* section). It's worth to mention, that oxygen can be made from water during electrolysis. It will be stored in special building, distributing and purifying the air into all neighbourhood houses and institutions.

Figure 46: Healthy diet is important for our body in such an environment

For food we made some prerequisitions and took the average values. We will assume consumption up to 1500 *kcal* for a patient daily (due to lower gravity on the Moon, everyday tasks needs less energy to perform; note, that hospital/nursing home patients don't have much activity during the day), and 2000 *kcal* for professional working and living in the Institute. According to U.S. Department of Agriculture's data on food consumption in years 2007 - 2010[31] and newer data (2010 - 2018) from European Food Safety Authority Database[32], weekly amount of food even for this demand is quite a heavy deliver. It's possible to reduce the mass to 2/3 of it by dehydrating.

Some of edibles are fortified with necessary vitamins and supplements. As you may notice, we are planing to perform regular examinations on Moon residents, so we can compose the optimal vitamin mixes to meet their needs.

As extra food we consider some fresh foods like fruit or vegetables, or imported for a individual's wish special beverages. After arrival from Earth, it can be refrigerated or frozen in warehouses outside Alldream Lunar institute. After delivered to our residents it would stay fit to eat for few days only, but it's provided as psychological support for everyone in the Institute. Astronaut Dan Bursch, who spent 6.5 months on ISS, agreed. "Getting fresh fruit on board was great," he said. He pointed out that what astronauts are missing is not only taste of fruits, but even smell of plants. As colony on the Moon develops, it may be possible to grow fresh food on site.

8.1.1 Production and waste

Of the total amount of waste generated by health-care activities, about 85% is general, non-hazardous waste comparable to domestic waste according to WHO estimations. The remaining 15% is considered hazardous material that may be infectious, chemical or radioactive and include: pathological waste, sharps waste, pharmaceutical waste, cytotoxic waste[33].

High-income countries generate on average up to 0.5 kg of hazardous waste per hospital bed per day; while low-income countries generate on average 0.2 kg[33]. However, it is difficult to assess the total amount of waste generated by our Institute given the lack of research and estimations associated with living on the Moon.

The collection principles of medical waste should be implemented as it is in hospitals on Earth including using of special-labeled containers for particular type of waste such as puncture-proof containers for sharp objects like needles. Large quantities of obsolete or expired pharmaceuticals stored in hospital should be returned to the pharmacy for disposal. Reusable instruments will be sterilized with autoclaves present in the Institute.

From the report on medical waste management by International Committee of the Red Cross[34], we know common techniques to deal with medical waste. When it comes to sharp objects like needles and infectious or potentially contaminated waste there's one, efficient way. We have to own small incinerator - device burning things in controlled way in high temperature (around 1000°C). Ashes from that process are handled as any other waste from the Institute.

Type of waste	Colour coding - symbol	Type of container
0. Household refuse	Black	Plastic bag
1. Sharps	Yellow and	Sharps container
2a. Waste entailing a risk of contamination **2b. Anatomical waste**	Yellow and	Plastic bag or container
2c. Infectious waste	Yellow marked "highly infectious" and	Plastic bag or container which can be autoclaved
3. Chemical and pharmaceutical waste	Brown, marked with a suitable symbol (see Annex 4, chapter 4: Labelling of chemicals). E.g.:	Plastic bag, container

Figure 47: Coding recommendations - WHO – UNEP/SBC 2005 [34]

One of the precautions is to produce as little solid waste as possible in everyday life of patients and residents, because we find it the worst type of rubbish to manage. Huge garbage dumps toxifying the soil and microplastic in the oceans are the most significant environmentals problems on Earth, so it would be the most wicked thing to do to make garbage dumps on the Moon or export garbage to the Pale Blue Dot. Of course it's not possible to eliminate it for good, but we will try our best.

When it comes to waste, water is still a supply that matters the most. At the Alldream Lunar Institute all water will be distributed by pipelines to avoid using plastic bottles. Also we prefer to use big containers from sturdy materials for our food. We will divide it for portions according to doctor's guidelines and patient's answers in quick survey (there are this days that you want to eat more or less than usual) - all automated to avoid food waste!

In the process of washing, solid waste will be collected on water filters. The vast majority of waste will be transported back to Earth in order to segregate and recycle some of the materials. There are various options what to do with organic waste - ESA project, MELiSSA has some brilliant ideas that we can adapt in our Institute, or in colony overall. One of this ideas is Photobioreactor where simple microorganisms like spirulina are fed with biomass generated as waste, and produced oxygen and human-food in exchange. For now, we assume that we will store some of our organic waste to nourish plants and other organisms (eg. algae) in our Lab, and the rest of it will be transferred outside the Institute as valuable resource.

As mentioned before, with modern systems of collecting used water from wash, toilet or even humidity from air, we will provide >90% of our water usage to water recycling service outside the Alldream Lunar Institute. On ISS, water are electrolyzed to make oxygen and there's some hydrogen left in the process. Then, this *waste* hydrogen particles are joined with *waste* CO_2 and becomes water once again. Oh my, chemistry is awesome!

Production of Alldream Lunar Institute for one full week:

Stock	Unit	Amount produced in one week
Sewage	litres [l]	18 396
CO_2	kilograms [kg]	700
Non-hazardous waste	kilograms [kg]	63
Bio-hazardous waste	kilograms [kg]	118
Medical waste	kilograms [kg]	32

Table 7: Production of Alldream Lunar Institute for one full week

8.1.2 Power plants

We calculated estimated electric power requirements analysing the article on energy consumption in healthcare facilities in United States, based on The Commercial Buildings Energy Consumption Survey[35]. The data is divided into many categories like Ventilation, Water Heating, Cooling, Computers etc. It also shows what is the difference in energy consumption for heating space in various climate zones. Taking an outside temperature into account is really important when at our site temperature amplitude is around 280°C!

The electric power will be provided from solar panels outside the Institute, as indicated in the competition requirements. However, as solar farm is so distant and not having uninterrupted power access would be perilous, we need our own supply. Our own solar panels idea got ruled out because of low efficiency compared to maintenance cost and stability/safety.

Supplies needed for full week in the Alldream Lunar Institute:

Supply	Unit	Amount for one week
Water	litres [l]	20 440
Breathable air mix	cubic meters [m^3]	1 659 000
Food	kilograms [kg]	7416
Power	kilowatt-hour [kWh]	21 211

Table 8: Supplies needed for full week

Electricity is a critical resource for the base. The problem with solar energy-dependent power supplies for the lunar base at Apollo 11 landing site is that the Sun shines here continuously during 14 Earth days, leaving next 2 weeks in cold darkness. Therefore, solar panels are only useful half a lunar day. The best solution to this problem are radioisotope thermoelectric generators. In order to avoid the danger caused by a possible failure of the radioactive setup, this power plant should be located far from the base, so radiation from isotopes would not be destructive.

Another challenge on the Moon is related to entering the Earth's magnetosphere during the Full Moon phase. The whole event lasts 6 days per month. There are no data about voltage changes influence on electric devices working at this time on the Moon. Also putative effects on humans caused by this phenomenon are not characterised, because manned missions on the Moon did not occur at this peculiar time. Therefore we propose to prevent unexpected risks and to equip the base with better insulators for all wiring and external walls of the infrastructures.

We computed energy consumption for our base which is about 3031 kWh / 24 h. In order to provide a slight surplus of energy, the most effective and the fastest way to ensure the supply of the right amount of energy to the base would be a small "power plant" in which the only source of power would be radioisotope thermoelectric generators, providing continuous access to electricity for a long time. Each kilogram of uranium would provide 500W of energy, meaning 8000 kg of uranium (1 kg in reserve) would be needed to generate the energy, the crew needs to survive.

As the backup, there should be also 14 spare battery packs, one set per day. In total, the batteries for one day should have a capacity of 15500 A and a voltage of 220 V, then it will give us about 3410 kW, which should fill the demand for one day (24 h). If necessary, some parts or modules can be disconnected to save energy so the batteries will last longer. Reducing the demand for electricity by half, the batteries will allow us to survive not 14 days but 28 days.

On the Moon, the intensity of solar radiation is so high that the solar panels will operate at 100 percent of their power. We assumed that each solar panel will generate 10 kW . So, 350 such panels will give us 3500 kWh, what will allow the base to survive during the 14 days of sunlight (half of the lunar day).

	Uranium	Accumulators	Solar panels
Quantity / Size	8000 kg	1 set per day	35
Power / 24 h	4000 kW	3410 kW	3500 kW
Location	10 km from the base	Direct connection	100 m from the base

Table 9: Diverse power supply system for the Alldream Lunar Institute

Batteries (accumulators) and solar panels are backup systems - a temporary solution until the uranium power plant is repaired, they are not designed to permanently support the base. The batteries can be recharged, however, after some time they would have to be replaced using locally produced biofuel from wastes processing.

8.1.3 Thermal protection

On the lunar surface there are huge day and night temperature fluctuations ranging more than 200 $^{\circ}C$. Thus it is necessary to prevent temperature changes inside the base so that the people inside will not boil nor freeze.

There are several materials that are great heat insulators. One of such material is LI-900 made of quartz glass fibers. This material is characterised by a very low thermal conductivity, high emissivity, low density - 1 m^3 has a weight of 144 kg and it was used as a heat insulator in space shuttles.

Aerogels are another example of thermal insulators. They are produced by replacing the liquid with gels based on silica gas, resulting in an extremely low density material filled more than 90 percent of air. The highly porous structure of this nanomaterial together with extremely small dimensions and complicated pore geometry makes it hard for a heat to transfer[36][37]. As a result, aerogels are excellent thermal insulators.

Beside passive insulators, external part of the base will be covered with the layer of water. This water will be also a storage tank for a technical water. Water will be located in the complex network of pipes, which are designed to induce water circulation based on the temperature gradient. Like a sea or an ocean, water will function here as a buffer reducing the thermal extremes. During the sunlight time on the Moon, external water tank will provide hot water to reduce costs of the power consumption.

Same solution will be used inside the base using air flows combined with windmills and air conditioning system.

8.1.4 Radioprotection

Cosmic radiation in deep space environment has a very negative effect on humans. People directly exposed to it may have health problems in the future.

Another source of radiation will be the "power plant" which will mainly operate with isotopes, which of course will be radioactive. The walls of this power plant will be shielded with a layer of lead to allow people work safely around.

In each airlock entering the base there will be a decontamination zone which will remove radioactive deposits from suits and equipment brought into the base.

One of the best ways to minimise cosmic and solar radiation today is to use polyethylene. Polyethylene belongs to the group of polymers (group of polyolefins) that consist only on carbon and hydrogen. It is worth mentioning that when considering what PE is, it should be remembered that it is not a single material with specific properties. In fact, it is a group of materials that can be used in various ways in everyday life. The properties depend on the reaction conditions (pressure, temperature, catalyst), but for the lunar conditions two types of polymers can be used:

1. UHMWPE (ultra-high-molecular-weight polyethylene) - for the production of bulletproof vests as well as tapes and reps in climbing and sailing
2. HDPE (high density PE, PE-HD) - High-density polyethylene obtained by low pressure polymerization[38][39]

8.2 How to maintain it in good condition?

A hospital is a place where proper hygiene and cleanliness are extremely important in order to reduce the possibility of proliferation of potential pathogens. The decontamination of rooms, facilities and operating fields is essential to limit the spread of diseases and reduce the risk of nosocomial infections. In our facility, we use hydrogen peroxide to decontaminate equipment and surfaces in closed rooms (operating rooms). It is highly effective at killing and preventing the spread of multiple-drug-resistant bacteria, or so-called hospital superbugs[40]. Povidone iodine or sodium hypochlorite are used to disinfect the operating field before the procedure. Based on current knowledge these antiseptic agents have the advantage not to cause resistances of pathogens[41]. Moreover, in each operating room there is a mobile lamp for disinfection with UVC rays.

There is also a possibility of using plasma in killing pathogens. As Matteo Emanuelli states in the pages of Space Safety Magazine:

"Plasma, which is formed when gas is ionized, is one of the four fundamental states of matter along with solid, liquid, and gas and it is the most abundant form of matter in the universe, because most stars are in the plasma state. Plasmas typically exist at thousands of degrees, and hot plasmas are regularly used to sterilize surgical equipment. A cold plasma is one in which the thermal motion of the ions can be ignored and only the electric force is considered to act on the particles. Recently, researchers have been able to make cold plasmas at atmospheric pressure and in a range of temperature between 35 °C to 40 °C [22]."

Also, a study performed by Svetlana Ermolaeva and her research team at the Gamaleya Institute of Epidemiology and Microbiology in Moscow, suggests that cold plasma is efficient in killing bacteria and can be treated as an alternative to antibiotics in wound healing. According to this study plasma is effective against pathogenic bacteria with multiple-antibiotic resistance in already infected wounds [42]. Plasma application could be performed by using a plasma pencil – an invention created by Mounir Laroussi, a plasma science professor at Old Dominion University, Norfolk, VA, USA [43].

Standard cleaning is carried out using robots that perform repetitive tasks such as vacuuming and washing floors. However, due to the specific nature of the hospital's activities and the need to keep it clean, human labor is essential in this matter.

8.2.1 Rescue procedures

On the Moon, maximum protection should be given to people located both inside the base and outside - on the lunar surface. Safety first.

Possible failures should be considered and prevented if possible. Every room should have access to fire extinguisher, first aid kit, flashlight and oxygen cylinder. Each of these items should be used in urgent and justified cases, such as: fire, trauma, temporary or long-term power outage, or leakage of poison gas.

Each crew member should be trained in first aid, health and safety rules and evacuation plan of the base. Each crew member should be also aware of the most important base systems, so in the case of unexpected problems, all people residing the base will be able to fix the problem or know what to do to protect their lives.

In case of a leak in any part of the base modules depended on the oxygen drop, that part of this modules will be immediately cut off from the rest to prevent the death of the crew and to minimise losses in research and equipment.

In case of problems with the rocket, which will transport people or necessary equipment, the upper part of the rocket will be separated and immediately returned back to the ground. The capsule with the crew will be equipped with parachutes and engines. Everything will be automated and programmed in such a way that in the event of a failure, the crew leaves the mission in one piece. Everything will be thoroughly checked and tested so that everyone can be sure that the robots won't fail. The possible evacuation of the base should take place as soon as possible, people should be transported by suborbital rockets / planes to other bases, they should receive the necessary care and await further instructions.

On the Moon, human life is the most important, no matter of price.

8.3 How communication looks like?

8.3.1 Space data and communication systems

Worldwide network is one of the greatest achievements in human history, and the most complex structure that humanity built. Thanks to Internet, our kind was able to accelerate progress at scale never seen before, by gathering the knowledge in easy accessible way and connecting almost whole world. Now we are expanding this creation even further – above the planet, to the space and other celestial bodies like our Moon. However space is much different than Earth, starting from the fact, that above our planet we mainly rely on satellites, acting as a physical infrastructure for data transfer. Earth–to-Space communication also has much longer distance to travel, so light speed limitations and lost data packets starts to cause a real trouble. In this case, space communication protocols are a bit different in comparison to protocols used on earth. To keep the standards and interoperability among systems, in 1982, major space agencies of the word like NASA, ESA, JAXA, ROSCOSMOS and others, founded The Consultative Committee for Space Data Systems (CCSDS), a multi-national forum for the development of space communications and data system standards. To ensure interoperability, decrease cost of development and maintaining of architecture, the data and communication systems in our clinic on the Moon implement technical standards and recommendations published by CCSDS.

8.3.2 Alldream Institute local area network

The network infrastructure on the surface of the Moon is not much different than networks we can find on Earth. We also took a lesson from the past that helped us to make some decisions right from the beginning.

Whole Institute is connected in private Local Area Network (LAN). Every room has an access to wireless Access Point (AP), consentient with well-known IEEE 802.11 standard. APs are placed just above the roof, so the signal has the best conditions to propagate. Their particular placement has been chosen on basis of electromagnetic field distribution map, and took into consideration the places with biggest distortions. At the end, every point of the hub is in the range of at least one AP. To ensure that, we presupposed a 40% overlapping of AP ranges. Distributed network works in WDS mode, in which the single, main AP (base station) is connected to the wired Ethernet, and their customers are other secondary APs (Repeaters), providing network connection to all wireless devices and terminals in their range (like laptops, robots, etc.). The huge benefit of this system is that the Institute employee can move from one room to another, between ranges of different APs without losing network connection on their mobile devices. The WDS protocols will take care of moving this connections. In addition to private LAN, the Institute is covered by twin public LAN for guests. On a daily basis this network has no access to internal services of the Institute, but in case of failure of main private LAN, this network can takes its role as a redundant system.

8.3.3 Moon Wide Area Network

Local Area Networks of Collins, Armstrong, Aldrin and Alldream, joined together form the Wide Area Network (WAN), in fact, creating the first extraterrestrial internetwork. Before Alldream Institute start its operation, the people at other outposts conducted very high bandwidth electronic communications via the constellation of LPS satellites. Communication subnet joining the WAN together uses the LPS constellation as a transmission lines. Let's focus on this transmission lines. For the simplicity, we can think about communication satellite as a microwave repeater that use multiple transponders to listen on some part of electromagnetic spectrum, amplifies received signal, change signal frequency to avoid interference and retransmit it. Of course LPS satellite do much more, but for now we are focusing only about WAN subnet transmission lines. As mentioned before, to exchange data, satellites use microwave frequency in range from 1-40 GHz. In this range we distinct few bands (L, S, C, X, Ku, K, Ka) and each band has two frequency ranges – lower for traffic from the satellite and upper for traffic to the satellite. Higher frequencies has an advantage of wider bandwidth what in practice result with faster data transfer, however the higher frequencies (short microwaves) are vulnerable to absorption by water particles in Earth atmosphere. Fortunately, on the Moon, we don't expect any rain in any foreseeable future, what give us possibility to use very high Ka bandwidth.

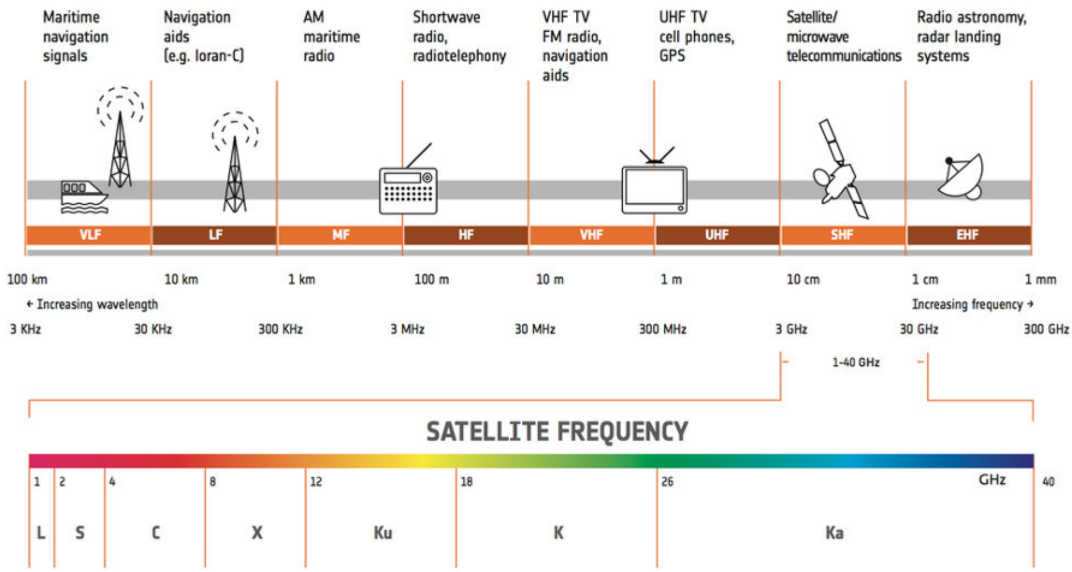


Figure 48: Different communication systems on the frequency scale[44]

The satellites orbit is another concern. From Earth perspective there exist a very attractive geostationary orbit at 35000 km, on which satellites seems to be motionless (their full round around the Earth takes the same time as Earth full turn). Because Moon is tidally locked to Earth, the only stationary locations for satellites, from Moon perspective, exist in Lagrange Points. This is why LPS constellation can't sit on lunar stationary orbit, and because of that the microwave transmitters in Alldream Institute, used to link network via LPS system, need to have additional tracking system to localize and aim the signal at satellites.

LPS constellation for sure is reliable data exchange system, but having a plan B is always reasonable. That's why, in Alldream Institute, we are also working on additional, independent links with other outposts using free-space optical communication system as a network Physical Layer. Details about its implementation is already published as a recommended standard by CCSDS[45][46]. The idea to use light in free-space as a data channel is very old and quite simple, however has some disadvantages that makes it difficult to implement in Earth-to-Earth systems. Using high frequency, infrared or visible light laser beams offer very high bandwidth at very low cost.

Transmission is always unidirectional – from transmitter to receiver, that's why both terminals need to have own transmitter and own receiver. Detection of light on receiver in agreed time scale equals to logical 1, and absence of the light equals logical 0. Laser light is focused into narrow beam what makes data exchange more secure, but it is also a greatest weakness of this method. It's particularly hard to hit small receiver with narrow beam via long distance, and even if we manage to successfully line-up transmitter and receiver, then thermal fluctuations of air will skew our alignment. Fortunately, on the Moon, just like the rain, we don't expect any air in any foreseeable future, what allow us to successfully establish free-space optical link as a second transmission line in WAN network between Alldream Institute and Collins base.

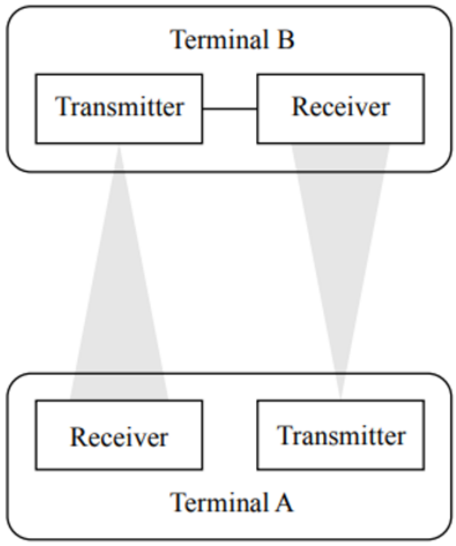


Figure 49: Optical Communications System[47]

8.3.4 Communication in application layer

The top layer of network models is the place where software applications are found and run for the end users. The absence of architecture standard for space systems applications over the years lead to the situation, where custom made systems does not allow to exchange data between each other. To deal with this situation, the Consultative Committee for Space Data Systems (CCSDS) proposed a reference architecture for space information management systems and recommended protocols to interchange data between them[48]. Although the standard is already 7 years old, what means prehistoric in rapidly changing IT world, it still point out the stable, proven, well-known concepts that are still in use in modern enterprise solutions.

The general recommendation is move towards distributed system of Service Oriented Architecture (SOA), which is an application architecture style that promotes construction of systems with well-defined standard interfaces. Entrails of this services, behind interfaces are black box, enabling autonomy in their implementation. Consumers of the service don't have to know anything about service inner working, or even its connection with other services. The only important thing from the outside is the service description. This enables a loose coupling between services and its implementations. Small, well-defined building blocks also support reusability of the services. The development of such systems require some coordination among agencies to establish common data definitions of the contents of the messages, common service behaviors and common service interfaces and methods.

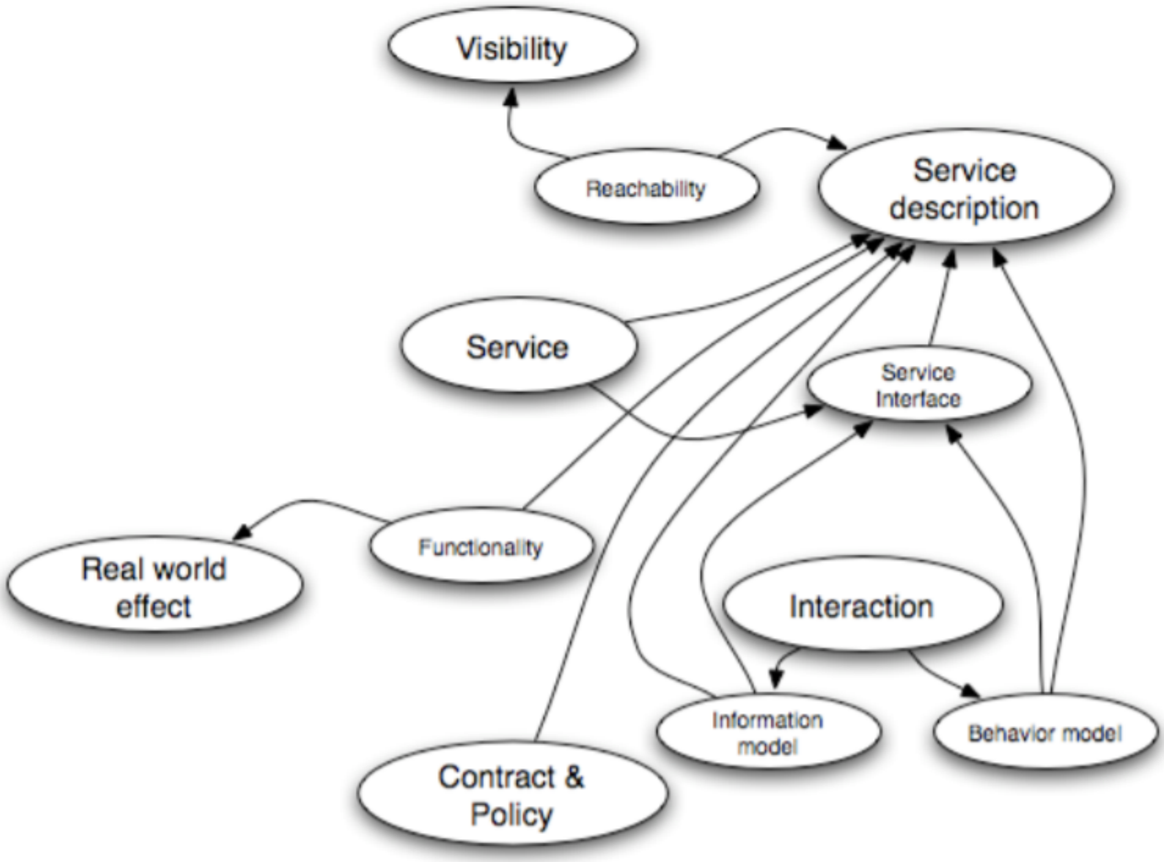


Figure 50: Service Description Conceptual Model[49]

The image above presents service description conceptual model. The service description represents information needed to use a service. It's not a one unitary description, but rather a set of elements that all together describe a service, for example – a reachability describe relation between service provider and service consumers. Description should provide enough information for them to interact with each other, for example location of the service or information protocols required to reach the service, everything required to ensure visibility of service provider to service consumer. Service functionality describes a result of service invoking, and by that, allows to conclude the real world effect of service invoking. Contract and Policy describe condition of use of a service, etc. All the details about SOA Reference model we can find in OASIS specification[49].

Services exchange data. Well-defined data is essential to ensure interoperability between the services. Let's imagine, that two different domains want to exchange the temperature data. However, Domain A interprets it as a human body temperature, and Domain B has in mind temperature of a room. Or both can refer the same temperature but Domain A interprets it in a Celsius scale, and Domain B in a Fahrenheit scale. Or data can has a different semantic (xml and json for example). That's why we need Data Models. Every domain should well describe their data model and two models together they should create Interchange Model for the data elements mappings. Both data Models and Interchange Model should be described by agreed Meta-Model (model of models).

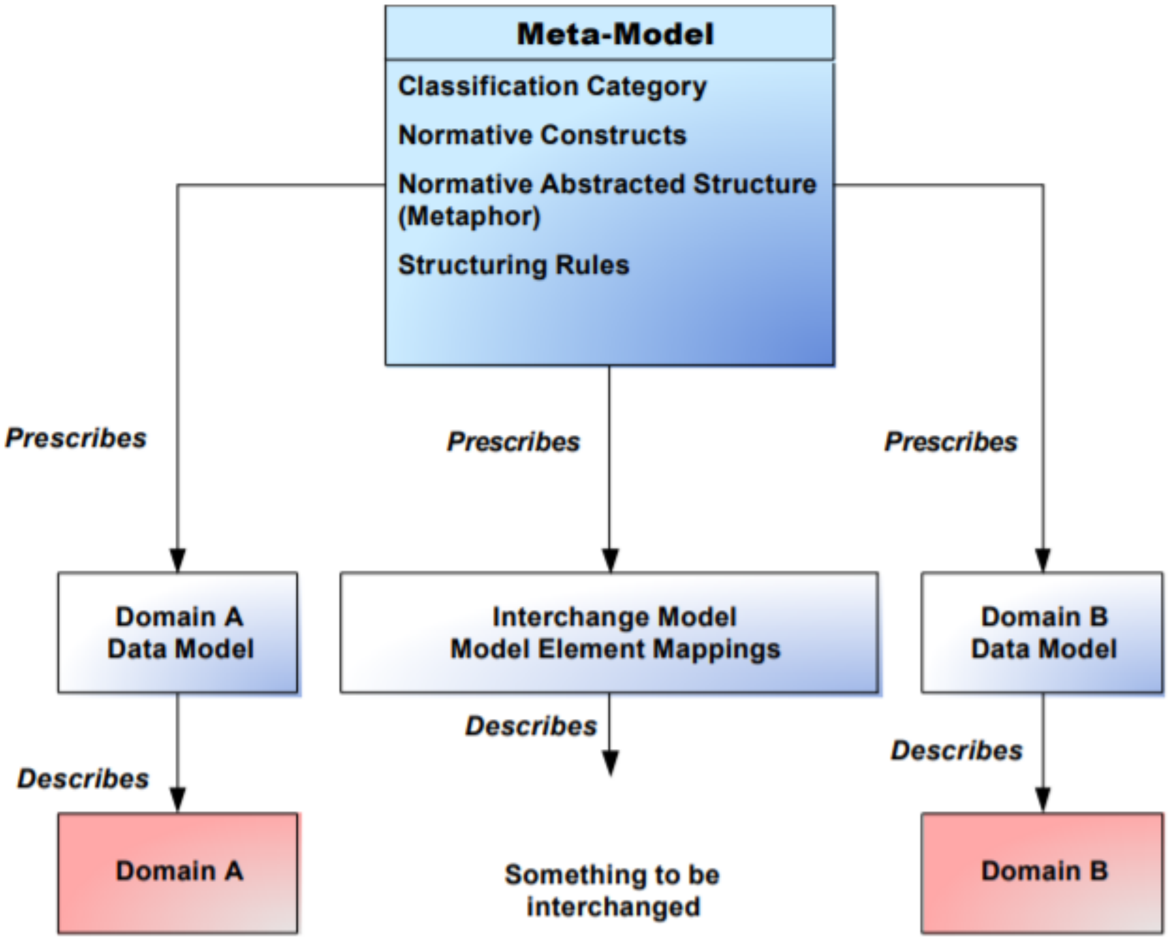


Figure 51: Domains, Data Models and Meta-Model [48]

Services exchange data via application layer protocols. There are a plenty of methods how the data can be exchanged between services – via HTTP(S), FTP(S), SMTP, JMS etc. On top of that there are architectural patterns for message exchange like Publish-Subscribe model or Request-Response, communication can be direct or there can be also involved an intermediator. Wide spectrum of available options resulted with number of space systems that can't operate with each other. In Alldream Institute we stick to CCSDS recommendations for the data exchange protocols but we can't assure that other outposts on the Moon or even Earth companies that want to change data with our systems will do the same. Our IT specialist agreed convention to always integrate our systems and services with external applications via Enterprise Service Bus. It is well-known conception for enterprises environments to use ESB as an intermediator for communication in Services Oriented Architecture. You can think about it as a generic adapter between incompatible systems. It provides a set of technologies to easily deliver and receive data via wide variety of protocols and to translate the data between different semantic models (like xml, json, flat files, etc.). It provides a way to link incompatible applications of our Institute and external systems without need to make any change in the applications on any side.

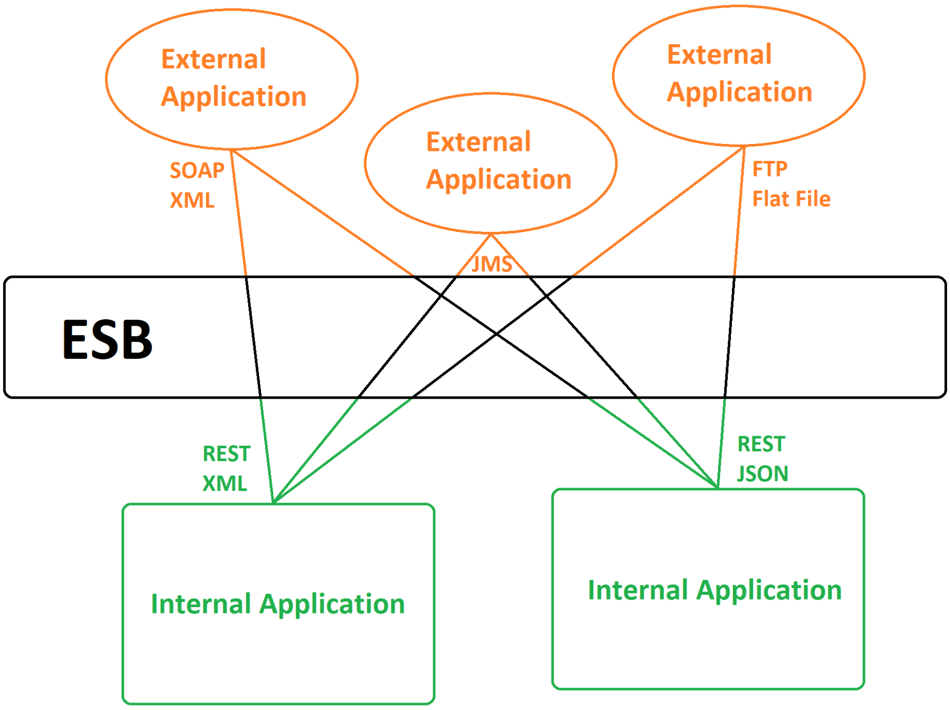


Figure 52: ESB ability to connect application incompatible in data semantic and transport protocols

On next pages we will present some applications that have been built for the everyday usage in the Institute. All this applications implementation follow recommended SOA model. They are built as a well-described services, exchange well-defined data via reliable protocols.

8.3.5 Personal data gathering sensors

Prevention is better than cure. This old catchphrase is still valid, even if you are living in hospital on the Moon. Early reaction for changes in human body can prevent further health loss, and therefore save priceless medical supplies, decrease workload of hospital personnel, save potential patient time and sometimes even life. That's why self-monitoring is so important part of daily routine.

Smart wearables and IoT devices helps with automatic data collection. Staring from simple smartwatch - this small device can take care of continuous measurement of body temperature, heart rate and it's fluctuations, blood pressure, sleep time and phases, body composition and even respiratory rate and breathing pattern. But it's just a beginning. Nowadays, in 2020, we already have smart toilets that can automatically analyze excreta, which are a great source of the data about human health[50]. This toilet can use computer vision to autonomously analyze urine using colorimetric assay, calculate flow rate and volume of urine and also classifies stool according to the Bristol stool form scale using deep learning. The best part is, that performance of this automatic measurements is comparable to the performance of trained medical personnel. Mentioned computer vision can do much more, home camera with face recognition algorithms can notice even subtle changes in body language, analyze voice and sentences context to look for a changes in the amplitude and frequency of the words spectrum to recognize emotions, detect anxiety, stress or fatigue[51]. Nowadays, systems like this are hot topic for car producers like BMW or Volvo. In our Institute, results of this analysis are source of medical data and

Data source	Sampling method	Data type
Smart watch	Continuous	Body temperature, Heart rate and its fluctuations, Blood pressure, Sleep time and phases, Respiratory rate, Breathing pattern, Basic body composition
Smart watch	Manual	Meals – nutrients, calories, Medicament
Smart toilet	Autonomous	Urinalysis, Stool analysis
Smart camera	Continuous	Emotions, Stress, Fatigue, Panic attacks, Physical injury, Loss of consciousness, Journal of physical and mental well-being
Clinic	Manual	Blood, Saliva, Detailed excreta analysis, Detailed body composition, Bones composition

Table 10: List of the medical data recorded to monitor physical and mental health

support physiological diagnosis. Recordings from inhabitants private quarters remain private, to not cause additional stress resulted by lack of privacy.

Apart from continuous and automatic measurements there are some kind of data that every inhabitant can insert into the system manually, for example consumed meals and medicament. This data also can tell us much about our state of being. Premade food package or medicine packets can be scanned by camera on our smart watch. The system knows the composition of every premade meal package, so it can calculate our daily nutrients and calories consumption. Another example are intentionally recorded journals of physical and mental well-being which will be subject of analysis by specialist from Institute or from Earth. In addition, every inhabitant need to visit healthcare clinic on regular basis, to make a detailed regular checkup of other important parameters, which he can't take by himself. This including: saliva and blood tests, detailed body and bones composition. The table 10 presents all kind of data that every inhabitant can insert into their personal account on Alldream Services System platform.

8.3.6 Alldream Services System

Alldream Services System (ASS) is a platform mandatory to use for every Moon base inhabitant who receive access to it at the first day. Platform is available in habitat intranet and can be accessed via any web browser from any personal terminal like laptop, tablet, etc. Inside its core resides a distributed databases system that holds every medical data gathered by personal data gathering sensors. It represents a medical history of every single day on the Moon, this data are priceless for prevention and diagnosis.

System provides a set of generic ad specific API to integrate every sensor that monitor our health. For casual user it expose a simple and intuitive interface called "MySensors" to add and pare personal data gathering sensors with private ASS database and check its status. The second module, "MyHealts", provides insight into actual vital parameters, measurements and compare it with medical recommendations. Module also allow to check all medical history and summary of previous clinic visits and consultations, gives access to prescriptions and referrals. System also make use of neural network algorithms, trained to search through Big Data sets in purpose

Module	Functionalities
MySensors	Pairing PDGS with ASS account, Checking available sensors and its status
MyHealth	Insight into actual vital parameters and measurements, Comparison of results with recommended values, Checking medical history, Checking summary, diagnosis and recommendations after visits in clinic
MyAlerts	Inform about minor health disruptions and provide simple recommendations, Inform about major health disruptions and propose a medical consultation or clinic visit, Inform about critical health disruptions and automatically send a distress call, Inform about sensor errors, Manually send a distress call
MyVisits	Incoming visits reminders, Registration for online consultations and clinic visits, Platform for online consultations
Options	Contact a platform support, Credentials change, Log-in history, Log-off particular terminal

Table 11: Functionalities of ASS platform modules

to find the patterns of deflections that are invisible on first sign for human. After noticing and recognition of such deflection system, via module "MyAlerts" warn about found disorders and propose a simple recommendation: rest or relax, propose change in diet or to drink more water to avoid dehydration or to increase daily physical activity. When noticing more complex health disruption, module warn user about it and propose a medical consultation, proper for recognized issue. In critical situations like heart attack, choking, consciousness loss or respiratory arrest, system automatically sends a distress call to clinic with LPS localization data of the personal data gathering sensor. Of course neural network are trained to distinguish sensor failure from real health issue and can also inform about faulty device instead of sending faulty distress call. Distress call can be also send manually from here. The last module, MyVisits, allows to book an online consultation with medic or plan a visit in the clinic. It also remind us about planned visit date and. For online visits, this module act as a videoconference platform, providing an audio-visual contact with doctor and message chat with functionality to share files. Recorded online sessions are available via MyHealth module.

Medical data shouldn't be available to anyone, apart from the data owner and the medical personnel, however the data owner can authorize access to the data to third-party, i.e. family member. The application itself encrypt data for the transfer to hide fragile private medical data content from unauthorized individuals, i.e. application support personnel.

8.3.7 HubOS

Until now you should already noticed that we love robots. But you may not know, that we all share one more affection – love to the IoT devices. Smart watches, smart monitoring, smart power plugs, smart coffee makers, smart shower cabins (with access to karaoke apps and social medias of course), all of this network connected devices surrounds us every day and provide monitoring and control over them from every place in the Institute. Even if not every one of us is an electronic engineering hophead, we all has to monitor our resources consumption. Space is hard. We can't go outside to breath with fresh air, take a 3 hours long hot shower and make a diet cheat day to participate in hot dog eating contest. Resources on the Moon are more precious than the gold (apart from the gold used in electronic because of its electrical conductivity – this one is priceless). Every inhabitant of Alldream Lunar Institute has granted particular amount of water, air, food and electric power as we explained in paragraph about life support systems. To monitor and control available resources and its consumption everyone who get an apartment in Alldream Lunar Institute get also an access to HubOS application that is a remote controller to our houses. HubOS is an application available in Institute network as a Web App. Its main purpose is to give us an interface to check our resources levels and apartment environment conditions. Application itself evolved from the HabitatOS, application developed by Analog Astronaut Training Center in twenty-tens and widely used in the twenty-twenties of 21th century on Moon and Mars mission simulations.

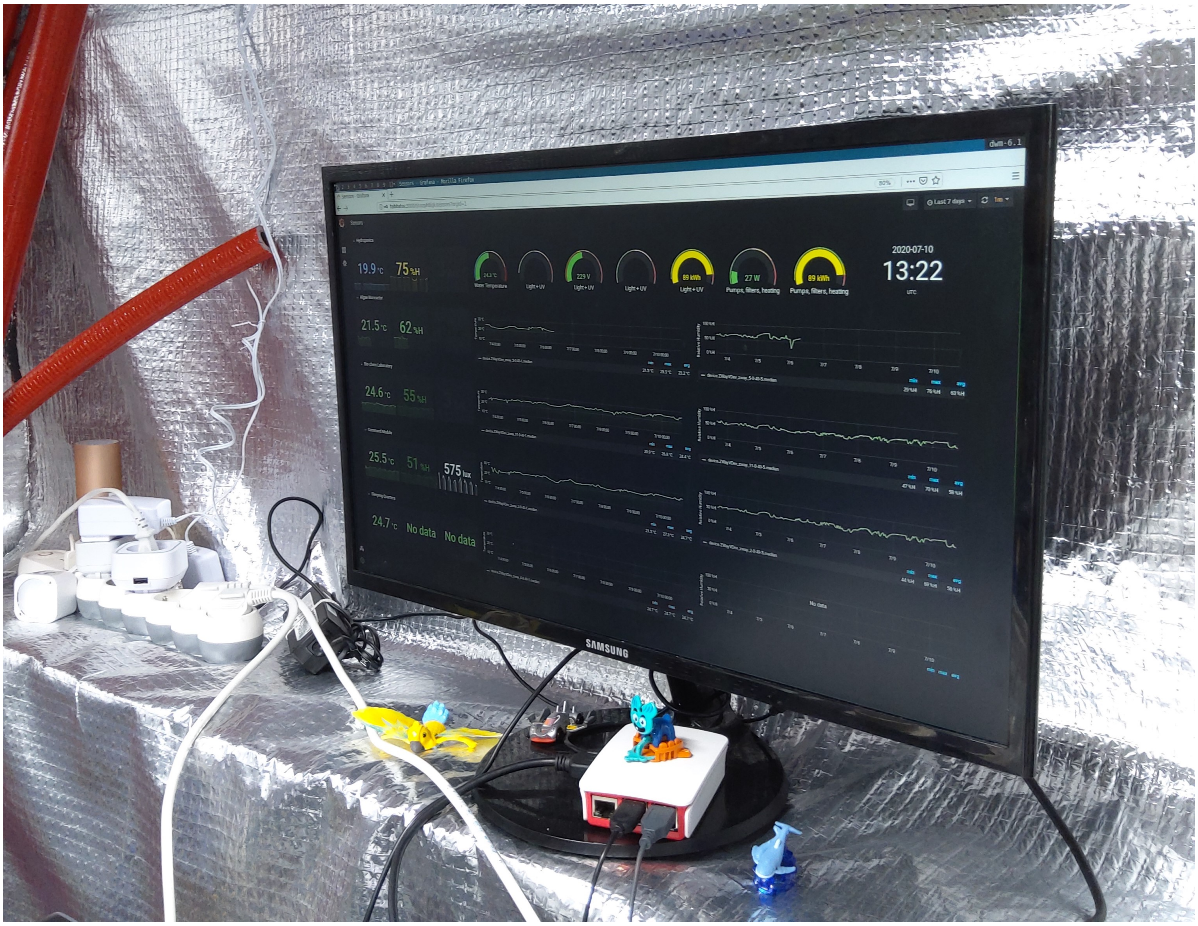


Figure 53: HabitatOS

HubOS, like ASS is spitted into modules. First and main module is a MyHub. It is a 2D projection of our apartment with few marked places, for example power plugs. Above every power plug, interface is showing numbers about its current power consumption per hour and estimated power consumption per day. The resource bar in up-left corner of the module shows available electric power per month and estimation about its consumption at the end of the month. If estimation comes close to the limit application warn us about it and ask to lower power consumption. If the estimation exceed available power limit, the system choose a device in our apartment and shut it down until we gather some reserves (at this moment, everyone is praying that system will not choose the coffee maker). The similar system works for water taps showing the current per-day consumption and estimated per month consumption and if the water consumption is too high, the system can also shut down the shower cabin, and force us to perform karaoke during pre-moist towelettes shower. The other markers on apartment projection shows current temperature, humidity, breathable air mixture composition, overall room light level and light level of sunlight simulator – the special lamp in our apartment that trigger D vitamin production in our bodies. The app also uses data from home monitoring system to measure and display the time we spend under this lamp and compare it with recommended value per day. Module also provide us an interface to control IoT device paired with our HubOS account. Every paired device show as a icon that we can add to particular place on the interface. The control options are dependent on the IoT device type. For example if we pair a smart coffee maker to our hub, we receive a coffee maker icon on MyHub module that we can place on the projection where the physical device stay in our apartment. By clicking on it we receive an access to device specific control interface. In coffee maker available options are following: pay and order a new package of coffee from the producer, check the current level of coffee in the grinder, sugar, milk and chocolate, turn on (instantly make a coffee), set up at hour (make a coffee at chosen time), coffee preferences (grind size, type of coffee, amount of sugar, temperature).

The second module MyDevices allow us to pair a new IoT device to our HubOS account. Sound similar to ASS MySensors module? It's not an accident. By use of SOA architecture in institute internal systems was able to reuse the same part of software with different parameters to adjust it to different application with minimum development effort.

The exact same story is with the last module – Options, which looks like exact copy of Options module from ASS application and in fact it reuse the same microservices with different parameters.

Module	Functionalities
MyHub	2D Projection of apartment, Power plugs current and estimated power consumption, Taps current and estimated water consumption, Rooms temperature, Rooms humidity, Rooms air composition, Rooms light level, Time spent under sunlight simulator, IoT devices control
MyDevices	Pairing new device with HubOS account, Checking available devices and its status
Options	Contact a platform support, Credentials change, Log-in history, Log-off particular terminal

Table 12: Functionalities of HubOS platform modules

9 How we want to make it comfortable?

Figure 54: Daily activities of all patients

As one of the competition rules is to *describe features that contribute to comfort and enjoyment of life on the Moon,* we wanted our patients to feel comfortable in our facility, so we decided that we want to add a whole part of the hospital which is responsible for care and recreation.

There is a gym, where all of the people staying in the hospital can take part in precisely planned exercise program, that enable sustaining bones and muscle strength, which is extremely important, when we have to face lower-gravity conditions and high risk of osteoporosis and associated fractures. Apart from Moon conditions - movement and exercise is healthy, prevent cardiovascular diseases and can help some patients in recovery process.

But we do know that gym is not for everyone, especially for patients that have already had broken bone or two - or patients that suffer from major depressive disorder that inhibit them from doing anything... Then we offer yoga classes along with mindfulness and meditation practice. It is scientifically proven that Mindfulness-Based Cognitive Therapy reduce stress and can be beneficial in patients with depressive disorders[52].

What is more, when we kicked off talking about psyche, it is important to mention that our psychologist along with neuropsychiatrist work hardly on coming up with new therapies that can help Moon inhabitants tolerate new environment, conditions and whole new world. They use art therapy to improve the patients mood and cognitive functions by creative methods of expression through visual art media. Pieces of art created by the patients are then hanged on the walls, where everyone can admire them.

Figure 55: The access to terrestrial resources of books

Corridors of the hospital can offer also contact with nature known from Mother Earth. There are plants with big green leaves like Ficus Elastica or Monstera Deliciosa. The color green evokes mainly positive emotions such as relaxation and comfort because it reminds people of nature.

Moreover, light conditions in our Institute are also precisely-planned. Lamps installed in the Institute simulate broad-spectrum sunlight that we are used to. Thanks to UV radiation there is a possibility of the synthesis of vitamin D in the skin, which is crucial, when we remind its role in bone metabolism. Due to skylights in the buildings it is possible to see the sunlight, which enable patients to see well-known sunrise and sunset, even though not from Earth - which is an important psychological factor that may help some of the patients that miss Earth. The access to terrestrial resources of books and movies and even video games with goggle VR/AR from Earth also contribute to patients' jollity and help to manage their free time during recovery.

Handrails deployed alongside the corridors are helpful for patients in maintaining the balance, that can be altered on the Moon, especially when you are ill or traumatised. They are topped with copper film that has antibacterial properties - which is one of the countermeasures against spreading pathogens within the Institute.

The care for people staying at the Institute is also visible in the interior. The interiors, designed to give the impression of spaciousness, are connected in various ways by wide corridors. The entire complex is surrounded by a corridor that not only serves as an escape route, but is also an ideal place for walks, thanks to the presence of, for example, plants. The interior design uses various textures and materials, especially in the living area, which was designed to give the impression of a home instead of a hospital.

To help maintain cleanliness, easy-to-clean materials were used in the hospital and laboratory sections. The ceilings are protected with foam, hidden under the outer material, which prevents head injuries.

To make it easier to move around the facility in all conditions, including in the dark (at night or in case of the need to use a backup power supply), special tabs have been designed on the floor that allow you to determine the distance from the nearest wall, and all passages are marked with fluorescent lights and LEDs which show the direction of traffic and possible routes.

All important pieces of equipment are marked in the same way, which is an extension of the 5S principle. Thanks to this, not only every thing has its permanent place, which makes it easier to keep order, but it is easy to locate even in the dark. What is more, in the event of the need to use an emergency power supply, the necessary energy can be transferred to the most important places - to maintain servers or power the operating room, instead of the standard lighting.

10 Let's imagine you are on the Moon

Why do you need our Alldream Lunar Institute and what you can do in case of emergency?

Figure 56: What can go wrong on the Moon?

10.1 What happens to our body in space and especially on the Moon?

The Moon is an unfriendly environment for humans. There are many potential threats and challenges facing future colonizers. Only some of them are known to us. Scientists have been working for years to determine the unequivocal influence of certain factors on the physiology of the human body. Factors such as: changed gravity fields, isolation and closed environment, space radiation have influence upon our bodies. So, what are the actual risks?

The acceleration due to gravity on the surface of the Moon is about 1,625 m/s^2, about 16,6% that on Earth's surface or 0,166 G [53]. Because weight is directly dependent upon gravitational acceleration, things on the Moon will weigh only 16,6% (about 1/6) of what they weigh on the Earth – you don't have to be worried about your weight anymore! However, this phenomenon has other consequences as well.

One of the most regularly documented physiological changes associated with the low-gravity environment is the process of bone demineralization, caused by the absence of weight bearing. An absence of load removes not only the direct compressive forces on the spine and long bones such as femur and tibia, but also the indirect loading on these bones from the pull of muscles on the various bone structures to which they are attached. Inevitably, this situation leads to osteoporosis, weakening of the bones and delayed healing of fractures [54]. Bone loss and increased level of calcium in the blood may lead to kidney stones formation and renal insufficiency. In addition to hypercalcuria, other factors contributing to renal stones include decreased urinary output and changes in the concentration of urine, with increased urinary phosphate and sodium.

Our hospital is ready to face such challenges. It has at its disposal densitometry device - DEXA - that allows us to monitor rate of bone loss and bone mineral density. DEXA – Dual-Energy Absorptiometry - is one of the most accurate of its kind – this system uses two low-dose X-ray beams of different energies to scan regions of the body suspected of bone loss. The reason two different X-ray energies are used is to distinguish between bone and muscle, since each tissue absorbs differently. Apart from that we offer countermeasures to bone demineralization – pharmacological and non-pharmacological interventions. Pharmacological intervention includes the use of osteoporosis drugs and supplements such as alendronate, calcitonin, Slow Release Sodium Fluoride, vitamin D, calcium. In addition to taking drugs the hospital uses a lighting system emitting the required amount of ultraviolet (UV) radiation to stimulate Vitamin D production and offers plenty of sports activities and exercises programs to prevent weakening of bones and muscles.

Apart from musculoskeletal system future Moon inhabitants will have to face also other problems associated with lower gravity. The most visible early physiological change is the redistribution of body fluid from the lower to upper body resulting from the elimination of the gravitational loading experienced on Earth. This can manifest as facial as the so-called 'puffy face' associated with facial oedema and reduced leg volume giving the characteristic 'chicken legs' appearance. Accompanying the fluid shift, plasma volume reduces by 10–15% as intravascular fluids shift into the extracellular space because of increased capillary permeability[55]. Moreover, some astronauts report a condition known as Spaceflight Associated Neuro-ocular Syndrome (SANS), which is related to poorer vision along with swelling of the eye's optic disc and intracranial hypertension. The brain scans performed upon those astronauts, who came back from space travel, revealed several key changes in their brain's structure that may suggest cerebral edema. Due to reduced gravity conditions the brain and the fluids in human body shift upwards, which increases pressure in the skull and may result in headaches and optic-nerve swelling that causes blurred vision.

What is more, otoliths in inner ear will respond differently to motion and changed sensory input can confuse brain causing disorientation, nausea, vomiting. All of these problems can be managed due to pharmacological medications present in our facility.

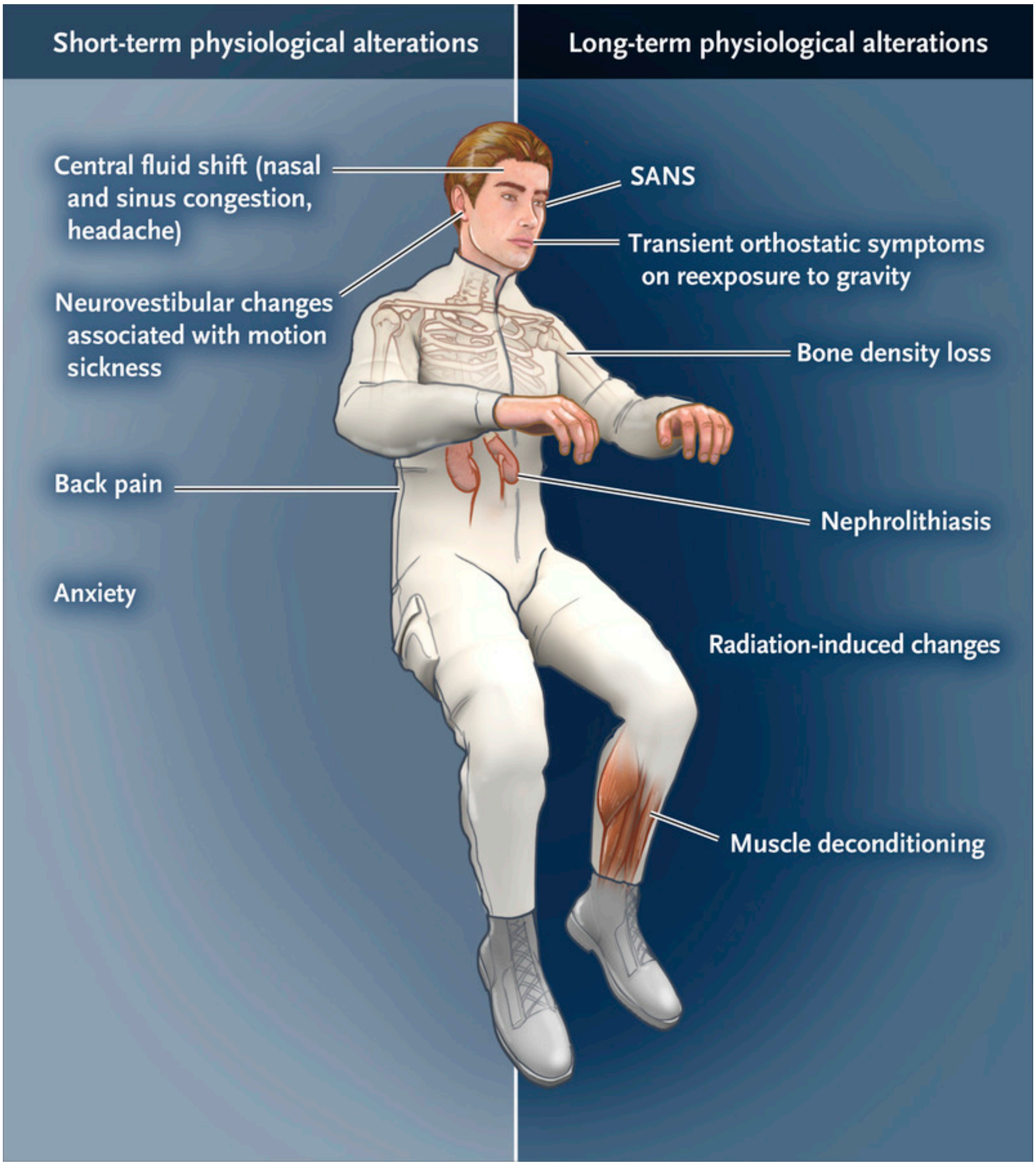


Figure 57: Human physiology in Space - The New England Journal of Medicine [56]

Our planet's magnetic field and atmosphere protect us from harsh cosmic radiation, but without that, you are more exposed to the treacherous radiation. Above Earth's protective shielding, radiation exposure may increase your cancer risk due to cellular DNA damages. Furthermore, study performed on mice shows that it can damage neuronal connections with both acute effects and later consequences, manifesting itself as altered cognitive function, reduced motor function, and behavioral changes. Space radiation can also cause radiation sickness that results in nausea, vomiting, anorexia, and fatigue. You could develop degenerative tissue diseases such as cataracts, cardiac, and circulatory diseases [57].

All of the above alterations can have a detrimental effect upon health and relationships between Moon inhabitants. Thankfully, our hospital is built from regolith layer that blocks high-energy space radiation. Also, antioxidants like vitamins C and A that we offer can help by sopping up radiation-produced particles before they can do any harm and due to state-of-the-art diagnostic technology we will be able to prevent serious harms before they give any visible symptoms.

The effects space environment upon the human body are widespread, affecting every biological system. Alteration of the regulation of the immune system, with elevated granulocytes, decreased lymphocytes, elevated B cells and decreased natural killer (NK) cells may lead to infections and latent viruses reactivation. Haemopoiesis also appears to be affected with reductions in red cell mass leading to a so-called "space anaemia'. For the respiratory system there are alterations in both static and dynamic lung volumes[55].

10.2 What about your psyche?


Figure 58: Taking care about your mental health is extremely important in such harsh environment

Based on space flight and analog evidence, the average incidence rate of an adverse behavioral health event occurring during a space mission is relatively low. Anecdotal and empirical evidence indicates that the likelihood of a behavioral condition or psychiatric disorder occurring increases with the length of a mission[58]. We should take it into consideration given the fact of actual living on the Moon and not only spending short amount of time during the space mission. There are many factors that may impact upon occurrence of a behavioral condition or psychiatric disorder. These include: sleep and circadian disruption, personality, negative emotions, physiological changes that occur when adapting to microgravity, lack of autonomy, daily personal irritants, physical conditions of life in space, workload, fatigue, monotony, cultural and organizational factors, family and interpersonal issues, and environmental factors[58]. Also, isolation and confinement may contribute to developing behavioral or cognitive conditions, and psychiatric disorders.

Disorders such as anxiety, post-traumatic stress, sleep loss/insomnia and depression can also develop unexpectedly in generally healthy individuals. That is why it is important to control mental health of the lunar inhabitants and to have a psychiatrist on the board. In our case, we do have a psychiatrist in our hospital. He talks to patients every day and reads mental journals about their daily performance. Due to cooperation with specialists from Earth it is possible to gather and analyze such journals from all of the people on the Moon. That may help in preventing some of the serious disturbances in their mental health.

There exist some psychiatric emergencies that may need to be managed within our facility. Examples include the development of delirium due to a head injury, or a brief psychotic disorder following a tragic event such as the death of a family member or an international catastrophe[58].

10.3 How our hospital works in practice?

In order to present the possibilities of our facility, we will present a typical patient's route from home to the hospital, along with an algorithm for proceeding in a given clinical situation.

List of examples of possible clinical cases:

- Space Motion Sickness
- Nasal/sinus congestion
- Constipation
- Headache
- Back pain
- Upper Respiratory tract infection
- Minor Abrasion
- Musculo-skeletal trauma
- Corneal irritation
- Insomnia
- Renal stone formation
- Acute urinary retention
- Cardiac Dysrrhythmias
  — Extrasystoles
  — Bigeminy
  — SVT
  — Sustained VT (asymptomatic)
- Urinary tract infection
- Gastroenteritis
- Prostatitis
- Serous otitis media
- Contact dermatitis
- Decompression sickness
- Aspiration of foreign body
- Radiation sickness
- Severe Decompression illness
- Barotrauma

- Osteoporosis
- Seizure
- Anaphylaxis
- Anxiety
- Depression
- Medication overdose/misuse
- Palliative treatment
- Diverticulitis
- Appendicitis
- Sepsis
- Herpes reactivation Cellulitis
- Otitis media/externa
- Dental
  — Cavity
  — Pulpitis
  — Toothache
  — Avulsion
  — Loss
- Eye penetration
- Limb amputation (lifesaving)
- Chest trauma/Pneumothorax
- Obstructed airway
- Haemorrhage
- Burns (thermal or chemical)
- Smoke inhalation
- Cardiogenic shock
- Malignancy
- Acute Glaucoma
- Compartment syndrome
- Head Injury
- Hypovolaemic shock

- Lumbar spine fracture
- Shoulder/elbow dislocation[55]

Documented surgical emergencies during analogue, Low Earth Orbit, and lunar missions include: trauma, arrhythmias, renal colic, infection, intracerebral haemorrhage, myocardial infarction, appendicitis, bone fractures, dental abscess, and need for amputation[58].

Let's assume the hypothetical case of a patient with acute appendicitis. Appendicitis is one of the most common causes of acute abdominal pain in adults and children, with a lifetime risk of 8.6% in males and 6.7% in females [59]. The appendix is a closed-end narrow tube attached to the first part of the colon. If the opening to the appendix becomes blocked or the fatty tissue in the appendix swells, bacteria, normally found within the appendix, may invade and infect the wall of the appendix. This infection results in appendicitis, to which the body responds by inflaming the appendix, which may ultimately lead to rupture, followed by spread of bacteria outside the appendix. Alternatively, the appendix may become perforated leading to an abscess or, in some cases, the entire lining of the appendix may be infected. Perhaps the most feared complication of appendicitis is sepsis, a condition in which bacteria enter the blood and infect other parts of the body [54]. Even on Earth sepsis in considered a serious complication, but to an inhabitant of the Moon that can't come back to Earth quickly such complication would be a death sentence.

Our patient's name is Agnieszka. She's 26-year-old and lives in a house on the Moon with her parents. In the morning, a few hours after breakfast she started to feel epigastric pain followed by brief nausea, vomiting, and anorexia. She took 200 *mg* of ibuprofen twice, but after a few hours, the pain shifted to the right lower quadrant. She used Alldream Services System (ASS) that can be accessed from every house on the Moon and added her symptoms to the database. Due to that doctors in the hospital were able to read her medical history and decide whether she needs to be transported to the hospital or not. Agnieszka presented classic symptoms of appendicitis that appear in around 50% of patients with this pathology. She was transported to the Alldream Hospital by medical rower and admitted to the diagnostic room for clinical evaluation and USG examination. In clinical examination: nausea, right lower quadrant pain, rigidity, guarding, rebound tenderness (Blumberg sign), Rovsing sign, decreased bowel sounds, no fever. To check for signs of infection, doctor has ordered a complete blood count (CBC) and urine test to rule out urinary tract infection or kidney stones as a potential cause of symptoms. To conduct this test a sample of patient's blood and urine was collected and sent to a lab for analysis. CBC showed leucocitosis of 15,000 white blood cells per microliter in the serum. USG evaluation showed widening of appendix lumen of 9mm, appendix wall thickening of 4 *mm* and hypoechoic swelling around the appendix. According to the Alvarado score (clinical scoring system used in the diagnosis of appendicitis) Agnieszka gained 8 points, which means that the diagnosis of appendicitis is probable. What is more USG imaging favors this diagnosis.

Alvarado score	
Feature	**Score**
Migration of pain	1
Anorexia	1
Nausea	1
Tenderness in right lower quadrant	2
Rebound pain	1
Elevated temperature	1
Leucocytosis	2
Shift of white blood cell count to the left	1
Total	**10**

Figure 59: Alvarado score [60]

Agnieszka had a quick surgical consultation and was admitted to the Operating Room. Treatment of acute appendicitis is open or laparoscopic appendectomy, but in our hospital the operation will be proceeded by surgical robot da Vinci controlled by the surgeon using the console and with telemedicine consultation with another doctor who is going to control some of the robotic arms from Earth. On Earth, reduced mess, smaller entry scars, and shorter recovery times from minimally-invasive surgery are revolutionary - that is why they are used on the Moon. The patient is tethered to the operating table, while the doctor, using a console, is tethered to the module structure via a movable chair, which prevent from lifting over due to lower gravity forces. Three small incisions were made to access the appendix after proper anesthesia controlled by anesthesiologist present in the OR. The da Vinci surgeon inflates abdomen with CO_2 gas which allows a clear view of the appendix. The appendix is detached by the help of Bipolar and Scissors and removed carefully through one of the incision sites. Appendectomy should be preceded by IV antibiotics. Third-generation cephalosporins are preferred [61]. For nonperforated appendicitis – which is Agnieszka's case - no further antibiotics are required. The procedure was finished within 45 minutes and Agnieszka was transferred to one of the patients room. 24 *h* after day of the operation she was able to move and walk normally across the corridors. She spent some time with other patients in the care and recreation unit, she tried her best in painting and watched some movies. After 48 hours of thorough doctors' follow-ups she was ready to come back home. Before she was discharged from the hospital, doctors helped Agnieszka learn how to care for her incision sites. They prescribed antibiotics or pain relievers to support her recovery process. They also advised her to adjust her diet, avoid strenuous activity, or make other changes to her daily habits while she heals.

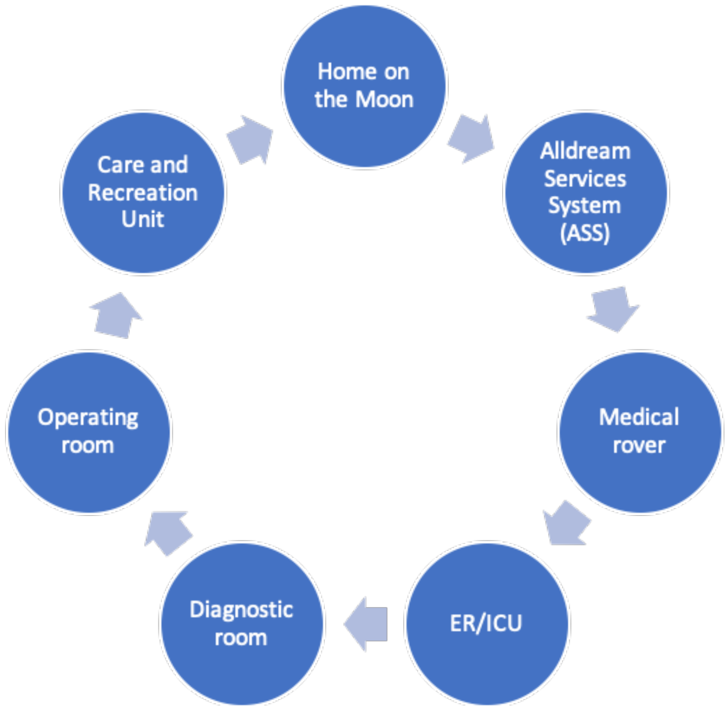


Figure 60: How to Get Away with Mur... Acute appendicitis

It may take several weeks for her to fully recover from appendicitis and surgery. If she develops complications, her recovery may take longer. Alldream Services System (ASS) available via any Agnieszka's mobile device allows her to provide her doctors with information about her health, new symptoms and possible complications of surgery.

10.4 How to take care of the health of residents in their own homes?

In case of emergency of sudden cardiac arrest or others, there are proper precautions in every home on the Moon. Every lunar inhabitant have to undergo at least a Basic Life Support (BLS) course to have an ability to maintain the patient alive until he or she can be transported to the Alldream Hospital. To help in giving the first aid there is Mobile Medical Module (MMM) in every home - MMM is a platform which enables stabilization while emergency medicine procedures such as Basic Life Support (BLS) and Advanced Cardiovascular Life Support (ACLS) are performed in microgravity environment. Microgravity environment decreases effectiveness of resuscitation procedures therefore MMM project objective is to provide support while performing chest compression, intubation, obtaining intravenous/intraosseous access, monitoring and transfer of care. Device is designed for both professional medical personnel and BLS level trained crew members. It was designed by a group of five medical students, one engineering student and assisting supervisors (with military background, ESA work experience) members of the Extreme Medicine Science Club with the Medical College of Jagiellonian University in Poland. The MMM device has already been tested in reduced gravity suspension-platform and underwater environment [62].

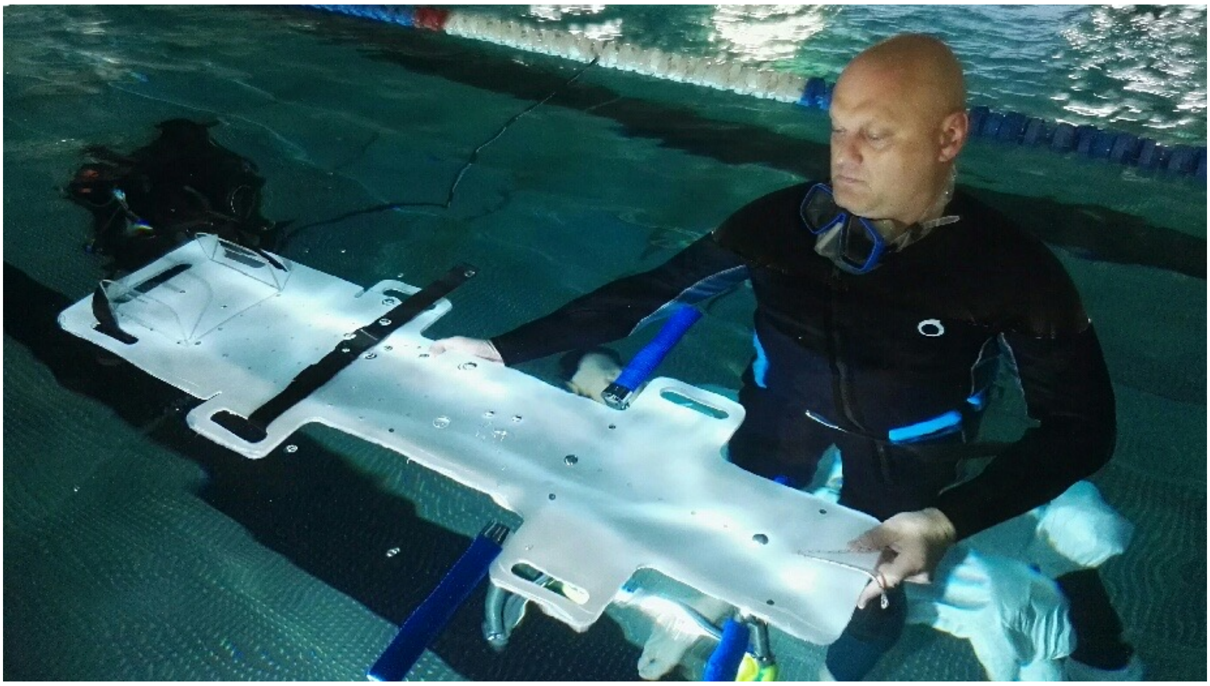


Figure 61: MMM - Mobile Medical Module - underwater tests[62]- Photo credit: Dr n. med. Arkadiusz Trzos

10.5 What is needed for our hospital to function?

Taking into account the assumptions of the competition and the hypothetical fact of living on the Moon permanently, its residents should be provided with the highest quality medical care. There is no shortage of drugs, other medicinal products or appropriate medical equipment. We took into account potential problems that could happen to the inhabitants of the new land and made sure that they could be resolved on the spot without the need to transport patients to Earth. Living on the Moon is not a short-lived space mission. It is a new life with certain needs - the old ones to which we are used to, as well as new ones related to unknown challenges.

Suppose a hypothetical patient whose medical condition requires the use of each of the products listed below. Based on the dosage of the individual drugs, the daily consumption of each drug was calculated. Then, the daily number of patients was assessed and the product consumption per week was converted.

All of the Moon inhabitants will be examined at least once a month in the hospital to control their health and prevent side effects of lunar conditions. Assuming the number of inhabitants of the Moon - 200 people - the hospital will admit about 7 people daily. Let us assume that 4 of them will require more specialized care and will be admitted for treatment in a hospital setting. That is why the average number of patients utilizing medicinal products is 4.

Medicinal products have been written using international names. As each of them can have different forms and the quantity in the package depends on the producer - examples of amounts are given based on the dosage of drugs in specific medical indications. Depending on the indications and route of administration the dosage of individual drug varies. The table shows the maximum daily consumption in the worst-case scenario e.g. 25 *mg* of Captopril is given orally in case of diabetic nephropathy, but in case of hypertension or congestive heart failure the maximum daily dosage is 450 *mg* according to international guidelines[63].

Some of the drugs and medical equipment could be produced on site in the laboratory and by using 3D printers. Unfortunately, it is difficult to predict which of them can be produced on a large scale, so at the beginning the hospital needs a full supply of all of these products. Some of them will be given to patients home to continue treatment for their chronic diseases. Thanks to this, doctors will have full knowledge about the medications taken by their patients and, on the basis of that, supplement their medical records with the necessary data that may be useful in the future.

Certainly, some drugs will expire due to long storage. Based on consumption data collected over an appropriate period of time, more precise deliveries from Earth will be determined so that nothing is missing and not much is wasted. Additional medications that may be needed, e.g. drugs used in oncology, can be provided as needed. Space-resilient medications and packaging that preserve the integrity of pharmaceuticals for long duration space missions have also been developed and can be used in that case. Powdered medications can provide the stability desired.

Disposable equipment usage was calculated taking into account the possible procedures, operations and constant hygiene of the patient. The possibility of emergencies, unforeseen situations or the possibility of damaging the equipment were taken into account - hence the excess product.

Product	Exemplary medicine	Usage per day <1 patient>	Usage per day <average quantity of patients - 4>	Weekly usage	Unit
DRUGS:					
Antibiotics	Amoxicillin	6g	24	168	g
	Azithromycin	500mg	2000	14000	mg
	Clindamycin	4,8g	19,2	134,4	g
	Ertapenem	1g	4	28	g
	Metronidazole	2g	8	56	g
	Erythromycin	4g	16	112	g
	Moxifloxacin	400mg	1600	11200	mg
	Ceftriaxone	4g	16	112	g
	Doxycycline	200mg	800	5600	mg
	Levofloxacin	500mg	2000	14000	mg
	Sulfamethoxazole and Trimethoprim	1600mg x 320mg	6400mg + 1280mg	44 800mg + 5120mg	
antifungals	Fluconazole	400mg	1600	11200	mg
antivirals	Valacyclovir	4g	16	112	g
cholinomimetics	pilocarpine	10ml	40	280	ml
acetylocholinesterase inhibitors	neostygmine	5mg	20	140	mg
muscarinic antagonists	atropine	3mg	12	84	mg
direct and indirect sympathomimetics	epinephrine	0,3mg	1,2	8,4	mg
	norepinephrine	0,4–0,8 mg/h	2,4	16,8	mg/h
	dobutamine	40 mcg/kg/min IV infusion	160	1120	mcg/kg/min IV infusion
	salmeterol	200 µg	800	5600	µg
alpha agonists	clonidine	1,8mg	7,2	50,4	mg
alpha antagonists	tamsulosin	0,4mg	1,6	11,2	mg
beta blockers	propranolol	320mg	1280	8960	mg
anticoagulants	heparin	60000 u	240 000	1680000	u
thrombolytics	alteplase	100mg	400	2800	mg
dyslipidemia drugs	atorvastatin	80mg	320	2240	mg
NSAIDs	acetylsalicylic acid	3g	12	84	g
	ibuprofen	3,2g	12,8	89,6	g
ACE inhibitors	Captopril	450mg	1800	12600	mg
diuretics	acetazolamid	1g	4	28	g
	furosemide	1500mg	6000	42000	mg
calcium channel blockers	amlodipine	10mg	40	280	mg
antiarrythmics	amiodarone	1200mg	4800	33600	mg
	digoxin	3000 µg	12000	84000	µg
antiemetics	metoclopramid	35mg	140	980	mg
	ondansetron	32mg	128	896	mg
h2 receptor blockers	ranitidine	300mg	1200	8400	mg
PPI	omeprazole	40mg	1600	11200	mg
laxatives	senna glycoside	17mg	68	476	mg
	bisacodyl	10mg	40	280	mg
antidiarrheal	loperamide	16mg	64	448	mg
medicines for diabetes	insulin	x	x	x	
	metformin	3g	12	84	g
glucocorticoids	dexamethasone	20mg	80	560	mg
	hydrocortizone	1,5g	6	42	g
opiates	morphine	1g	4	28	g
benzodiazepins	lorazepam	10mg	40	280	mg
antidepressants	sertraline	200mg	800	5600	mg
	venlafaxine	375g	1500	10500	g
atypical antidepressants	mirtazapine	45 mg	180	1260	mg
	mianserin	200mg	800	5600	mg
antiepileptics	carbamazepine	2g	8	56	g
	diazepam	60mg	240	1680	mg
	phenytoin	1g	4	28	g
antipsychotics	haloperidol	75mg	300	2100	mg
	chlorpromazine	1g	4	28	g
	olanzapine	15mg	60	420	mg
	risperidone	16mg	64	448	mg
nitrates	nitroglicerine	25mg	100	700	mg

bisphosphonates	alendronate	10mg	40	280	mg
antihistamines	loratadine	10mg	40	280	mg
anaesthetics	isoflurane	x	x	x	
	ketamine	3,6mg	14,4	100,8	mg
	lidocaine	500mg	2000	14000	mg
antithyroid agents	methimazole	6g	24	168	g
other:					
vit C		2000mg	8000	56000	mg
vit A		50 000 u	200 000	1400000	u
vit D		20 000 u	80 000	560000	u
calcium citrate		1,5g	6	42	g
sodium fluoride		200mg	800	5600	mg
calcitonin		100 u	400 u	2800	u
lithium		2g	8	56	g
drugs used in parkinsons	biperiden	20mg	80	560	mg
charcoal		3g	12	84	g
glucose in solution for infusion		4000ml	16 000	112000	ml
glucagon		30mg	120	840	mg
naloxone		80mg	320	2240	mg
IV infusions, saline 0,9% NaCl		4000ml	16 000	112000	ml
Packed red blood cells		4u	16	112	u
epoetin alfa		2g	8	56	g
sodium bicarbonate		15g	60	420	g
magnesium sulfate		20g	80	560	g
calcium chloride		4g	16	112	g
fresh frozen plasma, FFP		4u	16	112	u
platelet concentrates		4u	16	112	u
Potassium iodide		500 µg	2000	14000	µg
desmopressin		720 µg	2880	20160	µg
anti-tetanus immunoglobulin		6000u	2400	16800	u
birth control	etynyloestradiol + gestoden	0,02 mg + 0,075 mg	0,08 mg + 0,3 mg	0,56 mg + 2,1 mg	
	medroxyprogesterone	10mg	40	280	mg
DISPOSABLE EQUIPMENT					
masks		3	12	84	
gloves		10 pairs	40 pairs	280 pairs	
sterile gloves		4 pairs	16 pairs	112 pairs	
disinfectant liquid	Accelerated Hydrogen Peroxide	0,5 canister	2 canisters	14 canisters	
swabs		3	12	84	
compresses		20	80	560	
gauze		10	40	280	
bandages		10	40	280	
plasters		10	40	280	
catheters		5	20	140	
drainage tubes		3	12	84	
endotracheal tube		1	4	28	
laryngeal mask airway LMA		1	4	28	
nasal canula		1	4	28	
oxygen mask		1	4	28	
venturi mask		1	4	28	
oropharyngeal airway		1	4	28	
protective glasses		3	12	84	
disposable medical protective suit		4	16	112	
scrubs		3	12	84	
needles		10	40	280	
sterile dressing		10	40	280	
syringes		20	80	560	
urine collection bag		2	8	56	
sutures		20	80	560	
urine and faecal containers		3	12	84	
blood test tubes		20	80	560	
space blanket		1	4	28	
scalpels - surgical blades		10	40	280	

peripheral venous catheter		2	8	56	
sterile pads for the operating table and equipment		10	40	280	
IV infusion tubes		5	20	140	
ultrasound gel		200ml	800ml	5600ml	
suction pipe		1	4	28	
medical tape		1	1	2	
EXAMPLES OF REUSABLE EQUIPMENT					
IV pressure infusor		3	12	reusable	
surgical caps		2	8	reusable	
medical uniforms		3	12	reusable	
metal trays		3	12	reusable	
kidney dish		3	12	reusable	
laparoscopic trocars		20	80	reusable	
surgical robot arms		20	80	reusable	
neurological hammers		1	4	reusable	
ambu		1	4	reusable	
orthopedic boards		1	4	reusable	
ophthalmoscope mini		1	1	reusable	
laryngocsope		1	4	reusable	
retractors		5	20	reusable	
suture holder		5	20	reusable	
scissors		2	8	reusable	
Instrument set for orthopedic procedures		1	1		
dental tools set		1	1	reusable	
towel clamps		15	60	reusable	
scalpel handles		3	12	reusable	
portable extracorporeal shock wave lithotripsy device		1	1	reusable	
toothed forceps		2	8	reusable	
otoscope		1	4	reusable	
pulse oximeter		1	4	reusable	
thermometer		1	4	reusable	
tourniquet		1	4	reusable	

11 Summary

A facility such as the Alldream Lunar Institute will be indispensable if we want to colonize the Moon for good. This Institute combines the elements of a hospital, research facility and care and recreation space where every inhabitant of the Moon can feel at home. Modern technologies and the best specialists from the world of science are the two most important foundations of our project. Living in homes on the Moon is associated with exposure to conditions that we are not used to and which may pose new challenges. We know how factors such as radiation, lowered gravity and others affect human physiology, but we do not know the long-term effects of exposure to such conditions. Assuming the concept of living on the Moon permanently, the medical and research facility dealing with these problems will be extremely important, especially in the context of plans for the further conquest of the solar and other systems present in the Deep Space.

The presence of a comprehensive care facility on the Moon will make it easier for potential astronauts to move to the Moon and the opportunity to develop and expand the range of skills will be a motivating stimulus for future space explorers. More research in the field of space medicine and space biology is needed, because without it, we could expose humans to dangers that we cannot predict nowadays. We hope that our Institute will provide extensive scientific activity related to this topic and will enable the further development of humanity not only in space, but also on Earth, because, as many situations from the past prove, some inventions originally implemented in space can also be used on Earth .

Human curiosity and willingness to constant development will provide our Institute with a continuous flow of people willing to implement their ideas and will enable us to cross cosmic borders.

Home is a place where people live. We created a big home designed to be the most safe for life base in the deep space environment on the Moon. Our home is not only safe but it provides unique experiences and investigations leading for better understanding what life is, what are life's limitations and possible ways for development and transformations leading for life sustainability in extraterrestrial environments. Safety in our Home on the Moon comes not only from technology and used materials but also from a diverse network created from human neuronal networks well-trained on Earth and incubated on the Moon. People living in the Alldream Lunar Institute are selected experts loving their work, full of passion and enthusiasm. They share their results with people living on Earth. Their work brings profits to the Earth, for example, they develop new treatments for diseases, especially associated with ageing. They develop new drugs, new food, and new reusable materials to make our planet Earth healthy again.

We don't know, if Alldream Lunar Institute will be built, but homes on the Moon will definitely appear. How people living on Earth will look at the Silver Globe, knowing that there are another homes out there? All this new emotions await us in near future! Hopefully we will all witness those days of glory!

The Sky is no longer the limit!

11.1 How this project can develop in the future?

Alldream Lunar Institute is a project with potential for further development. Research findings and technological inventions trail new possibilities and new people interested in STEM - which leads to new people on the Moon. If population is bigger also the rate of possible medical scenarios increases, which means that adding new ideas and countermeasures against their consequences would be crucial. But more people also means more fresh ideas and the possibility for designing new buildings and even better and more advanced laboratory also rises. Scientists that come to our Institute would be able to conduct new research projects and expand science and technology, that could bring us to deep space and contribute to inevitable colonization of new lands. The more people involved in the space industry and space sciences, the more opportunities await for us in space.

Ad Astra!

Figure 62: Fly us to the Moon

12 Acknowledgments

We would like to cordially thank organizers for giving us opportunity to participate in the Home on the Moon Project, to enjoy teamwork and learn a lot about the Moon.

This project is the result of a teamwork of analog astronauts and everyone directly involved in our project.

We would like to thank Piotr Torchała for help in preparing 3D models and Matt Harasymczuk for help in editing the report.

Without you, this project wouldn't be the same!

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References

[1] Lunar reconnaissance orbiter: Temperature variation on the moon. https://lunar.gsfc.nasa.gov/images/lithos/LROlitho7temperaturevariation27May2014.pd.

[2] Harasymczuk M. *Badania geofizyczne w trakcie załogowej eksploracji Księżyca w ramach programu Apollo*. 2020.

[3] Smithsonian National Air and Space Museum. Apollo missions. https://airandspace.si.edu/explore-and-learn/topics/apollo/apollo-program/orbital-missions/.

[4] Thomas Schwagmeier and Eric M. Jones. Apollo traverse maps superimposed on terrestrial sites. https://www.hq.nasa.gov/alsj/TraverseMapsEarth.html, 2015.

[5] Lunar gravity model. http://lunarnetworks.blogspot.com/2012/04/new-lunar-gravity-model-highest.html.

[6] P. J. Hickson. *Lunar Surface Temperatures From Apollo 11 Data*. 1970. .

[7] C. J. Cremers. *Thermophysical Properties of Apollo 14 Fines*. JOURNAL OF GEOPHYSICAL RESEARCH, 1975.

[8] S. J. Keihm and M. G. Langseth. *Surface brightness temperatures at the Apollo 17 heat flow site: Thermal conductivity of the upper 15cm of regolith*.

[9] Mark Robinson. Lroc's first look at the apollo landing sites. http://lroc.sese.asu.edu/posts/157.

[10] Gazetteer of Planetary Nomenclature International Astronomical Union (IAU) Working Group for Planetary System Nomenclature (WGPSN). Mare tranquillitatis. https://planetarynames.wr.usgs.gov/Feature/3691.

[11] Michael E. Bakich. Target apollo landing sites. https://astronomy.com/magazine/2019/06/target-apollo-landing-sites, 2019.

[12] Eric M. Jones. Apollo 12 image library. https://www.hq.nasa.gov/alsj/a12/images12.html#AVLO.

[13] Oceanus procellarum. https://en.wikipedia.org/wiki/Oceanus_Procellarum.

[14] National Oceanic and Atmospheric Administration. Space weather: Storms from the sun. https://www.noaa.gov/explainers/space-weather-storms-from-sun, 2016.

[15] Lunar and Planetary Institute. Lunar map catalog. https://www.lpi.usra.edu/resources/mapcatalog/.

[16] Smithsonian National Air and Space Museum. Apollo 14 landing site. https://airandspace.si.edu/explore-and-learn/topics/apollo/apollo-program/landing-missions/apollo14-landing-site.cfm.

[17] Lunar and Planetary Institute. Apollo 11 mission. https://www.lpi.usra.edu/lunar/missions/apollo/apollo_11/landing_site/.

[18] Smithsonian National Air and Space Museum. Apollo 11 landing site. https://airandspace.si.edu/explore-and-learn/topics/apollo/apollo-program/landing-missions/apollo11-landing-site.cfm.

[19] ESA / Science & Exploration / Space Science / SMART-1. Shackleton crater: Smart-1's search for light, shadow and ice at lunar south pole. https://www.esa.int/Science_Exploration/Space_Science/SMART-1/Shackleton_crater_SMART-1_s_search_for_light_shadow_and_ice_at_lunar_South_Pole, 2006.

[20] Dr. David R. Williams. Moon fact sheet. https://nssdc.gsfc.nasa.gov/planetary/factsheet/moonfact.html.

[21] National Aeronautics and Space Administration MSC-TOPS-45. Robonaut 2: Medical opportunities. the future of robotics and medical care. https://technology.nasa.gov/patent/MSC-TOPS-45.

[22] Matteo Emanuelli. Future of space medical devices: Robotics, cold plasma and compact mri. 2014.

[23] MBBS MSc David A. Enoch and MBBS MSc Sani H. Aliyu. Is clostridium difficile infection still a problem for hospitals? 2012.

[24] CDC Centers for Disease Control and Prevention. Frequently asked questions about clostridium difficile for healthcare providers. 2012.

[25] Tinganelli W, Hitrec T, Romani F, and et al. Hibernation and radioprotection: Gene expression in the liver and testicle of rats irradiated under synthetic torpor. https://pubmed.ncbi.nlm.nih.gov/30654467/, 2019.

[26] The science behind animal-assisted therapy, April 2013.

[27] Therapy animals supporting kids (task) program manual, August 2010.

[28] Brian Reed, Engineering Bob Reed, Water, and Leicestershire Development Centre, Loughborough University. How much water is needed in emergencies. https://www.who.int/water_sanitation_health/publications/2011/tn9_how_much_water_en.pdf.

[29] José Manuel Villafruela, Inés Olmedo, Félix A. Berlanga, and Manuel Ruiz de Adana. Assessment of displacement ventilation systems in airborne infection risk in hospital rooms. 2019.

[30] Centre of Disease Control and Prevention. Guidelines for environmental infection control in health-care facilities. https://www.cdc.gov/infectioncontrol/guidelines/environmental/appendix/air.html.

[31] U.S. Department of Agriculture. Food consumption and nutrient intakes database. https://www.ers.usda.gov/Data/FoodConsumption/.

[32] European Food Safety Authority. The efsa comprehensive european food consumption database. https://www.efsa.europa.eu/en/food-consumption/comprehensive-database.

[33] Yves Chartier, Jorge Emmanuel, Ute Pieper andv Annette Prüss, Philip Rushbrook, Ruth Stringer, William Townend, Susan Wilburn, and Raki Zghondi. *Safe management of wastes from health-care activities*. World Health Organization (WHO), 2014.

[34] International Committee of the Red Cross. Medical waste management. https://www.icrc.org/en/doc/assets/files/publications/icrc-002-4032.pdf.

[35] Md. Rasheduzzaman Khaled Bawaneh, Farnaz Ghazi Nezami and Brad Deken. Energy consumption analysis and characterization of healthcare facilities in the united states. 2019.

[36] Aerogel.org. About Aerogel. http://www.aerogel.org/?cat=21.

[37] Inn-Therm. Aerogel (aerożel) – historia produkcji. https://inn-therm.pl/aerozel-historia-produkcji/.

[38] Jak chronić się przed promieniowaniem w kosmosie. https://mlodytechnik.pl/technika/29502-jak-chronic-sie-przed-promieniowaniem-w-kosmosie.

[39] Polietylen. https://pl.wikipedia.org/wiki/Polietylen.

[40] Johns Hopkins Medicine. Hydrogen peroxide vapor enhances hospital disinfection of superbugs. 2012.

[41] Günter Kampf. Antiseptic stewardship - biocide resistance and clinical implications. 2019.

[42] Svetlana A. Ermolaeva, Alexander F. Varfolomeev, Marina Yu. Chernukha, Dmitry S. Yurov, Mikhail M. Vasiliev, Anastasya A. Kaminskaya, Mikhail M. Moisenovich, Julia M. Romanova, Arcady N. Murashev, Irina I. Selezneva, Tetsuji Shimizu, Elena V. Sysolyatina, Igor A. Shaginyan, Oleg F. Petrov, vgeny I. Mayevsky, Vladimir E. Fortov, Gregor E. Morfill, Boris S. Naroditsky, and Alexander L. Gintsburg. Bactericidal effects of non-thermal argon plasma in vitro, in biofilms and in the animal model of infected wounds. 2010.

[43] Mounir Laroussi, Claire Tendero, Xinpei Lu, Sudhakar Alla, and Wayne L. Hynes. Inactivation of bacteria by the plasma pencil. 2006.

[44] ESA / Applications / Telecommunications & Integrated Applications. Satellite frequency bands. https://www.esa.int/Applications/Telecommunications_Integrated_Applications/Satellite_frequency_bands.

[45] CCSDS The Consultative Committee for Space Data Systems. Optical communications physical layer. https://public.ccsds.org/Pubs/141x0b1.pdf, 2019.

[46] CCSDS The Consultative Committee for Space Data Systems. Optical communications coding and synchronization. https://public.ccsds.org/Pubs/142x0b1.pdf, 2019.

[47] CCSDS The Consultative Committee for Space Data Systems. Optical communications coding and synchronization. 2019.

[48] CCSDS The Consultative Committee for Space Data Systems. Reference architecture for space information management. https://public.ccsds.org/Pubs/312x0g1.pdf, 2013.

[49] C. Matthew MacKenzie, Ken Laskey, Francis McCabe, Peter F Brown, Rebekah Metz, and Booz Allen Hamilton. Reference model for service oriented architecture 1.0. https://www.oasis-open.org/committees/download.php/19679/soa-rm-cs.pdf, 2006.

[50] Seung min Park, Daeyoun D. Won annd Brian J. Lee, Diego Escobedo, Andre Esteva, Amin Aalipour, et al. A mountable toilet system for personalized health monitoring via the analysis of excreta. https://www.nature.com/articles/s41551-020-0534-9, 2020.

[51] Pierre-Yves Oudeyer. Emotion recognition method and device - us7451079b2. https://patents.google.com/patent/US7451079.

[52] William R. Marchand. Mindfulness-based stress reduction, mindfulness-based cognitive therapy, and zen meditation for depression, anxiety, pain, and psychological distress. 2012.

[53] C. Hirt and W. E. Featherstone. A 1.5 km-resolution gravity field model of the moon, April 2011. .

[54] Erik Seedhouse. *Trailblazing Medicine*. Springer-Praxis, 2011.

[55] B. N. Posselt P. D. Hodkinson, R. A. Anderton and K. J. Fong. An overview of space medicine. 2017.

[56] Jan Stepanek, Rebecca S. Blue, and Scott Parazynski. Space medicine in the era of civilian spaceflight. 2019.

[57] Laurie J. Abadie, Charles W. Lloyd, Mark J. Shelhamer, and NASA Human Research Program. The human body in space, February 2020. https://www.nasa.gov/hrp/bodyinspace.

[58] Ph.D. Jancy C. McPhee and Ph.D. John B. Charles. *Human Helath and Performance Risks of Space Exploration Missions*. US National Aeronautics and Space Admin, 2010.

[59] Matthew J. Snyder, Marjorie Guthrie, and Stephen Cagle. "acute appendicitis: Efficient diagnosis and management". 2018.

[60] Dr Mike Cadogan. Alvarado score - life in the fast lane. 2020.

[61] Parswa Ansari. Appendicitis, April 2020. https://www.merckmanuals.com/professional/gastrointestinal-disorders/acute-abdomen-and-surgical-gastroenterology/appendicitis.

[62] Matt Harasymczuk, Agata Kolodziejczyk, MD PhD, Lt. Col. (ret.) Arkadiusz Trzos, Michał Korman PhD, Zuzanna Tkaczyk, Anna Tofilsk, Kacper Dykas, Dominik Felkle, and Aleksander Materniak. Mobile medical module (mmm). 2019.

[63] The Food and Drug Administration. Capoten® (captopril tablets, usp) rx only. https://www.accessdata.fda.gov/drugsatfda_docs/label/2012/018343s084lbl.pdf.

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Analog Astronaut Training Center is a private company, which accelerates human spaceflight scientific studies. AATC was created by former European Space Agency professionals: engineer and scientist. In 2018, the company established a laboratory to simulate space environment for scientific experiments focused on space biology and medicine. The facility is located in Rzepiennik, South of Poland. It specialises in operational trainings for scientists, engineers, space enthusiasts and future astronaut candidates. Beside scientific projects, co-supervision of engineer-, master- and doctoral theses, AATC organizes rocket workshops, stratospheric missions and scientific lunar and martian analog simulations. *In 2020 the company has reached 26 successfully organized analog simulations, what positions Poland on the top in Europe considering the number of organized expeditions*. Most of trained analog astronauts continue their career in the space sector. AATC helps them to develop and grow by helping in publishing their work on international platforms, by sharing their precious international contacts and collaborations and involving them in multiple ongoing space projects.

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We invite you to familiarise with the unique publication. We will move over 300,000 km further and several years ahead. Fasten your seat belts, our next stop will be the Apollo 11 landing site. This is where the Alldream Lunar Institute will be built - a space hospital project for the “Home on the Moon” competition organised by the Aldrin Foundation.

This is the first such project that was created by analog astronauts to rise a discussion about the safe exploration of the Moon or other planets. We wanted to combine our experiences and answer the challenge of keeping astronauts healthy and fit in deep space environment. We hope that this publication will inspire you to take up the challenge and deepen the problems and solutions we have presented related to human space exploration in the future.

ISBN 978-83-956752-1-8