HUMAN SETTLEMENT ON THE SURFACE OF MARS

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ABSTRACT

Ever-expanding human curiosity is leading humanity further into an exploration of the universe, search for another form of life, the expansion of the human presence further into the Solar system, and crewed mission to Mars are just a part of it. Therefore, the purpose of the thesis is to build a base for general knowledge, explore the new and emerging field of space architecture, and create a legacy for others to continue further research.

Mainly knowledge about the Mars exploration was gathered by extensive literature review, existing concepts, ideas, and project analysis interviewing experts in the field, and finally exploring ideas and concepts through the design development using knowledge analyzed previously.

So, the thesis is collecting general information about Mars, concepts, and ideas on how to approach the threats and complications related to the human presence on Mars. The important part of it is the interviews with experts that shed a light on the way of thinking, nuances, and new ideas in the field.

It can be seen more as an introduction to the field of space exploration from an architectural point of view. It does not intend to point out any particular statement or idea, even if some can be traced in the design development chapter, but to explore existing knowledge and deliver it to the reader.

Keywords:

Mars, Martian settlement, space exploration, radiation, gravity, distance, atmosphere, temperature, meteorites, life support system, human factor, resource utilization

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INTRODUCTION

After the Apollo program, an interest in space exploration was at its peak - after the successful landing on the Moon, for many Mars was the next logical step. The Space Shuttle program was one of such attempts, developed as part of the Space Transportation System (STS)[1]. But with the economic crisis and slow but steady fall of interest in space exploration, an enormous NASA budget of the APOLLO missions period get a reduction[2], and many plans had to be adjusted to way more modest possibilities.

But with the recent progress in rocketry development, and because of the influence of some personalities involved in the space exploration and rocket development industry, interest in it has grown significantly.

Because of the growing development in rocketry and space exploration, new opportunities have emerged, and so many architectural practices have shown an effort to explore and exploit those opportunities.

1 D. S. F. Portree, "Integrated Program Plan "Maximum Rate" Traffic Model (1970)", Wired, April 18, 2012. Retrieved on 05.07.2022 on: www.wired.com/2012/04/integrated-program-plan-maximum-rate-traffic-model-1970/
2 M. Tolson, "Mission Moon | Part 9, After Apollo, Budget realities limit NASA options", June 27, 2019, Retrieved on 05.07.2022 on: www.houstonchronicle.com/local/space/mission-moon/article/After-Apollo-budget-realities-limit-NASA-options-14045367.php

Reasoning

In its majority of concepts of the near future space and Mars exploration are considering different ways or details of how to get to the celestial body (in this case - Mars), fewer ideas are exploring how to sustain the continuous or temporal human presence on the Martian surface (or under it).

Therefore, this thesis is one of attempts to explore the architectural constitutive of the human exploration of deep space.

In Search of Life

The main reasoning behind nowadays Mars exploration missions is a search for life on the planet, conditions where it could emerge (as the liquid water), or traces that it possibly left somewhere on the surface or under it. Curiosity and our (human) desire for exploration are leading us toward new horizons, and Mars is one of them. Scientific interest was always a leading force for any mission outside Earth's influence. Only in recent years has space exploration become a subject of commercial interest as space tourism or resource exploitation.

The secret of life on Mars was fascinating to the scientific public for a long time, starting from the idea that *canals* on Mars were built by an intelligent race, prosed by Camille Flammarion, French astronomer, in 1892[3], Red planet had occupied the imagination of many. The idea of life on Mars has faced much reasonable skepticism and with the development of our understanding of the planet, of technologies for observation and exploration, this idea has significantly changed. From green people on the surface of Mars, now even the idea that the bacterial or simplest form of life could survive the harsh Martian environment is becoming less believable. Any observations that are showing a possibility that a life ever existed on Mars or could exist[4] now are discussed and criticized in a way to not leave any doubts.

And a human presence is a crucial step for a proper exploration and research of the Martian surface for any signs of life or traces of its ancient existence. It will serve not only in a proper material selection but also in the possibility for a decision making on the place, quality, speed, and mobility in research efforts, it is making quick decision making on the place possible and so on. And the important part of it is to not contaminate Mars with the Earth's life taken together with the explorers.

3 D. A. Weintraub, "Life on Mars: What to know before we go", Princeton university press, 2020, p.98

4 R. Orosei, "The Global Search for Liquid Water on Mars from Orbit: Current and Future Perspectives". Life 2020, 10, 120, 2020

The Call of Adventure

In the book 'Case of Mars' by Robert Zubrin and Richard Wagner[5], the colonization of Mars is shown as an analog to the colonization of North and South America in the XVII century. When the main reason for people going there was, of course, to obtain new resources, richness, and power, but also to call for fame and adventure[6]. Of course, this adventure, and rush for power and wealth destroyed the indigenous population, local culture, and civilization. But contemporary history cannot allow repeating the same errors done before, those were terrible facts in human history, and they can teach us how not to approach new challenges and opportunities that we will face on Mars. Luckily, today's situation is different in many ways, there is no indigenous intelligent population (at least no signs of such were found), only a possible primitive bacterial type of life; we also have developed a law system that prohibits a probable extensive impact on the Martian environment[7], but the exploration and maybe, even, colonization of Mars should follow more careful and sustainable approach.

In its first steps, exploration of Mars will be a dangerous endeavor, there are many ways how the Martian environment can kill people that are trying to approach it. It will not be a gentle tour ride for a wealthy person to see new horizons, in its beginning phase, when there are so many unknown factors this ride can kill or seriously traumatize those who will take a challenge, similarly to how it was for the first explorers of America. Therefore, this mission will need proper people ready to take risks and responsibility for their audacity, even if it means face their death.

5 R. Zubrin, R. Wagner, "Case of Mars", 1997, p. 144

6 T. Brown, Motivations for Colonization, June 2, 2022, National Geographic Society. Retrieved on 05.07.2022 on: education.nationalgeographic.org/resource/motivations-colonization

7 "Treaty on principles governing theactivities of states in the exploration and use of outer space, including the moon and other celestialbodies ("Outer Space Treaty")", United Nations Office for Outer Space Affairs (UNOOSA), 1966. Retrieved on 29.06.2022 on: www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/outerspacetreaty.html.

Human Expansion

Reaching out to Mars and establishing a human outpost on its surface potentially can create a new branch of the economy, a new frontier for exploration, research, and influence establishment. This step forward in human history probably will lead to a new loop of resource exploitation, probable conflicts for influence, wealth, and power, and new technological competition; even properly regulated by international law commercialization of the space industry will eventually lead to the break in the law or its deviation towards commercial activities support[8]. But together with the economic machine exploitation that leads human progress, further space exploration also has a potential for development in the art world and enrichment of the cultural and humanistic spectrum of human activities.

The fact that the human race will be present somewhere else than the Earth's surface already questions our perception of the Earth as the only possible home for humanity, it will enlarge our adaptability to extreme environments and our desire for further exploration of the world around us.

Because of the complexity and enormously high cost of transport connection between Earth and Mars, it can also develop as nothing more than a research outpost, as it is with the Arctic exploration. Even more, Martian exploration and its surface are protected similarly to the Arctic[9], where no big city construction is possible. Therefore, for Martian colonization been possible law should be changed or reinterpreted in a way that will allow such activity to exist.

8 I. Fino, "Building a New Legal Model for Settlements on Mars", Froehlich, A. (eds) "Assessing a Mars Agreement Including Human Settlements", Studies in Space Policy, vol 30. Springer, Cham. 2021

9 "Outer Space Treaty", United Nations Office for Outer Space Affairs (UNOOSA), 1966

Rapid Rocketry Development and Cost Reduction

As it was written previously, the recent growth of the rocket industry with the development of new types of reusable rockets like Space X Falcon9 or Starship proposes a wide range of opportunities for space exploration. Of the range of rockets that are possible to deliver cargo to Mars Starship rocket developed by Space X is the most promising. Its possible characteristics[10] (it is still under development) like 100 tons of cargo to Mars (with the additional orbital refueling), size of the cargo bay, and a possibility to land it on the surface are proposing a range of opportunities to look on the Mars exploration in a bigger scale.

These emerging factors are allowing architects and engineers to develop different ideas that are less restricted to the weight and size limits. But the new system of delivery brings up new challenges regarding how to adjust ideas to it.

10 "Starship Users Guide", Space Exploration Technologies Corp., March 2020

PLANETARY
FACTORS

To understand the specific of working on other celestial bodies different than Earth, one should surrender many facts that are taken for granted here.

Those factors such as radiation, reduced gravity, or thin atmosphere not only pose a substantial danger for the first explorers stepping on the surface of Mars but also are game-changers in terms of the constitutive world viewing principles. And in terms of construction, production, and raw materials extraction - those factors have an actual and particular outcome.

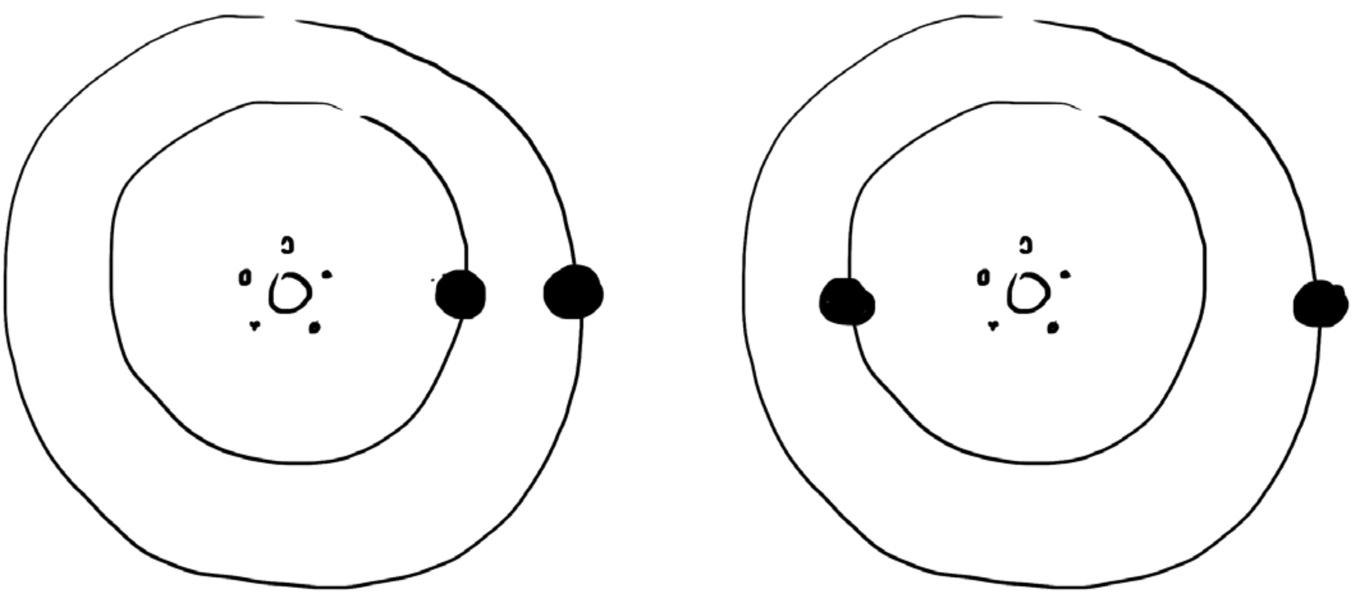
Once occupied, it would be a different world, with different rules.

DISTANCE

Mars is not the nearest planet to the Earth, Venus is a way closer, but conditions that are present on this celestial body require more advanced and costly solutions to get to the surface or to stay in an upper atmosphere. Therefore, Mars would be an optimal option.

But it is indeed far away. At its closest distance to Earth, in the so-called 'opposition' (terminology that comes from ancient astronomers when a geocentric point of view still dominated the scientific field), it is about 56 million kilometers away, and at its farthest, on another side from the Sun, in 'conjunction' position, it is 400 million kilometers away. [1]

1 R. Zubrin, R. Wagner, "Case of Mars", 1997, p.59



Logistics

There is no possible propulsion system that can connect those two celestial bodies in a straight line from point A to point B - all existing now or in the near future spacecraft need to respect planetary dynamics and momentum conservation principle (any escaping body from the surface of Earth will possess Earth's velocity and trajectory). Using trajectory discovered in 1925 by German mathematician W. Hohmann, [2] it would require using as little as possible energy to travel to another celestial body. And in the case of Mars, it occurs when it is in 'conjunction' position with the Earth. It is possible to deviate from it to get to the destination quicker, but the more one does, the more energy is required. In any case, it will need to travel around 400 million kilometers to get to the red planet using the closest trajectory[3], which is a thousand times the distance that Apollo astronauts traveled to the Moon.

Of course, it does not mean that you will need 3000 days to get to Mars (Apollo astronauts get to the Moon in 3 days), but it will take substantial time and energy to perform.

On its way to Mars, the spacecraft needs to escape the field of influence of Earth, to perform it spacecraft should achieve departure velocity (hyperbolic velocity, about 3km/s). After it does escape Earth's field of influence it flies across the solar system, accordingly to the momentum conservation principle, with its departure velocity + velocity of the Earth (which is relative to the Sun about 30 km/s). What was not the case for Apollo missions on the way to Moon that had to deal with the body in the Earth's gravitational field

Leaping around the solar system with a speed 20 times bigger than was true for the Apollo missions (relatively to the Earth) it will still require about 150 days to get to the destination.

Hohmann transfer between Earth and Mars takes 258 days to perform[4], and it is the cheapest in terms of fuel consumption. Such a long period in a transfer would be fine for cargo, but to fly a crew it would a way better to choose a quicker option, accordingly to Robert Zubrin Mars Direct plan[5], it doesn't take too much additional propellant to reduce a transfer time to about 180 days.

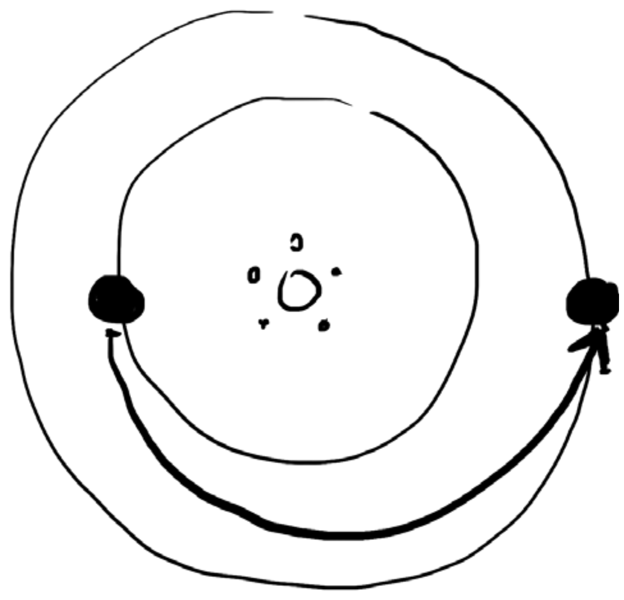
150-day transfer discussed before is possible, but it would take much more propellant and would make aerobraking maneuver more dangerous (it is the most efficient way to slow down, using atmosphere of the planet, the vehicle enough, so it can land on the surface), therefore it is better to perform the 180 days for crew mission and 258 for cargo.

2 A. Miele, M. Ciarcià, J. Mathwig, "Reflections on the Hohmann Transfer". Journal of Optimization Theory and Applications 123, 233–253, 2004

3 Y. Wei, Y. Zhang, "The Simulation and the Calculation of the Shortest Hohmann Transfer Orbit to Mars". Journal of Applied Mathematics and Physics, 7, 2384-2400, 2019

4 A. Stinner, J. Begoray, Journey to Mars: the physics of travelling to the red planet. Physics Education, 40(1), 35–45, 2005

5 R. Zubrin," The Mars Direct Plan" , 282(3), 52–55, 2000



Economics

It is hard to predict what would be an actual price for the interplanetary transfer about 50 years from now, but it is clear how much it costs now and how much it can cost in 5 or 10 years, considering the rapid development of the super-heavy lift rockets of Saturn V (NASA rocket that delivered APOLLO astronauts to the Moon) class that is capable of Earth-Mars transfer.

It is possible to estimate today's costs of such a journey from an average price for the kilogram from the last Perseverance rover launch that successfully landed on the surface of Mars in 2020. So, the launch itself was about 243 million dollars[6], while the mass on the lunch of the rover (without its complex landing system and Ingenuity copter (about 1.8kg)) was about 1025 kg, which means that the cost for each kg of the rover delivered to Mars was about 237 000 dollars (as the landing system, parachutes, heatshield, etc. were taking part in delivery the rover to the surface they are assumed as a part of the launch system).

Another limitation of such a journey is the mass capability of the rockets, Saturn V or Ares type rockets can deliver up to 28.6 tons to the surface of Mars[7]. Meanwhile, the Space Launch System (SLS), which is in development by NASA since 2011, could bring 46t in its block 2 Cargo configuration to Trans-Lunar Injection (TLI) or Moon[8].

But a breakthrough will be the development of reusable rockets as SpaceX and Blue Origin are doing. Eventually, with the orbital refueling, SpaceX states that their system of a Starship upper stage and Heavy Booster first stage can deliver more than 100 tons to Mars[9]. Accordingly, to Elon Musk[10] such a journey can cost less than 500 000 dollars for a person[11] (as the 'median cost of the house in the United States[12]), which would be about 7000 dollars per kilogram, what is 33times less of the Atlas V price.

It is hard to base proper calculations on the cost of delivery to the Mars surface as the information given is vague and the rocket system is still in development, but it can give an approximate image of future prices and how precious each object can be if delivered from Earth to the Mars.

6 C. Dreier, "Cost of Perseverance, in Context", The Planetary Society, 29 Jul 2020, Retrieved on 26.06.2022 on: www.planetary.org/articles/cost-of-perseverance-in-context

7 R. Zubrin, R. Wagner, "Case of Mars", 1997, p.78

8 "NASA'S Space Launch System Reference Guide", NASA, March 2022, p. 15

9 "Starship Users Guide", Space Exploration Technologies Corp., March 2020

10 E. Musk, "Making Humans a Multi-Planetary Species". New Space, 5(2), 46–61, 2017

11 D. Lyle, "Average House Price by State in 2021", 2021, accessed 28.06.2022 on: https://www.fool.com/the-ascent/research/average-house-price-state/

12 E. Musk, "Making Humans a Multi-Planetary Species", 2017, p. 48

GRAVITY

Mars's average diameter of 6779 km is almost twice shorter compared to Earth's (12742 km). In the case of Mars, it also means that it has a smaller mass and consequently weaker gravitational field, which is about 38% of the Earth's one. [13]

13 E. Musk, "Making Humans a Multi-Planetary Species", 2017, p. 47

But weaker gravitation means not only that astronaut will jump higher (of course, he/she will), but also several mechanics that we get used to here, on Earth, will not work in the same way on Mars, maybe, will not work at all.

Zero gravity influence on a human body

Before talking about Mars's 0.38G influence that we know little about, it would be better to discuss an influence of microgravity (almost zero gravity, like on the ISS or other spacecraft) or zero gravity that is quite well studied by astronauts on ISS (International Space Station), Mir station, SkyLab. A number of them were staying in orbit for long periods, for example, Valeriy Polyakov (437 days), Vladimir Titov and Musa Manarov (366 days), [14] Mark Vande Hei (355 days), Scott Kelly (340 days) [15], and harmful consequences are well known.

14 R. Pearlman, "One Year in Space: A History of Ultra-Long Missions Off Planet Earth", 26 March 2015. Retrieved on 06.28.2022 on: www.space.com/28947-yearlong-space-missions-history.html
15 M. Garcia, "NASA Station Astronaut Record Holders", 21 April 2022. Retrieved on 06.28.2022 on: www.nasa.gov/feature/nasa-station-astronaut-record-holders

Long-duration exposure to a zero-gravity environment will cause cardiovascular deterioration, decalcification and demineralization of the bones, general deterioration of muscular fitness, and depressed immune system[16].

As a countermeasure to such conditions, different techniques were implemented on ISS and other space stations before, and the everyday extensive 3hr exercises were proven to be good enough measures for muscular and to some extent cardiovascular deterioration but there are no particular measures against demineralization of the bones[17].

16 T. S. Aurora, C. Tabaresh, "Microgravity and the human body". Physics Education, 30(3), 143–150, 1995
17 R. Zubrin, R. Wagner, "Case of Mars", 1997, p.86

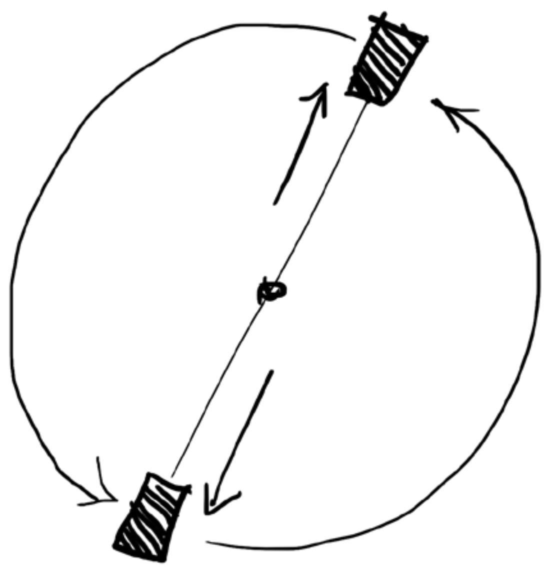
Artificial gravity concept

But Zero-G ramifications can be potentially avoided - there are several concepts and ideas for the artificial gravity spacecraft that can transfer astronauts to the surface of Mars. One of such proposed Dr. Robert Zubrin[18], who separated the spacecraft into two parts: a living habitat that then has to land on the Red planet and used upper stage that pushed the spacecraft on its transfer orbit. Both ends should spin on long cables around a common center of mass, creating an artificial gravity using centrifugal force. These physical principles can be easily observed in a washing machine - when it's working all of the liquids and clothes are distributed around the curved surface of its drum, out from the axis of rotation.

F = (0.001 1) W2R

Accordingly, to the equation, where 'F' is the gravitational force measured in G (1G = gravity on the surface of Earth), 'W' is the rotation speed measured in rotation per minute (rpm) and 'R' is the length of spinning arm in meters. So, there are two options: one is to have small spinning arm and high rotation speed, and another is the long spinning arm and lower rotation speed. And the second one is preferable as it gives better load distribution and centrifugal forces. But it makes the tether system more complicated.

18 R. Zubrin, R. Wagner, "Case of Mars", 1997, p.88



Reduced gravity influence on a human body

Nevertheless, the main objective which defines the livability of a long or even permanent stay on the surface of Mars is the potentially harmful influence of the reduced gravity on the human body and health.

Problem is that there are not so many places where this affects can be properly studied, we have extensive data on how microgravity influences the human body but not exactly the reduced gravity. The closest such an environment to Earth to examine would be Moon, but Apollo astronauts spend too little time on the surface of the Moon to make proper conclusions about health and wellbeing damages from being in a reduced gravity environment (the longest stay was done by astronauts of the Apollo17 mission that lasted for 74 hours, 59 minutes, 38 seconds[19]).

19 C. Lethbridge, "Apollo 17 Fact Sheet". Retrieved on 28.06.2022 on: www.spaceline.org/united-states-manned-space-flight/apollo-mission-program-facts-sheet-index/apollo-17-fact-sheet/

Application in a construction industry

The reduced gravity is directly influencing the load requirements for the structures applied. The problem in most cases is not in load requirements but the low quality of materials applied, therefore most concepts that are using In-Situ Resource Utilization or 3d printing technics are also utilizing catenary models as the most reliable and easy to implement[20].

20 T. Prater, T. Kim, M. C. Roman, R. P. Mueller, "NASA's Centennial Challenge for 3D-Printed Habitat: Phase II Outcomes and Phase III Competition Overview", 2018 AIAA SPACE and Astronautics Forum and Exposition, 2018

Raw material extraction

In-situ resource utilization (ISRU) is a key for self-reliable and sustainable development on the surface of Mars, but to extract raw materials, collect, or excavate them from the surface one should understand the difference between Earth and Mars conditions.

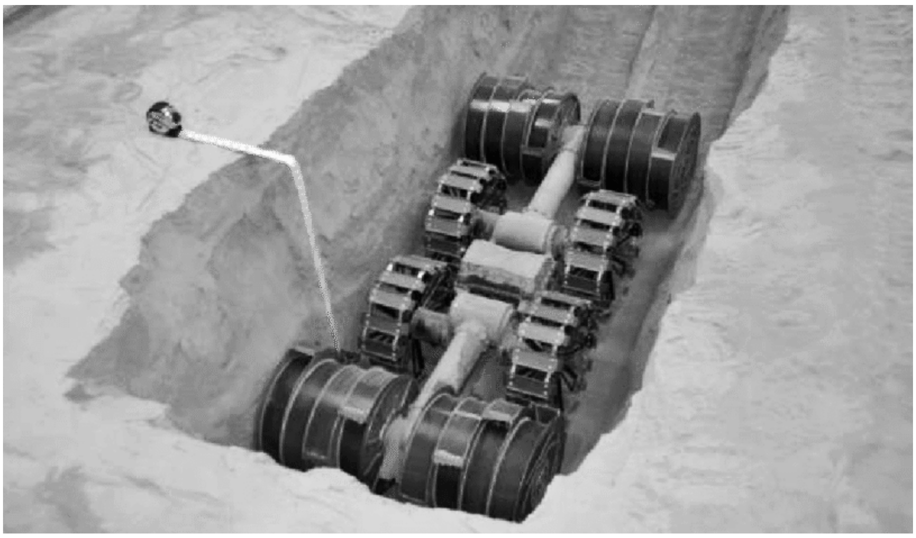
Most excavation or soil collection techniques on Earth rely on heavy and massive machinery to create a 'counterweight' for the digging forces. There are plenty of examples of such techniques: backhoes, loaders, scrapers, etc., all of them are dependent on the machine's mass for effective operation.

But the requirements for the work on the surface of Mars are different because logistics and prices for the payload mass of the extraction machinery should be minimized, additionally weight of the machine and the ability for its work as 'a counterweight' will be reduced by the smaller gravity of the Mars. Therefore, alternative designs are needed, that can be lightweight, utilize low power, and be robust enough for harsh Martian conditions.

The Regolith Advanced Surface Systems Operations Robot (RASSOR)[21] can be a good example of a concept of a robotic precursor that can do its work while being lightweight enough (less than 500 kg). After a proper technology demonstration and proving that it is possible to excavate and utilize regolith in such a manner, the project assumes that multiple mini excavators can be delivered on the surface on small landers and then operate in a swarm making the mission scalable and affordable.

It is possible to assume that at a later stage of the Mars colonization if such stage will appear, that industrial plants will produce their heavy machinery from the available materials, but before it happens, those plants should be constructed, and feedstock needs to be excavated, and those operations need to utilize technics described above or alternatives that will use similar principles.

21 "Regolith Advanced Surface Systems Operations Robot (RASSOR)", IEEE Big Sky 2013, 3 February 2013



RADIATION

Martian astronauts will be exposed to two types of radiation: solar flares and cosmic radiation that is coming from deep space.

Solar flares are a wave of protons that burst from the Sun - this event is irregular, unpredictable, and happens about once per year. The amount of radiation an unprotected person in outer space is exposed to is deadly, however, a modest amount of shielding stops it. For example, a person on a spacecraft protected only by its hull would receive about 38 rem, while if one stays in a shelter inside, it can be reduced to 8 rem. If the person stands on the surface of Mars inside the habitat, because of the atmosphere and surface shields, it will be even less (about three rem). Such an event can happen once a year, and the numbers used are from the most giant recorded solar flares (February 1956, November 1960, August 1972) [22].

Cosmic rays are different - they are composed of particles with much higher embedded energy. Therefore, you need much substantial shielding to stop them. It is different from solar flares as it is constant but small in amount of radiation.

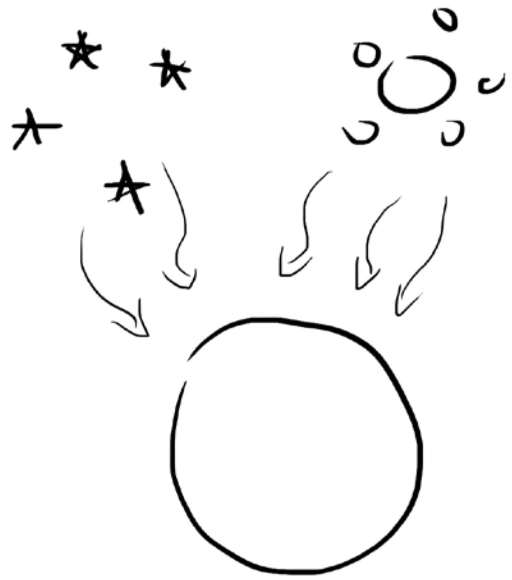
In outer space, an astronaut is exposed to 20 – 50 rem per year (depends on the solar activity - the more active Sun is, the fewer cosmic rays are reaching the inner solar system) with an average of 35 rem per year. On the surface of Mars, astronauts will already be protected from cosmic radiation from one side by the planet itself. The other part can be covered by a shelter made of regolith or other available material. In this way, radiation exposure can be reduced to 6 - 7 rem per year or even less (9 if it is unsheltered).

If we summarize the numbers together and assume that we use the Mars Direct plan[23] of about 910 days long, radiation exposure would be 52 rem on average for the whole duration of the mission, with about 10 rem a year on the surface of Mars and 43 rem (per year) in transit between the planets. That is the same as what astronauts on the ISS (International Space Station) are exposed to[24].

22 R. Zubrin, R. Wagner, "Case of Mars", 1997, p.84

23 R. Zubrin, R. Wagner, "Case of Mars", 1997, p.45

24 R. Zubrin, "Colonizing the Red Planet: Humans to Mars in Our Time", Archit. Design, 84: 46-53, 2014



Radiation thresholds

That is true that exposure to substantial amounts of radiation can and will kill. Was it the Chornobyl nuclear reactor explosion or the bombing of Nagasaki and Hiroshima - these examples show how radiation can be deadly. But they also provided information on what, how much, and how long radiation exposure will cause unrecoverable consequences.

Studies of the victims of these disasters revealed that prompt doses less than 75 rem (rem – radiation health effect unit[25]) results in no apparent health effects, while between 75 and 200 rem, radiation sickness will appear in from 5 to 50 percent of exposed individuals, at this point almost everyone recovers within weeks. At 300 rem deaths are starting to appear, rising to 50 percent at 450 rem and 80 percent at 600 rem, almost no one survives 1000 rem dose[26].

As was described before, possible exposure of the individual would be 52 rem for a period of 910 days with its biggest prompt exposure about 8 rem in outer space and 3 rem on the surface. Which is less than the prompt exposure threshold of 75 rem for any symptoms of radiation sickness to appear[27]. But it is only 8 rem less than the Nasa Permissible Exposure Limit for an individual astronaut of 600 mSv[28] (Sv = 100 rem; 600 mSv = 60 rem[29]) for total career radiation exposure astronauts.

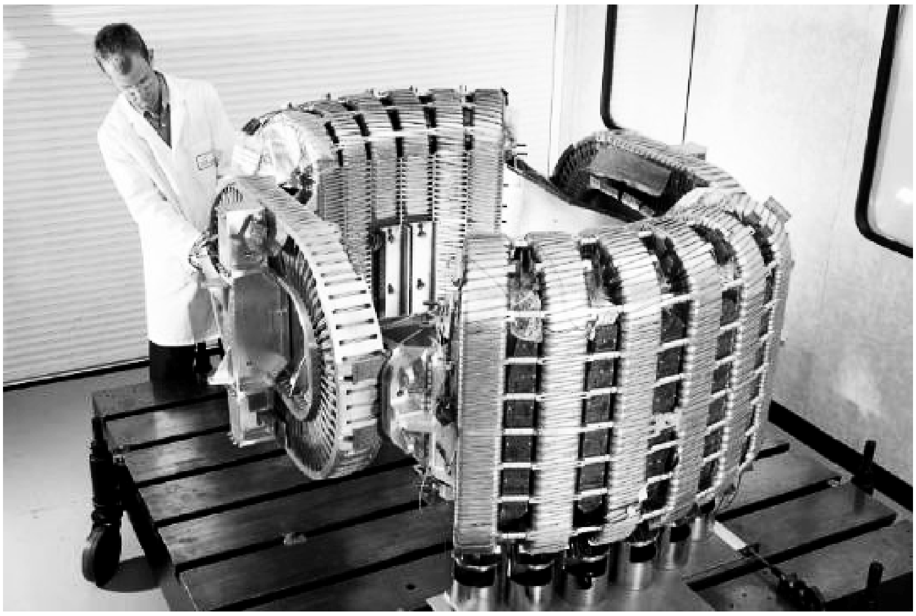
25 "Radiation Terms and Units", EPA.gov. United States Environmental Protection Agency. 06 May 2022. Retrieved 05.07.2022 on : www.epa.gov/radiation/radiation-terms-and-units

26 R. Zubrin, R. Wagner, "Case of Mars", 1997, p.83

27 R. Zubrin, R. Wagner, "Case of Mars", 1997, p.83

28 "NASA Technical Standard, NASA Space Flight Human-System Standard: Volume 1: Crew Health", National Aeronautics and Space Administration, 01 May 2022, p. 29

29 M. Langford, P. A. Bieri, "Space Radiation – Frequently Asked Questions", NASA.gov, National Aeronautics and Space Agency, 18 March 2022, Retrieved on 05.07.2022 on: srag.jsc.nasa.gov/spaceradiation/faq/faq.cfm



Active Shielding

Even if the crew does not meet great solar flares or any other substantial radiation source, it will need additional protection during the interplanetary flight (the Martian mission phase with the most significant radiation exposure) and on the surface of Mars. There are many ideas on how to protect the crew on the surface, but they are not applicable for an interplanetary phase.

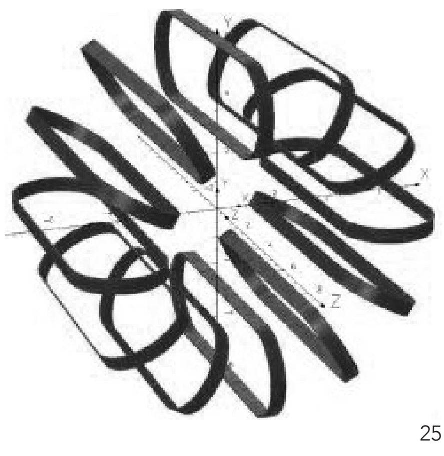
But the technology of the Active Shielding is the one that potentially will serve as the protection of astronauts in deep space travel. The idea behind it is to use an electromagnetic field to deflect solar flares and cosmic radiation particles[30], similar to how Enterprise's shield from Star Track was deflecting attacks on the spacecraft. And protection of the crew during interplanetary flight would be an excellent application for the technology as the active shielding does not produce secondary radiation as it is with the bulk passive shielding when the radiation particles hit a rigid surface and create x-ray radiation.

But together with the significant theoretical advantages, the technology lacks real-life applicability. For its functioning, it needs a substantial amount of energy, and it is massive and complex; it is hard to manage the amount of energy stored in the superconductor or the electrostatic field produced by it[31]. Although, with the recent progress in superconductor development, those concepts have become handier [32], even if they are still hard to implement in the on-surface habitat due to the complexity, this technology is rapidly advancing.

30 P. Spillantini, "Superconducting magnets and mission strategies for protection from ionizing radiation in interplanetary manned missions and interplanetary habitats", 68(9-10), 2011, p. 1431

31 D. Fry, S. Madzunkov, J. Simcic, A. W. Hunt, Application of scaling methods to foster ground development of active shielding concepts for space exploration. Acta Astronautica, 178, 2021, p. 297

32 P. Spillantini, "Superconducting magnets and mission strategies for protection from ionizing radiation in interplanetary manned missions and interplanetary habitats", 2011, p. 1433



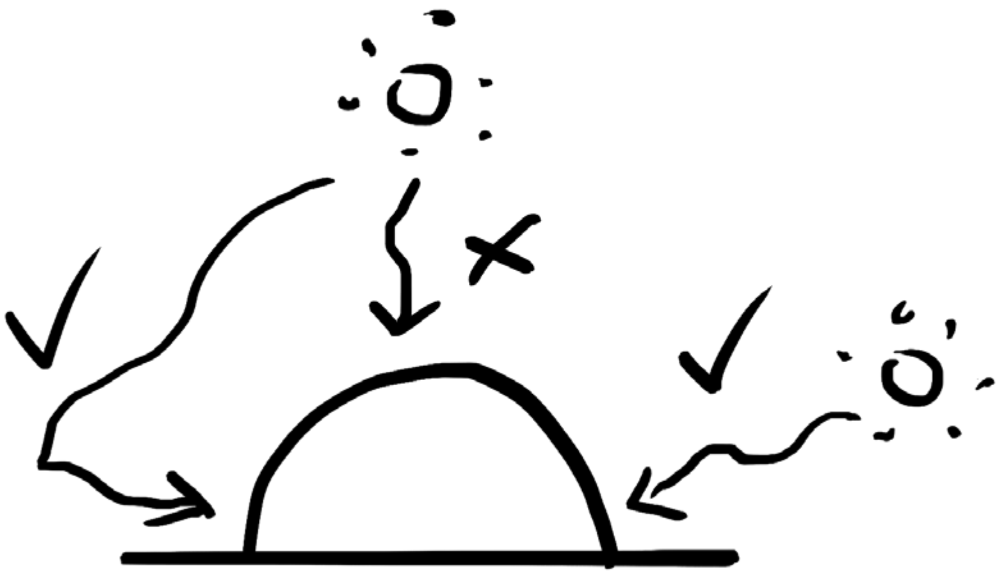
Angle difference of exposure

The main thing that protects an individual on the surface of Earth is not its magnetic field but its atmosphere. In terms of mass, it is about 10 meters of water equivalent, which shields us from cosmic radiation. On Mars, with its atmosphere of about 1% of Earth's would be 0.1 meters, but it is if looking straight up. However, if looking in every direction where the radiation is coming from, it would be about 0.6 meters of the water equivalent that creates a powerful shield against solar flares and cosmic rays at specific angles. It is not protected from cosmic rays, but solar flares will not make it to the habitat[33].

From the previous statements, it is seen that a significant part of the radiation received by the individual is from the transit through interplanetary space. At the same time, the average exposure on the surface is much less while still relatively high compared to the Earth's average radiation background.

33 R. Zubrin, R. Wagner, "Case of Mars", 1997, p.85

While the radiation exposure during the interplanetary flight is not what usually architectural practice can solve, securing the surface stay even more, is the question that architects can address.



ATMOSPHERE AND TEMPERATURE

The atmosphere of Mars was discovered for the first time in 1780 by German-born British astronomer William Herschel. He also measured the tilt of the planet's rotation axis and started to discuss the seasons on the Red Planet[34].

34 M. C. Malin, M. H. Carr, M. J. S. Belton, "Mars". Encyclopedia Britannica, 30 Jul. 2021, Retrieved on 8.11.2021 on: https://www.britannica.com/place/Mars-planet

Composition and surface pressure

Martian atmosphere mainly consists of carbon dioxide (CO2), which is about 95,3% by weight ratio to the rest, which is about nine times the quantity that exists in nowadays Earth's massive atmosphere; it also includes Nitrogen, water vapor, and noble gases (argon, neon, krypton, and xenon).

It is known that only a tiny amount of water is present in the atmosphere today, but it plays a vital role in atmospheric chemistry and meteorology. The atmosphere is near saturation, and water-ice clouds can be observed, often within valleys or craters. Thin clouds are expected at the morning terminator (the line between the lit and unlit surface of the planet), and orographic clouds can be observed in topographic features like volcanoes and craters. And most of these clouds are composed of water ice. Some such features as dust devils are observable, too, it is too small to see from the Earth, but it was observed from the Mars orbit or at various spacecraft landing sites[35].

Because of the absence of liquid water on the surface (due to low pressure), atmospheric water vapor has its source in the Martian soil. And it seems that undersurface layers have a great abundance of ice: the 2001 Mars Odyssey [36] spacecraft confirmed that ice is present 1 meter under the surface at latitudes higher than 60°; the Phoenix lander found ice below the surface, but we do not know how deep it extends, for example, the Mars Reconnaissance Orbiter showed some photos of the new impact crater exposing an ice layer about 74 cm thick [37]. But in lower altitudes, ice is unstable, and even in the soil, it tends to sublime into the atmosphere.

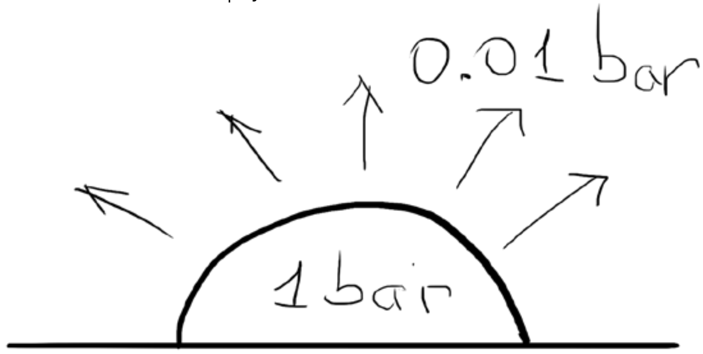
But even though this thin atmosphere is slowly disappearing, different constituents in the upper atmosphere are losing into space. It is also influencing the isotopic composition of the remaining gases. For example, hydrogen, as one of the most volatile elements, escapes the atmosphere very quickly, while its heavier isotope deuterium lasts. As a result, Mars's atmosphere contains five times more deuterium than Earth's [38], making it attractive from the point of view of the fusion nuclear power industry, as it is one of the primary fuels for the fusion nuclear reaction.

Atmospheric pressure at the surface is less than 1 % (about 0.006) of the Earth's and can change the landscape by 15 because of significant differences in Mars's topography. Because of such low pressure and relatively low average surface temperature, water molecules cannot exist in liquid form, only as ice or vapor, even if the atmosphere is effectively saturated with water vapor[39].

But it is believed that Mars once had a much thicker atmosphere that was 'blown away into space by solar wind and Sun's ultraviolet radiation, which were even more intense than nowadays in the early solar system.

35 M. C. Malin, "Mars". Encyclopedia Britannica, 30 July 2021
36 N. Florent, " Water measurements on Mars using neutron spectroscopy data from the Mars Odyssey orbiter", 2020
37 Harish, S. Vijayan, N. Mangold, A. Bhardwaj, " Water-ice exposing scarps within the northern midlatitude craters on Mars". Geophysical Research Letters, 2020

38 V. Krasnopolsky, "On the Deuterium Abundance on Mars and Some Related Problems", Icarus 148, 597–602, 2000
39 M. C. Malin, "Mars". Encyclopedia Britannica, 30 July 2021



Seasons

The atmosphere of Mars has significant seasonal shifts in pressure because of carbon dioxide. In the winter, it solidifies, settles on poles, and then sublimes (returns directly into a gas) in the spring. Because the south polar cap is more extensive than the northern one, in southern winter, the atmospheric pressure reaches its minimum, while in the southern summer, it is at its maximum. It is also a consequence that in southern summer, Mars is at its closest to Sun, and in southern winter - at its farthest (Mars orbit is eccentric). Therefore, it becomes possible for a significant carbon dioxide cap on the south pole to form and then receive some extra heat that sublime the formed cap in the summer. Because of the extensive presence of CO2 in the atmosphere, pressure can vary by 26 percent as huge quantities (7.9 trillion metric tons) of carbon dioxide leave and reenter the atmosphere each year.

Dust storms

From the nineteenth century, astronomers could observe the seasonal shifts and existence of dust storms on a planetary scale. Later it was confirmed by the robotic exploration by the United States and the Soviet Union in the 1960s. Dust storms are common on Mars - they can happen at any time but are most frequent in southern spring and summer.

Because of the significant atmospheric seasonal shifts and a rapid rise of the atmospheric pressure during southern early summer (about 12 percent in a few months), massive winds are forming that pick up and transport vast quantities due to the higher-than-average sun heat of the dust. Most of the occurring storms are regional in extent and can last a few weeks, but every second or third year, dust storms reach a global scale. Their peak wind speed can be up to 100 km/hour and be high enough to cover the whole planet so that only the highest peaks (up to 21 km above the planet's mean radius) are visible.

The storms raging during southern summer and gradually die out with the approach of autumn in the southern hemisphere. Therefore, clean weather can be generally expected in the northern hemisphere during its spring, summer, and fall [40].

In 1971 Soviet spacecraft Mars 2 and Mars 3 were attempting to land on Mars near 45° south latitude. At the same time, a colossal dust storm was on its rise. As a result, none of them survived parachute descent.

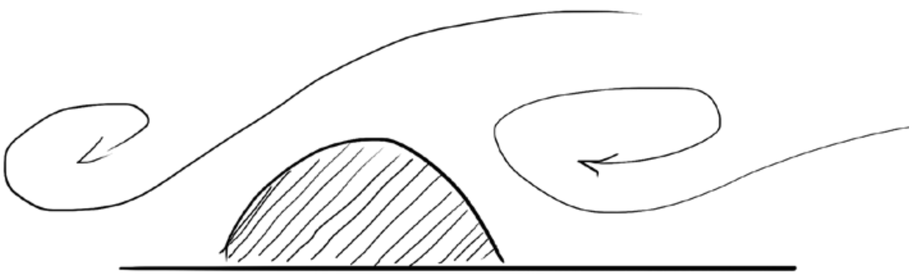
Parachuting into a Martian dust storm is not a good idea, but it is totally different if you are already on the ground when the storm hits. Because of the light atmosphere (less than 1 % density of Earth's), the dynamic pressure of the 100 km/hour wind on Mars is equal only to that of 10 km/hour (2.8 m/s) on Earth's surface felt like a light breeze. Many robotic landers serve on the surface for years and are subject to the dust storm yearly, which does not question their functionality. If the storm's winds speed can reach up to 100 km/hour (about 28 m/s) average speed on the ground level during the year is about only 2 m/s [41].

Dust storms also block the surface's visibility from orbit, blocking any radio signal coming in or out, but local visibility on the surface is not impaired much. It does reduce light levels so that reduction in efficiency can be expected with solar panels, but it does not fog out the area to the observer on the surface.

Most of the danger that dust storms can present is objects like parachutes or balloons with a lot of "sail area." Also, dust contamination of the interior of habited space can be dangerous, as the Martian dust can be very toxic due to its fine size and composition.

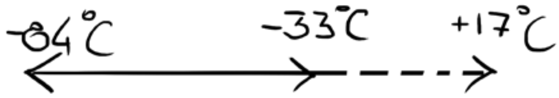
40 Zubrin R., Wagner R., "Case of Mars", 1997 p.91

41 Zubrin R., Wagner R., "Case of Mars", 1997, p.137



Surface temperatures

Surface temperatures highly depend on latitude and can change drastically during the day-night cycle. At the Viking 1 and Pathfinder landing sites (about 20° Northern latitudes), temperature could be low as -84 °C just before the sunrise, or -33 °C in the early afternoon (Δt = 51 °C), which would be much larger than those that are occurring in desert regions on Earth. The temperature difference is much more significant close to the ground. It happens because of the thin and dry atmosphere that allows the surface to radiate heat very quickly at night. An average daytime surface temperature would be about -20 °C, close to the values experienced in Antarctica during winter. However, above a very dark surface in summer, daytime temperatures can peak up to +17 °C [42].



42 M. C. Malin, "Mars". Encyclopedia Britannica, 30 July 2021

METEORITES

Meteorites can impose hazards to any Martian surface missions, and the question is more about how significant the probability is that one will hit the ground equipment. The mass distribution and meteoroid flux on the Mars orbit or the surface is now unknown. Several simulation models and calculations were made, but they do not have detailed information on the hazard's realness towards the ground mission [43].

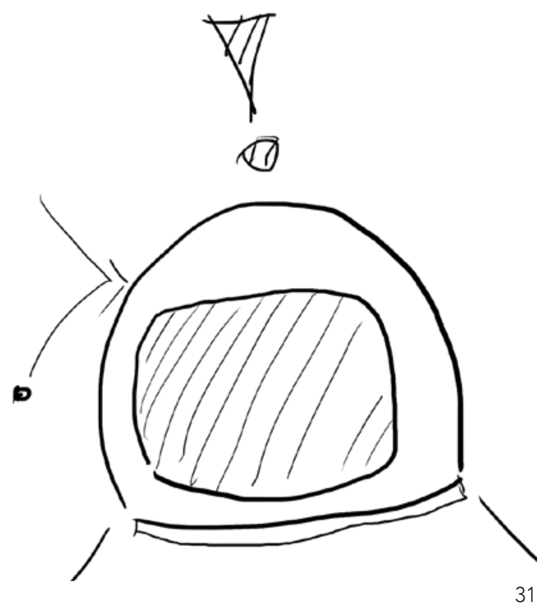
But it is believed that meteoroid impact probability is significantly higher than on Earth or Moon's surface because of the proximity of Mars to the asteroid belt because of its thin atmosphere and lack of a Martian magnetic field [44].

Even the thin atmosphere of Mars protects the surface enough from the meteorites, less than one kilogram. It also can vary with the altitude, considering a significant difference in the Martian landscape. Depending on the impacted surface, there is also an additional secondary fragmentation risk.

But a thin atmosphere also significantly slows down the impact speed of the meteorites to the small enough parameters for their survivability. Together with an arid and lifeless environment, Mars's surface can accumulate a great number of meteoroid material that can be significant in the further study of the Martian climate or solar system history or be a good nutritious source for a probable agricultural purpose [45, 46].

43 A. M. Al Husseini, L. Alvarez Sanchez, K. Antonakopoulos, "Access Mars: Assessing Cave Capabilities Establishing Specific Solutions: Final Report", 2009
44 C. Schröder ,"Meteorites on Mars observed with the Mars Exploration Rovers", 2008

45 P. A. Bland, T. B. Smith "Meteorite Accumulations on Mars", 2000
46 A. G. Tomkins, M. J. Genge, A. W. Tait, S. L. Alkemade, A. D. Langendam, P. P. Perry, S. A. Wilson, " High survivability of micrometeorites on Mars: Sites with enhanced availability of limiting nutrients". Journal of Geophysical Research: Planets, 124, 2019, 1802–1818



HUMAN ACTIVITY
FACTORS

With the introduction of human beings into the equation of Mars exploration, together with it, a significant number of factors are starting to play a crucial role. Support of human activity on the planet will need many resources. A considerable additional complication of the mission architecture starts to arise, the need to protect the crew from environmental threats and the necessary infrastructure to be developed and established. Humans that will be lucky to be chosen for the mission to Mars will need proper psychological and medical support and observation. Many complex interconnected relationships start to appear when humans become the center of the mission architecture. The environment in which this human operates plays a crucial role in how the mission is passing.

ENVIRONMENT CONTROL AND LIFE SUPPORT SYSTEM

The main difference between a crewed mission to Mars and robotic exploration is that a human-crewed mission, besides its significant advantages, also needs a vital infrastructure and resource base to be brought together with humans to sustain a higher degree of their survivability. Because of the complexity of the endeavor and the high degree of its failure, and its tremendous cost, not only in economic aspects but most importantly in political and prestige aspects, preparation for it takes a very long time. Proper technology advancement, methodology, and understanding of the environment itself should exist before the departure of any human beings on the surface of Mars.

In terms of technology and using existing local resources, the environmental control and life support system (ECLSS) plays a significant role in keeping the human crew alive. Usually, it consists of separate modules regulating different critical components of the atmosphere (O2, CO2, N2), water purification, its reuse and production, and waste (organic, human activity, or inorganic) management. Nowadays, it appears as a massive and complex system that uses chemical reactions to obtain needed elements or regulate the atmosphere.

The ECLSS system consists of different categories that control aspects of human life in isolated and confined environments. For example, ECLSS of the International Space Station has several functions: Atmosphere Revitalization (AR), which mainly consists of CO2, O2 control, contaminants, and microorganism control; Atmosphere Control and Supply (ACS), which also consists of atmospheric composition and pressure control, storage of main constituents; Temperature and Humidity Control (THC); Water Recovery and Management (WRM); Waste Management (WS); Fire Detection and Suppression (FDS); Vacuum System (VS). It also has a subsystem called Crew Health Care System (CHeCS), which consists of categories of Food Storage and Preparation, Thermally Conditioned Storage, Whole-body Cleaning, and Housekeeping[1]. Those functions mainly focus on supporting the environment where a human can survive and properly function; in general, any ECLSS system is a recreation of Earth's complex self-sustaining environmental system. Living nowadays, ECLSSs are heavily dependent on a supply chain that will be able to deliver main elements (like Hydrogen) to support chemical reactions that are keeping the system going.

1 S. Do, "Towards Earth Independence – Tradespace Exploration of Long-Duration Crewed Mars Surface System Architectures",

Doctor of Philosophy Thesis, MASSACHUSETTS INSTITUTE OF TECHNOLOGY, 2016

Bioregenerative Life Support System

The next step toward a self-sustaining Life Support System that resembles the complex environmental control system on Earth is a Bioregenerative Life Support System. The technological development mission to Mars has a 5% risk of mortality and 10% risk of morbidity[2], unprecedented for an endeavor with such a high investment cost. Therefore, a self-sustainable system is a crucial factor in the possibility of the mission to Mars.

Mainly BLSS is shown as the systems that work based on microalgae or bacteria life cycle. Using microalgae or bacteria as a basis of LSS gives a broader range for its application, like water purification, O2 production, N2 and CO2 fixation and regulation, and solid waste management.

Bioregenerative LSSs look very attractive because, from the outside, it looks like microalgae and bacteria can do many things. It seems like the same thing can simultaneously support different functions. But for various tasks like O2 generation, water purification, etc., there is a need to use different types of bacteria or microalgae, and they have different conditions to thrive: some need just light and water, and other CO2 concentrations, some cannot survive microgravity, some does survive and thrive. Therefore, such systems give bigger self-reliance and more freedom for Earth's supply. However, they also need a proper sensitive approach when a specific type of microalgae or bacteria is used in particular conditions and for a specific function [3].

BLSS also can be based on plant growth. The greenhouse is part of the BLSS as it produces O2 and fixates CO2 while growing food for astronauts. Growing food on a board of the Martian habitat needs a proper selection of species, and the main factors will be CO2 reduction, compatibility with aquaponic and aeroponic systems, nutrition value, and diversity [4].

Bioregenerative systems are giving more freedom from Earth's supply; therefore, its implementation will probably be a part of the future crewed Mars missions, but the scale and complexity need to be adjusted accordingly to each context. In some cases, traditional chemical based LSS can be preferable to Bioregenerative LSS, depending on the goals required to achieve and the conditions it is situated.

2 D. P. Häder, M. Braun, R. Hemmersbach, "Bioregenerative Life Support Systems in Space Research" , Gravitational Biology, Springer Briefs, Space Life Sciences, 2018

3 L. J. Mapstone, M. N. Leite, S. Purton, I. A. Crawford, L. Dartnell, "Cyanobacteria and microalgae in supporting human habitation on Mars", Biotechnology Advances 59 (2022) 107946, 2022, p.6

4 C. A. Mitchell, "Bioregenerative life-support systems ", The American Journal of Clinical Nutrition, Volume 60, Issue 5, November 1994, Pages 820S–824S

In-Situ Resource Utilization

It does not matter which Life Support System we will choose, it will need some resources to sustain, water for an algae reactor, electricity for an environmental control system, hydrogen for chemical-based LSS, etc. Therefore, it will need some supply of primary resources to maintain the system's functioning.

A great deal in lowering the delivery mass of the needed resources is In-Situ Resource Utilization (ISRU). Whether water ice mining or fuel production from CO2 absorbed from the atmosphere, ISRU principles would significantly reduce the mass of delivery from Earth and help sustain continuous human presence on Mars.

And Mars offers several ways the main components, such as oxygen or hydrogen, can be obtained from the environment. But it will need another approach towards getting those elements than we used on Earth. Like oxygen and carbon for fuel, production will need to be obtained from the atmosphere, while water and hydrogen will need to be mined from water ice trapped under a layer of soil or in permafrost[5]. Martian regolith, with special additives, can serve as a base for greenhouse gardening[6].

The martian environment offers many ways how to sustain a human settlement, but they are complicated and require different ways of thinking to be obtained and other technologies. Some of them, such as atmospheric CO2 capture technology, already exist and are shown to be useful also on Earth[7].

5 R. Zubrin, R. Wagner, "Case of Mars", 1997, p.124

6 S. Bohle, H S. Perez Montaño, M. Bille, D. Turnbul, "Evolution of soil on Mars", Astronomy & Geophysics, Volume 57, Issue 2, April 2016, Pages 2.18–2.23

7 B. Metz, O. Davidson, H. C. Coninck, M. Loos, L. A. Meyer, "IPCC, 2005. Special report on carbon dioxide capture and storage" Cambridge University Press, Cambridge, United Kingdom and New York, USA, pp. 442. Mckinsey & Company, 2008.

HUMAN FACTOR

The most common psychological factors challenging astronauts in space are isolation and confinement. These factors, or environments characterized by them, are unified under the ICE environments abbreviation (Isolated, Confined, and Extreme). And these are characteristics that are typical for nowadays or near-future space exploration.

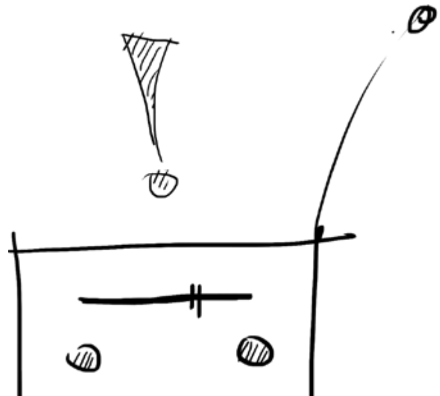
Communication

ICE environments influence how people communicate with each other during isolation, and understanding the social implications of working and living in space needs proper attention. It includes communication between crew members and communication between crew and mission control.

Mars is a pretty remote place; it can take about 20 minutes for the signal to be received and 20 minutes for a response to be transferred. Such conversations with delays are considered by Albert A. Harrison as "sequential monologs"[8]. It can be somewhat remodeled here on Earth so that the communication would have the same time lag, giving a good base for researchers to study and for astronauts to prepare.

The problematic effects of communication on crewmates and mission control are well documented. A famous example would be when astronauts on Skylab IV in the 1970s turned off any communication from mission control for 24 hours because they felt they were working too hard, while the ground control crew had the opposite perception. Of course, it had terrible consequences for the whole team in orbit, but it also changed the approach toward future missions to lessen potential tensions. And 20 minutes lag will influence the communication, which can create another reason for a conflict or, contrarily, work as some buffer, giving time for a crew to "cool down" before a response.

8 A. A. Harrison, Y. Clearwater, C. McKay, "The human experience in Antarctica: applications to life in space". *Behavioral Science, 34:4*, 1989, p. 253-271.



Isolation and Mood

Isolation can drastically affect mood, but current research also shows that ICE environments change mood and feelings inconsistently. Therefore, it is making it hard for researchers to predict astronauts' responses. Even more, focusing on negative experiences and spirit in isolation can bias our understanding of what happens over a long period in ICE environments.

"The coping ability of the individual has been underestimated and the difficulty of the environment overgeneralized" [9]

During the research, isolated and non-isolated groups from Antarctica and the Arctic were compared, and no significant changes in anxiety levels between the groups were found. Such findings suggest that adverse effects of isolation are caused more by personal experience or perception of the space by the individual than the environment itself.

"Positive psychology" is a relatively new form of study that accordingly to Peter Suedfeld "focuses on pleasant emotions and thoughts, constructive attitudes about the future, etc."[10]. This study challenges the perception that a desire to be alone holds a negative interpretation of how happy a person is. It offers a different perspective on 'the harmful effects of living and working in space.

Challenging aspects of the ICE environment attract some individuals who willingly choose isolation because of the benefits of self-growth and experience. The astronauts can feel motivated to return to space, perceived as a stimulus for growing and strengthening, and remember it with joy and pride.

The possibility of looking at the psychological effects of the ICE environment from both angles gives a broader view of what would happen with people in a long-term space mission. Moreover, it provides hope that it may not involve anxiety and stress.

Homesickness can be another psychological threat that can strike astronauts on their mission to or on Mars, which can cause depression, withdrawal, anxiety, absent-mindedness, and phobic avoidance. To feel more connected to home, astronauts on ISS (International Space Station) have reported that one of their favorite things to do is to look at Earth from space [11,12]. But what will happen when you cannot see Earth in the illuminator? What is the case on Mars. Should astronauts carry a telescope with them to have access to look back on the home planet?

Homesickness is real for someone working and living in a distant place like Mars, even for a healthy and well-balanced adult. And until the time when the potential colonies, first Martians, will be born, those people born on Earth and working on Mars will need a comfortable and familiar environment.

9 J. Mocellin, P. Suedfeld, J. Bernadelz, M. Barbarito, "Levels of anxiety in polar environments", *Journal of Environmental Psychology, 11, 1991*, p.266.

10 P. Suedfeld, "Invulnerability, coping, salutogenesis, integration: Four phases of space psychology", *Aviation, Space, and Environmental Medicine, 76*(6), 2005, B61-B66

11 G. M. Sandal, G. R. Leon, L. Palinkas, "Human challenges in polar and space environments", *Reviews in Environmental Science and Bio/Technology, 5, 2006,* 281-296.

12 M. M. Connors, A. A. Harrison, F. R. Akins, "Psychology and the resurgent space program", *American Psychologist, 41*(8), 1986, 906-913.

Importance of a Design

Some preliminary research on the habitability of the spacecraft shows that privacy features, access to windows, individual preferences for lighting and colors, and the design of natural elements are essential in terms of the psychological wellbeing of the personnel. In addition, personalizing the living and working areas brings a sense of familiarity and access to leisure activities like games, hobbies, and celebrations, bringing nostalgia and comfort for a crew, including live animals and plants supposed to reduce stress and boredom as pictures and personal items.

Culture

The essential factor that defines the effectiveness of a long-term mission is culture, not only because astronauts from different ethnical and cultural backgrounds will work together but also because Mars's surface does not belong to any nation; therefore, it has all chances to become a ground for a new one to emerge. A few factors affect multicultural communication: language, patience, tolerance, respect towards other cultures, gender roles, stereotypes, conflict management, and resolution.

There is no clear and generally accepted definition of culture, but some suggestions can be made. According to Arrindell, culture is "the collective programming of the mind that distinguishes the members of one group or category of people from another."[13] It can include background, nationality, native language, discipline, career motivation, and organizational identity, encompassing different norms, values, traditions, and attitudes.

It is hard to determine which personal characteristic may be culturally related and how the influence may influence personality or professional and organizational identity. Therefore, it may be hard to make a helpful guide on how to ease potential cultural conflicts. Even more, all cultural factors mentioned before are interconnected and influence each other, making analysis more complicated.

Negative interpersonal interactions between crewmates have been reported, and such interactions led to interpersonal conflict, social exclusion, stress, and loss of productivity. It is better to predict potential problems and choose countermeasures before than ignore cultural differences simply because of the complexity of knowing if the cultural aspect is at the root or not.

Another aspect that plays a role within a culture is the sub-culture that individuals are creating in ICE environments. For example, being professional comes with a group identity that limits the effect on behavior. It is some adaptation of the individual needs to the group needs, resulting from a need to create stability in an unstable and unfamiliar environment.

13 W. A. Arrindell, "Review of cultures consequences: Comparing values, behaviors, institutions, and organizations across nations". Behaviour Research and Therapy, 41(7), 2003, p.861-862.

Gender

Gender is an essential part of the space industry culture, not only due to the biological difference but also because of the beliefs and politics. At the beginning of space exploration, men were the only gender accepted for space missions. With the further development of society and broader acceptance of women in different work roles, female astronauts showed as much competence as their male counterparts. It is believed that mixed-gender crews are more stable than single-sex groups, where women have demonstrated a positive influence on group interaction[14, 15], as they are more receptive to the emotional wellbeing of other members[16].

Despite the problems between men and women that can occur in the long-term space mission, it is suggested that both genders be present in a crew as it appears to balance the group behavior.

Heterosexual interactions have been most studied in space-oriented research. However, there is no empirical research on the homosexual population within missions just due to a small number of cases to work with—some examples of homosexual astronauts, such as Sally Ride, for example. However, by the time of her service as an astronaut, she had to hide it, as recently coming out was a career-wrecker for an astronaut.

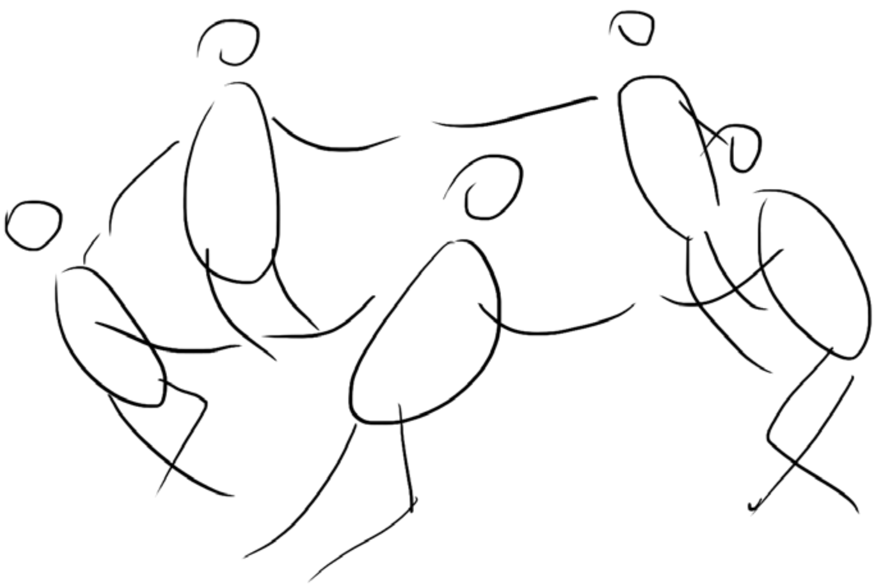
And this behavior is not helping in establishing equality, and there is a need for more open discourse concerning the topic to move forward[17].

14 G. M. Sandal, "Culture and tension during an international space station simulation: Results from SFINCSS99", Aviation, Space, and Environmental Medicine, 75(7), 2004, C44-C51.

15 S. L. Bishop, "Evaluating teams in extreme environments: From issues to answers", Aviation, Space, and Environmental Medicine, 75(7), 2004, C14-C21.

16 P. M. Kahn, G. R. Leon, "Group climate and individual functioning in an all-women antarctic expedition team", Environment and Behavior, 26(5), 1994, 669-697.

17 R. Slobodian, "Psychosocial Challenges of Living in Space: Isolation and Culture", 2012



UN Outer Space Treaty

The Outer Space Treaty was opened for signature by three depository governments (the United States, the United Kingdom, and the Russian Federation) in 1967. After this year, its first two articles become the primary document regulating human activity rights and limitations in outer space or on celestial bodies, including the Moon. The first article defines four central freedoms regarding outer space: freedom of use, exploration, access, and scientific investigation, while article II talks about the primary limits of the activities in outer space, such as the non-appropriation principle of claiming sovereignty by occupation or by any other means[18].

If the non-appropriation principle towards the celestial body is clear, its resources' status is vaguer. The UN Outer Space Treaty Article 2 does not mention the use of outer space resources. What leads to locally introduced legislation for the commercial use of outer space, such as title IV of the US Commercial Space Launch Competitiveness Act of 2015. Which states: "The United States does not, by an enactment of this Act, assert sovereignty, exclusive rights or ownership of any celestial body" [19]. But the same act gives US citizens the right to exploit and sell outer space resources. And similar laws were introduced by several other nations like Luxemburg, Russia, UAE, etc. [20]

With the further development of the rocket industry, outer space and its resources have become more accessible, and the evolution of the outer space law towards commercialization and exploitation of outer space is the answer to the new opportunities that are opening.

The existing international outer space law in the form of the UN Outer Space Treaty is not ideal. With new challenges and opportunities arising, it should be developed or even changed accordingly. It should not prohibit space exploration but encourage, sustainably and responsibly, and for human settlement on Mars to exist, changes in nowadays law should be implemented.

Because of the arising challenges and possible threats regarding chaotic and unsustainable exploitation of outer space, there are many concepts and proposals for maintaining international and commercial relationships in outer space. [21]

18 "Treaty on principles governing theactivities of states in the exploration and use of outer space, including the moon and other celestialbodies ("Outer Space Treaty")", United Nations Office for Outer Space Affairs (UNOOSA), 1966. Retrieved on 29.06.2022 on: www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/outerspacetreaty.html.

19 "U.S. Commercial Space Launch Competitiveness and Entrepreneurship Act", Pub. L. No. 114-9, 2015, Retrieved on 29.06.2022 on: www.congress.gov/114/plaws/publ90/PLAW-114publ90.pdf.

20 I. Fino, "Building a New Legal Model for Settlements on Mars", Froehlich, A. (eds) "Assessing a Mars Agreement Including Human Settlements", Studies in Space Policy, vol 30. Springer, Cham. 2021

21 Fino, I. "Building a New Legal Model for Settlements on Mars", 2021

MOBILITY

The main reason for a human endeavor to Mars is the scientific interest that this planet embodies: search for life, exploration of the early Solar system history, and research of the planet's habitability. And to conduct as comprehensive research as possible for a crew that will arrive on the surface of Mars, there will be a need for a wide range of mobility to cover long distances from the base to a potential research site. Moreover, with the probable further development of the human settlement on Mars with the foundation of new ones, new challenges will arise on how to connect them in terms of communication or transportation.

Communication

To cover as much area as possible during exploration and research expeditions, the first Martian explorers needed proper communication to stay in touch. But the diameter of Mars, which is about half of the diameter of the Earth, makes it more complicated. The problem is that a direct radio signal will work until the horizon, until immediate visibility. In addition, the more prominent curvature of the planet due to its smaller diameter makes the distance of the direct radio connection more minor. If the surface were flat, it would be after 40 kilometers, and the Martian surface would be full of hills, valleys, craters, and other obstructions.

The easiest way to overcome it would be to use a communication satellite on a synchronous orbit that will "hover" on the equator, orbiting with the same speed and direction as the planet's rotation. [22] Making communication easier for researchers on the rover.

But what if the satellite will break or will be "shadowed" by the harsh Martian terrain? In this case, the team on the distant research mission can use a ham radio as a backup plan. Mars has an ionosphere that can be used to reflect radio signals, making possible short-wave radio communication. Because of the density of the Martian ionosphere, the radio signal can only have a frequency of about 4 MHz during the day and 700kHz at night, which is not possible to make high data transmission, but it enables to have voice communication or engineering telemetry[23].

22 R. Zubrin, R. Wagner, "Case of Mars", 1997, p.109

23 R. Zubrin, R. Wagner, "Case of Mars", 1997, p.108

Navigation

Before a proper GPS navigation satellite system on Mars is established, to maintain far-reach observations, first explorers will need to use less elegant ways to navigate. However, exceptionally accurate and informative maps of the Mars surface are already available from orbital imaging. A team's main obstacle would be finding its location, documenting any scientific findings, or preventing getting lost in an unfamiliar environment.

A radio beacon (a device that is using radio signal to transfer its location) can be a solution, but it reaches only its horizon (about 40 km). Going forward, this limited exploring team should carry additional beacons that they will station on their way[24], but it is the subject of failure, which would mean deadly danger for explorers.

A magnetic compass (compass that uses Earth's magnetic field to show magnetic North) works well as a navigation tool on Earth but has no practical use on Mars, as it does not have a magnetic field.

But techniques of celestial navigation can be beneficial in this case. It has several advantages: it is an optical instrument, so it is immune to electromagnetic interference, it is quite a reliable way of navigation, it is pretty accurate, and it can work all day long, as much as the celestial reference body is visible. On the other hand, what can be a problem during dust storms when dust particles obscure the sky - it cannot work in complex lighting conditions; also, the cosmic radiation can disrupt the work of the instrument[25]. Therefore, an additional, alternative system of navigation should be established.

Different stelar orienteers should be established as references to determine latitude and longitude. Finding a latitude can serve well bright stars of Deneb and Alpha Cephei as the celestial pole is almost halfway between them. To determine longitude, you need one of the three celestial bodies: Sun, Martian satellites Deimos or Phobos to be present in the Martian sky [26].

An alternative could be visual navigation, which uses imaging, and optical sensors to accomplish navigation tasks. It can use different types of cameras in the visible and infrared spectrum, has high accuracy, is intuitively understandable for the operators, and can be used for obstacle avoidance. However, it also has minuses as the processing data is quite large, as it is visually based navigation, any weather effects like a dust storm will affect the system's effectiveness [27].

24 Y. Ou, H. Zhang, "Mars final approach navigation using ground beacons and orbiters: An information propagation perspective", Acta Astronautica, 2017, p.490-500.

25 H. Liu, "Autonomous Navigation for Mars Exploration", in G. Pezzella, A. Viviani (eds.), "Mars Exploration - a Step Forward", Intech Open, London. 2020

26 Zubrin R., Wagner R., "Case of Mars", 1997

27 H. Liu, 'Autonomous Navigation for Mars Exploration', 2020

Ground vehicle

During the Apollo mission, several vehicles were sent and utilized on the surface of the Moon. Light Roving Vehicles (LRV) was a small unpressurized vehicle that was lightweight and suitable for small-range mobility[28]. It had some flaws in operating in a low gravity environment on the lunar regolith, but it was doing its job.

Like LRV for Mars, exploration will be a need in a small unpressurized vehicle for small-range activities. Indeed, some exploration was done into the design of the proper small unpressurized vehicle for Mars. Such types as All-Terrain Vehicles (ATVs) and buggies could be analogs of what would be needed for the Martian research outpost. It would depend on the space suit wore, but a two-wheeled, motorcycle-type vehicle could propose an excellent off-road capability if it is possible to operate it comfortably and safely[29].

To reach further points of interest that are not in the service of the small vehicles, some medium-sized unpressurized or semi-pressurized cars will be needed. Similarly, commercial or military off-road vehicles or tracks existed on Earth but adjusted to the Martian environment. It will depend on the mission's architecture, the tasks needed to be performed which choice of the unpressurized or pressurized vehicle will be made.

For further exploration, a long-duration and long-distance missions crew will need proper radiation protection, enough space for storing resources and scientific instruments, and accommodate the team for about 14 days. In addition, such a rover can be a backup habitat in an emergency, adding to the system's survivability[30].

In any case, a ground vehicle should be adjusted to the Martian environment. A standard combustion engine will not work in the Martian atmosphere; there is no possibility of burning the fuel, as only the oxidizer will be transported along with the fuel. A possible solution would be the use of the electric engine, but in this case use of the vehicle will be limited to the latitudes closer to the equator. In contrast, the northern and southern latitudes will be less acceptable due to lesser solar gain. Unless a different source of electricity will be used, such as a portable nuclear reactor[31].

28 G. Giancarlo, "Next Stop Mars || Mobility on Mars", 2017, 218–238.
29 G. Giancarlo, "Next Stop Mars || Mobility on Mars", 2017, p.224

30 G. Giancarlo, "Next Stop Mars || Mobility on Mars", 2017, p.228

31 L. Hall, "Kilopower", 2021, Retrieved on 05.04.2022 at: www.nasa.gov/directorates/spacetech/kilopower

Long-Range Mobility

After establishing the permanent base on the surface of Mars, there will be a need for a long-range mobility solution to connect separate research outposts or rapidly deliver a significant amount of resources from one point on the planet to another. Without a well-established railway or road system, it would not be easy to do with surface rovers or trains (or any other analog). The thin atmosphere is becoming an obstacle to quick air connections. However, the Ingenuity hover that landed together with the Perseverance rover showed that it is possible to have propelled transportation on Mars[32]; also, balloons can be a solution for air transport[33]. But for a rapid transport system, Martian's low gravity and thin atmosphere offer a great opportunity, making a way better condition for the propulsion system that it is on Earth.

These could be a ballistic vehicle that goes out of the Martian atmosphere and can travel from one side of the planet to another, or it can be a supersonic plane. In any case, it will need a vast amount of propellant to be produced on the Martian base. But if possible, a range for the research and other activities can go 4000 kilometers away from the source of propellant. Furthermore, this distance can be outperformed if the nuclear-based vehicle is introduced that can feed on the compressed CO2, in this way eliminating the need for carrying return propellant with it[34].

32 M. von Ehrenfried, "Ingenuity. In: Perseverance and the Mars 2020 Mission", Springer Praxis Books. Springer, Cham. 2022

33 G. Giancarlo, "Next Stop Mars || Mobility on Mars", 2017, p.233

34 R. Zubrin, "28th Joint Propulsion Conference and Exhibit - Methods for achieving long range mobility on Mars", American Institute of Aeronautics and Astronautics 28th Joint Propulsion Conference and Exhibit - Nashville,TN,U.S.A. , 06 July 1992 - 08 July 1992.

RESOURCE
UTILIZATION

While the factors described before are unavoidable and mainly represented as the main threats, a few more factors substantially impact the decision-making process.

The water and materials available and many others directly influence the conditions of any mission on the surface of Mars.

WATER DILEMMA

Water is a crucial component for human survival and an essential part of the production of necessities such as fuel, plastics, building materials, food, etc. However, it is not a solution to transport water from the Earth due to complex and costly logistics, except in the first stage of the developing Mars base. It is possible and relatively cheaper to transport only hydrogen and then make water already on "the site," mixing with the oxygen from the CO2 of the Martian atmosphere. But with further development and increased human activity requirements, finding a local water source is necessary.

Climate influence

One of the main characteristics of the Mars climate is the almost absent water in its liquid form and the low percentage of water in the atmosphere due to the extremely low atmospheric pressure and low surface temperatures. But atmospheric water vapor is believed to originate from a subsurface ice layer or Martian soil. Indeed, already existing observations[1] show an abundance of water ice under the Carbon dioxide layer on polar caps and under Martian soil (regolith), especially in the Northern hemisphere, as well as the presence of it in the Martian soil minerally bounded.

1 A. M. Harri, "Mars Science Laboratory relative humidity observations: Initial results", J. Geophys. Res. Planets, 119,2014, p. 2132–2147

Availability

The most viable option to find water on the surface of Mars is in its Northern hemisphere. It is believed that the depressed region close to the Martian Arctic was a large water basin in earlier planet's history, protecting its surface from most meteorite impacts[2]. The northern hemisphere generally shows more residual traces of hydrological activity. Furthermore, because of the inclined orbit of Mars and subsequently, the difference in seasons changes for both hemispheres Northern pole cap is less covered with CO2. Therefore, water ice is more exposed, as it plays a significant role in the atmosphere's humidity[3]. Consequently, it is possible to conclude that the Northern hemisphere is generally wetter than the Southern.

It is possible to extract the water from the surface of Mars in different methods, but firstly it will need to be found. Rover crews can do it with ground-penetrating radar that can follow more minor resolution radar investigations from orbit or balloon-borne probs. For example, the Perseverance rover with its Ground Penetrating Radar GPR is following previous sounding from the Martian Express and Martian Reconnaissance Orbiter; therefore, the existence of water on the surface, underground, or history of the water on Mars is already well studied, and there are existing plenty of research, primarily based on orbital scans and observations, with probable or existing sources of water (frozen and liquid) [4].

Mars's surface reveals a lot of evidence of groundwater upwelling in its past, which would require the presence of a global groundwater system[5]. Together with a suggestion of theoretically existent manifested heat sources relatively close to the surface in active seismic regions (or active in a relatively near past of about 10 million years), it provokes a possibility of existing geothermally heated pools of liquid waters[6]. Such a well will be helpful not only as a source of water but also

2 R. Zubrin, R. Wagner, "Case of Mars", 1997, p.124

3 A. M. Harri, "Mars Science Laboratory relative humidity observations: Initial results", 2014, p. 2134

4 R. Orosei, "The Global Search for Liquid Water on Mars from Orbit: Current and Future Perspectives". Life 2020, 10, 120, 2020

5 F. Salese, M. Pondrelli, A. Neeseman, G. Schmidt; G. G. Ori, "Geological Evidence of Planet-Wide Groundwater System on Mars", J. Geophys. Res. Planets 2019, 124, 374–395.

6 M. J. Fogg "The Utility of Geothermal Energy on Mars", Journal of The British interplanetary Society, Vol. 49, pp. 403-422, 1996

for geothermal power.

To date, no evident sources of the liquid water underground were found, even though it was a primary scientific target for a radar sounding, Mars Advanced Radar for Subsurface and Ionospheric Sounding (MARSIS) onboard Mars Express (2003) and higher-resolution Shallow Radar instrument on Mars Reconnaissance Orbiter (MRO) (2005) have failed to detect underground liquids.[7] However, current geothermal heat estimates suggest that groundwater's depth would be several kilometers at low altitudes and more significant towards the poles[8], potentially putting any stable aquifers beyond the radar's reach.

The exception would be recent evidence of the subglacial liquid water beneath the South polar cap obtained through orbital radar sounding by MARSIS. Evermore further analysis provides evidence for other wet areas in its surroundings, suggesting the presence of the complex hydrologic system[9]. However, the finding still creates discussion among researchers on its trustfulness.

Another good option would be to find brines (saturated salt solution can be liquid at a temperature of -55o C) that can be present under Martian soil or ice in liquid form without the presence of the geothermal source. Furthermore, such brines were found by the Phoenix lander in 2009, which was sent to the Martian arctic to study the habitability potential of the ice-rich soil and the history of the planet's water.

The Phoenix's Wet Chemistry Laboratory chemical soil analysis revealed large amounts of perchlorates and salts that can produce liquid aqueous solutions at Martian temperatures. Such discovery can suggest that microbial life can be possible on Mars. [10]

After brines, water ice can be a good source too. As was written above, there are vast deposits of water ice under polar caps and undersurface. There are no sizeable permanent ice deposits southern of 75o northern altitude, but theoretically, it can be found northward of 40o north latitude under a 1 meter of soil. It is also possible to find local anomalies that preserve ice from subliming, like in some cold crevice, lava tube, cavern, or shadowed scarp. [11]

Martian soil has some water in it too, with the higher percentage in Northern altitudes or deeper underground, it is believed to be about 4%, and there are presented clays and gypsum that can have a lot bigger percentage of water embedded in themselves. Alpha Proton X-ray Spectrometer analysis of the Mars Pathfinder Mission in 1997 revealed that some of the examples of the Martian soil had up to 4% of water (H2O) by weight embedded inside it[12].

7 J. J. Wray, "Contemporary Liquid Water on Mars?", Annu. Rev. Earth Planet, Sci. 2021, 49:141–171

8 S. M. Clifford, J. Lasue, E. Heggy, J. Boisson, P. McGovern, "Depth of the martian cryosphere: revised estimates and implication for the existence and detection of subpermafrost groundwater", J. Geophys. Res.115(E7): E07001, 2010

9 R. Orosei, "The Global Search for Liquid Water on Mars from Orbit: Current and Future Perspectives", 2020

10 Nilton Renno, "Liquid saline water on Mars" SPIENewsroom, 18 June 2009. Retrieved on 20.04.2022 at: www.spie.org/news/1661-liquid-saline-water-on-mars?SSO=1

11 Harish, S. Vijayan, N. Mangold, A. Bhardwaj, "Water-ice exposing scarps within the northern midlatitude craters on Mars". Geophysical Research Letters, 2020

12 N. Florent, "Water measurements on Mars using neutron spectroscopy data from the Mars Odyssey orbiter", 2020

Cryosphere

Accordingly to Stephen M. Clifford, 'The Martian cryosphere is defined as that region of the crust where the temperature remains continuously below the freezing point of water.'; 'The zonally averaged thickness of the cryosphere may vary from 0–9 km at the equator to ~10–22 km at the poles'[13]

It is believed that 90-95% of all Martian water is trapped in the cryosphere as an underground ice or the groundwater under it, which can be heated above the freezing point by the radiogenic heating from the Martian core. But recent observations by MARSIS orbital sounding radar have shown no traces of the liquid subpermafrost groundwater, and there can be two explanations: that subpermafrost water does not survive on Mars or that it is more profound than MARSIS 3–5 km maximum sounding depth[14].

13 S. M. Clifford, J. Lasue, E. Heggy, J. Boisson, P. McGovern, M. D. Max , "Depth of the Martian cryosphere: Revised estimates and implications for the existence and detection of subpermafrost groundwater", J. Geophys. Res.,115, 2010, p.1

14 S. M. Clifford, 'Depth of the Martian cryosphere', 2010, p. 14

Mining

From the point of view of the complexity of extracting water, it would be easier to find an already liquid water source as a geothermal source or brine. Because there will be no need for heavy machinery for extraction and excavation of solid deposits as it is with ice and additional power to melt it[15], meanwhile, the geothermal well can also become a source of energy. At the same time, any liquid source also can be interesting from the point of view of finding an ancient form of Martian life. Even more, it will be more interesting for the research mission to Mars to find such a source precisely because of the reason of finding traces of past or present life (if such ever existed on the surface of Mars).

But the problem with liquid deposits is that on Mars, we know little, and those that we found are in small quantities or, as with the source under the South polar cap, it is quite disputable[16]. So, before any more significant source of liquid water under a tangible depth has been found - the solid ice deposits will be the primary water source. It will be hard to harvest ice deposits, and it is more probable that Martian explorers will find frozen mud or permafrost that they will need to be cleaned from dust contaminants.

15 R. Zubrin, R. Wagner, "Case of Mars", 1997, p.125

16 J. J. Wray, "Contemporary Liquid Water on Mars?", 2021

Permafrost is rarely readily available lower than the highest latitudes, but the water of hydration in the soil is widely accessible on the planet's surface. By heating, these water molecules can be released and then condensed. To do so, you need a heater - it can be a stationary factory or a transportable heater that can work onsite. In any case, there will be a need for energy ranging from 9 to about 100 kW -hr/kg depending on a chosen technique[17].

There also can be another approach that uses more low-tech solutions but does not involve significant cost to implement. For example, using a transparent cupola or tent to use a greenhouse effect to heat the surface inside and release some part of the absorbed humidity and then condensate it. The tent will be made of lightweight and transparent materials, so it can be moved around easily, allowing to mine different areas daily[18].

17 G. James, G. Chamitoff, D. Barker, "Resource Utilization and Site Selection for a Self-Sufficient Martian Outpost", NASA/TM-98-206538, 1998, p. 21

18 R. Zubrin, R. Wagner, "Case of Mars", 1997, p.128

In search of Life

The main reason for our curiosity about Mars is the search for life, significant resources of the Martian missions are led towards the goal of finding that we are not the only genesis of life. A crucial role in preserving traces of possible ancient life on Mars or even some examples is playing water, ice, and by-products like clays. Therefore, this research for finding water on Mars is firstly initiated by a search for life and only after supporting this life in the form of the (possible) future astronauts and other examples of Earth's life that they will bring.

The universe is plentiful in life-building blocks: mainly carbon, oxygen, nitrogen, hydrogen phosphorous, and sulfur. And Mars is rich in carbon as a backbone of life as we know it, as well other four elements are present and somewhat abundant there. We also know that Mars was much like Earth in its early history, a wet and warm planet. From our findings here on Earth, scientists estimate that life formed in the early history of the world, about 800 million years after its formation (that was about 4.5 billion years ago) [19].

'Without question, Mars is the closest place in the universe where we plausibly might find extraterrestrial life. For centuries, astronomers repeatedly have claimed to have discovered evidence suggesting Mars harbors life; however, to date, all of these findings have either been disproven or become highly disputed.' [20]

Stable underground reservoirs of liquid water are considered the most promising habitat for the remaining life to exist on Mars or for its traces to be found (also, its isolation could prevent the spread of any life forms). It could have been transported by the groundwater to a greater depth and then been protected from radiation, harmful chemical reactions, and desiccation. At the same time, it could be sustained by hydrothermal activity, radiolysis, degassing, and water-rock reactions. [21]

19 D. A. Weintraub, 'Life on Mars: What to know before we go', Princeton university press, 2020, p.2

20 D. A. Weintraub, 'Life on Mars: What to know before we go',2020, p.4

21 V. Stamenković, L. W. Beegle, K. Zacny, "The next frontier for planetary and human exploration", Nat Astron 3, 116–120, 2019, p.1

RESOURCE UTILIZATION

In general, the elemental composition of Mars is similar to Earth, with comparatively small differences due to the parallel history of the formation of the planets. The smaller size of Mars made it cool down quicker, and because of its closer vicinity to the asteroid belt, it is different now. But it is generally known that oceans of liquid water existed there billions of years ago, and even possible that life, at least in its primitive form, could be present on Mars too. Therefore, minerals and materials broadly used on Earth can also be found on Mars, as the critical factors of their formation were present in Mars's history.

Regolith as a material for construction

The most abundant and more accessible to find material for building a Mars base would be Martian regolith (soil), and it is the most optimal one to use. It can serve as brick, with some additives as a feedstock for 3d printing, or even in its raw form melted by a microwave 3d printer[22] or a laser machine[23] in the desired shape.

Clay-type minerals are easily found in the Martian surface soil, which is a good source for any ceramics and pottery production. Silicon oxide is the most common mineral in the regolith, opening a door for glass production[24]. While in the same time, calcium and sulfur in the SNC meteorites (Abbreviation of 3 groups of Martian meteorites (that are coming from Mars after possible significant impact or volcanic activity): shergottites, nakhlites, and chassignites) [25] are present in the form of gypsum, what can be used by itself in the construction or baked to obtain lime, what has many uses in the building[26].

22 M. Barmatz, D. Steinfeld, M. Anderson, D. Winterhalter, "3d microwave print head approach for processing lunar and mars regolith", In Lunar and Planetary Science Conference, volume 45, 2014, p. 1137

23 M. Fateri, A. Gebhardt, "Process Parameters Development of Selective Laser Melting of Lunar Regolith for On-Site Manufacturing Applications", Int. J. Appl. Ceram. Technol.,2014, p. 1–7

24 R. Zubrin, R. Wagner, "Case of Mars", 1997, p.134

25 A. H. Treiman, "The SNC meteorites are from Mars". Planetary and Space Science. 48 (12–14): 1213–1230, October 2020

26 C. C. Pazar, "Resource Utilization on Mars", Colorado School of Mines Center for Space Resources, 2020

Ceramics and Glass

Bricks sound somewhat like a low-tech solution for the Martian base, but it is one of the most optimal materials that can be made on-site. Together with the 3d printers using regolith feedstock, it can be the first product produced on and out of the Martian soil.

Bricks, in general, are pretty easy to make; they have been done since the first civilizations started to appear on the Earth's surface, and they will probably be a base for the first human settlement that will appear on Mars. For its production, you do not need complicated technology. For example, in some regions on Earth, it is still used in the form of so-called 'earth brick' that is backed in comparatively lower temperatures than the industrial-produced bricks (only at about 300oC). For the process, water is needed, and with some additional modernization to the oven, we can recover water. Together with bricks, other ceramic products can be made from clay-rich soil[27].

The same regolith iron-rich dust that is the most abundant material on the surface can be used for the mortar. Present in the soil, gypsum can be used for the production of the plaster, while if it is baked, lime can be made and has several other uses in the construction industry, which includes cement and concrete[28].

It appears that on the surface of Mars are several crucial components that would be needed for masonry structures. Therefore, it is making the catenary model an optimal option for the first constructed on Mars human habitats; keeping it compressed will make the system stable.

But the problem is that in the pressurized living premises main load will be primarily tensile due to the difference between existing Martian atmosphere pressure and inner living space pressure enough for the comfort of people. If the internal pressure is about 0.3 of that one on the sea level on Earth, which is about 34.5 kPa or 0.3 atm (it was used for SkyLab station), then the structure will experience 3.5 tons per square meter of exploding pressure[29]. It can be counteracted by about 2.5 meters of the soil-filled on the top of the structure underground or with additional sealing of plastic membrane that can bear the tensile force. In the recent concept of the 3d printed habitat by AI SpaceFactory (MARSHA) that won the NASA 3d printing challenge, a mix of the regolith and bioplastics was used, which can be another solution for the problem of tensile forces[30].

Duricrete material developed by Martin Marietta company in the 1980s is a Martian regolith-based material that, in its original form, consisted just of a pre-wet regolith. And after the setting achieve 50% of the strength of concrete[31], gypsum and gravel can enhance it even further, making it closer to the concrete by its consistency. It can be used for 3-d printing of wall partitions, floor slabs, furniture, and even simple tools; it also does not melt in the warm interior atmosphere as the Ice printed structures do. But it should be treated with enzymes to neutralize toxic perchlorates[32].

While at the same time, silicon oxide is found in the Martian soil in significant quantities[33], an opportunity for glass production to develop. The problem would be a high ferric oxide (Fe2O3) concentration in the regolith, making the output of optical-quality glass is more problematic as it should be cleaned from iron oxide particles.

On one side, it would be a complicated and energy-costly process. However, from another side, those iron oxides or what will form after the extraction process will be easily used for metallurgical purposes. In this case, there will be plenty of iron-free material for glass production.

27 G. James, G. Chamitoff, D. Barker, 'Resource Utilization and Site Selection for a Self-Sufficient Martian Outpost', NASA/TM-98-206538, 1998, p. 21

28 G. James, 'Resource Utilization and Site Selection for a Self-Sufficient Martian Outpost',1998, p.20

29 R. Zubrin, R. Wagner, "Case of Mars", 1997, p.120

30 "MARSHA, AI SpaceFactory's Mars Habitat", AI SpaceFactory, Retrieved on 08.06.2022 at: www.aispacefactory.com/marsha

31 R. C. Boyd, P. S. Thompson, B. C. Clarck, "Duricrete and Composites Construction on Mars", Martin Marietta Planetary Sciences Laboratory, The case for Mars 111: Strategies for exploration – General interest and overview. Sen Diego, CA, Univelt, Inc.. 1989, p.539-550

32 T. Dzieduszynski, "Case Study 2: MARS: 10-50-150. Circular Economy of the Martian Architecture - A 3D-Printed Ice Habitat", 2019, p.5

33 G. James, 'Resource Utilization and Site Selection for a Self-Sufficient Martian Outpost',1998, p.19

Metals

In terms of further developing the Martian community and settlement, the existence of metal manufacture is necessary. And the planet provides rich resources to support its production. Furthermore, Mars is considered to have more metals than Earth.

Steel

Ferric oxide or hematite (Fe_2O_3) is the most accessible and abundant industrial metal on the surface of the Red planet and gives its color. Soil consists of 1/5 of iron, and about 16% of the rocks are iron rich[34]. Therefore, extracting pure iron from hematite can be a relatively straightforward process. There can be two methods to do it suitable for the Martian conditions: one is the use of carbon monoxide, and another one can use hydrogen that can be obtained by electrolysis of the water.

Some alloying elements required to produce carbon or alloyed steel are standard on the Mars surface. Carbon, manganese, phosphorus, and silicon are abundant, while chromium, nickel, and vanadium are present in significant enough quantities. Allowing for proper production of any steel desired as soon as the manufacture of iron is implemented[35].

34 M. D.West, J. D.A.Clarke, "Potential martian mineral resources: Mechanisms and terrestrial analogues", Planetary and Space Science 58, 2010, p.579
35 M. D. West, "Potential martian mineral resources: Mechanisms and terrestrial analogues", 2010

Aluminum

Aluminum is quite common metal on Mars as well. However, it is present in the form of alumina (Al_2O_3). This challenging oxide requires a complex and energy-expensive process of its electrolyze in the molten cryolite at 1000oC. The process is endothermic, so it needs much energy to proceed, and in Mars conditions, energy will be a high value, making the production of aluminum an expensive process. With such a high value, it will be hard to use this metal for common structures, but it can serve well in an exceptional use as the electro wire taking advantage of its high conductivity and lightweight[36].

36 R. Zubrin, R. Wagner, "Case of Mars", 1997, p.134

Silicon

In the production of any modern electronics, silicon is an essential element. It also takes part in the production of the photovoltaic panels that play a crucial role in the power supply of the Martian base.

The feedstock of the manufacturing of the silicon metal as silicon dioxide (SiO_2) and as a significant rock-forming element is in abundance on the Mars surface, the observations by the 2001 Mars Odyssey Mission show that its concentration varies from 18.5% to 21.5%[37].

To extract silicon, you must mix silicon dioxide with the carbon in the electric furnace. Carbon can be obtained as waste material for propellant production, but the overall process of silicon manufacturing is highly endothermic[38].

37 W. V. Boynton, G. J. Taylor, L. G. Evans, R. C. Reedy, R. Starr, D. M. Janes, K. E. Kerry, D. M. Drake, K. J. Kim, R. M. S. Williams, M. K. Crombie, J. M. Dohm, V. Baker, A. E. Metzger,8 S. Karunatillake, J. M. Keller, H. E. Newsom, J. R. Arnold, J. Bru¨ckner, P. A. J. Englert, O. Gasnault, A. L. Sprague, I. Mitrofanov, S. W. Squyres, J. I. Trombka, L. d'Uston, H. Wa¨nke, and D. K. Hamara, "Concentration of H, Si, Cl, K, Fe, and Th in the low- and mid-latitude regions of Mars", JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 112, E12S99, 2007, p.9

38 R. Zubrin, R. Wagner, "Case of Mars", 1997, p.134

Copper

The conditions are a bit different with copper - its existence in Martian crust is unlikely or rare to find[39]. Even if there is a discussion about its possibility and quantity on Mars, there was no significant finding that would say that copper (Cu) can be obtained in the amounts needed.

The problem is that such a concentration of copper ore can be found only where the complex hydrological and volcanic activities took place at the same time. Such processes have occurred on Mars as well as on Earth, making it possible to find copper ore[40],but this topic is highly discussed.

39 M. D. West, "Potential martian mineral resources: Mechanisms and terrestrial analogues", 2010, p.581

40 R. Zubrin, R. Wagner, "Case of Mars", 1997, p.136

Plastics

Today all the home commodities are mainly made of plastics; in general, many things are made of plastics or have plastic components. So while on Earth, it becomes a tremendous planetary scale problem, on Mars, it can be a key to the survival or development of the human settlement.

With the abundance of carbon and hydrogen, it is possible to obtain plastics on Mars. The key is the production of synthetic ethylene and syngas, which can be done from CO2 and hydrogen, with the extended process of obtaining the oxygen from the same feedstock. After a few chemical reactions, C2H4 or ethylene can be produced, which is an excellent fuel and a base for the petrochemical and plastic industries[41].

41 C. C. Pazar, "Resource Utilization on Mars", 2020, p.2

Ethylene is a primary feedstock for manufacturing polyethylene, polypropylene, and many other plastics. Accordingly, these plastics can be used to manufacture clothing, bags, insulation, bottles, etc. Numerous applications of the plastics that are accessible here on Earth will also be possible on Mars, offering enormous benefits and possibilities necessary for the development of the human settlement on Mars.

'One possible implementation of plastics will be the production and construction of huge inflatable domes that can serve as inhabitable space. Because of the partial atmospheric protection, the requirements for the surface inhabitable spaces are much lower than, for example, for possible Moon habitats. A range of functions that can be performed under such a structure is pretty broad, including habitation and agriculture. And requirements for the materials are dictated mostly by the performance toward tension loads and not by radiation protection. The greenhouse effect created by such a transparent dome is what is needed in the harsh and cold Martian environment. Inflatable domes made of Kevlar can be up to 50 meters in diameter, only 1 millimeter thick, and support a 1/3 atm atmosphere, which is necessary to support humans[42]'.

42 R. Zubrin, R. Wagner, "Case of Mars", 1997, p.120

Agriculture

'On 12 March 2013, NASA announced that results from Curiosity revealed evidence of the primary elements needed for sustaining life – carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur – raising the possibility of ancient microbial life on Mars.' Shannon Bohle, H Saul Perez Montaño, Matt Bille and Doug Turnbull[43].

If the soil of Mars has enough resources to sustain ancient microbial life, it has an opportunity to support agriculture on the surface of Mars. And considering the high cost and complexity of delivering anything on Mars's surface, it would be evident that Martian explorers will need to grow their food.

And Martian surface gives enough conditions for it to happen. Firstly, it has all the elements for living species, like hydrogen, oxygen, carbon, and nitrogen. Then the atmosphere has already created the necessary protection from radiation for plants to be grown on the surface of Mars, and the only problem is to provide adequate atmospheric pressure. If this problem is solved, you can harness enormous power for growing plants freely supplied by the Sun.

Plants require a tremendous amount of energy. Artificial aquaponic and aeroponic farms use much energy to grow any adequate number of crops. As a result, not all of them are fully grown, and only selected species can be developed in such an environment. Crops grown under inflatable transparent domes are already protected enough from radiation by the Martian atmosphere and receive sufficient sunlight (43% of Earth) to produce various species in large quantities to support Martian researchers[44]. As it is on Earth, the soil fertility on Mars varies and depends on location. The most fertile or appropriate for growing plants is believed to be soil from the ancient river deltas[45]. Accordingly, future Martian settlement sites should consider the possibility of extracting soil for agricultural purposes.

To use Martian soil for growing crops is a controversial question as from one side, from what we know about it, it contains enough resources and minerals for growing crops, but it is unfertile mainly without a proper enhancement. Four main factors prohibit the use of in-situ Martian soil: reactive nitrogen, particle size, density, and pH. But the careful treatment of the ground with nitrogen-fixing bacteria, earthworms, and nematodes that excrete nitrogenous waste might partially alleviate this problem[46].

Mushrooms could be a nutrition source, and they can grow on food waste, transforming 70% of it into edible protein. In addition, it does not need light to grow, only humid, dark, warm room, and oxygen, making it ideal for underground habitation.

It is little possible that cattle, sheep, goats, rabbits, and other domestic animals will have a place in the food production on Mars or any other celestial body as it is an inefficient way to produce food in large numbers. However, insects could be a good source of animal-based protein, and they do not need much space and not so much nutrition, grow and breed fast, therefore can be harnessed continuously, they also can take part in the recycling process, waste management, pollination, and be a pet giving some stress relief and contributing to the biodiversity of the Martian settlement[47].

Another species that can efficiently transform the waste plant material into protein would be different types of fish (tilapia, loach fish) [48], which can thrive in the isolated environment of the research station. Its excrements also can be used as fertilizer or nutrition for plants. The problem is that fish has an enormous loose of muscular and bone weight in a zero-gravity environment[49]. But nothing is known about the reduced gravity environment and its influence on fish. It would be another good nutrition resource if it survives and can thrive in it.

43 S. Bohle, H. S.Perez Montaño, M. Bille, D. Turnbul, "Evolution of soil on Mars", Astronomy & Geophysics, Volume 57, Issue 2, April 2016, Pages 2.18–2.23

44 R. Zubrin, R. Wagner, "Case of Mars", 1997, p.130

45 S. Bohle, "Evolution of soil on Mars", p. 2.21

46 S. Bohle, "Evolution of soil on Mars", p. 2.22

47 R. Kok, A. van Huis, "Insect food in space", Journal of Insects as Food and Feed, 2021; 7(1): 1-4

48 K. Tomita-Yokotani, S. Anilir, N. Katayama, H. Hashimoto, M. Yamashita, "Space agriculture for habitation on Mars and sustainable civilization on earth" In: Proceedings of the 4th International Conference on Recent Advances in Space Technologies, 11-13 June 2009, Istanbul, Turkey, pp. 68-69.

49 H. Hirata, A. Iida, "Zebrafish, Medaka, and Other Small Fishes (New Model Animals in Biology, Medicine, and Beyond) || Fish in Space Shedding Light on Gravitational Biology", 10.1007/978-981-13-1879-5(Chapter 5), 2018, p.85–97

Growing materials

It is also possible to have trees on the Mars surface, while how they will react to the 0.3g, no one knows, but at least they will have a sense of direction., so it is possible to survive for them in the Martian environment. If they do, it can serve as nutrition as orchards and at the same time as construction or furniture and other commodities material, considering the rate of growth, need for space, etc. quite expensive material in Martian conditions, but still possible[50].

Another cellulose material that can serve well for construction and domestic commodities is bamboo. It does not need as much space, time, and conditions as trees have, making it ideal for its purpose under Martian base conditions[51]. However, it has little nutritional value, so it cannot replace trees.

A possible alternative could be a mushroom mycelium (the root of mushroom) as a building material. It has an excellent ratio of its weight to compressive strength, even if it is much less than one of concrete (30 psi of the mycelia compering to 4000psi of concrete) [52]. Because of its porosity, it can serve as insulation material[53] or as packaging, furniture, and even as a structural material[54]. One of the challenges in using the material for the specific purpose of the space architecture is that it needs some substrate or a base to grow. Usually, mycelium is seen as a part of the composite material. It is hard to see it as different material, but it is possible to look at it as a great additive to more traditional materials[55].

50 R. Zubrin, R. Wagner, "Case of Mars", 1997, p.132
51 X. De Kastelier Interview, 2022

52 I. Bonnefin, "Emerging Materials: Mycelium Brick", 2017. Retrieved on 24.06.2022 at: www.certifiedenergy.com.au/emerging-materials/emerging-materials-mycelium-brick
53 Z. Zimele, I. Irbe, J. Grinins, O. Bikovens, "NOVEL MYCELIUM-BASED BIOCOMPOSITES BUILDING MATERIAL", 2019
54 Y. Hajar Arifin, Y. Yusuf, "Mycelium Fibers as New Resource For Environmental Sustainability", Procedia Engineering 53 (2013) 504 – 508, 2013
55 J. Jauk, H. Vašatko, L. Gosch, M. Stavric, "MYCERA - A SUSTAINABLE FUTURE BUILDING MATERIAL CONSISTING OF CLAY AND MYCELIUM", 2021

Algae

For a human settlement to survive, there will be a need to satisfy many requirements, and algae, microalgae, and cyanobacteria in specific can help achieve some of these requirements. Microalgae (and cyanobacteria) can be crucial in supporting human activity on Mars. Different types of microalgae can support a broad spectrum of functions: it can keep a breathable atmosphere, supply nutrient-rich food, purify water, recycle waste, be a source of biopolymers for clothing, packaging, utilities, or 3d-printed articles; it can have several pharmaceutical implementations, and even take part in the fixation of some elements from the Martian atmosphere, such as nitrogen, or bio-mining of metals from the Martian regolith[56]. Field of application of microalgae is quite broad. It typically includes different species to maintain various tasks with additional needs. For example, some do not need lighting to survive, while others require natural or artificial light and more complex reactors.

An additional characteristic of some microalgae is their resistance to radiation[57], which can make them thrive in a tank without proper radiation shielding. Even more, the water tank, or reactor, together with microalgae, can serve as some radiation shielding, with an appropriate layer of insulation to protect water from freezing. And some architectural concepts of the future Martian habitat, such as the Martian habitat concept done by Redhouse studio, Cleveland, USA[58], are trying to implement these features of the microalgae and make it not only part of the Biological Life Support System (BLSS) but also part of the habitat envelope.

56 L. J. Mapstone, M. N. Leite, S. Purton, I. A. Crawford, L. Dartnell, "Cyanobacteria and microalgae in supporting human habitation on Mars", Biotechnology Advances 59 (2022) 107946, 2022, p.6

57 L. J. Mapstone, "Cyanobacteria and microalgae in supporting human habitation on Mars", 2022, p.4

58 "Mars Habitat Architectural Design Plans', Redhouse studio. Retrieved 22.06.2022 at: www.redhousestudio.net/pages/research/mars-habitat-designs

Bioplastics

As mentioned before, microalgae and byproducts of its lifecycle can serve as a feedstock for the production of the biopolymers and be a base for clothing, utility production, or 3d printing items. Bioplastics based on starch, cellulose, and polyhydroxyalkanoates (PHAs) are biodegradable. They can be a good substitute for petroleum-based plastics, especially PHAs, as they are similar to ordinary plastics. It also shows a low level of toxicity, antimicrobial activity, etc., and it even can be used in medical applications for prosthetic implants, drug delivery systems, etc. [59]

There are different ways to obtain biopolymers, except microalgae feedstock: it could be various terrestrial plants, mushrooms, animal-based, and food waste. It has different properties depending on its origin, and for particular applications, some biopolymers would suit better than others[60]. But generally speaking, considering the limited condition of the Martian settlement, algae feedstock for biopolymers would be the optimal choice[61].

A great example of the application of biopolymers in construction would be a winning entry[62] of NASA's Centennial Challenge for 3D-Printed Habitat in 2018, developed by AI SpaceFactory[63], New York, USA, which used a composite material of Polylactic Acid (PLA) reinforced with basalt fiber.

59 L. J. Mapstone, "Cyanobacteria and microalgae in supporting human habitation on Mars", 2022, p.11

60 E. Shlush, M. Davidovich-Pinhas,"Bioplastics for food packaging", Trends in Food Science & Technology 125, 2022, p.73

61 L. J. Mapstone, "Cyanobacteria and microalgae in supporting human habitation on Mars", 2022, p.12

62 T. J. Prater, T. Kim, M. Roman, R. Mueller, "NASA' s Centennial Challenge for 3D-Printed Habitat: Phase II Outcomes and Phase III Competition Overview". In: Proceedings of the 2018 AIAA SPACE Forum. Orlando, Florida. 17-110 September 2018.

63 "MARSHA, AI SpaceFactory's Mars Habitat", AI SpaceFactory

ENERGY PRODUCTION

Propellant

Propellant production on the surface of Mars is a crucial step to making human settlement on Mars possible and to doing anything meaningful once it is built. And the best feedstock for it is the Martian atmosphere.

The most obvious and easy-to-produce choice is the methane + oxidizer bipropellant. To produce, it requires hydrogen, which can be transported from Earth at the starting phase, but in later stages, it should be sourced locally[64]. It is only 5% of the overall propellant weight, so it does not require much fuel to transport. However, its storing will be problematic, as hydrogen boils off from any known enclosing material due to its small atomic size and needs much insulation. But it is partially solvable, and the loss rate is easy to calculate, so the additional reserve of the hydrogen can be brought[65]. In the later phase, hydrogen can be extracted from the Martian water ice or other water sources with further development of the Martian base.

When hydrogen is delivered to Mars or extracted from its water sources, carbon and oxygen are the only elements that would be required. And both can be acquired from the 95% carbon dioxide (CO2) Martian atmosphere.

Once acquired, it can be reacted with hydrogen in the so-called Sabatier reaction (methanation). It produces methane and water from carbon dioxide and hydrogen. Then water can be separated into oxygen and residual hydrogen, which can be used again[66].

64 C. C. Pazar, "Resource Utilization on Mars", 2020, p.2

65 R. Zubrin, R. Wagner, "Case of Mars", 1997, p.102

66 C. C. Pazar, "Resource Utilization on Mars", 2020, p.2

Sun and Wind

There is possible to use two types of solar power systems on Mars: dynamic and photovoltaic. The dynamic solar system uses a parabolic mirror to concentrate sunlight on a boiler to heat a fluid turning a turbine. Because of its low-tech principle, it is easy to assemble or manufacture what can be important for Mars base and can be a source of heat power[67]. However, on the other side, it is less reliable than other systems because of the reliance on movable parts and its need for clear skies to function appropriately, which is not the case during dusty weather (about half of a year for Mars).

Photovoltaic panels are more reliable as they can function well even in a dusty atmosphere, typical for Mars, except for heavy dust storms. But it would be harder to manufacture this type of solar panel, even if all elements are available on the Mars surface.

Both systems will need a continuous cleaning from highly contagious Martian dust, especially during Northern autumn and winter (dust storms season on Mars).

The wind is another possibility to generate electrical power. While the low surface winds velocity and low atmospheric pressure make possible wind power supply at the height of the outpost negligible, winds well above the thick surface layer are high as 60 m/s[68]. In some regions with wind production favoring landscape as the narrow valleys or long low-angle slopes, the wind is believed to reach speeds high as 25-30 m/s[69]. With the specific buoyant type of wind turbine design using an inflatable hydrogen structure as a lifting force, it is possible to reach stronger winds at higher altitudes. It would produce a modest amount of energy. However, it could be a valuable source of energy that could be used during dusty weather that will lessen the effectiveness of any solar-based system.

Because of their periodic and intermittent nature, harnessing energy during dust storms would be useless. However, if the balloon-type of windmill harnesses the wind, it would be desirable to have a retractable system that can hide the balloon in a nasty dust storm.

67 R. Zubrin, R. Wagner, "Case of Mars", 1997, p,138

68 R. Zubrin, R. Wagner, "Case of Mars", 1997, p.137

69 G. James, G. Chamitoff, D. Barker, "DESIGN AND RESOURCE REQUIREMENTS FOR SUCCESSFUL WIND ENERGY PRODUCTION ON MARS", 1999, p.3

Geothermal

Solar and wind power supply are attractive because they are deployable almost anywhere, but it has a modest output in Mars conditions. Therefore, it is forcing us to seek other power sources that can work well in Mars conditions and still produce the desired energy for further development.

Such an option could be geothermal power, which uses the high temperatures underground that boil fluid such as water and uses steam to turn a turbine. A geothermal well would be a powerful source of power for a Martian base. At the same time, it would be a valuable source of liquid water. The position of the geothermal source can determine the placement of the future Martian settlement or city.

It is now less sure that geothermal power supplies on Mars do exist. However, Mars still has active seismic areas: Tharsis, upper regions of Elysium, Arcadia, and Amazonia are believed to be still active[70]. If a water table exists within a kilometer underground and the area was active in the past, this water could be hot enough to present a practical power source.

Accordingly to Fogg[71], the amount of territory associated with volcanic activity within 500 million years is quite large. A few kilometers deep for these territories will be enough to bring up boiling water.

70 M. J. Fogg "The Utility of Geothermal Energy on Mars", 1996
71 M. J. Fogg "The Utility of Geothermal Energy on Mars", 1996

Nuclear Fission Power

One of the best ways to provide electric and thermal power in the early stage of the Martian settlement development would be nuclear reactors produced on Earth. Because of the low availability of other efficient large-scale ways to power human activity on Mars, it is almost the only possible.

In 2018, a successful experiment using Kilopower Reactor Using Stirling Technology (KRUSTY) proved that small-scale nuclear fission reactors are not only possible but already available[72]. The main task of the development of the system was to supply a future hard-reaching location, including future Moon and Mars missions, to have a possibility of the local self-reliable manufacture or in-situ resource utilization. In the case of Mars, nuclear fission power would be almost the only option available for any manufacturing, except geothermal power, if it would be found.

72 L. Hall, "Kilopower", 2021, Retrieved on 05.04.2022 at: www.nasa.gov/directorates/spacetech/kilopower

Nuclear Fusion Power

The problem with nuclear fission power is not only the complexity of the technology and the inability to replicate it without a proper supply chain but also the complexity of obtaining and processing the fuel material. Most probable, it will need to be delivered from Earth as the reactor itself.

A possible solution to it could be nuclear fusion power. The complexity of implementing the technology is even more significant. Furthermore, it is still under development. But in terms of fuel, Mars can propose more extensive accessibility than Earth has. The atmosphere of Mars is rich (in comparison with Earth) in deuterium[73], and it plays a crucial role in some types of Fusion reactors. Deuterium, also known as heavy hydrogen, is one of the stable isotopes of hydrogen. The main difference from protium (usually referred to as hydrogen) is that deuterium has a neutron in its nuclei while protium does not. It is proven that deuterium-tritium fuel is effective in fusion reaction as it needs less temperature than other elements to reach it and release more energy[74].

Therefore, developing the technology of fusion energy production could be one of the solutions for future Mars settlement.

73 V. Krasnopolsky, "On the Deuterium Abundance on Mars and Some Related Problems", Icarus 148, 597–602, 2000

74 M. Lanctot, "DOE Explains...Deuterium-Tritium Fusion Reactor Fuel", Office of Science, Retrieved on 20.06.2022 at: www.energy.gov/science/doe-explainsdeuterium-tritium-fusion-reactor-fuel

CASE STUDY
ANALYSIS

From the beginning of written human history, people were excited about stars. Their desire to reach it has started a lot closer to modern days.

One of the first mentions of an extraterrestrial journey was in Jules Verne's "From Earth to the Moon" (1865) and its sequel "Round the Moon" (1870). The book used a gigantic cast-iron gun to send humans to the Moon in an aluminum capsule. The book inspired the first science-fiction film, "Le Voyage Dans la Lune" (The Trip to the Moon) (1902) by Georges Méliès[1] - those were the first depictions of possible human space habitats.

1 https://badphilosopher.com/a-trip-to-the-moon/

Long before chemical propulsion rockets became a thing, it was an idea that was answering the question of existing methods at that time, which later developed into the concept known as "a space gun" or "a Verne gun." [2] It would not be a proper way to launch people into space, as the loads on the missile are enormous, but it is impressive how the XIX century mind came up with a basic working idea for a problem that became on time only 100 years after.

A big step toward space exploration came during the Second World War, with the development of a chemical propulsion system. Then after defeating Nazi Germany, those innovations become available to Allies countries.

Visible changes started to appear a few decades later, during the Cold War, when rockets began to be used for more scientific purposes. At this time, the first artificial satellite was sent into orbit around Earth; the first human was sent to space. The culmination was a Moon landing of the Apollo 11 mission in 1969. It lasted until Apollo 17 in 1972 and eventually was canceled due to budget cuts. [3]

The fact of the Moon landing and its possibility has inspired many bright minds to think about more ambitious plans to settle on the Moon or, even further, on Mars. At this time, many ideas came up for the human habitats out of the Earth's atmosphere. At this time, SkyLab and Salut stations were put into orbit, eventually growing into a collaboration project that became a Mir station and International Space Station.

The last significant progress of astronautics was a reusable rocket development done by SpaceX [4]and the inclusion of the private companies on the market of space deliveries that made a launch price much lower, therefore investing in another growth of ideas for extraterrestrial habitats that emerged further.

2 R. Petrescu, R. Aversa, B. Akash, F. Berto, A. Apicella, F. Petrescu, "Project HARP". Journal of Aircraft and Spacecraft Technology. 1 (4): 249–257, 2017

3 M. Tolson, "Mission Moon | Part 9, After Apollo, Budget realities limit NASA options", June 27, 2019

4 "Starship Users Guide", Space Exploration Technologies Corp., March 2020

CASE STUDY

DISTANCE

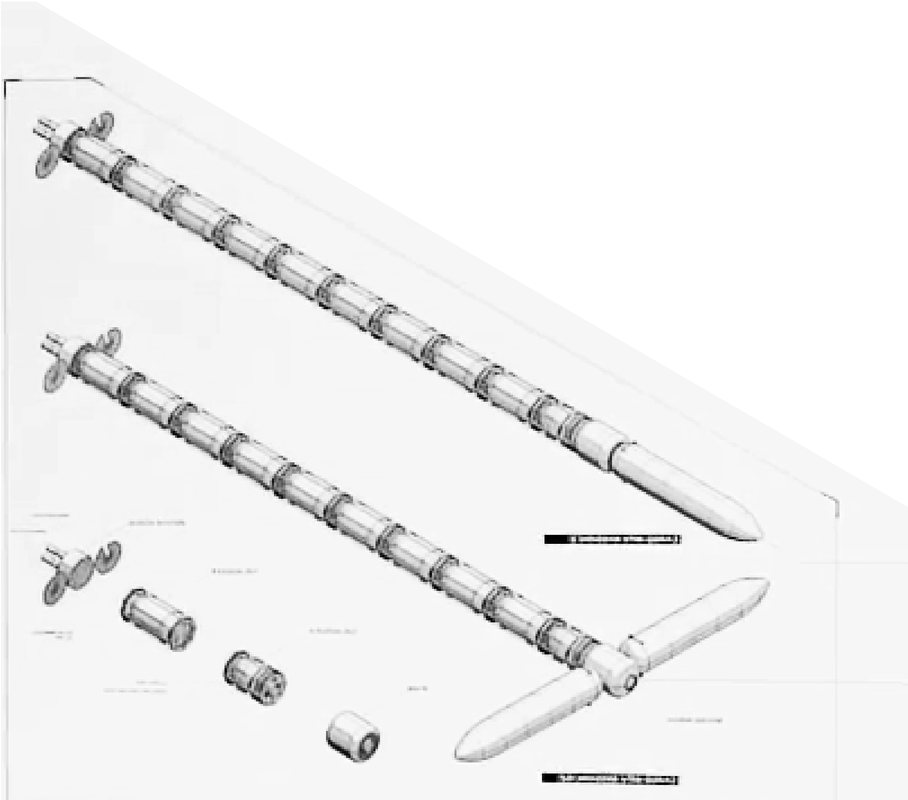
As said before, the incredible complexity of delivering things to Mars is in its distance toward Earth which changes from 58 million km to 400 million km. In addition, the solar system's planets constantly move around the Sun, making things even more complicated.

To get to Mars using existing technology, you would need a giant rocket that can get a delivery out of the Earth's field of influence, achieving so-called escape velocity, and then get to Mars, which most ideally can happen only once in 2.5 years. It will need to break through the Martian atmosphere and safely land on the surface to minimize fuel usage. There is a need for a tremendous amount of propellant and expensive equipment for all these processes. With the landing on the Moon process being much more accessible, there is no need to wait 2.5 years for a transfer window or escape Earth's gravitational influence. However, it still requires tremendous fuel usage and a giant rocket.

Therefore, this issue is always addressed in different ways in projects for extraterrestrial habitats: some propose a huge orbital constellation for the delivery of materials and equipment, others use lightweight materials for delivery, or in situ resources to build a habitat or a complex of all these solutions.

A big step towards lessening the transfer prices came with the development of reusable rockets, shown mainly by SpaceX Falcon 9, Falcon Heavy, and Starship (still under development)[5]. Other companies present some of the other launch vehicles, such as Blue Origin with its New Glenn and New Shepard, and many others are still developing their concepts.

5 "Starship Users Guide", Space Exploration Technologies Corp., March 2020



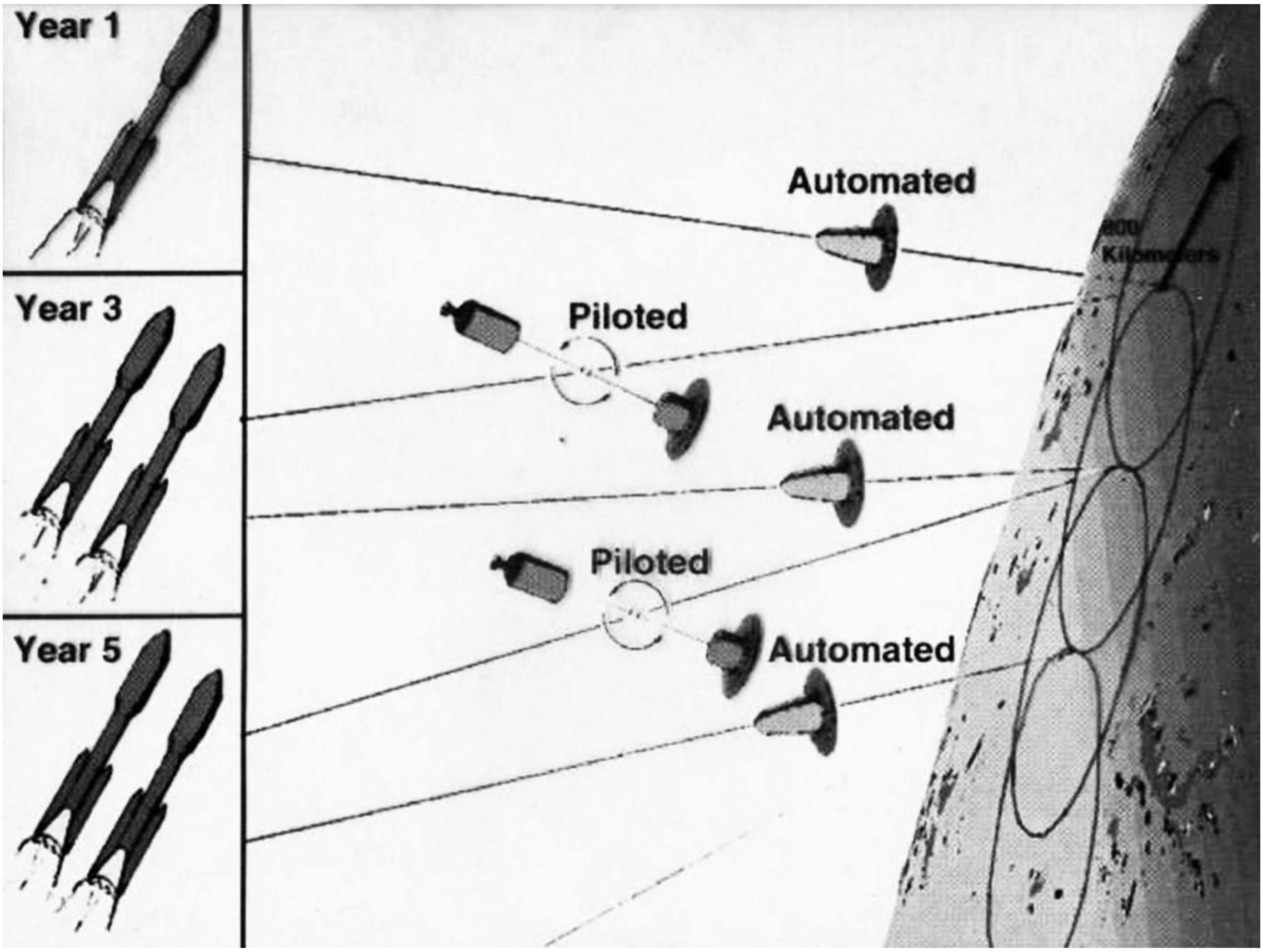
One of the examples would be a Hassell studio design for a Mars habitat[6], and this project does not only explore the architecture of the habitat itself but also the architecture of the mission launch. It proposes to have a prominent orbital constellation to deliver people, cargo, construction robots, and all needed equipment. This constellation is quite massive and complex but is possible to achieve.

6 "NASA 3D Printed Habitat Challenge", Hassell studio, 2018, Retrieved on 25.12.2021 at www.hassellstudio.com/project/nasa-3d-printed-habitat-challenge

While the delivery system is interesting and feasible, the landing system does not show a proper design to survive the Martian atmosphere entry, which is the most probable scenario for the Martian transfer.

Another example of a delivery system would be the SOM Moon Village design[7]. It also provides an architecture of the launch, but on a much smaller scale because of the smaller distance. Each habitat is going to be delivered separately and ready to use. It has its own descending and delivery modules that need to be coupled similarly to how it was with the Apollo 11 mission. It is possible to do so, and there have been many examples of execution of such maneuvers before.

7 "Moon Village", SOM, 2021, Retrieved on 25.12.2021 at www.hassellstudio.com/project/nasa-3d-printed-habitat-challenge

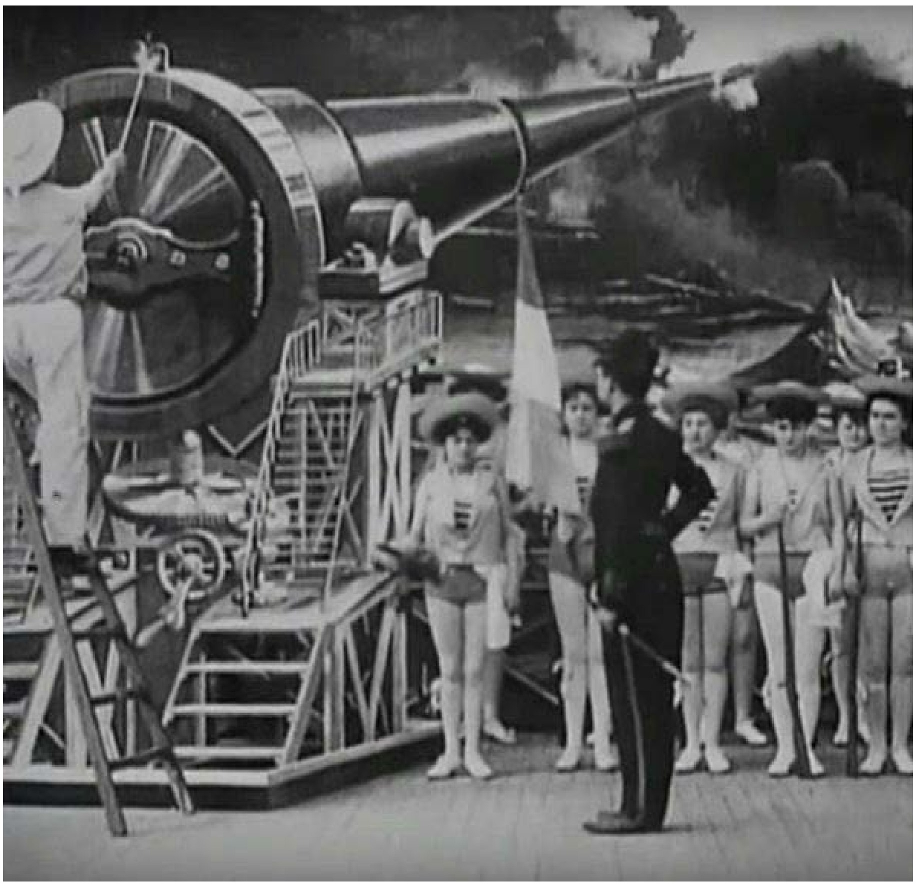


Then the most execution-driven and complexity-free mission architecture is Mars Direct by Dr. Robert Zubrin[8]. It envisions few technological improvements in on-site fuel production or rotational mechanism for habitats that would support artificial gravity, etc. But in terms of launch mechanics and delivery of anything on Mars, it is the minor complex, therefore most probable way to get to the Red Planet.

8 R. Zubrin," The Mars Direct Plan" , 282(3), 52–55, 2000

In any case, those concepts are way less dangerous for people and more probable than the idea proposed by Jules Verne in the book "From Earth to the Moon" in 1865[9], where was used a gigantic gun to launch a crew of 3 men and one dog to the orbit around the Moon.

9 J. Verne "From Earth to the Moon", 1865



CASE STUDY

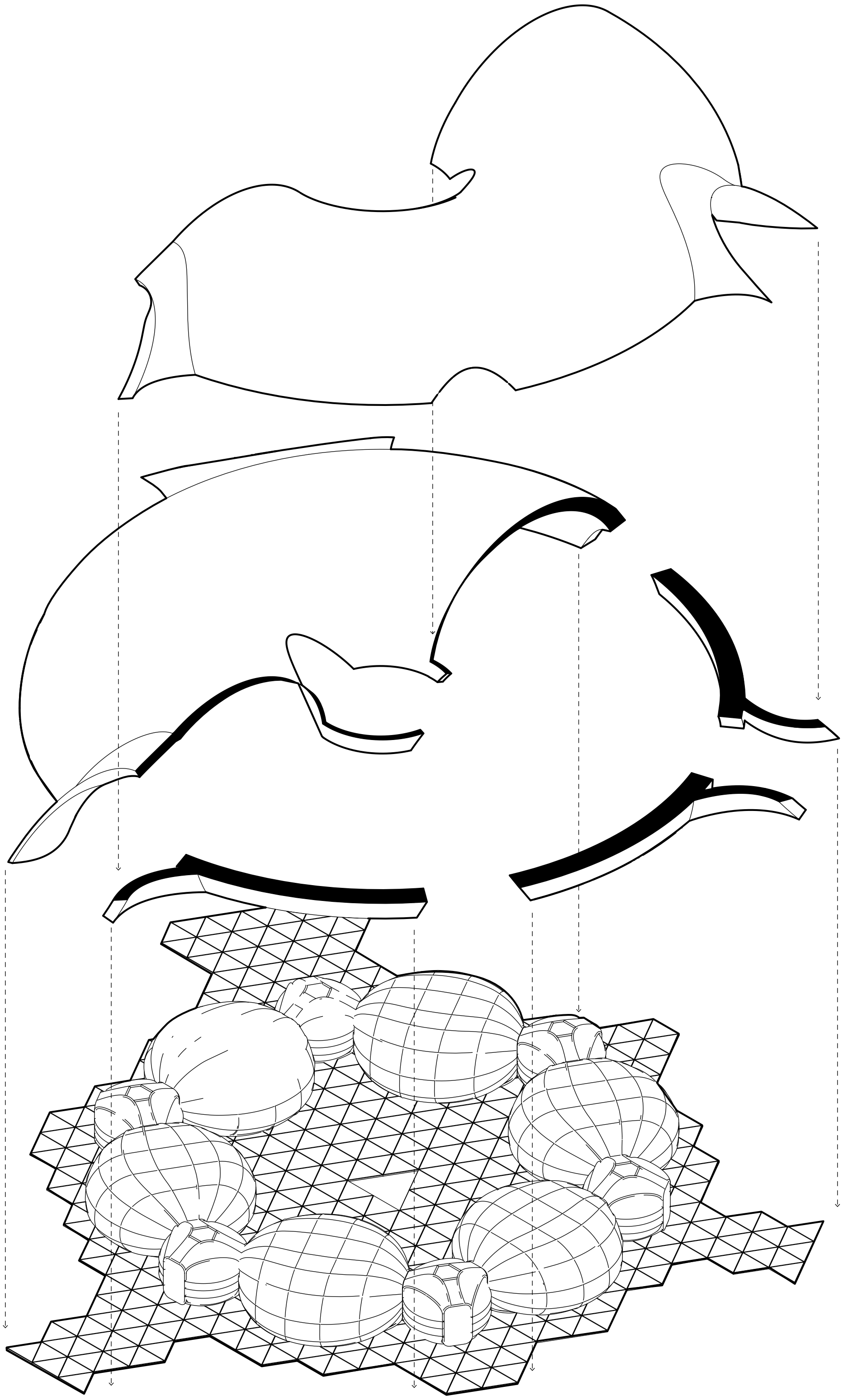
GRAVITY

At the Martian surface, free-fall acceleration would be about 1/3 g (1g = 9.8 m/s2)[10]. Accordingly, the structure's bearing capacity would be three times more than the same structure on Earth.

The lower gravity on Mars also means that much longer spans for load-bearing structures are possible, but it also means that gravity plays a way more minor role in anchoring structures to the soil.

The projects address gravity differently, but all of them mention it regarding stability. Therefore, they are analyzed in this chapter in terms of how they managed both notions.

10 E. Musk, "Making Humans a Multi-Planetary Species", 2017, p. 47



In most cases, limited knowledge of the material (regolith), its characteristics, and implications in the lower gravity environment leads to using the catenary model. The Hassel studio Mars habitat[11] would be a perfect example. In this case was used a structure that is possible to construct without the need for scaffoldings, like the dome of Santa Maria del Fiore in Florence.

The shape of the outer shell structure in its base is a torus, as it covers habitation with a circular arrangement and creates a small courtyard inside.

As the site conditions and stability will be uncertain, the project implies a plate foundation. In this case, it looks like tiles as it serves only for a relatively light inner habitat.

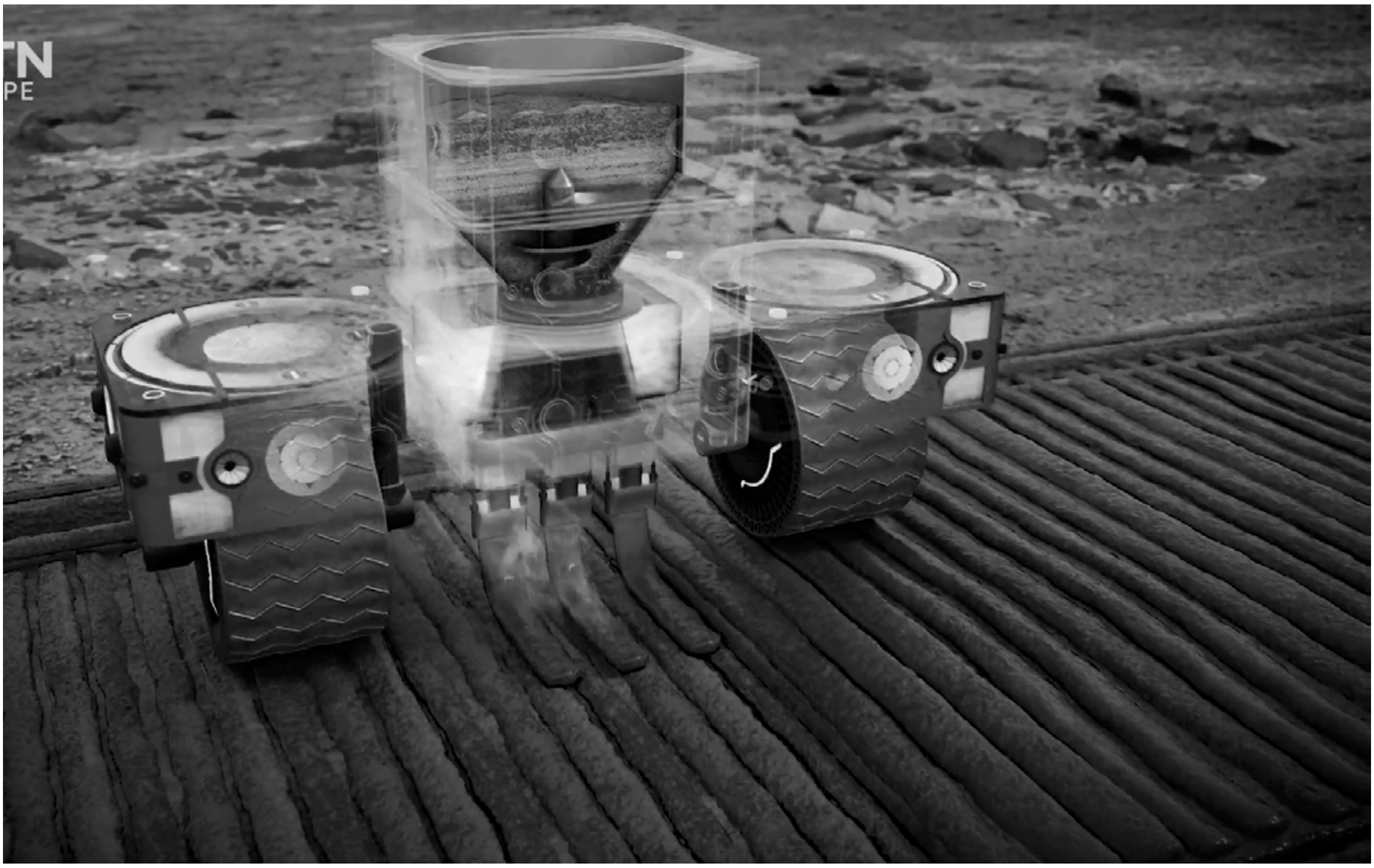
11 "NASA 3D Printed Habitat Challenge", Hassell studio, 2018, Retrieved on 25.12.2021 at www.hassellstudio.com/project/nasa-3d-printed-habitat-challenge

The construction itself implicates the usage of a swarm of drones or robots that need to construct the structure of the shell automatically[12]. This new concept had never been applied in the construction industry. Therefore, it requires a lot of time and investment to have practical application.

By the idea of the construction, the regolith has to be "baked,"[13] probably by microwave "hob" inside the drone, so it will avoid the usage of a binder, therefore making a mass of the delivery of materials and tools to the Red Planet less.

12 Gheorghiu, O; Wilkinson, S; Musil, J; De Kestelier, X; Maddock, R; Yang, X; Dierckx, J; (2016) Preliminary findings from a multi-robot system for large-scale extra-planetary additive construction. In: Making Space Accessible and Affordable to All Countries. Proceedings of the 67th International Astronautical Congress (IAC 2016). (pp. pp. 8678-8689). International Astronautical Federation (IAF): Red Hook (NY), USA

13 M. Barmatz, "3d microwave print head approach for processing lunar and mars regolith", 2014



CASE STUDY

RADIATION

The thin atmosphere and lack of magnetic field on Mars allow a large amount of sonic flare and cosmic radiation to bombard the planet's surface. And it applies requirements for a design to have shielding against various radiation forms from Sun and space. For example, high-energy cosmic rays are heavy nuclei, protons, and alpha particles, while solar flare radiation consists of high-energy protons. Because of the different compositions, those types of radiation also have various penetrating depths and harmful influences on living beings.

Collison of the high-energy electron with the metal conductors or the shielding material can create secondary X-ray radiation that is more dangerous for humans than shielded particles.

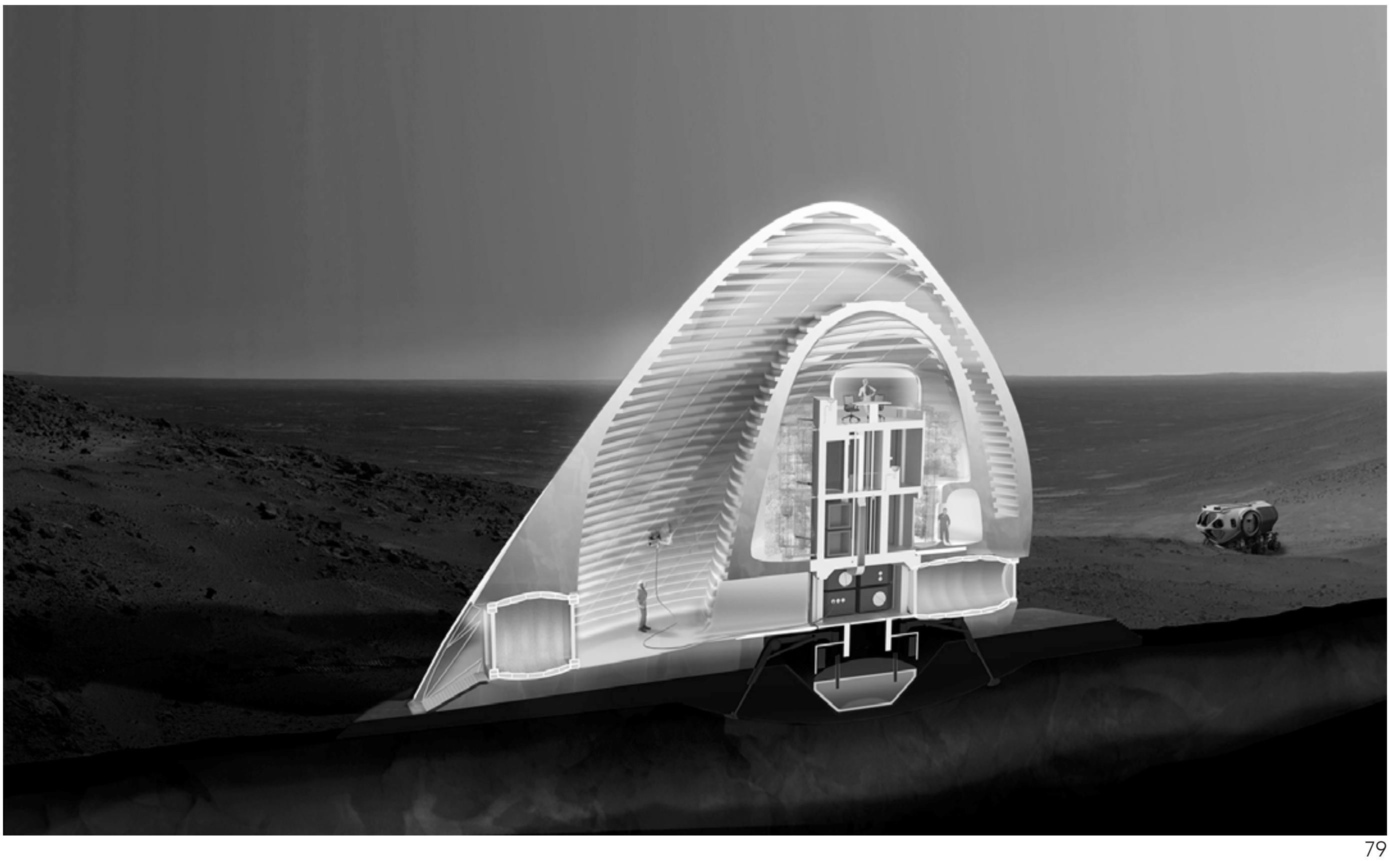
Well thought design focused on radiation was proposed by CloudsAO and SEArch+ in their Mars Ice House project[14]. There are two variations of the concept, but the idea, in general, stays the same, the use of the water ice as the primary material for the outer shell of a habitat. This solution protects from radiation as water works incredibly well against it. There is a need only for a 5 cm thick ice layer to lower the influence of the radiation to a safe level. The difference is in how the idea is elaborated, and both projects are worth looking at.

14 Morris, Michael & Ciardullo, Christina & Lents, Kelsey & Montes, Jeffrey & Rudakevych, Ostap & Sono, Masa & Sono, Yuko & Yashar, Melodie. (2016). Mars Ice House: Using the Physics of Phase Change in 3D Printing a Habitat with H2O.

The first variation[15] has a few constitutive components: transfer habitat, which is prefabricated and delivered on a place lander, then it has inner pressurized habitat enveloped in the protective ice shell and the 'yard.' That is another pressurized outer space that does not have any particular function but has another layer of the ice shell. A double-shell solution allows for a proper counteraction to the external environment - the outer body reacts and absorbs all the temperature and atmospheric differentiations. At the same time, the inner shell does not lose its integrity and unity. Separate pressurized spaces give a possibility that the inner habitat will function and protect the astronauts even if the outer shell is damaged.

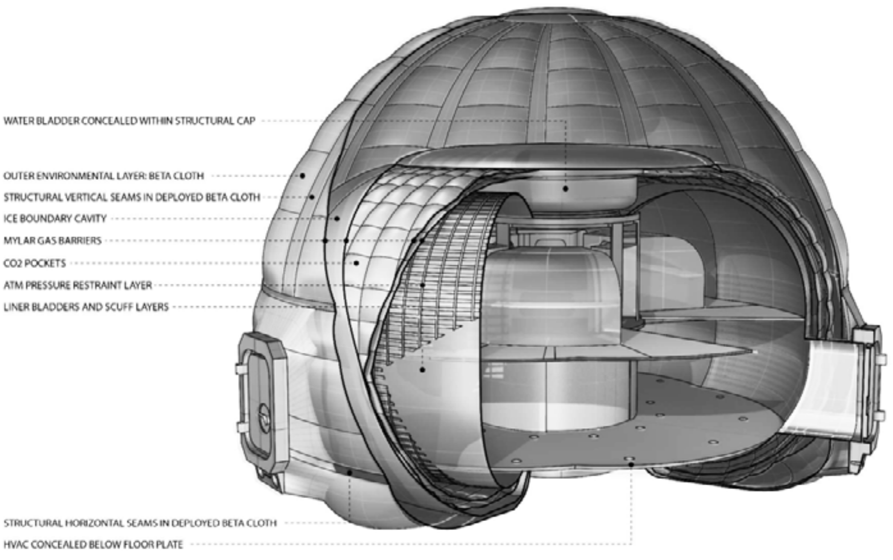
15 "Mars Ice House", CloudsAO, 2015, Retrieved on 25.12.2021 at: cloudsao.com/MARS-ICE-HOUSE

The design does incorporate a solution for subliming the ice from the shell to the outer atmosphere. However, it does not envision the 3d print technique by water or ice in the thin (0.01atm) Martian atmosphere, where no liquid clear water can exist. It also lacks the idea of how this amount of ice or water should be collected or transported.



The second variation[16] is more straightforward in its design and does not include the idea of 3d printing for its construction. In return, it envisions an inflatable transparent shell filled with water that should be extracted directly on Mars. As it has a more straightforward idea for construction, it appears to be a more viable variant than its later 3d printed option.

16 "Mars Ice Home", CloudsAO, 2016, Retrieved on 25.12.2021 at: cloudsao.com/MARS-ICE-HOME

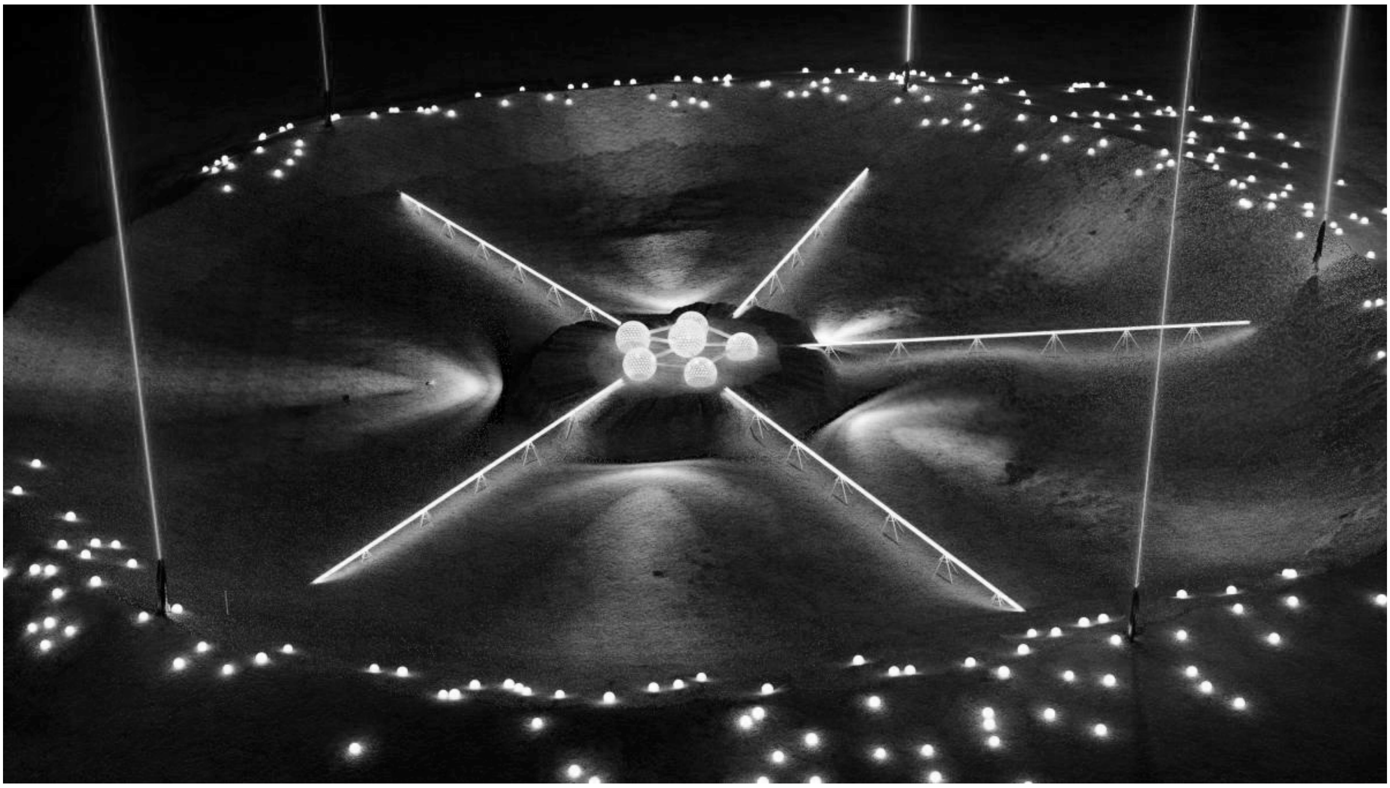


In the case of Star City[17], which MIT researchers developed, the solution for radiation danger was conceptually simpler: to go underground. Mars has many unique features that can be used to build safer human habitats: caves and caverns, lava tubes, and of course, many craters. So the authors decided to use a slope of the crater to cover the circular city that goes under.

It is an obvious solution but still leaves some unsolved questions about the structural stability of the Martian soil or how to excavate these tunnels in a permafrost condition[18].

17 Lordos, George & Lordos, Alexandros. (2019). Star City: Designing a Settlement on Mars.

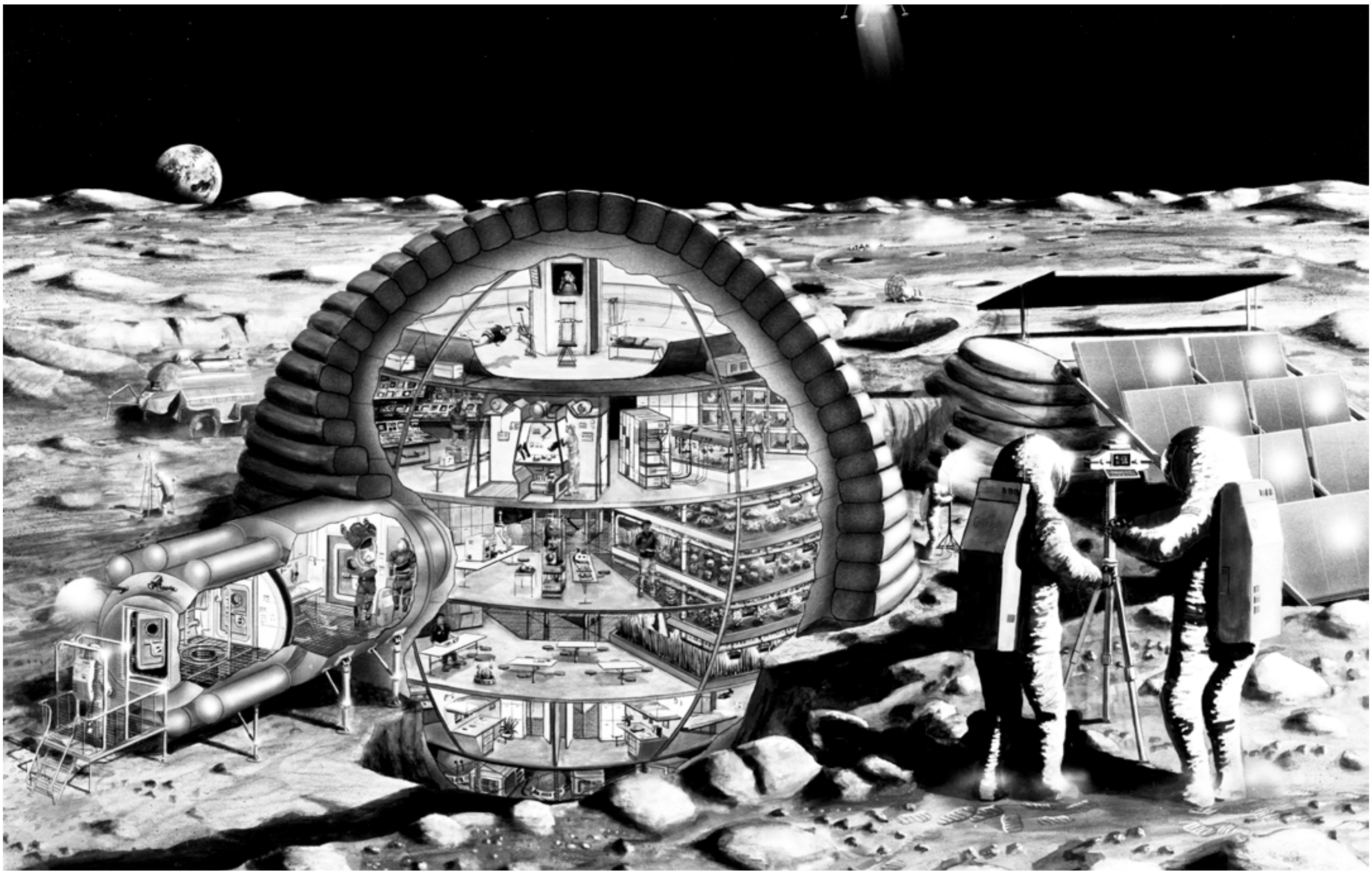
18 S. M. Clifford, 'Depth of the Martian cryosphere', 2010



CASE STUDY

ATMOSPHERE AND TEMPERATURE

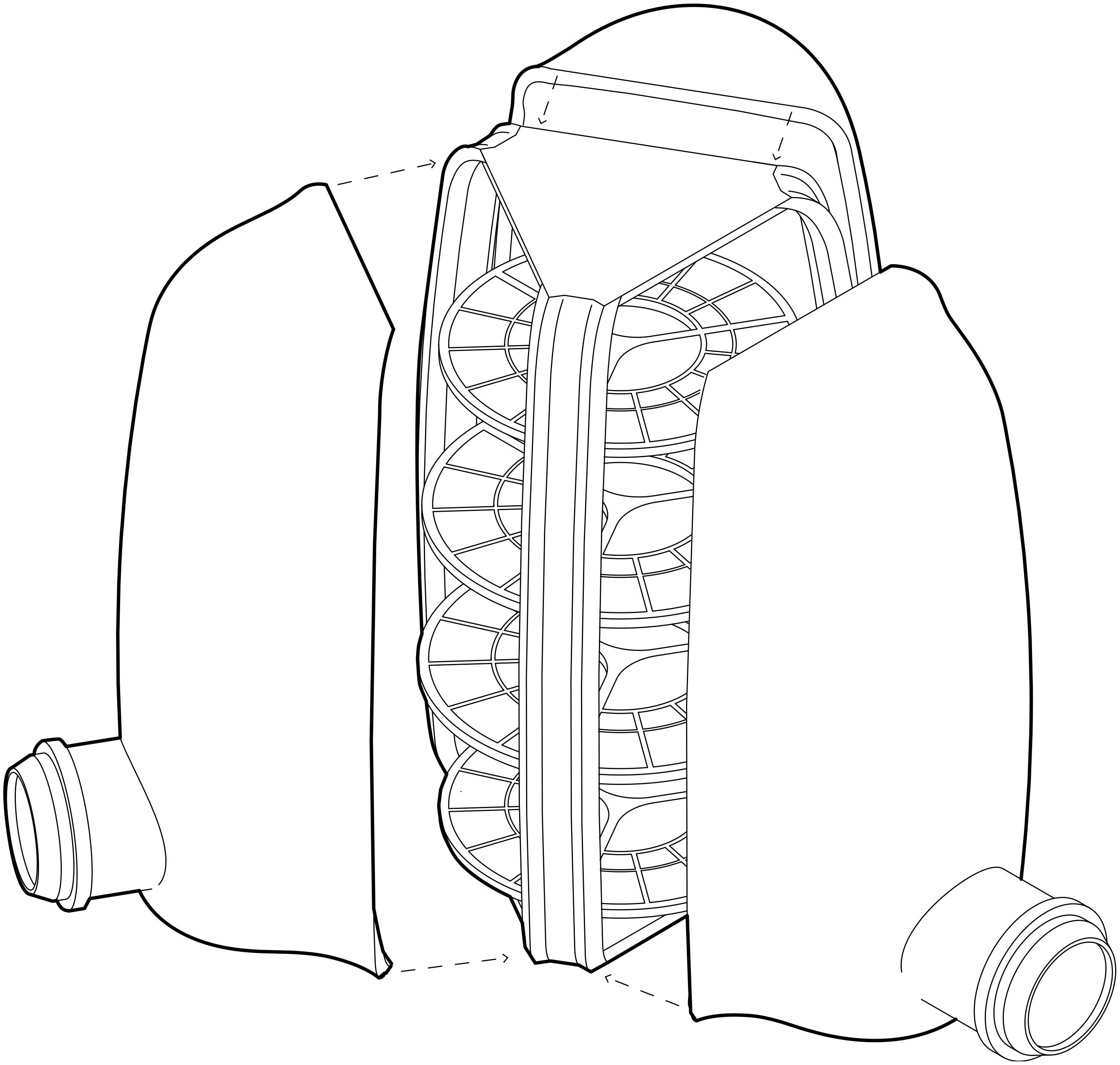
As the atmosphere on the surface of Mars is about 1% of the Earth's, Moon does not have any, combined with lower gravity, making tension loads the main priority. Therefore, mainly inflatable habitats are shown to show an interconnection between structure and its environment in this chapter.



Lacus Veris Inflatable Lunar Habitat, a concept proposed by NASA in 1989[19], was a sphere of 16m in diameter and was supposed to shelter a crew of 8 people. Inner pressure had to be 1 atm but could be even smaller. It consists of 4 floors with a total area of 594 m2. The outer envelope would weigh only 2200 kg using Kevlar material, so it is an excellent area-to-weight ratio.

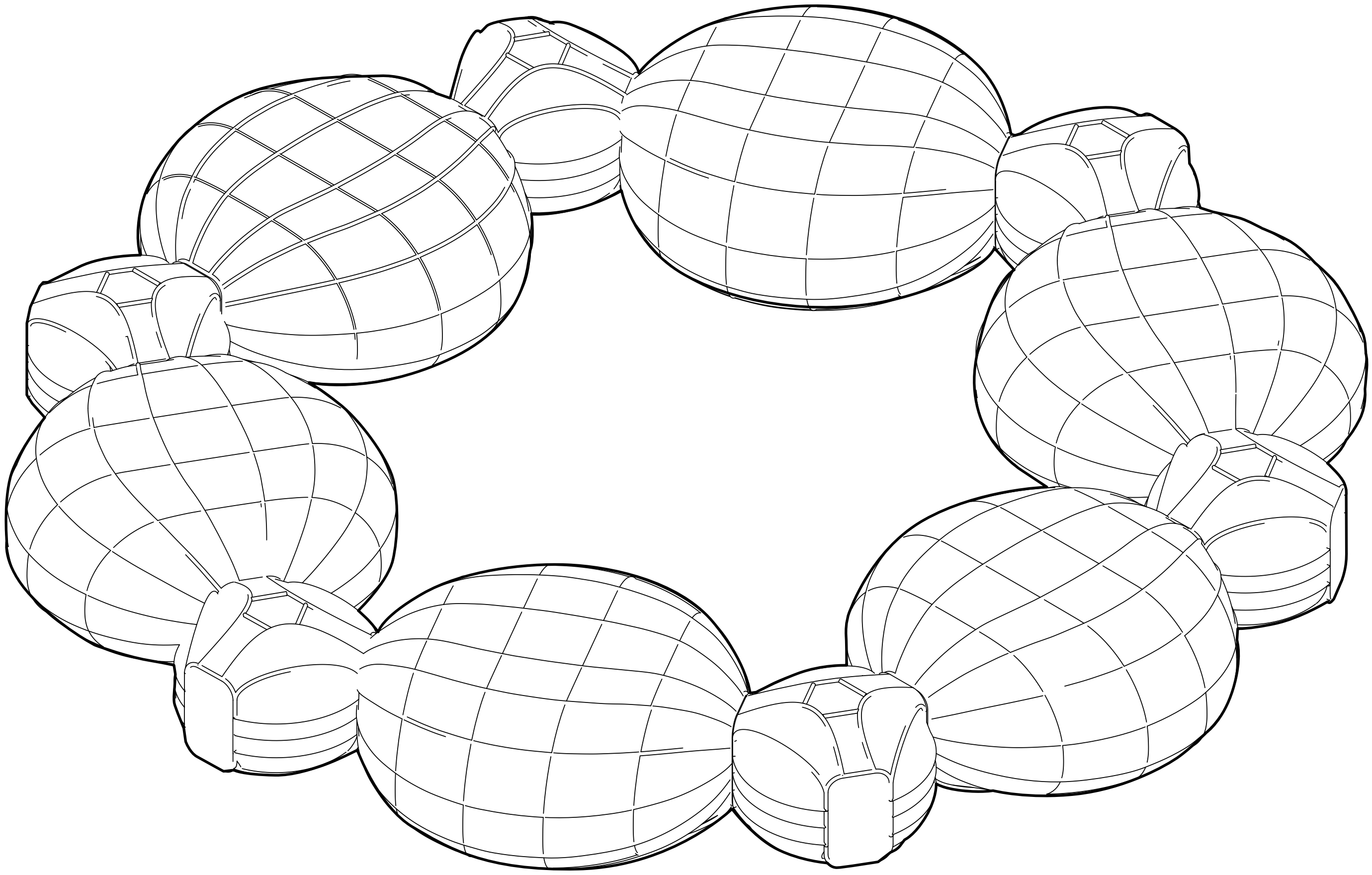
19 Roberts, M., Inflatable Habitation for the Lunar Base, The Second Conference on Lunar Bases and Space Activities of the 21st Century, Proceedings from a conference held in Houston, TX, April 5-7, 1988. Edited by W. W. Mendell, NASA Conference Publication 3166, 1992., p.249

A supporting structure consists of internal beams alongside the outer envelope's interior like lines of longitude and latitude on a globe. However, this structure is needed only in case of loose pressure and for structural rigidity because of the outward pressure of 101 kPa that supports the outer envelope by itself. Therefore, to protect the habitat from solar flares, there was a proposed 3m layer of sandbags from the Lunar regolith with a vertical load of 7.8 kPa easily supported by internal pressure.



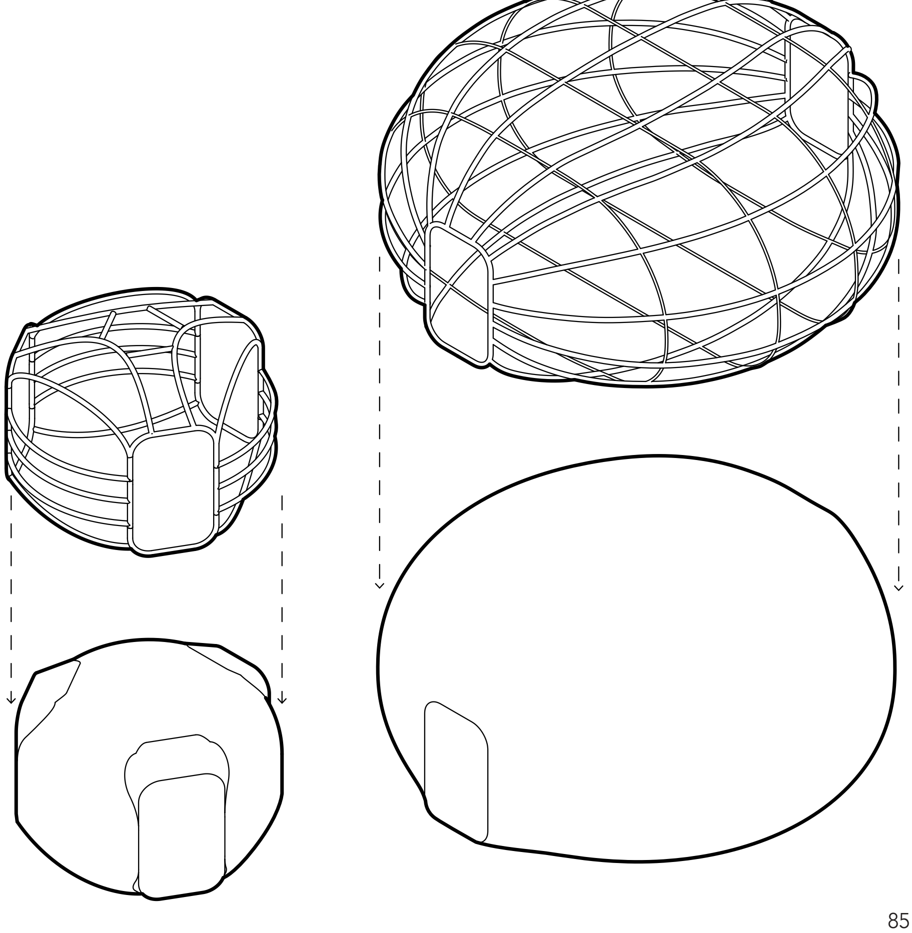
In the Moon Village project done by SOM[20], the main idea is to deliver an almost ready-to-use habitat on the surface of the Moon, so it needs to be stacked inside a fairing of the delivery vehicle (SLS, Starship, or New Glenn). Therefore, to use as much as possible of the practical volume, the habitat is inflatable, with a steel outer framework that works as the main load-bearing element. On the Moon, there is no atmosphere, so the tensile loads from the inner pressurized space would be the main loads on the structure. So, the Moon Village habitat concept uses it to its advantage, making the focus on flexible materials.

20 "Moon Village", SOM, 2021, Retrieved on 25.12.2021 at www.hassellstudio.com/project/nasa-3d-printed-habitat-challenge



Hassell studio Mars habitat[21] has its exciting feature. As the main outer shell faces all environmental dangers (meteorites, radiation, etc.), the inner inflatable shell does not need to be heavy and thick. In addition, because of the low atmospheric density, heat loss is slight due to relatively small heat exchange through the walls.

Due to trim weight and double-shell system, the inner shell is supported mainly by internal pressure. At the same time, structural rigidity is implemented by the similarly inflated tubes that encircle the cover, like longitude and latitude lines on the globe.

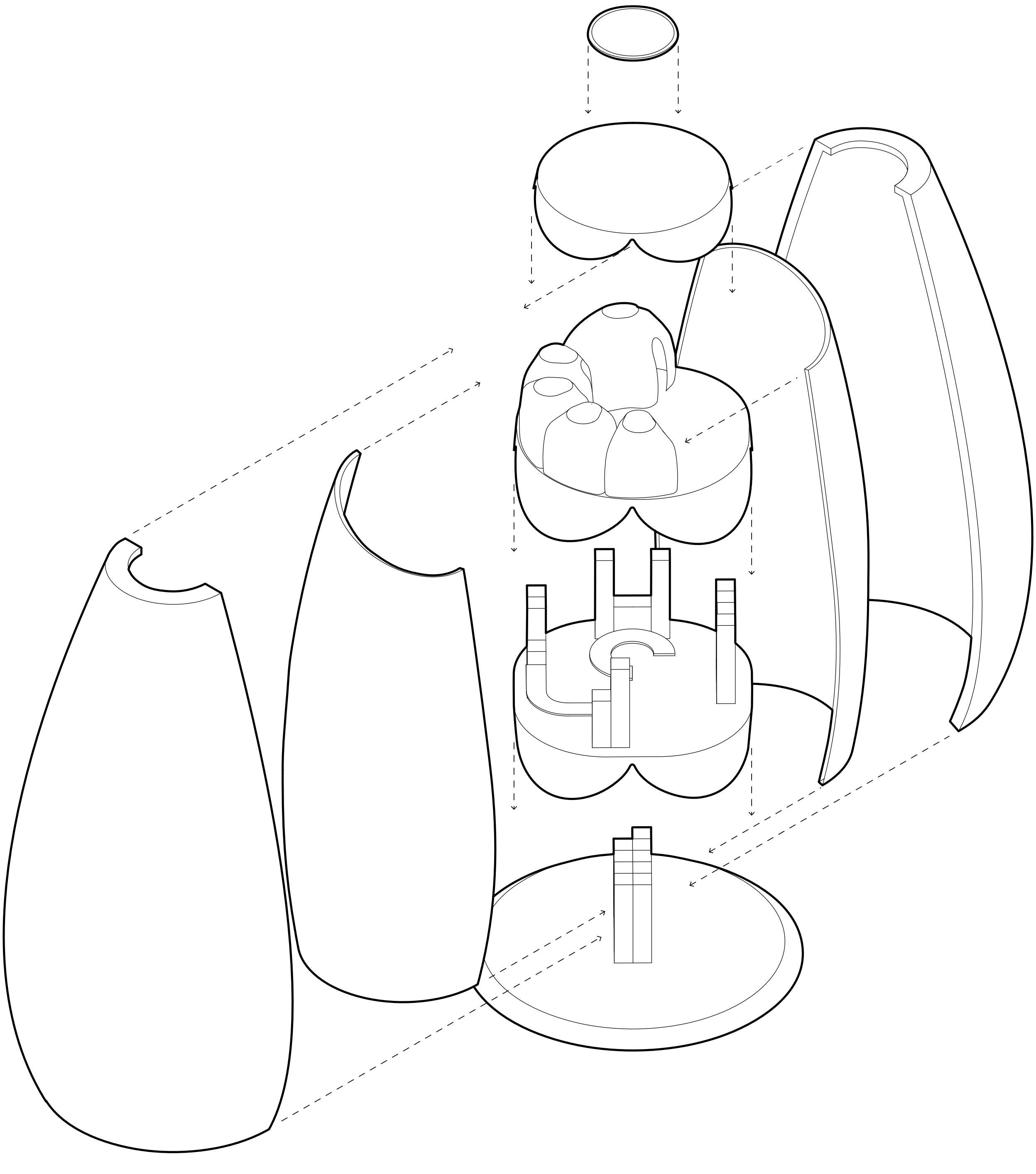


21 "NASA 3D Printed Habitat Challenge", Hassell studio, 2018, Retrieved on 25.12.2021 at www.hassellstudio.com/project/nasa-3d-printed-habitat-challenge

While the MARSHA project by AI SpaceFactory[22] uses another principle. Its shell is mainly rigid; even with bioplastic additives as a binder, it still implements the catenary model and regolith as the primary material. But AI SpaceFactory, in this case, encloses a habitat in an egg-like shape, so even with the significant tensile forces working on the structure, it can withstand it.

This is another example of the double-shell system, where the outer shell acts as a primary barrier toward an aggressive external environment, simultaneously expanding, shrinking, and responding to it in one or another. It allows the inner shell to work separately and constantly work as central support for the stress loads of the floors.

22 "MARSHA, AI SpaceFactory's Mars Habitat", AI SpaceFactory, Retrieved on 08.06.2022 at: www.aispacefactory.com/marsha



CASE STUDY

METEORITES

On the Mars surface, the precise probability of the micrometeorite impact is unknown. It is well known that because of the less dense atmosphere and vicinity to the asteroid belt, it is much higher than it is on Earth. But it is for sure that the probability of the impact of the meteorite-destroyer is relatively low, and it is not even possible that the Martian habitat would survive such an event.

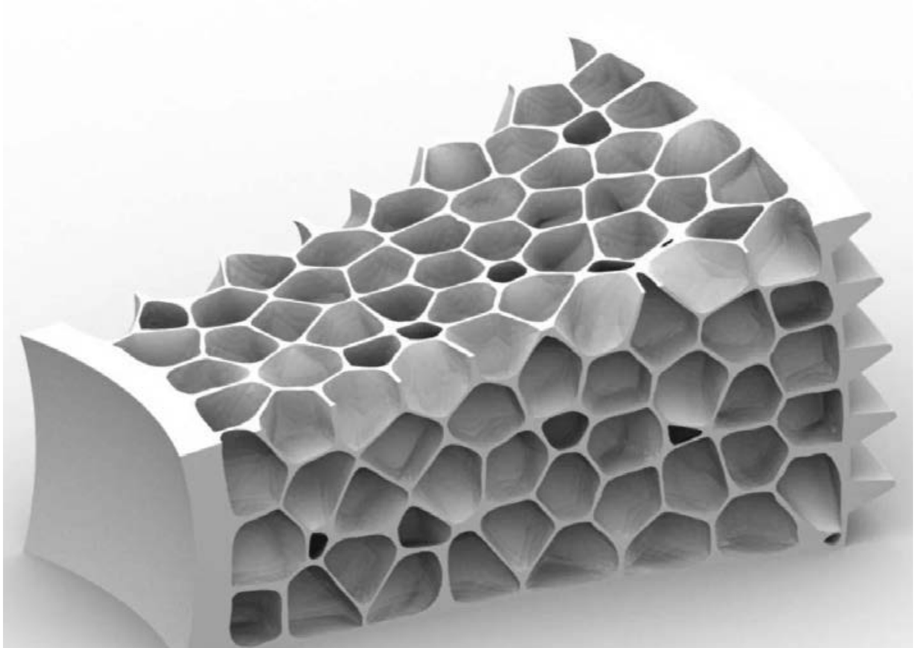
In the case of the micrometeorite impact danger, it is smaller than the danger from cosmic and solar flare radiation. Therefore, an outer shell that can protect from the radiation or lower its influence on the safety measures will probably also protect from the micrometeorite impact.

Mainly the micrometeorite protection is shown as a stuck of sandbags or a layer of the regolith on top, which is generally enough. But in the case of the Hassell studio Martian habitat, the protection from meteorites went further[23].

The structure is simple: it uses regolith for construction as the primary material. However, it implicates a catenary model due to uneven material behavior and a more straightforward construction process that automated robots can use.

23 Gheorghiu, O; Wilkinson, S; Musil, J; De Kestelier, X; Maddock, R; Yang, X; Dierckx, J; (2016) Preliminary findings from a multi-robot system for large-scale extra-planetary additive construction. In: Making Space Accessible and Affordable to All Countries. Proceedings of the 67th International Astronautical Congress (IAC 2016). (pp. pp. 8678-8689). International Astronautical Federation (IAF): Red Hook (NY), USA

But more attractive, in this case, is its inner structure of the outer shell that reminds a 3d Voronoi grid or beehive cassettes. The inner sandy material (raw regolith) is enclosed in a rigid frame (melted regolith or mixed with a binder). Therefore, in a moment of the impact, micrometeorite will face different by its consistent materials, which will effectively slow it down, mainly by sandy regolith as the rigid partition works primarily to encapsulate the fine regolith.



CASE STUDY

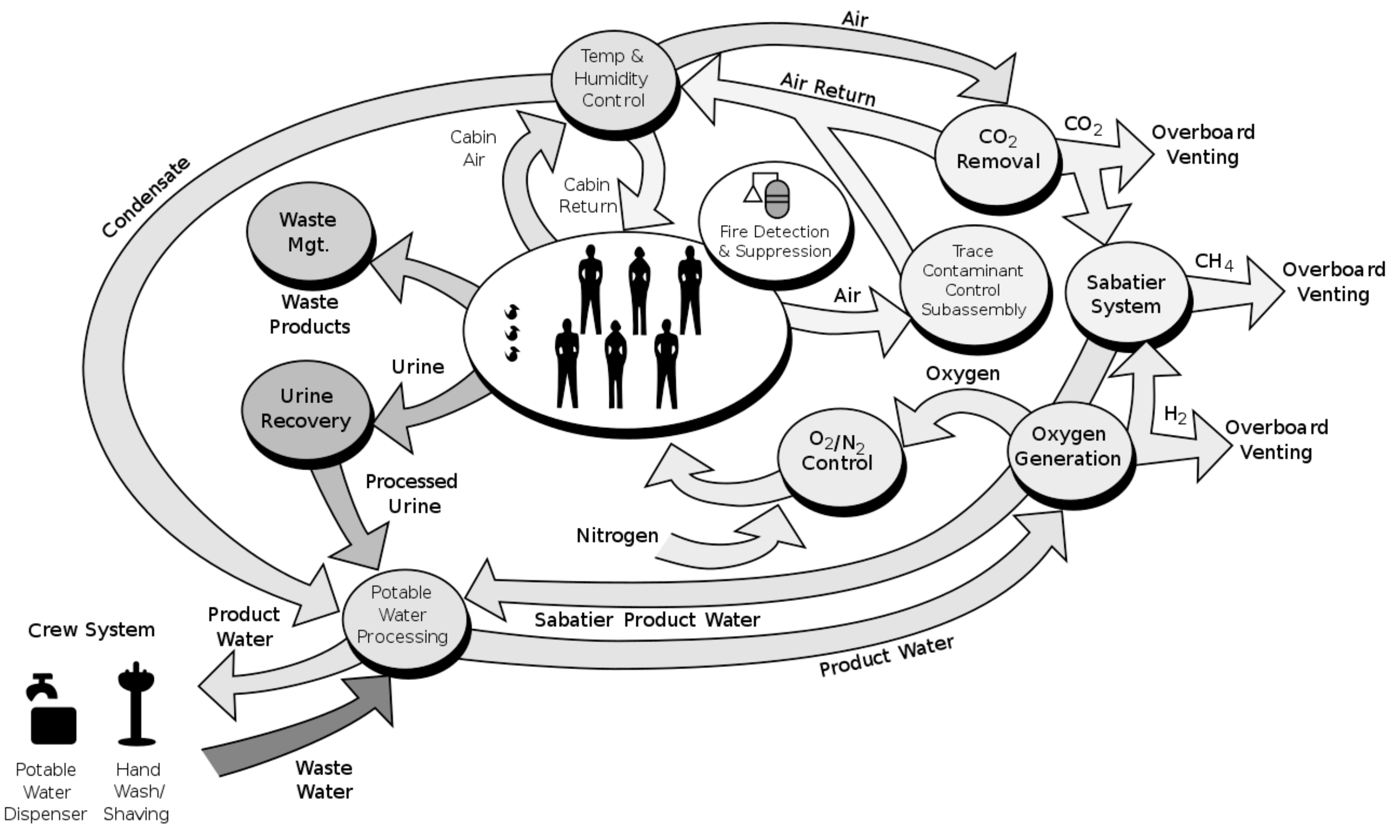
LIFE SUPPORT SYSTEM

For each long-staying human mission in space, there is a need for some environment control and life support system. Some types of such systems date back XIX century when the additional balloons of oxygen were used to support balloonists or mountain climbers that were exciding the altitudes with breathable air. And until the time of human space exploration, it was already well developed, especially considering the use of submarines, where the extended stay underwater was crucial for the survivability of the crew.

Regarding the space habitat, a regulated environment and life support systems are the most critical parts. While systems that control levels of oxygen, nitrogen, CO2, etc., do not allow the crew to die, systems that recycle urine and water expand the survivability of the mission without additional delivery of the needed elements.

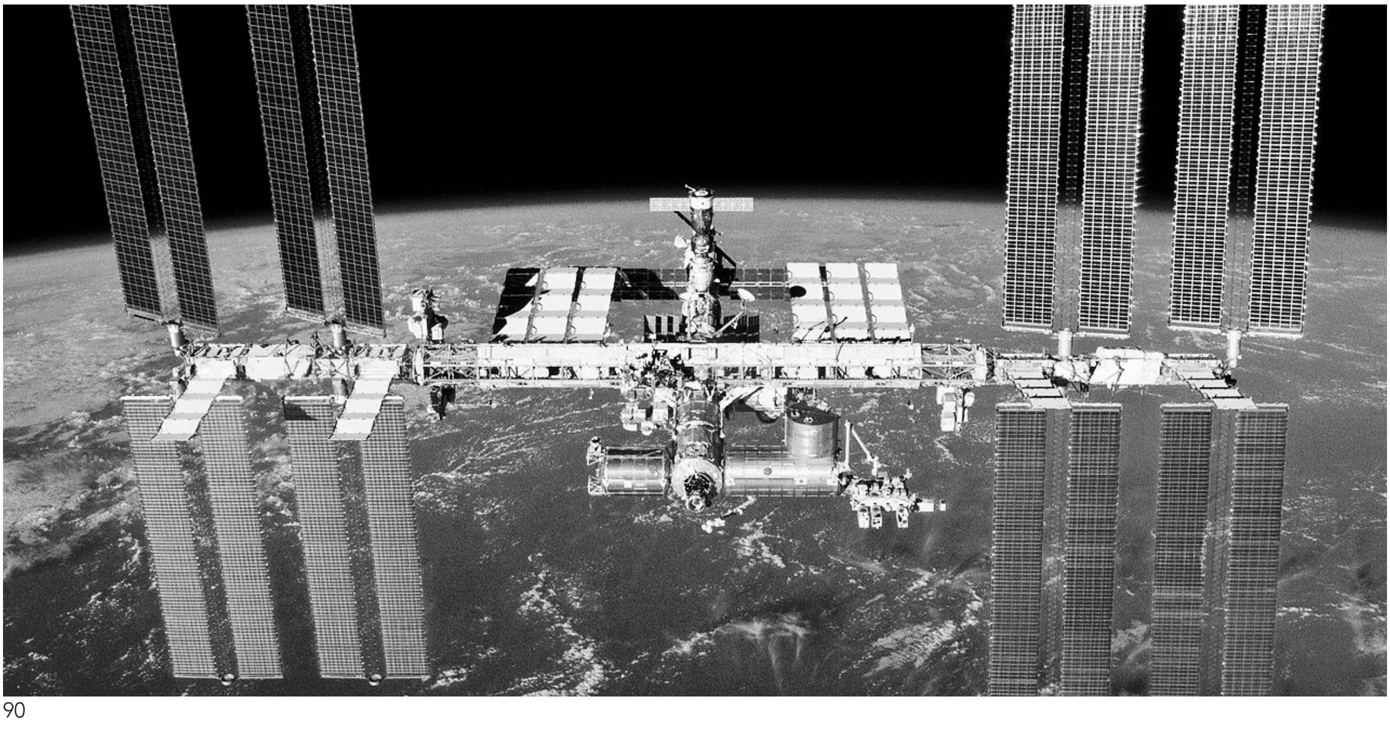
Nowadays, ECLSS mainly supports good air conditions and water recycling. Such things as food lost parts of the oxygen, nitrogen, and water are regularly resupplied. But in the further development and expansion of human space exploration, there is a need for a more significant specter of things that can be resupplied in a place and for lighter and more efficient existing systems.

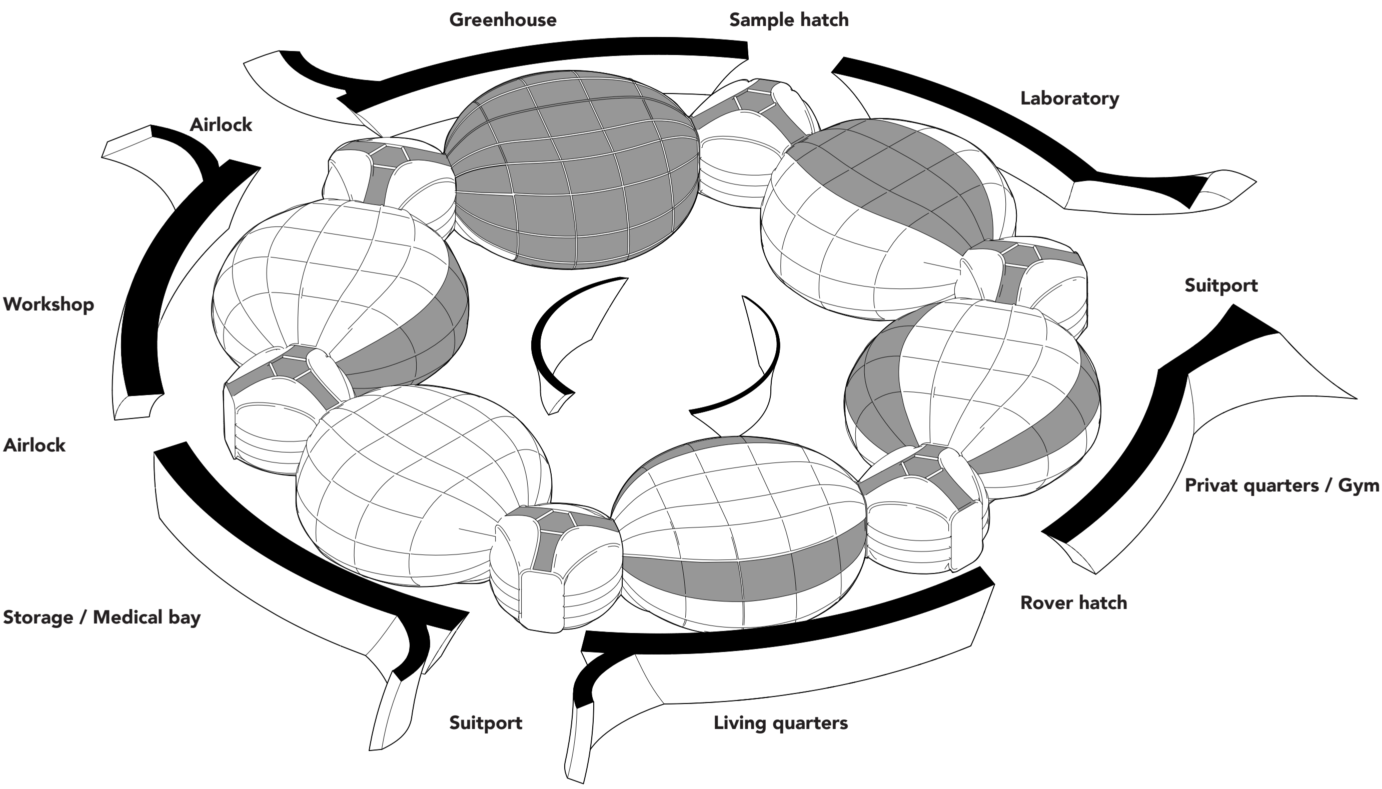
No less important part of the ECLSS is the backup systems that can be used in case the main one is lost.



One of the most prominent examples of the existing and working life support systems operating in space would be International Space Station[24]. It has several modules that have in its function ECLSS systems, and most important, it has worked for decades supporting the life and work of astronauts in an artificial environment. It is basic in its functions: potable water supply through water reclamation, food supply, breathable cabin air supply (oxygen generation system), air pressure control (maintained at 101. kPa), air temperature regulation through a heat exchanger, human waste management and waste disposal, fire detection and suppression. Another essential characteristic of the LSS is its substitutability; if one of the parts will be lost because of its important place, it should have a few ways to be replaced or bypassed without risk for a crew or the mission. Therefore, modules of the ECLSS on the International Space Station are duplicated in case part of the system is malfunctioning.

24 D.Layne Carter (2009). "Status of the Regenerative ECLSS Water Recovery System (2009-01-2352)", NASA/SAE. Retrieved 25.02.2022 at: ntrs.nasa.gov/citations/20090033097





The substitutability of the parts of the system becomes one of the main ideas for the Hassell studio Martian habitat[25], where each module is replaceable, and even if one of them is lost, the system will work because of the circular arrangement.

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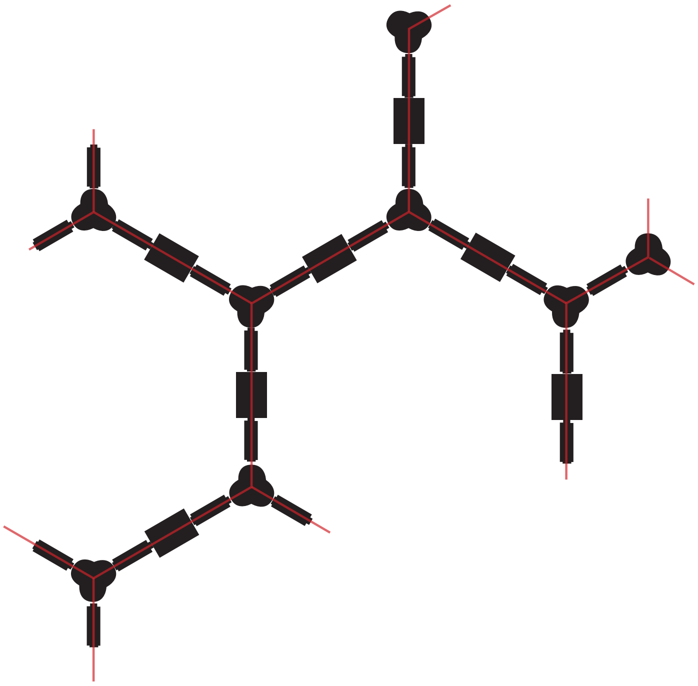
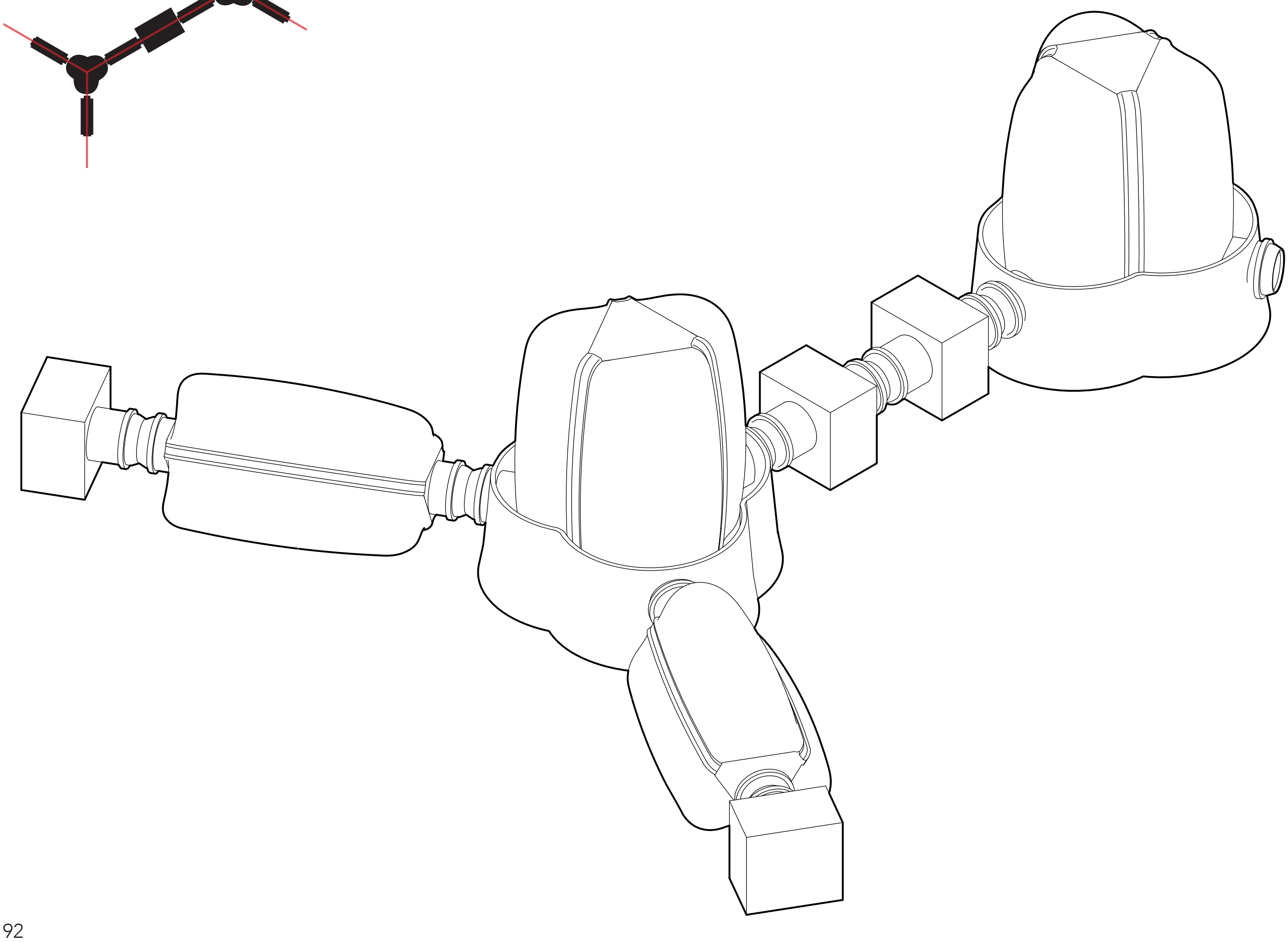
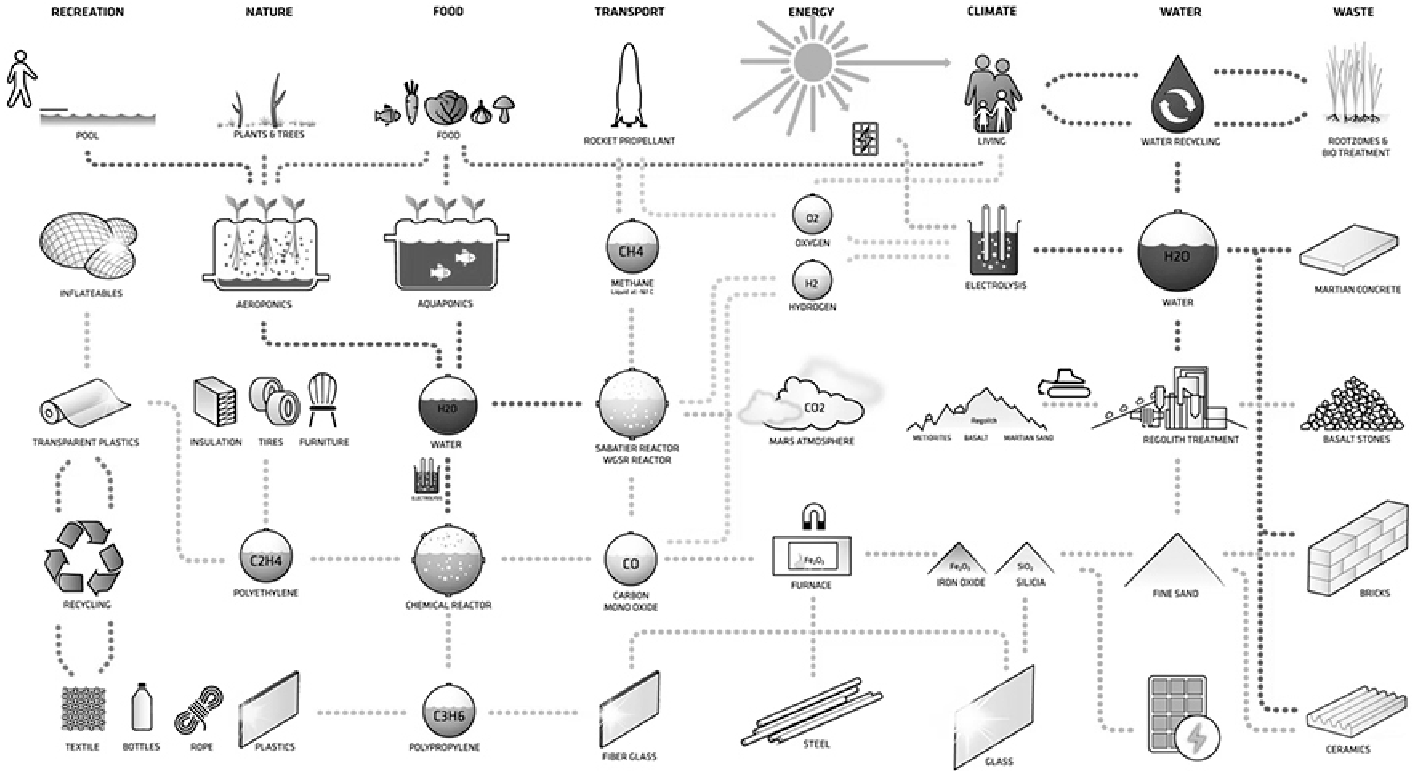
25 "NASA 3D Printed Habitat Challenge", Hassell studio, 2018, Retrieved on 25.12.2021 at www.hassellstudio.com/project/nasa-3d-printed-habitat-challenge

A similar approach is shown in the Moon Village by SOM[26]. However, in this case, replaceability is displayed on a bigger scale when each habitat becomes a part of the system, with every new element making system more secure. Of course, each habitat, together with a specific function, has its LSS system.

26 "Moon Village", SOM, 2021, Retrieved on 25.12.2021 at www.hassellstudio.com/project/nasa-3d-printed-habitat-challenge







In the Science Mars City, BIG[27] went even further, as the city's system of scale needed to have a broader view of Environment Control and Life Support. Most concepts that encompass city-scale have in mind a circular economy. Those ideas differ in detail on how the economy can work, but generally, the idea always stays the same. As with the Martian City of BIG, it does not detail how the materials or crucial elements will be extracted to support the system. However, it shows a general idea and schemes of how it can work in the Martian environment.

Suppose the question is about a city-scale large population on Mars. In that case, it is the only way how it can develop and thrive because it would be enormously expensive to support such a population by importing resources from Earth.

27 "Mars, Mars Science City", BIG, 2017 Retrived on 27.12.2021 at: big.dk/#projects-mars

CASE STUDY

HUMAN FACTOR

One of the most discussed topics about people going to Mars is a human factor, more precisely, human mental wellbeing in isolated and confined environments. And the reason is simple: the crewed mission that will happen on the surface of Mars will last for years, with the same people enclosed in a relatively small environment, and if a conflict occurs, it will put at risk the whole mission and an enormous amount of resources that would be needed to implement it.

One of the solutions explored in the concepts of extraterrestrial habitats is to make appropriate space for astronauts for work and personal life. Martian habitat of the Hassell studio and Moon Village habitat of SOM[28] give enough information for a proper analysis of the internal spaces to compare it to the human body and assume some level of comfort of the inhabitants and some characteristics that influence it.

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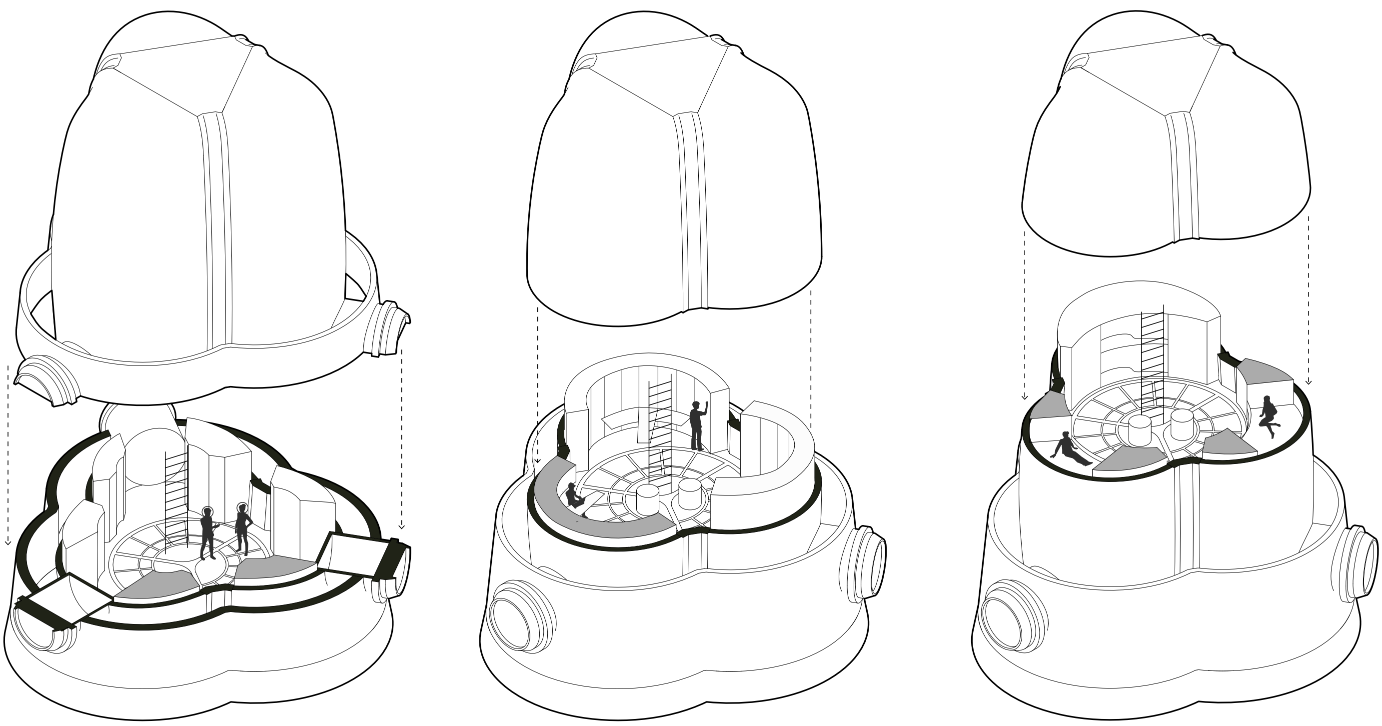
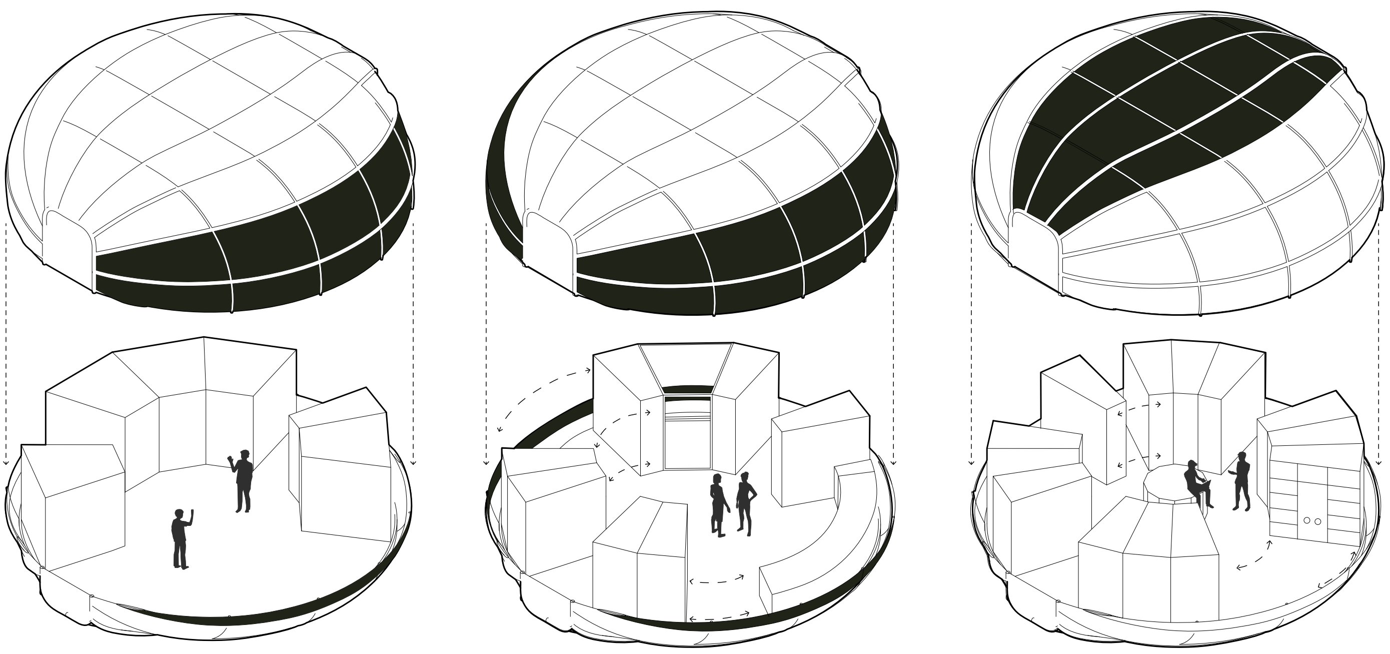
28 "Moon Village", SOM, 2021, Retrieved on 25.12.2021 at www.hassellstudio.com/project/nasa-3d-printed-habitat-challenge





In the Hassell studio Martian habitat[29], the movable modular furniture allows the space to be modified following the needs of the people working or living inside. In case of need, it can be adjusted to the function in use at a particular moment. The habitat size and each module are big enough to allow various actions, events, or simultaneous work.

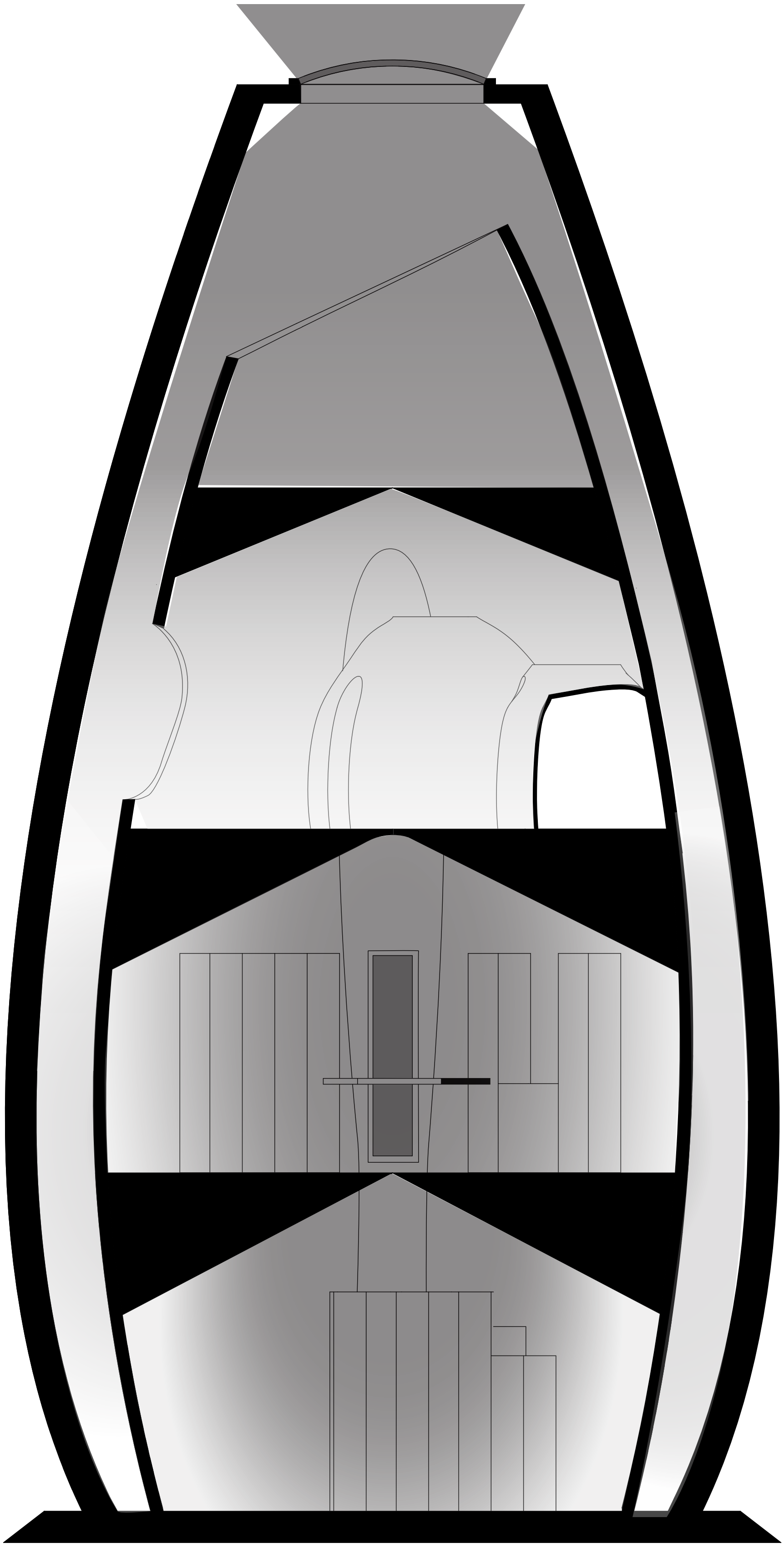
29 "NASA 3D Printed Habitat Challenge", Hassell studio, 2018, Retrieved on 25.12.2021 at www.hassellstudio.com/project/nasa-3d-printed-habitat-challenge

In the case of the Moon Village habitat, it has enough space for the crew to function. It has also designated an area for a team's personal life and, in comparison to the human-scale rooms of the habitat, has comfortable and appropriate dimensions allowing different actions to happen simultaneously. Because of the difference in structure and general concept of the habitats, the lunar habitat developed by SOM is comparatively smaller than the Martian habitat by Hassell studio. However, it still supports big enough space for a crew to work on a mission.

Another question that is opened by some concepts is the role of the natural light in the sleeping cycle of the astronauts and their wellbeing. Considering the harmful influence of the radiation on the human body and the ample amount in the environment out of the Earth's magnetosphere or atmosphere, it requires ingenuity to make it possible to enter inside a human habitat.

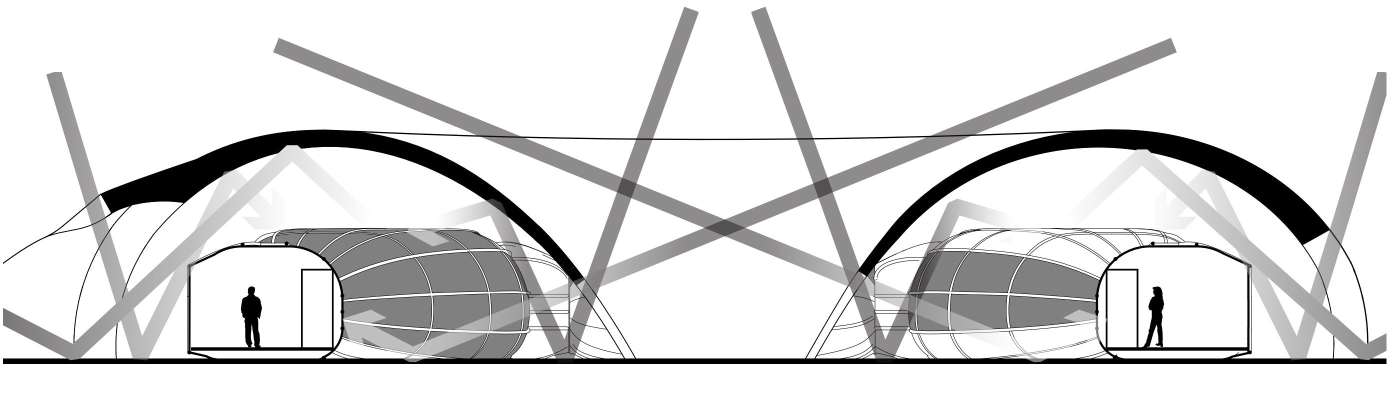
A good tool for it would be the use of water or ice water as a translucent material that allows light rays to get through but also protects from radiation. Exactly such a solution for the MARSHA project by AI SpaceFactory[30] was used for the design of the upper window to create an ambient natural light in the habitat.

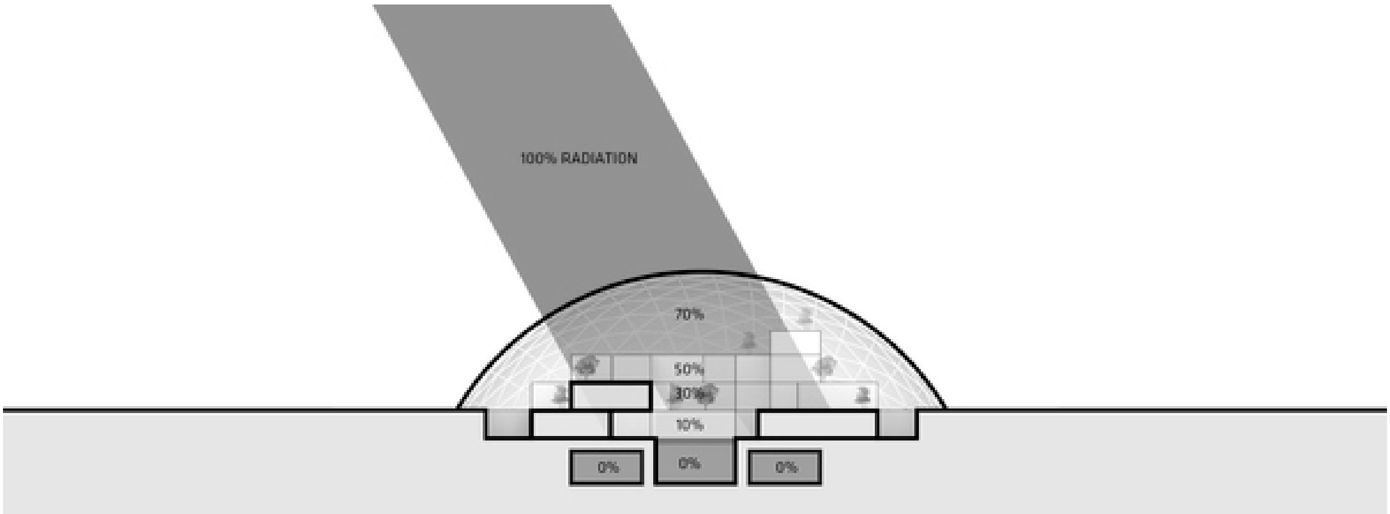
30 "MARSHA, AI SpaceFactory's Mars Habitat", AI SpaceFactory, Retrieved on 08.06.2022 at: www.aispacefactory.com/marsha



A different solution was proposed by Hassell studio[31]. In their Martian habitat, they presented big transparent windows that are protected from the direct light and radiation by the outer shell, 3d printed from regolith. However, this solution allows an interior view in an internal courtyard, allowing reflected light to enter the habitat.

31 "NASA 3D Printed Habitat Challenge", Hassell studio, 2018, Retrieved on 25.12.2021 at www.hassellstudio.com/project/nasa-3d-printed-habitat-challenge





Radiation exposure is gradually reduced as you move down the buildings. On the rooftops, the dome serves as the first layer of protection. However, areas between and under the buildings and water roof have added protection while still allowing daylight to enter.

BIG[32] proposes another way to tackle an enclosed environment in their Martian Science city, where the scale of the project is playing as an advantage. However, at the same time, it proposes a layered structure for radiation protection. While it has big airy spaces that have a size of a neighborhood or a small town, giving at the same time variety of different points of interest that can support the wellbeing of the citizens, it also allows natural light to penetrate the transparent outer shell. By leveling the city with the occasional use of water as a protective layer, it lessens the influence of the radiation the lower it goes. Such a solution allows for various functions to be distributed on different levels accordingly to the level of the radiation, some of which include a short time of exposure to natural light.

32 "Mars, Mars Science City", BIG, 2017 Retrived on 27.12.2021 at: big.dk/#projects-mars

CASE STUDY

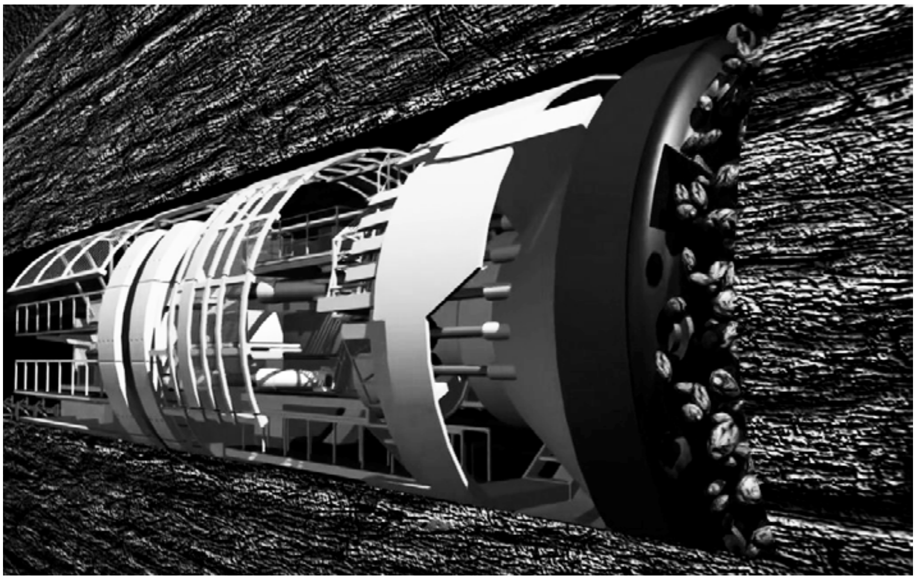
MOBILITY

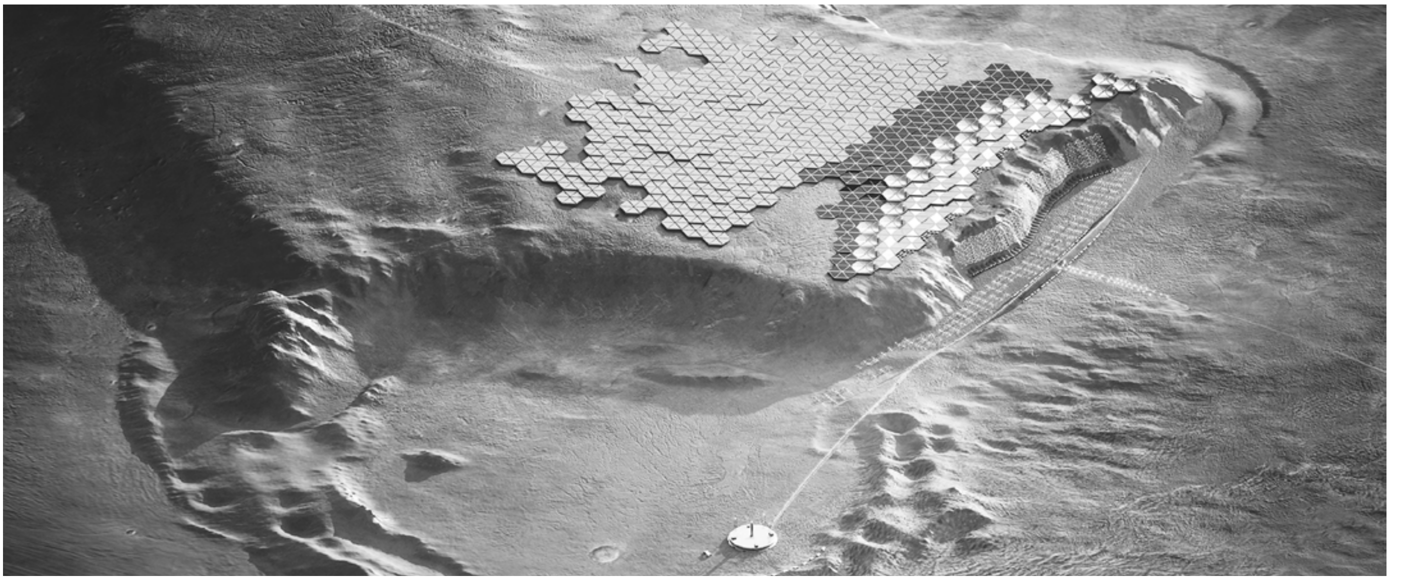
To support the research activity on the surface of Mars, the crew stationed there will need some transportation to have the ability to observe and research at a significant distance from the base. It would be an essential point for the research outpost, but it is difficult to express it in terms of a design for an Arctic base type.

At the same time, ideas or concepts that include city-scale need to have an appropriate solution for transportation inside the city, outside, or between cities. And in this case, should exist a variety of different solutions with different speeds and characteristics. If transportation is situated outside the protective environment of the habitat, it needs to be protected from radiation and other influence of the extreme environment.

A great example of fast underground mobility is the hyperloop concept, which is now actively developed by several companies here on Earth. Because it is underground or enclosed, it can be safe and fast transportation on Earth and Mars, connecting essential parts of the probable future Martian society.

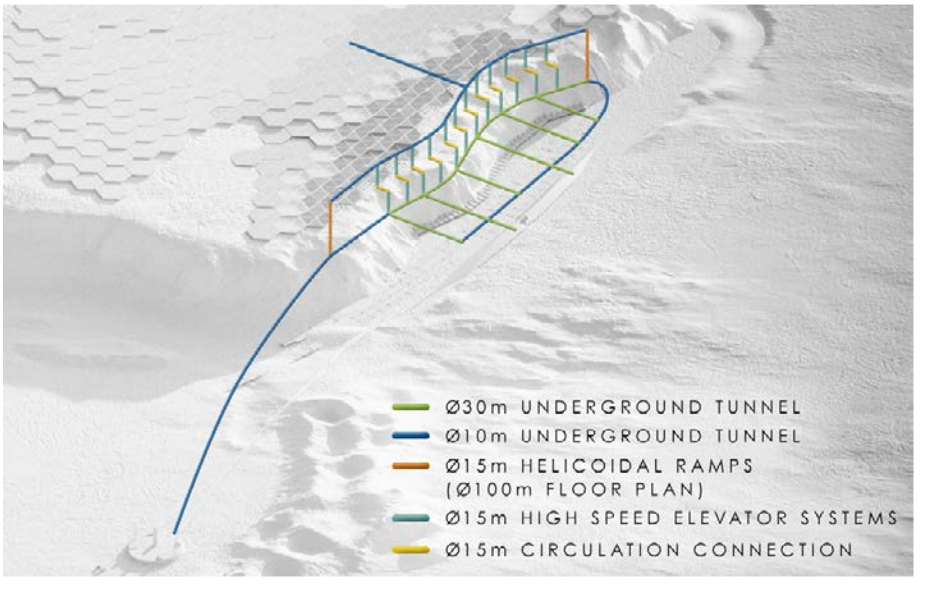
It would be possible, of course, if the appropriate infrastructure to build this were in place on Mars. Therefore, a significantly developed settlement should be present, including the scale of the connections and the need for this infrastructure to exist in the first place. But most probably, the human settlement of a city-scale on Mars, if it exists, will be partially or entirely underground, so the infrastructure to dig tunnels will be already there once such a city appears.

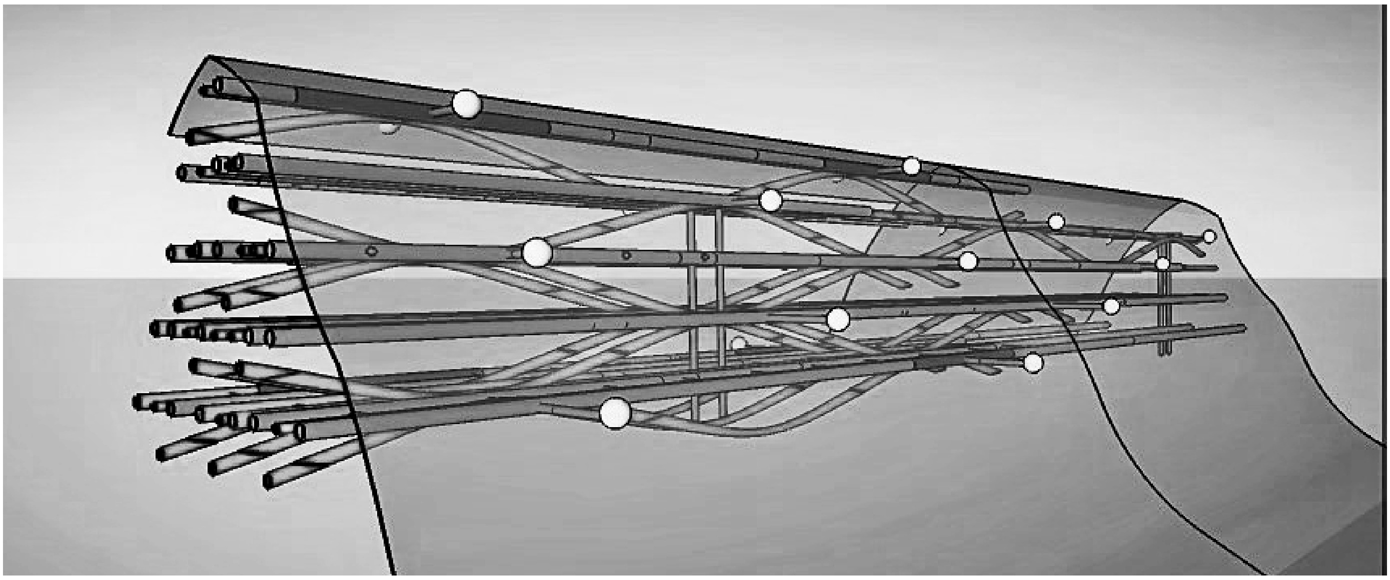




Concepts like a Nuwa City by Abiboo[33] is one example of an underground city development where tunnels play a central role in residential, production, or work functions and the connection between them. As the concept makes an advantage of the steep Martian landscape to build along it, internal links become an essential part of it, mainly horizontal and vertical ones. The project predicts that horizontal communication would happen with light electric trains and buses, also between cities. However, it is also possible that maglev trains will appear with the further development of the Martian settlement.

33 Anglada-Escudé, Guillem & Sureda, Miquel & Detrell, Gisela & Munoz, Alfredo & Pearce, Owen & Apostol, Engeland & Rodriguez, Sebastian & Florido, Veronica & Casanova, Ignasi & Cullen, David & Banchs-Piqué, Miquel & Hartlieb, Philipp & Ribas, Laia & Torre, David & Miralda-Escudé, Jordi & Gómez-Pastrana, Rafael & Soler, Lluís & Betriu, Paula & Atalay, Uygar & Beard, Rory. (2021). "The Nüwa Concept. A development model for a self-sustainable city on Mars"





The Star City concept that George and Alexandros Lordos[34] developed from MIT and the University of Cyprus has also implemented an underground development of a city along a ridge of a crater. Again, it is a linear city, even if encircled, where transportation and the horizontal connection play the central role. It is another example of a tunnel-based environment; therefore, all internal communication should utilize an underground transport system where metro or hyperloop type can be suitable.

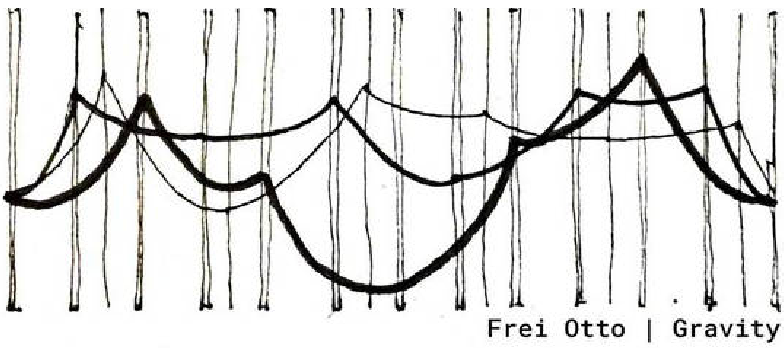
34 Lordos, George & Lordos, Alexandros. (2019). Star City: Designing a Settlement on Mars.

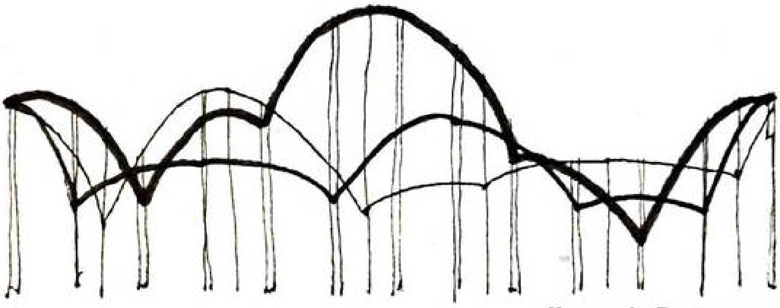
CASE STUDY

WATER DILEMMA

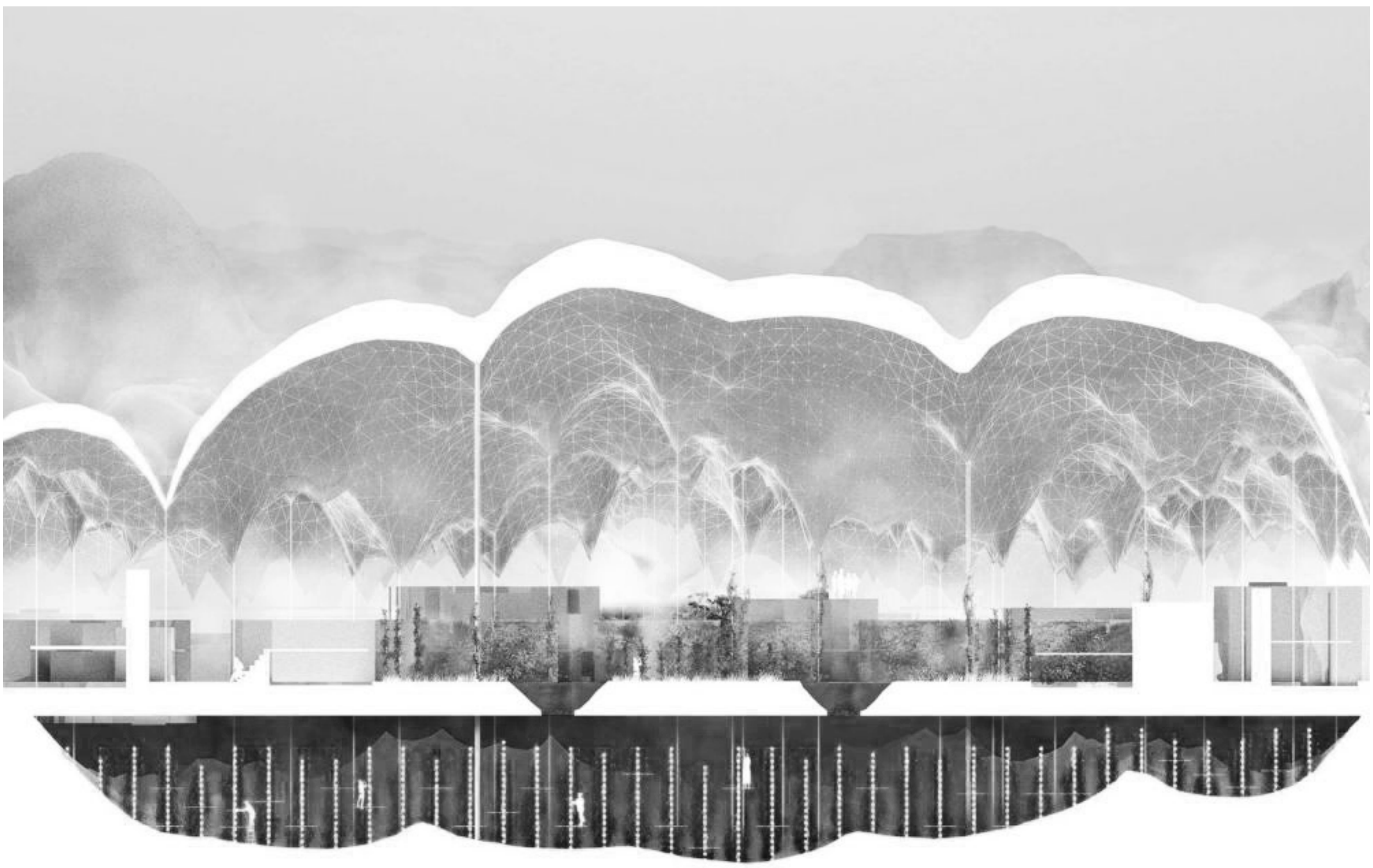
Water is the essential resource for life, as we know it, to exist, and it will be a crucial part of the ecosystem for a future human settlement on Mars. It is present on Mars in large quantities, but not in the form it used to be on Earth. There is a negligibly small portion of liquid water, at least as it is known for now, in the form of brines and salty solutions. Mostly it is preserved like water ice under the regolith layer or covered by CO2 ice, which holds it from subliming into the atmosphere. It would not be easy to extract, but it will have numerous applications in agriculture, production, construction, etc.

Ice Sky concept by Saga Space Architect[35]s proposes a unique implementation of the water ice existing on the surface of Mars as a protective shell on top of a town-like settlement. It is not the first idea to use ice as a translucent shielding against radiation in the Martian habitat. For example, Cloud architects were using the same vision for their Ice House[36], but it is one of not many architectural articulations of the idea.





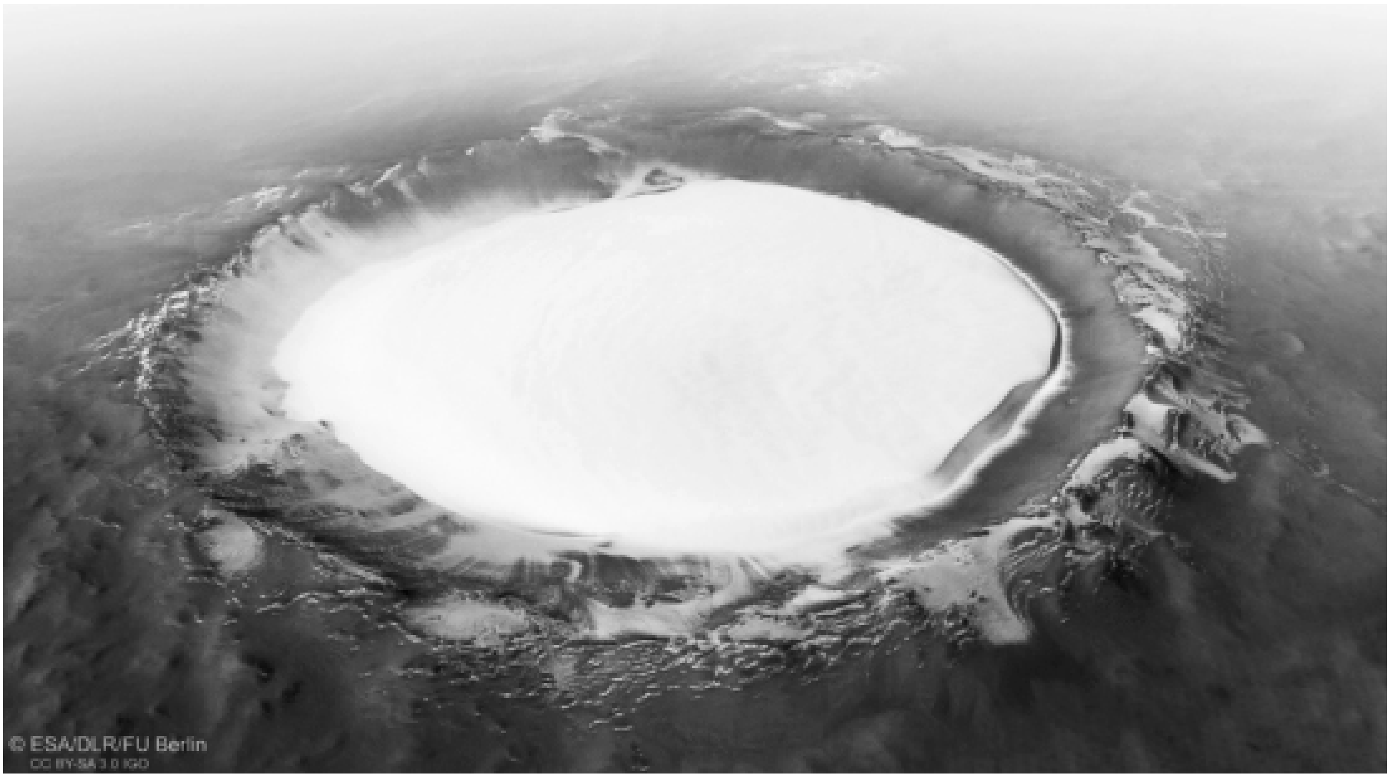
35 "Ice Sky", SAGA Space Architects, Retrieved on 21.02.2022 at: saga.dk/projects/ice-sky
36 "Mars Ice Home", CloudsAO, 2016, Retrieved on 25.12.2021 at: cloudsao.com/MARS-ICE-HOME

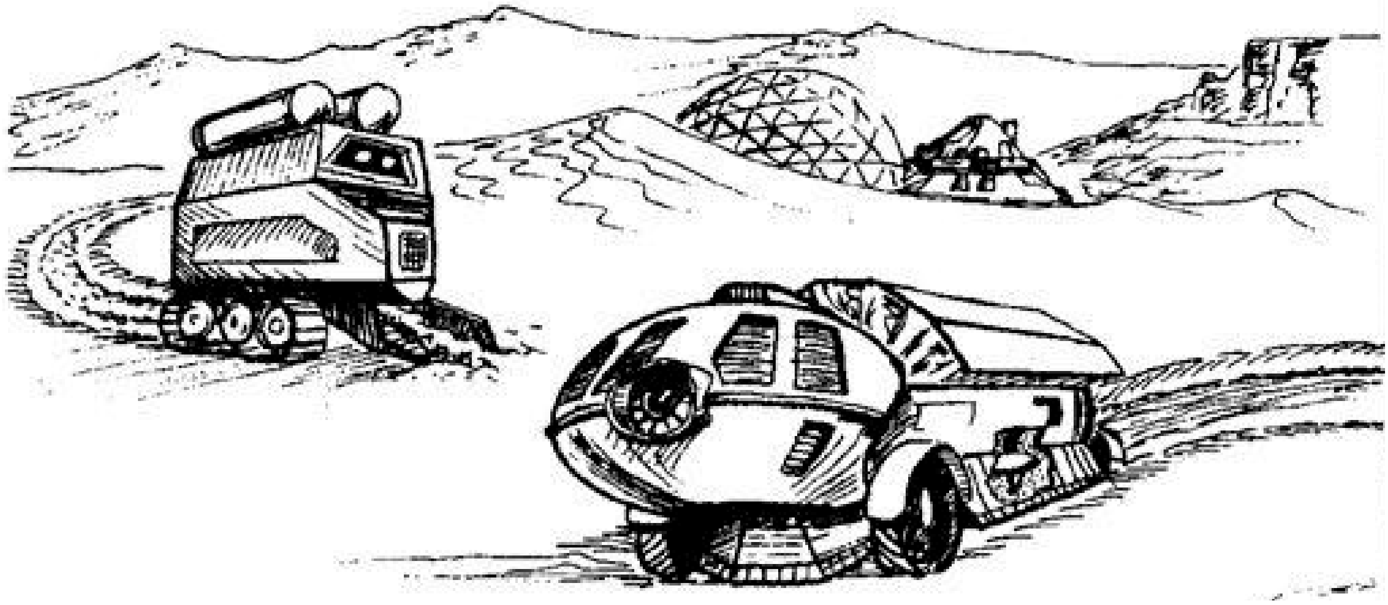


Robert Zubrin expressed a similar idea in one of his articles, "Sublake settlement for Mars,[37]" he proposed to use a Korolev ice-filled impact crater for a city under water. For this reason, it is possible to melt the ice inside a crater using a nuclear reactor and create an under-ice, underwater settlement that will be inside a fabric cupola or an air pocket of melted ice.

Because ice has a 92 % density of liquid water, melting an ice column of 50m high will result in a 42 m tall column of water and 8 m of the void. Exactly this void can be pressurized and used for a settlement, but for each cubic meter of inhabitable space, about five cubic meters of water will be produced from melted ice. And this amount of water can be used for the advantage of the inhabitants resulting in an aquatic type of agriculture and settlement development.

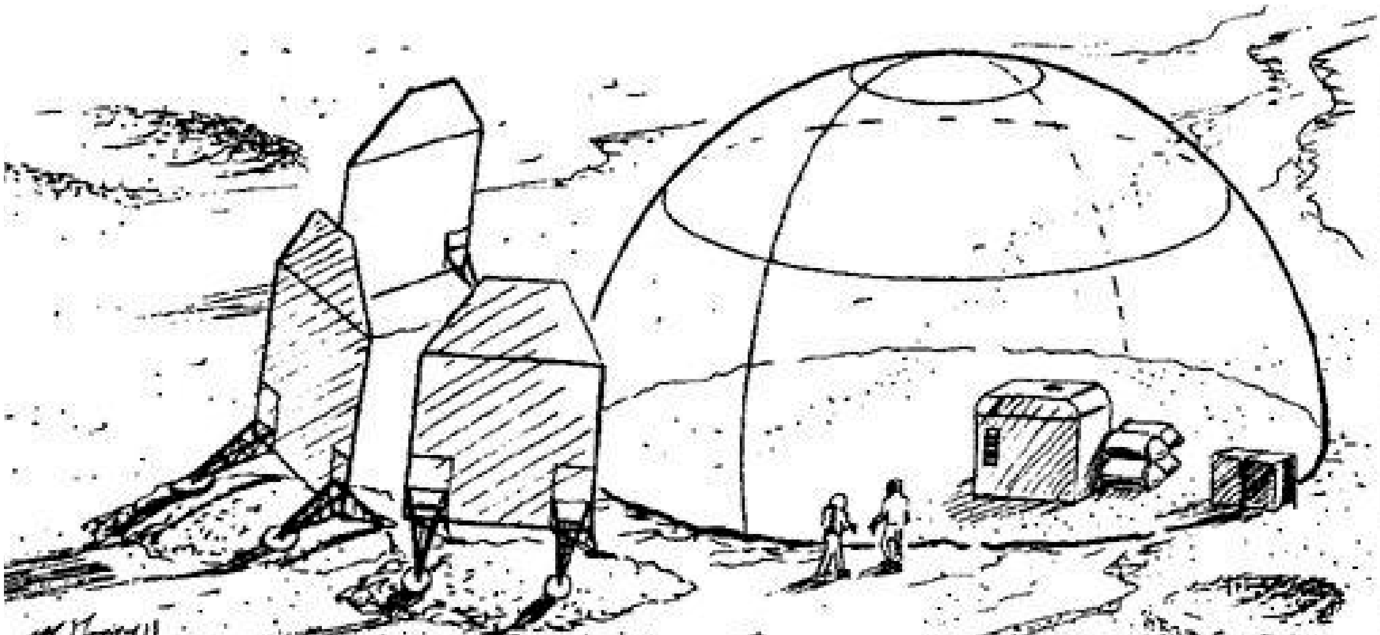
37 P. Gilster, R. Zubrin, "Sublake settlement for Mars", 2020, Retrieved on 25.12.2021 at: www.centauri-dreams.org/2020/05/29/sublake-settlements-for-mars/





Delivering water or hydrogen from Earth to Mars has a tremendous cost for each kg of delivery. Therefore it is crucial to find ways how water can be found and extracted from the surface of Mars. In his book, "Case for Mars," Robert Zubrin[38] explained some techniques for how it would be possible to mine water ice or extract it from the soil. Because of the complexity of delivering anything on Mars, it also needs to be lightweight and mobile solutions, but the most important this book shows are that it is possible to do.

38 R. Zubrin, R. Wagner, "Case of Mars", 1997



CASE STUDY

RESOURCE UTILIZATION

Local resources need to be used as much as possible to lower the cost of constructing the Mars or Moon habitats. And it implies not only construction techniques and materials but also every part of future researcher's and colonist's life. If it is possible to construct, grow and produce every item needed locally, the only weight that will have a cost will be people and resources to sustain their transfer. In this case, it will be possible to think about humans in space as explorers and researchers and as colonists, makers, and builders.

Starting in the 70s, following the successful landing on the Moon by Apollo 11 astronauts, several ideas were developed about the human habitat on the Moon. One of which was proposed by Nader Khalili[39], an author of the super adobe technique, which now is one of the most spread construction techniques in developing regions, where no proper supply chain and sustainability is the main priority. It implicates the use of the local soil as the primary material and uses the sandbags technique widely used in military purposes.

In his idea for a Lunar base, he uses the same technique, but, in this case, sandbags need to be filled with the Lunar regolith. The forms of the habitats of the Lunar base are similar to the houses built with the superadobe technique. Several prototypes were made to show the implication of the method. With NASA, Nader Khalili participated in research about materials and habitat possibilities on the Moon.

For example, later, Inflatable Lunar Habitat is also using sandbagging the habitat with Lunar soil to protect it from direct radiation on the surface.

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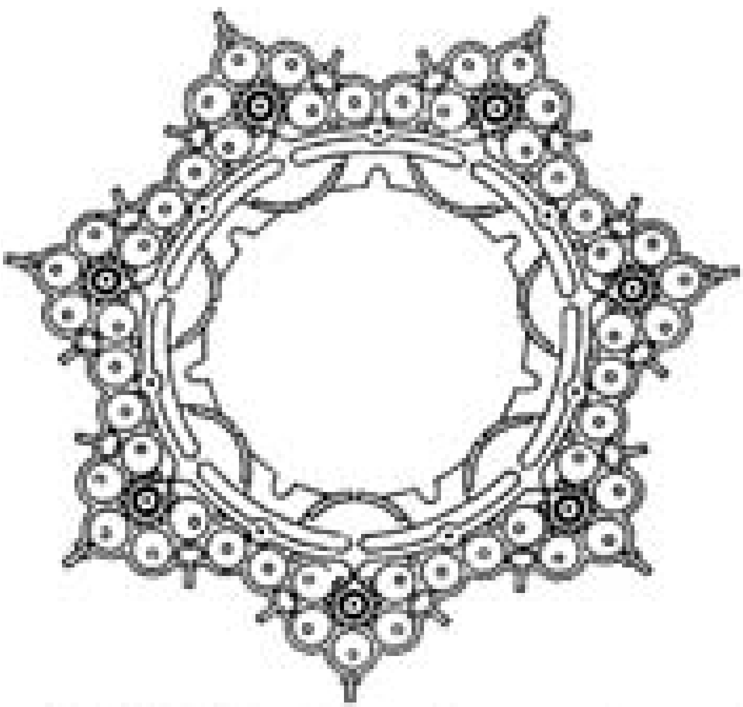
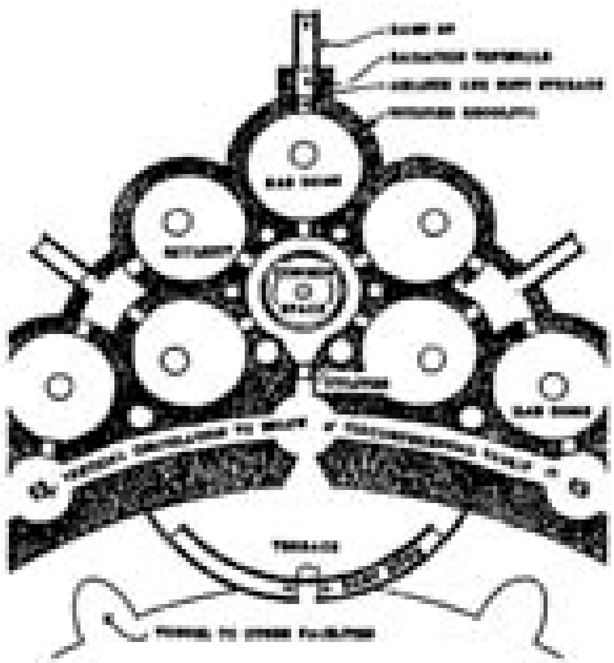
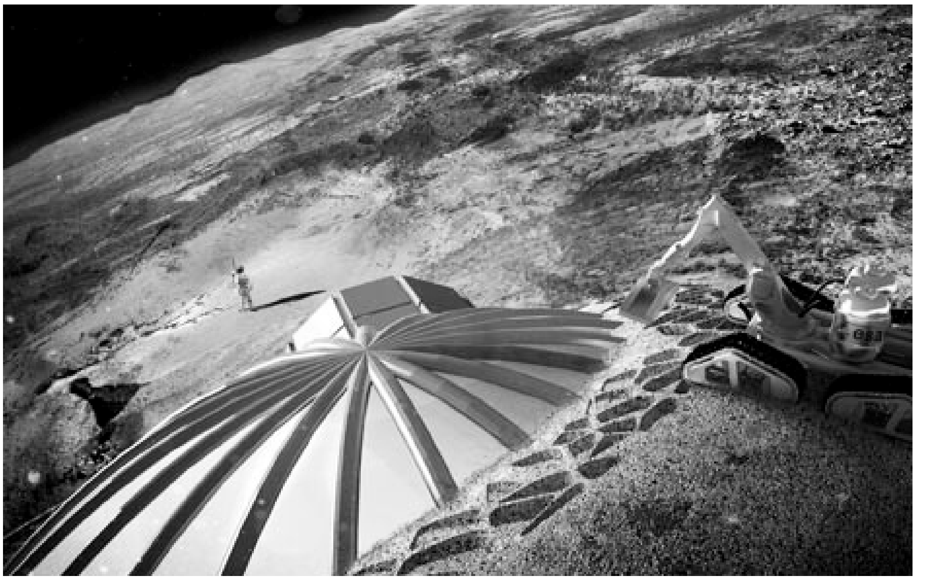
39 "Sandbag Shelter Prototypes", Cal-Earth Institude, 1992

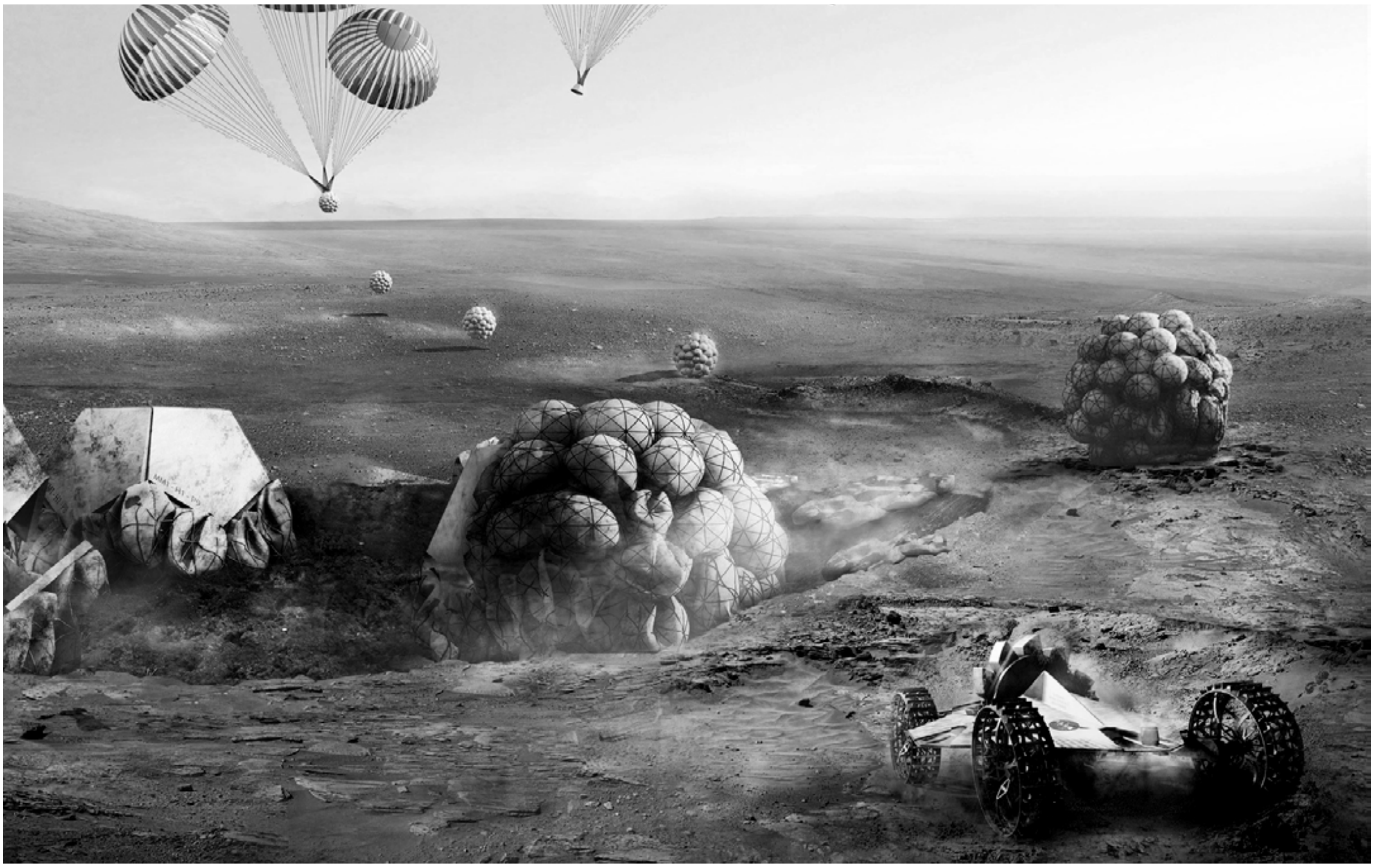




Works of the Foster+Partners on the Lunar[40] and Martian[41] habitats are good examples of the development of the principles that lead to Nader Khalili's works, but with the implementation of new technologies like 3d printing and the use of a swarm of robots to construct.

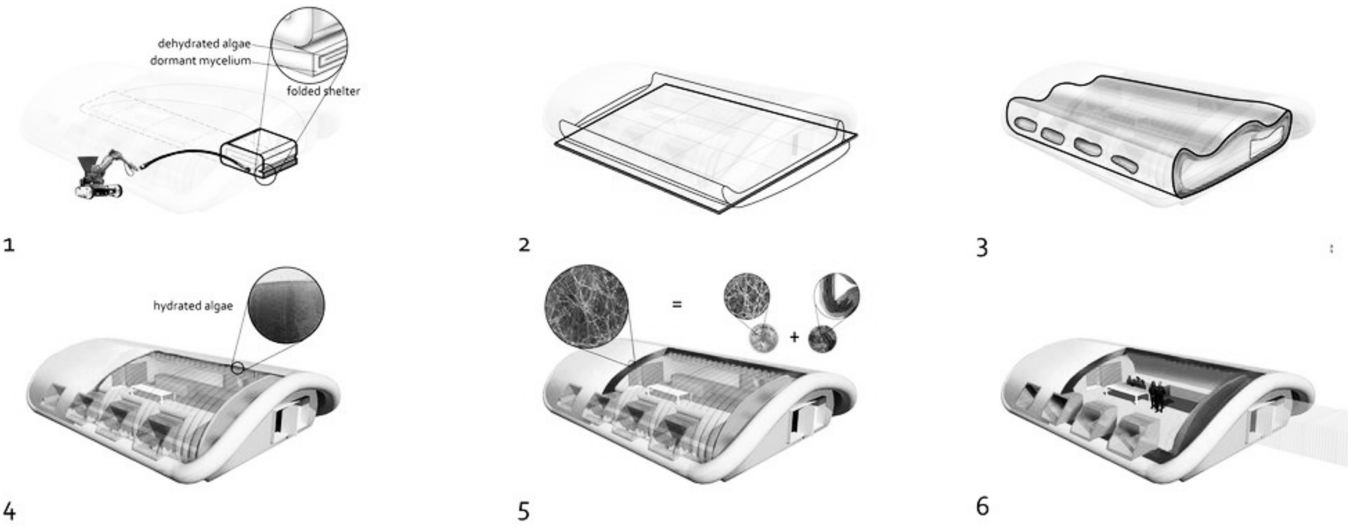


40 "Lunar Habitation", Foster+Partners, 2012, Retrieved on 12.11.2021 at: www.fosterandpartners.com/projects/lunar-habitation/
41 "Mars Habitat", Foster+Partners, 2015, Retrieved on 12.11.2021 www.fosterandpartners.com/projects/mars-habitat/



The Lunar habitat by Foster+Partners was one of the first implementations of the swarm robot construction technique. Later, in the Martian habitat, this idea was developed further, advancing the concept in general and each of the robots separately. Such elements as digger get a new digging feature that was better adjusted to the lower gravity, and printing machine using not a 3d printing tool but a laser or microwave emitter that was melting the regolith instead.

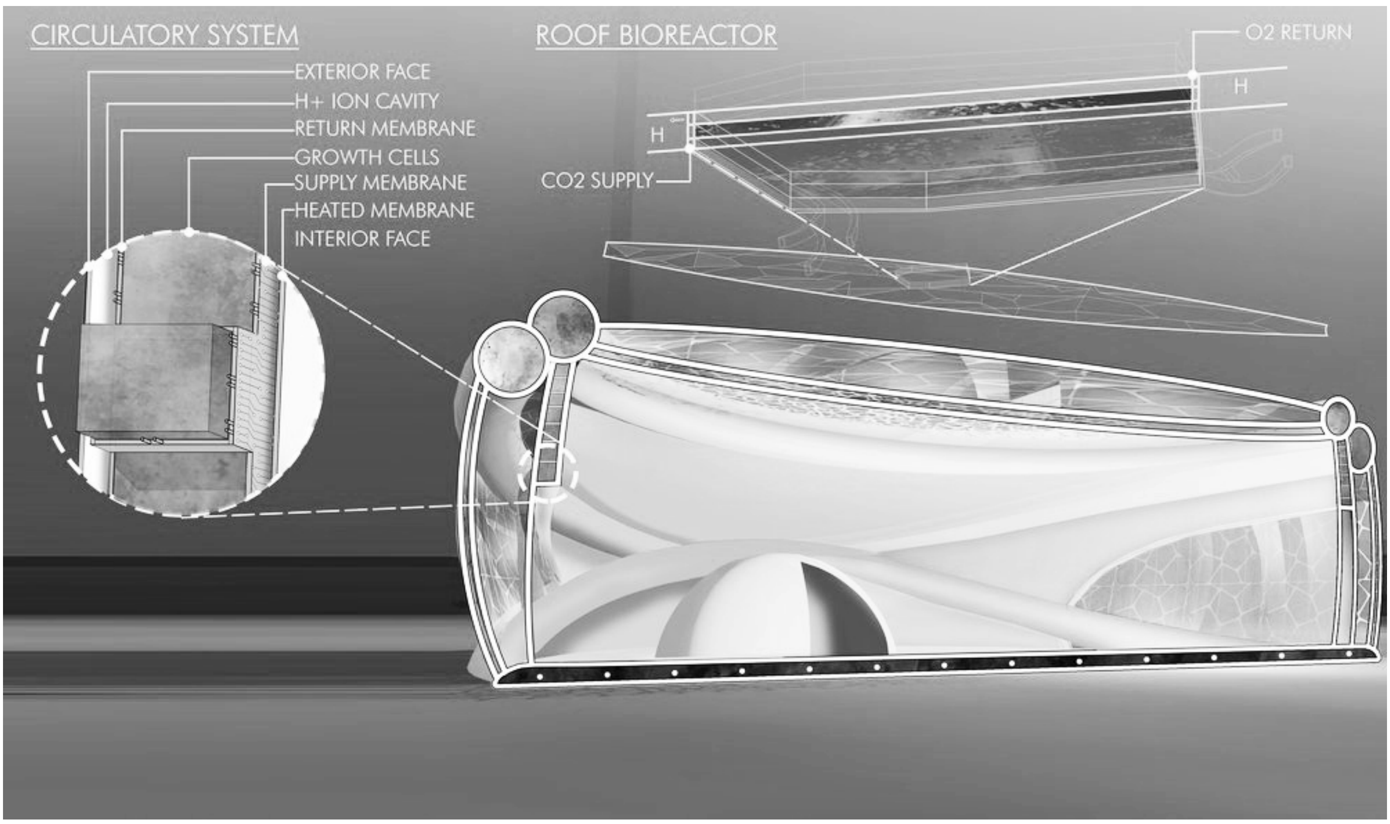
A different view was shown by the Martian habitat developed by Hassell studio. Implementing bamboo as a material for furniture and floor decking in the project represents a vision that construction materials can be grown on Mars instead of mining them. Of course, it is hard to predict how bamboo would thrive in an environment with lower gravity, as for some plants, gravity defines their direction of growth. But this idea expresses a different view on possible production and construction on Mars.



Solution proposed by RedHouse Studio use water seeded with algae as the outer layer, in this way using it as a part of the radiation shielding layer, it also use it to inflate the habitat in the first stage of its construction.

In order to protect algae it also is having an insulation layer and electric heating system for it.

Usage of algae as a part of the life support system in the Martian habitat allows to create an organic solution that will simultaneously clean a water and produce O2 from extensive CO2 resources of Martian atmosphere. Algae needs water to exist, so the container with water, where algae reproduce can be used also for the radiation shielding.



CASE STUDY

LANDSCAPE APPLICATION

The surface of Mars is exposed to extreme conditions: radiation, thin atmosphere, high-temperature differentiations, but it still has ‘safe heavens,’ if it is possible to call that, zones or areas that are slightly safer or that can propose a cover from extreme environment. Mars has numerous such landscape features. It could be lava tubes, caves, or crater hills that would partially or cover possible inhabitants from radiation, meteorites, etc. And these landscape features were extensively studied for a potential human habitat. Only that no one could enter these caves, lava tubes, or test load-bearing characteristics of an indigenous rock makes those ideas slightly vague and blurry.

Nuwa City, developed by Abiboo[42], is taking advantage of the steep hills to make a habitat for the city. It is already underground, therefore shielded from radiation, but a Martian cliff that the project utilizes protects from underground radiation and gives numerous points where the city can interact with the outer environment. It is vital for collecting natural light, which would be necessary for agriculture, urban green, and inner inhabitants' wellbeing.

42 Anglada-Escudé, Guillem & Sureda, Miquel & Detrell, Gisela & Munoz, Alfredo & Pearce, Owen & Apostol, Engeland & Rodriguez, Sebastian & Florido, Veronica & Casanova, Ignasi & Cullen, David & Banchs-Piqué, Miquel & Hartlieb, Philipp & Ribas, Laia & Torre, David & Miralda-Escudé, Jordi & Gómez-Pastrana, Rafael & Soler, Lluís & Betriu, Paula & Atalay, Uygar & Beard, Rory. (2021). "The Nüwa Concept. A development model for a self-sustainable city on Mars"

CASE STUDY

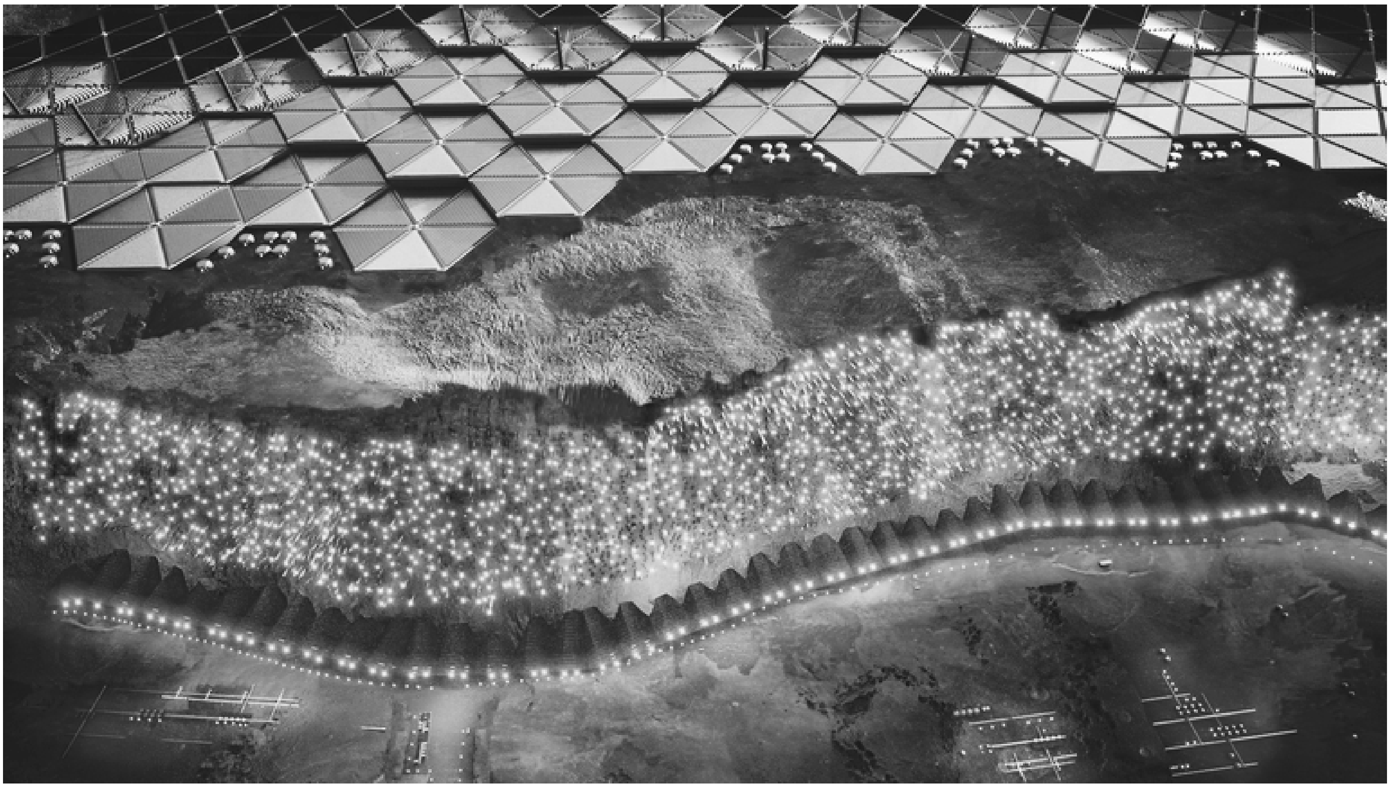
ENERGY PRODUCTION

With water extraction, life support systems, and agriculture, energy production is a core function that will help future explorers, colonists, and researchers sustain future Mars settlements. Almost every concept or idea of the Martian habitat tries to answer this topic, mainly utilizing the solar panels, like a Nuwa city concept by Abiboo[43] studio with a large solar panels array. But there are also different ideas and concepts of geothermal, wind, and nuclear power. Each has its pros and cons. Therefore they will need to be well balanced for an implication on Mars.

Wind and solar thermal power are more easily adjustable for a low-tech approach, but they are limited in effectiveness due to the planetary characteristics of Mars. While photovoltaic panels can also be produced from the materials available on Mars, it is a more complicated process. Like all solar energy plants, it has no energy generation at night. Geothermal has its limit in use also. Later research shows a small amount of liquid water (and only under the South pole), and all of it is presented by salt solutions.

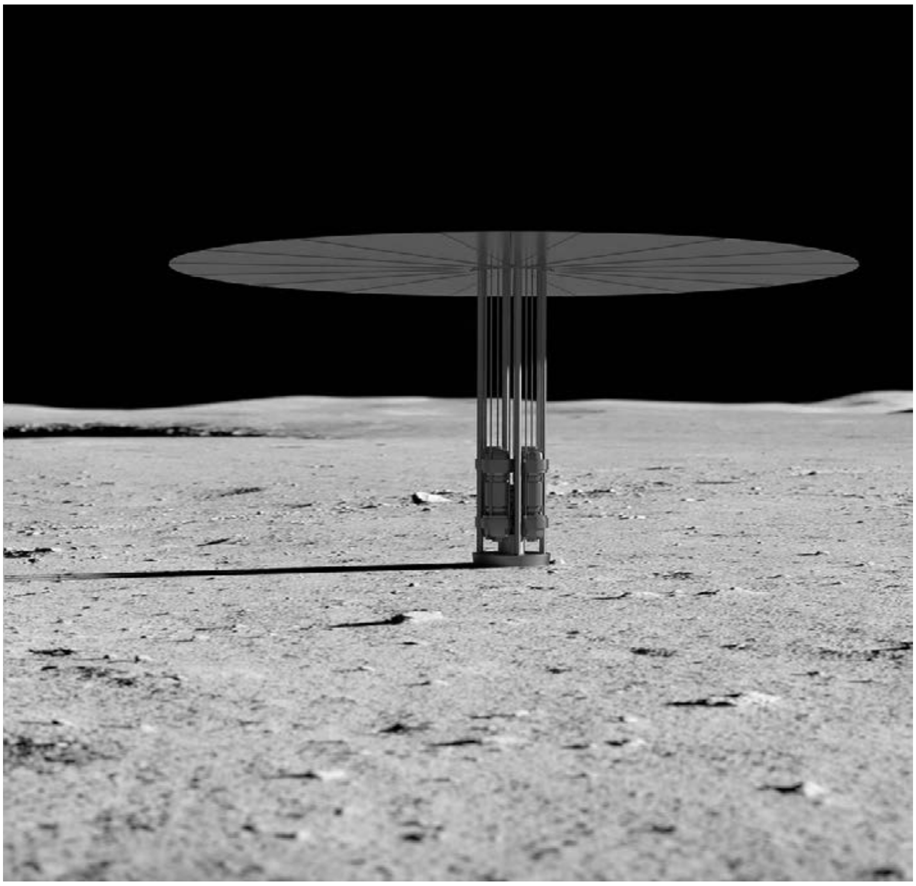
In contrast, the thermally heated water due to geothermal activity is available under the cryosphere (frozen Martian crust) but will need a complicated process. At the same time, nuclear energy proposes a reliable and stable energy source that works day and night. However, the complexity of the production makes it impossible to be reproduced without a developed infrastructure and supply chain. Therefore for the first stages of the Martian settlement development, it will need to be delivered from Earth.

43 Anglada-Escudé, Guillem & Sureda, Miquel & Detrell, Gisela & Munoz, Alfredo & Pearce, Owen & Apostol, Engeland & Rodriguez, Sebastian & Florido, Veronica & Casanova, Ignasi & Cullen, David & Banchs-Piqué, Miquel & Hartlieb, Philipp & Ribas, Laia & Torre, David & Miralda-Escudé, Jordi & Gómez-Pastrana, Rafael & Soler, Lluís & Betriu, Paula & Atalay, Uygar & Beard, Rory. (2021). "The Nüwa Concept. A development model for a self-sustainable city on Mars"



And for nuclear fission reactor to be transferred from the Earth to Mars, it is needed to be mobile and lightweight enough to be packed inside the fairings of the chosen delivery transport. And NASA had a long time working on the nuclear reactor concept for a possible Moon or Martian habitat called "Kilopower."[44] Finally, in 2017 from November through March Kilopower Reactor Using Stirling Technology (KRUSTY) experiment was conducted that showed the reliability and readiness of the system. Such a reactor can produce up to 10 kW of electric power, and 4 of such reactors will be enough to power future human outposts on the Moon.

44 L. Hall, "Kilopower", 2021, Retrieved on 05.04.2022 at: www.nasa.gov/directorates/spacetech/kilopower



	Jules Vern's "From Earth to the Moon"	Abiboo Nuwa City	NASA Inflat-able Habitation for the Lunar Base (1989)	R. Zubrin Mars Direct	International Space Station
Distance	✓	✗	✓	✓	✓
Gravity	✗	✗	✓	✗	✓
Radiation	✗	✓	✓	✓	✓
Atmosphere and tempera-ture	✗	✓	✓	✓	✓
Meteorites	✗	✓	✓	✗	✓
LSS	✗	✓	✓	✓	✓
Human factor	✗	✓	✗	✗	✓
Mobility	✗	✓	✗	✓	✗
Water dilemma	✗	✓	✗	✓	✗
Resource utili-zation	✗	✓	✓	✓	✗
Energy produc-tion	✗	✓	✓	✓	✓
Landscape application	✗	✓	✗	✗	✗

	Foster+Partners Mars habitat	BIG Mars Science City	AI Space Factory MARSHA	Hassell Mars Habitat	SOM Moon Village
Distance	✓	✗	✗	✓	✓
Gravity	✓	✗	✗	✓	✓
Radiation	✓	✓	✓	✓	✓
Atmosphere and temperature	✓	✓	✓	✓	✓
Meteorites	✓	✗	✓	✓	✓
LSS	✓	✓	✓	✓	✓
Human factor	✗	✓	✓	✓	✓
Mobility	✗	✓	✓	✓	✓
Water dilemma	✗	✗	✗	✗	✗
Resource utilization	✓	✓	✓	✓	✓
Energy production	✗	✗	✗	✓	✓
Landscape application	✗	✗	✗	✗	✓

SPECIALIST
INTERVIEWS

The vital part of the research effort is interviews with specialists in space architecture. With the general understanding of the topic conducted through the literature review and project analysis, the interview gives an additional depth in knowledge of nuances and details. Moreover, it opens a view of the thoughts and ideas of the people behind the projects and a glimpse of their focus and way of thinking.

Valentina Sumini

MIT researcher, currently working at PoliMi. Researcher and a Space Architect at MIT Media Lab in Responsive Environments and Space Exploration Initiative.
Was working together with SOM and ESA on the Moon Village.

Dmytro Khyzhniak.

I am a student of Turin Polytechnic. And I'm currently studying architecture and working on my thesis on the topic of human settlement on Mars.

I would like to ask you, what are the main differences between architecture on Earth, and building and constructing something on Mars or Moon?

Valentina Sumini.

There are several differences, the first one will be, that when you design for another planetary body, you have to start from the mission itself. So you have to be very explicit in terms of how many assets you like to bring over there, for how long people are staying there, etc.

And once you define it, you must design the habitat, all the volumes, and then identify the technologies that will enable humans to survive in this environment. Based on that, you will have to choose which type of class of habitat we would like to use: pre-integrated and then deployed and pressurizing CO2 or built using an in-situ material, resource utilization (ISRU).

Another difference, besides Mission Operation costs, will be environmental challenges, which we can find on other planetary bodies: the absence of an atmosphere, or a very thin atmosphere, as in the case of Mars, the reduced gravity condition, that changes the perception of space and change dynamics of the construction itself, our movement changes too; extreme temperature variation, isolation, the risk of radiation, galactic cosmic rays, and micrometeoroid impact and so on.

As soon as we go farther than low earth orbit, then we have to conceive a long-duration mission, especially in the case of Mars, when the entire mission can last up to two, or three years. It means that you have to deal with the psychological aspect of isolation in a confined and extreme environment. It is where architecture and design come in and try to find the best way possible to help humans to recognize what we find on Earth and what they can consider home.

I find very inspiring new processes that are computationally based, that are taking into account different aspects, disciplines, and merging into unique processes. Not just aesthetically guided but a collection of different aspects: psychology, engineering, material science, aerospace engineering and competitional design and the human factor design principles, and so on, to lead to an output that can be aesthetically pleasing, but mainly is also extremely coherent.

D. K.

Thank you for your answer. You mentioned that the design process is not only about aesthetics, it is also about the process, and, of course, architects are not solely taking part in it. But for me, as a student of architecture, it is interesting, what is the role of architects in this process? And what is the importance of architecture?

V. S.

A space architect has a role of a coordinator: meaning that this is the person who helps structure the process, organize life in the extreme environment, and coordinate the different experts in different fields to achieve a sustainable infrastructure.

My way would be to use technology and computation to coordinate all these aspects. And partially, my research is devoted to designing new computational design tools that can help an architect incorporate those aspects into the design process.

But the way we can enable autonomous construction is also a very challenging and interesting aspect. Because of how the role of architects will be evolving over the years, going towards the direction of a sustainable human presence, the sustainability of having robots working with the material they can find in place. Probably, also robots will need to have a sort of autonomy during the design and construction process, while designers will have to make some design choices accordingly to the landscape. We have the morphology mapping of the Shackleton crater, which is a perfect location that has been identified by NASA and other space agencies to build on, but we do not have detailed information - it will come from robots that will be there. And they will have to be able to optimize a structural wall when they will be building. In this case, the architect will have the role to coordinate, understanding, to oversee what they're doing.

And this is why I think that the role of architects will change over time, especially the space architects since we have to deal with this autonomous construction issue. So won't be the architect anymore to design a structure, but will be a designer code embedded in the robots that will build the structure.

Another important aspect of the architecture will be how to design interiors to avoid conflict and the negative effects of isolation and confinement. Because most the missions are challenged by these effects and can lead to depression, destructive behavior, and attitudes, the mission could fail if astronauts, for example, start fighting and something unpredictable can happen.

So how an architect can through design prevent a negative behavior or attitude in a long-duration mission. Such design will include different adaptive and responsive interfaces that could connect with the user and change shape and functionality to help astronauts sustain this long-duration mission. So we have to conceive the habitat as a machine, which is no anymore a static environment like medieval buildings, that we have here in Italy, but would be an interactive environment, that will communicate with us. As architects, we've been trying to understand which type of communication we would like to have in the habitat and which interfaces be helpful to have this interconnectivity and this responsiveness.

D. K.

This topic is quite interesting. What do you mean in terms of interaction, do you mean interacting with a sense of touch, visually, or do you mean interacting with the habitat like with a robot?

V. S.

So when we think about responsiveness in a design we think of different senses, but it is important to see a habitat as a multi-sensory experience that can be customized accordingly to one's own needs. With the use of artificial intelligence, machine learning understands the user behavior and tries to react. There are several projects that we are doing at the MIT media lab and in the responsive environments research group, where the entire environment changes color, shape, and projections, according to the level of focus that some cameras can perceive from a user or people passing by.

It will open up an entire field of human-computer interaction. This field was usually devoted to a machine intended as robots, but now we are going to a scope where the robot can become a habitat itself. That is interesting - how we can have some interaction that creates happiness within the habitat.

D. K.

In-situ resource utilization was mentioned already, regarding, how Martian conditions, resources, and terrain features can be used in the design of the habitat? And how the vernacular architecture on an extraterrestrial body can look?

V. S.

One can think of different approaches. The first one would be to use the environment that you can find there to optimize your habitat configuration, for example, take advantage of lava tubes.

This tube allows you to inflate a pressurized habitat inside and have protection from cosmic radiation and meteoroid, micrometeoroids, it is a natural protection that is extremely useful.

Otherwise, the terrain immersion regolith with some additives behaving like high-performance concrete can be used for 3d printing to find a way to generate roads and bricks for a settlement.

Or one can use water like ice, it will sublimate on the Mars surface, but water ice is present underground, so one can extract it and use it. Water is a perfect element to protect against cosmic radiation and solar flares, it can be used as filling material.

And one can think of other stratigraphy using glass and polyethylene which are materials that you can generate started from the Martian regolith. So you can think of different types of stratigraphy based on what you can find.

But of course, to process those materials you will need energy, and you cannot just rely on solar energy to do this. So, part of the master plan that was used for the Moon Village will have to incorporate nuclear reactor plants to generate enough energy to process materials. And this will be one of the major challenges as well.

D. K.

In our case here, on Earth, natural lighting is essential for human wellbeing: for mental health or hygiene, and it is interesting how it can apply to the Martian or Moon environment? How do today's experts try to answer the dilemma when solar flares and cosmic radiation are deadly outside of the Earth's atmosphere, but the sunlight is so needed.

V. S.

If you control the material that you're going to use, you can have a perception of the outer environment outside your habitat. If you use an opaque envelope system together with regolith shielding, you won't be able to see outside, and this might be a major psychological challenge.

Some researchers focus on projections, so you can project what you can see outside on the inside, even if the wall is opaque, and you can let yourself sort of translucency.

International Space Station's cupola module is protected from galactic cosmic rays by the Van Allen belt because it is in the lower Earth orbit. So this is why the cupola is so effective in transparency. But if you go further, then you will need 1.5 meters of water, and with such width, you will not have the same transparency anymore, you can perceive the color outside, see the blue sunset on Mars, understand what the conditions are outside, but would not be able properly to see it.

Some researchers are considering windows, like the cupola that has chatters to prevent any impact. Then you can open it up at some point and close it again to be an active system.

But we have to get used to different conditions, especially if we want to live inside a lava tube where we don't have any perception of the outer environment.

D. K.

You took part in the Moon Village project together with European Space Agency, and SOM studio. I would like, to ask you: What was your role? And what were the main goals of this project? What interesting obstacles that you faced and what do you have to work on?

V. S.

This project was a multi-year effort, the first idea to participate in this project came up in 2017. ESA commissioned SOM to develop this project, so SOM searched for academic partners to work on it and eventually contacted me and my advisor. We started a series of conversations about environmental aspects, and technological solutions, we also discussed the concepts of an ideal city because we had to design one in a pristine environment of the Moon, where you don't have any architectural references.

We went with the concept to follow the rim of the craters, to build sort of a linear city that follows the morphology of the landscape, started to generate different sections there for different types of urbanization: the habitats, launching and landing pads, and roads to connect all of these.

The most innovative part came when we had to brainstorm the habitat concept. So far we have the International Space Station which is mainly composed of rigid modules. And there is Bigelow Aerospace which deployed the entirely inflatable BEAM Module, which is based on previous studies from the trans-hab. Bigelow Aerospace kept evolving on this concept with the main core and inflatable outside.

So we thought, what if we could combine the two? And we came out with the concept of having a trilobite structure, where you have a rigid element that can fit within the payload fairing system of the rocket, and an inflatable structure that going to be pressurized and deployed once the habitat will be placed on the site. Floors and other systems could be folded during the launch and then unfolded afterward to open up floor level inside these inflatable elements.

But this solution is bringing more complexity to construction and production, and you also need the outside ring to protect against cosmic radiation or micrometeoroid impact. You don't have any outside shielding on the Moon's surface. Then technological aspects were covered by ESA.

And now the project is finished, in the sense that we gave it to ESA and now they are continuing to work on some specific technical aspects like additive manufacturing and autonomous construction systems.

D. K.

What can be the reason for us as humans to establish a human presence on Mars, or Moon village on the Moon, because of its tremendous cost to do.

V. S.

It challenges humanity to change the way we design and build structures, to prove that we can generate an ecosystem on other planetary bodies and live there. I think that idea is not just to have "a planet B", but to foster our awareness and ability to live inside this solar system and probably one day even beyond. Knowing that is possible, that we do have the technology that will enable this and improve, that can be a possibility for future generations. Because of course, we belong to Earth, and we didn't have to go and look for other planet B but having the possibility to choose where you're going to live, I think is freedom.

And in terms of design, it will open up a new way of creativity. You have to design in these pristine environments where nothing is there yet. You can think of new vernacular space architecture, it can be built easily and sustainably using new methods, and new construction techniques. Prove that it's possible to automate an entire process, that robots not only can build but also design, they can be the new designers for our future homes. We will probably see architecture that we are not used to, something that a human being won't be able to design or build.

For humanity, of course, it's a challenge, but it's also an opportunity to be free and explore other worlds besides Earth. The thing is having the possibility to do it is gives you a sense, of freedom that is unique.

And of course, all things that are learned from doing a design in this harsh environment and understanding the state-of-the-art can be brought back to Earth.

David Cullen

Professor of Astrobiology and Space Biotechnology, School of Aerospace, Transport and Manufacturing (SATM), Cranfield University. Was an adviser to the Hassell Mars Habitat and ABIBOO Nuwa City.

Dmytro Khyzhniak.

You have participated as an advisor of ABIBOO studio on Nuwa Martian concept city, it is also possible to assume that you helped to develop the Martian habitat together with Hussell studio?

Can you please describe some interesting obstacles you faced when you were working on those projects, and what was your role in the process?

David Cullen.

I suppose one of the points is that when coming from a science background, is getting used to the kind of thought and work processes that architects employ, getting comfortable with a different type of workflow, of what people consider important, it's just a multidisciplinary aspect.

I guess another point, and this is my opinion, and I've only reinforced it by working with space architects. And I think that both Abiboo and Hassell are doing the right thing. And some other space architects perhaps are not doing that. And that is not thinking about their design solutions in a big enough context. And what I mean by that is thinking starting from the surface of the Earth, with nothing on Mars, or nothing on the Moon, something realistic in terms of infrastructure, and supply chains, so that any produced designs could be implemented. In other words, the materials can be supplied sensitively, to the point of use of the infrastructure to handle those materials, process them, construct them, validate their construction, and maintain their use, to power them to provide all the services you need for those habitats.

So that's another point and then offers combined to the question, what is my role? Hopefully, I don't design the buildings. But what I do I am asking: "Yeah, but think about this, what are you going to use to move that, from this position to that position? How are you going to provide power to it? How much power do you need? What's the size of the power system?" Trying to add that level of reality into design workflows so that what comes out, can stand quite detailed critique.

D. K.

It is reasonable. When I did my research, it was the first thing that felt to my eye when projects were not sensitive to today's state-of-art of technology and the possibility of ours.

D. C.

When you say about the state-of-the-art of the moment, that doesn't make sense. What is state-of-the-art now is relevant if you're building a habitat now, but if you are constructing a habitat in 10, 20, or 30 years, what you should not be doing, is making detailed design decisions about what is the state of the art now.

What you should be doing is trying to predict what the the-state-of-the-art will be at a relevant timescale that will then be implemented in those structures, if not, you can make all kinds of design decisions, which appear nonsensical because there'll be outdated. So what you should be doing is to ask "what if?" questions, for which you can learn more about a concept, which you can then feed forward into future design phases.

One of my arguments is that many good design solutions we think of are often inadvertently directed down a certain route because of legacy supply chains. So one of the benefits of trying to design a Lunar or Mars habitat that will be implemented in 20, 30, or 40 years, is the immediate benefit that they may have on society, if doing so correctly, we can come up with innovative out of the box, kind of blue skies thinking that actually may turn out to be very sensible solutions to us back on Earth now to deal with different social problems.

D. K.

If we can look even further, at colonization, if we can imagine it will happen, what resources, discoveries, and other advantages Mars can propose to its pioneers?

D. C.

This is something we struggled with when we were looking at the Nuwa, Martian city competition entry study we did with ABIBOO. Which is, why do you need a million people on Mars? What would they do?

For the immediate goals - not a million, but 100 or even a 1000s? Then we can use analogs of what we've got on Earth. For the idea of exploiting specific local science that adds to the science argument, there is the geopolitics argument - the national prestige, there is also technological development, and there's the emerging thing about high-value tourism experiences. There is also the whole aspect of inspiration, and that so that gets you to a few hundred people.

It is starting to get almost a transient population. People are always there, but the population is transient. It is an extreme Antarctic station type thing: we have a bit of tourism, a bit of inspiration, science, technology development, geopolitics, and sustains a few hundred, or a couple of thousand people. But it's not a truly separate independent society. But when you jump to that, which is enough to be an independent society, like tenths of thousands, hundreds of thousands or millions people. Then yeah, but quite a question: What is that society doing on Mars? What are economics look like?

Let's assume that in 20 years, we have routine human missions to Mars, possibly even with this idea of having some permanently human presence. But it's still very much the equivalent of an Antarctic base scenario that requires a few tenths hundreds of people at most. And the assumption is that it relies quite substantially on a supply chain that has a connection to Earth. These are some of the arguments we started developing, trying to document them in the Nuwa report. If you then start going to a million people, there's no way we can envisage that you could rely upon Earth for anything other than a high value, low mass supply chain.

Remember that the big cost of sending stuff from Earth to Mars is just the energetics of accelerating mass out of the Earth's gravity well and, to some extent, getting it safely on the surface of Mars. So that's why we always think about those supply chains being to the point when it becomes economically unfeasible to keep transporting mass from Earth to Mars. And with a million people, there's no way that the vast majority of the mass needed to support those humans on Mars would come from Earth, it has to come from local sources. And therefore, that becomes an intriguing model, a worst-case scenario of saying what happens if we want to grow over 20 years, 30 years, a community from a few thousand to up to a million, where there is no existing local supply chain. And we've got to develop that with only a minimal mass input from Earth.

And I think that's quite an interesting question, what would that look like? Because obviously, that could be a model for going to how we need to always have a revolutionary approach on Earth, to supporting societies compared to this evolutionary approach, by evolutionary, I mean, inherently limited by the legacy we're building upon, as opposed to starting with a completely blank sheet of paper. So what intrigued me was not so much Mars, but the idea of trying to think about a scenario where you had to locally support a million people without building upon historic legacy supply chains.

And part of it comes down to why are people there? And what are they doing?

D. K.

Thank you. I would like to know also is it possible to think that Mars can sustain life? Does it have all resources needed?

D. C.

So the question is if you assume that Earth life needs a typical Earth atmosphere, then clearly you need domes. So then you've got the question of two things. One is about physical infrastructure, the domes, the infrastructure you need, you're not going to have that from Earth. Therefore, how can you use local resources to create those domes? That's one question. The other question is, how do you sustain life? Assuming you have a structure that you can pressurize, how do you keep regenerating the atmosphere?

And obviously, Mars has most of what you want. If you think about the elements we need: we need oxygen, which has a lot of it in the atmosphere, obviously, chemically in the form of carbon dioxide. Also, in the ground, the near subsurface, the PSP, lots of water, ice, and plenty more oxygen. So just with water, and carbon dioxide, you can chemically transform them into things like polymers; there's plenty of nitrogen in the atmosphere, not in a good chemical form, but it can be processed.

And a lot of those processes are easily done by Earth biology. And if you look at the Nuwa concept, the idea was there - we would harvest Earth microorganisms to do all of those functions: do photosynthesis, to do Nitrogen fixation. Therefore, there are plenty of local resources for life support, even for going to a population of a million.

Broadly, is there the kind of materials present on Mars that you could use to support life? And is there a vaguely a mechanism to try and get them into the right form? I think the answer is yes.

D. K.

I hope you have time for one more question. We know from past studies that Mars had conditions where life could emerge, also we know from last scientific research that there possibly can be an under-ice lake under the South pole, where the life possibly could be preserved.

D. C.

The latest interpretation of that is no more so ambiguous. So when that data was first released about two years ago, it was emphasized that this could easily be a liquid. Now, some people have started saying, well no, that perhaps is the less obvious solution to explain the radar reflection signals. So although it's still possible, it was deemphasized a little bit. But there is still an argument that Mars was present life a few billion years ago and the possibility that some of that could survive to the present day in certain niches in the subsurface.

D. K.

Yes, and what does that mean for humanity if we find life somewhere on Mars?

D. C.

The first question is, if we find Martian life, right? Is it Earth life? Because there are mechanisms in which any material on Mars, from a few billion years ago, could transfer microbes within meteorites, and protect them enough so they can seed the Earth? In other words, is it further examples of a single Genesis and single evolution of life, which is what we see on Earth? In that case, it doesn't tell us anything. It just confirms the theory that you can transfer material between Earth and Mars. And therefore, life emerged either on the Earth and transferred to Mars, or on Mars and transferred to Earth. It tells us nothing about the potential for life elsewhere in the universe.

So that's the first question, is it an example of the same single genesis of life as we have on Earth? Or does it appear to be completely independent? If it is? If we find a second data point saying, there is another example of life emerging, independent of the life that we see on Earth, then great, it's starting to kind of bias are data towards something that feels more realistic.

But again, bring it back down to reality. At the moment, you would never be allowed to have a million people on the surface of Mars, because there are agreements in place to try to preserve the Martian environment. A bit like Antarctica, that there are global political agreements, that you can't simply go to Antarctica and build towns, same with Mars. COSPAR has agreed that if you go to Mars, you should implement certain procedures to minimize the potential of Earth organisms, microbes, or spores being carried on the spacecraft and contaminating the Martian environment. It could make doing science on Mars much more difficult because you start looking around and you're finding this earth contamination, therefore it is difficult to ask us questions about the evolution of life on Mars. It is also an ethical one, if we take any Earth organism there, they could kill off any indigenous Mars life that might be there. At the moment, those agreements are such strict that you have to be phenomenally rigorous to clean your spacecraft and show that it's clean before you fly it, so there is no way you can easily have a human on Mars and meet those criteria.

So those criteria would have to be revised to allow a manned mission or human mission to Mars in the future. It would have been sorted out well before you get anywhere near the million people. But there are the ethical aspects of what is going to be the impact of having that society on Mars on the Martian environment? And what should we do about that, given that we know, on Earth, how bad it is got when we have not thought about the ethics of sustainable development?

Xavier De Kestelier

An architect at Hassell studio in London, chief of innovation department, former architect in Foster+Partners, was responsible of Lunar and Mars Habitat project there and most recent work at Hassell on Mars Habitat (for NASA 3d printing competition).

Dmytro Khyzhniak.

I am already familiar with the Hussell studio project of the Martian habitat and with Foster and Partners Martian and Lunar habitats, and it is fascinating how your team is implementing technologies that are only starting to appear and how the ideas are developing through those designs.

And I would like to know your view on the main difference between building on Mars and Earth?

Xavier de Kestelier.

Nothing. It is the same design methodology - you look at a site, you look at the site conditions, at the weather conditions, you look at the environment, and then you start from there. And then for the project on Earth, you do the same thing - you look at the environment and the climatic conditions, the only difference is that Mars's conditions are extreme. And that is more fun because it is the environment that usually you do not design for. But I do not believe there is a massive difference between the design for Earth and Mars.

D.K.

What is the importance of architectural presence in designing a space habitat?

X.K.

I think architects are fundamentally important in this process. Look at what would have happened without having a designer on board on Skylab, first product design had no windows in it. Engineers did not think it was necessary to have a window because it was just a weak spot in the structure. Imagine being a Skylab astronaut and not seeing Earth ever.

I think architects need to play a much more central role in designing human habitats in space, not just choosing a color. The architect is the one who gets the overall vision and brings all the specialists together. For that reason, architects have a central role in space development.

D.K.

Can we speculate what will Martian vernacular architecture look like in 100 years?

X.K.

You need to start thinking of what will be easy to do on Mars, material-wise. One of the things that I always thought of is a bit of a weird one. If you look at sci-fi, you can see that everything is made of plastics and metals. But it is hard to have an injection molding machine in space and deal with plastics. It will be easier to grow bamboo. So, rattan furniture could be a good virtue that would find a use. I think that habitat might be made of materials that you can perceive as very earthy, and not very spacey as you see them in sci-fi movies, it might be things that people grow, so maybe made of bamboo that grows fast. That could be vernacular.

D.K.

That was one of the solutions, your team has used in the Martian habitat.

X.K.

For the finishing series, bamboo was used for the flooring, and the chairs were plastic, but they were made from 3d printed recycled plastics from medical waste or packaging. Also, we had an idea about clothes that could have been made from the landing parachutes. You must think more in a circular economy, think about what will things look like if you were recycling, upcycling, and not relying on the Earth economy to do manufacturing. And we are used to having many things around us with a worldwide supply chain, we can get everything from anywhere. But what if you can only make things out of a few materials on Mars? What if you ever could manufacture out of four materials? What would your world look like?

We can look at an example of the log cabins built by the pioneers in America. And just by cutting logs in a certain way, they made these cabins without metal fixings or screws, they just stacked wood. There was a limited amount of material, a limited manufacturing technology, and you have a very particular vernacular.

D.K.

An interesting feature was shown in the Martian habitat of Hassell studio, using indirect natural light. Because farther Earth's magnetosphere and atmosphere usually sunlight is understood as deadly radiation. But at the same time on Earth, natural light is crucial in terms of hygienic and human wellbeing. How have you come up with the idea to have these openings?

X.K.

We just looked at courtyards used in Mediterranean countries, where a courtyard is there to create a view across the building and to stop direct sunlight from hitting. So, the Martian habitat used the same principle, we had a courtyard that open a view to the outer environment and allow for indirect light to enter. And this is a simple architectural application, it is something we do everywhere in the Mediterranean.

D.K.

I would like to ask you, what was interesting in the projects of Hassell studio Martian habitat or Foster and Partners Lunar or Martian habitat, when you were working on it, like some obstacles or occasions?

X.K.

I think, for me, the most interesting of these projects is that it is a field that has not been looked at that much, there are only a few people architects in the world that look at space. And the most exciting is that you can work with many people, and everything has an influence. I could work with psychologists, engineers, Mars meteorologists, anthropologists, experts in inflatable architecture, etc. I think the most fun thing is that we were able to work with a whole heap of different experts on this.

And we work in extreme environments, that is fun, too. There were many constraints. There is nothing more boring than getting a client that wants to build a beautiful villa when the budget is unlimited. There are no constraints, no challenges.

D.K.

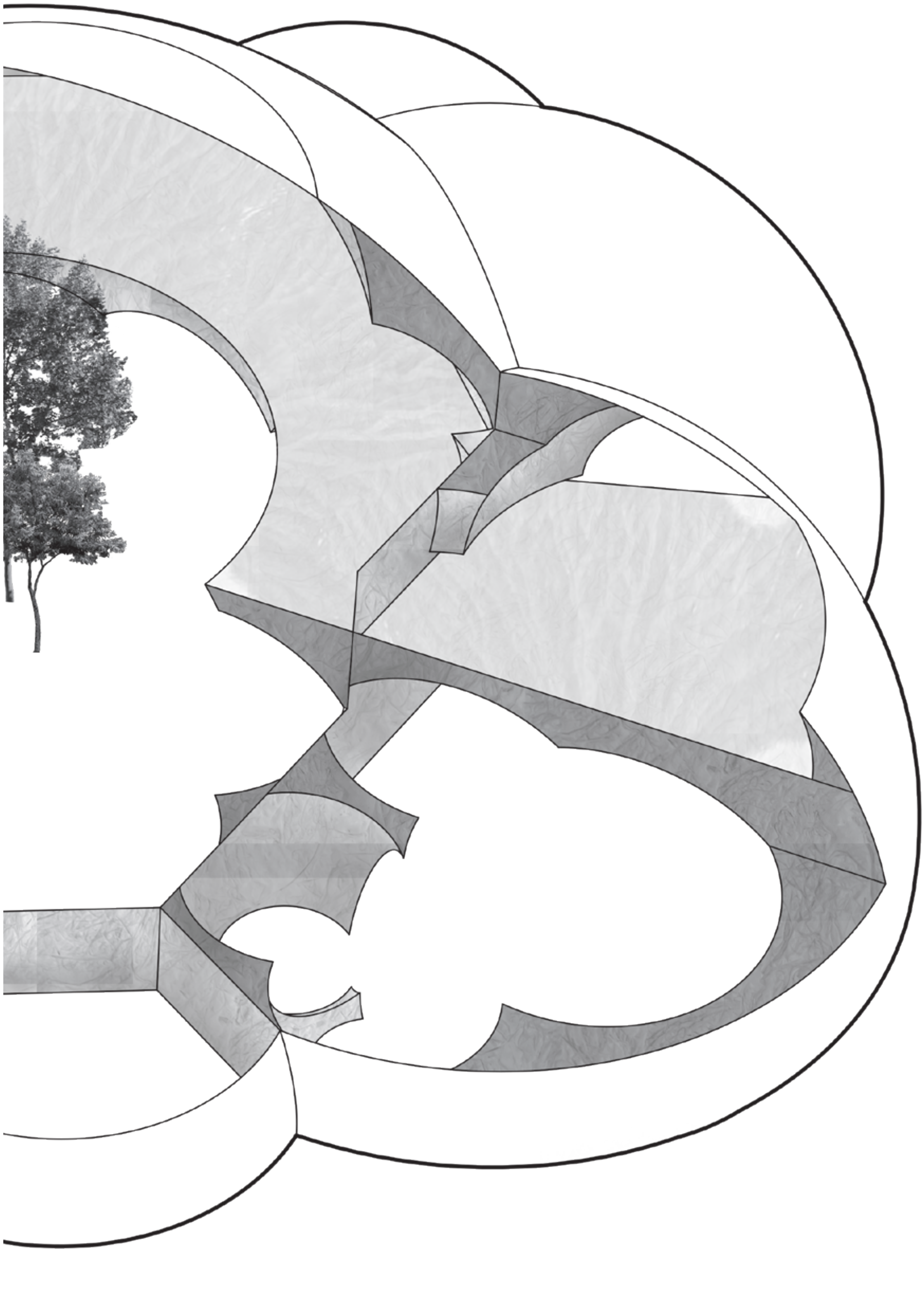
What can be the reason for us, humanity to establish any human presence on the surface of Mars despite the tremendous cost of doing it?

X.K.

I do not 100% follow Elon Musk's idea that we need to have a million people on Mars in less than 100 years. I am thinking more online if we would go to Mars, analogy I am using, is how we go to Antarctica. You have never been to Antarctica, we are not there to inhabit Antarctica. We do not build cities in Antarctica, that would be ridiculous as it is a very hostile environment, and Mars is even more dangerous. But we would have to do research and explore it because we are humans, it is in our genes and our blood.

DESIGN SOLUTION

An essential part of the research efforts is a meditation on the possible human settlement on the surface of Mars. Project development allows a more detailed view of specific solutions and problems of work on another planet. The design solution demonstrated in this thesis intends to explore the possible approach that may exist 20 or 40 years from now, when the question of the human presence on Mars will become a probable reality. Therefore, a proposed project is intentionally more on the abstract side without focusing on details.



MISSION DEFINITION

Introduction.

To understand what type of mission is needed, one should understand why different national administrations, private companies, and particular personalities are striving for space exploration. From scientific interest to resource exploitation, reasons vary from mission to mission.

First missions to Mars will face great uncertainty and risk involved in such an endeavor. Therefore the safety of crewmembers will be an essential part of the mission. It is only emphasized more by the high political importance, where prestige and public image play a crucial role. Losing crewmates would be disastrous because of the death of the living human being but more impactful because of the loss of the public will to perform such costly initiatives[1].

The first missions to Mars will be a testing ground for different technologies, strategies, and so on to support safety in a dangerous environment, create an artificial environment, sustain life there, etc[2]. Then, when the human settlement meets safety requirements and proven technologies are established, the research reason will become a priority, leading to the development of the Martian settlement towards a particular path.

1 D. Adler, "Why did NASA retire the Space Shuttle?", 12.11.2020 Retrieved on 12.07.2022 at: https://astronomy.com/news/2020/11/why-did-nasa-retire-the-space-shuttle

2 M. B. Rappaport, C. Corbally, "Program Planning for a Mars Hardship Post: Social, Psychological, and Spiritual Services". In: K. Szocik, "The Human Factor in a Mission to Mars". Space and Society. Springer, Cham., 2019, p.2

Mission Statement and Scope.

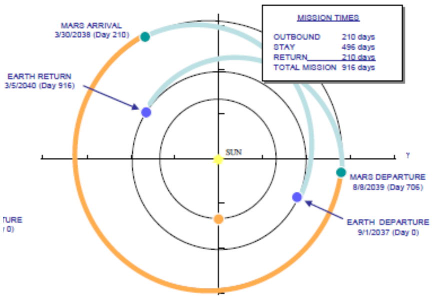
To create a sensible and tangible project on the surface of Mars, one should define its purpose and goal of it. Regarding the existing rules of space exploration, the colonization of Mars as such cannot be pursued[3]. Therefore, if talking about human presence on the surface of Mars, it can be addressed from a scientific interest point of view first, and then with the probable expansion towards production and transportation to support self-sufficiency and maintenance of the Martian settlement.

Regarding the safety factor, Mars offers several opportunities to shelter future astronauts from radiation and meteorites: it can be lava tubes, hills, and craters that provide a different degree of protection. But it is unknown the conditions that possibly exist there: is it suitable for living modules to be there, is it safe enough to construct or assemble anything around or inside it, is the soil ideal for digging and supporting ceiling or any structure on top, etc.

Accordingly, the first habitat that will appear on the surface of Mars will appear on the surface, not under. But with further observation and research of the Martian landscape features, those settlements can expand, or new can arise, also under the surface. Therefore, it would be preferable to use a flexible structure for the habitat to be appliable in both options.

The surface placement of the habitat also supports the research scope as it provides better mobility options and easier access to the surface and outside environment.

3 "Treaty on principles governing theactivities of states in the exploration and use of outer space, including the moon and other celestialbodies", 1966



b) Conjunction Class: Long-Stay Mission

	Conjunction	Opposition
Outbound transit time	180 days	180 days
Inbound transit time	180 days	430 days
Mars stay time	550 days	30 days
Total mission time	910 days	640 days
Mission propulsive ΔV	6.0 km/s	7.8 km/s
Venus flyby needed?	No	Yes
Average mission radiation dose	52 rem	58 rem
Zero gravity exposure	360 days	610 days
Mission cost	Lowest	Highest
Mission accomplishment	Highest	Lowest
Mission risk	Lowest	Highest

Item	Need/ man-day	Fraction recycled (kg)	Wasted/ man-day	ERV Reqs 200 days in (kg)	Hab Reqs 200 days out (kg)	Hab Reqs 600 day Surface	Hab Reqs Total kg
Oxygen	1.0	0.8	0.2	160	160	0	160
Dry food	0.5	0.0	0.5	400	400	1200	1600
Whole food	1.0	0.0	1.0	800	800	2400	3200
Potable water	4.0	0.8	0.0	0	0	0	0
Wash water	26.0	0.9	2.6	2080	2080	0	2080
Total	32.5	0.87	4.3	3440	3440	3600	7040

Earth Return Vehicle	Tonnes	Hab	Tonnes
ERV cabin structure	3.0	Hab structure	5.0
Life-support system	1.0	Life-support system	3.0
Consumables	3.4	Consumables	7.0
Electrical power (5 kWe solar)	1.0	Electric power (5 kWe solar)	1.0
Reaction control system	0.5	Reaction control system	0.5
Communications and information management	0.1	Communications and information management	0.2
Furniture and interior	0.5	Lab equipment	0.5
EVA suits (4)	0.4	Crew	0.4
Spares and margin (16 percent)	1.6	EVA suits (4)	0.4
ERV cabin total	11.5	Furniture and interior	1.0
Aeroshell	1.8	Open rovers (2)	0.8
Light truck	0.5	Pressurized rover	1.4
Hydrogen feedstock	6.3	Field science equipment	0.5
ERV propulsion stages	4.5	Spares and margin (16 percent)	3.5
Propellant production plant	0.5		
Power reactor (80 kWe)	3.5		
ERV total	28.6	Hab total	25.2

Mission Parameters.

To find out the needed parameters for the mission, one should define an approximate number of the crew that will be sent to the surface of Mars. To do so, one should ask the question: What will those people do there? How are they going to do it?

There can be two options: a mission for 2-3 years that will send one or a few crews that will return to Earth. Another option would be similar to International Space Station or any arctic station when you have a transient population. However, it is ever-changing with people arriving and going back to Earth.

Choosing between conjunction and opposition trajectories for the arrival of Mars for the project is better to choose the one that affords more time to stay on the surface. Therefore, a conjunction trajectory would suit better. In this case, the rules should be changed or interpreted to allow an extended stay on Mars.

For a crew of 4 people that will follow a conjunction trajectory for arrival and return journeys, the need for consumables (for a stay and transfer periods) will be next: 160 kg of Oxygen, 3200 kg of food, and 2080 kg of water, including partial Oxygen and water recycling. Then habitat, power generator, solar panels, etc., will have their mass.

For option 2, it is possible to use the same reference for the calculations but try to extrapolate it for the double amount of stay days to have at least two crews overlapping. Therefore, for one crewmember, it would be 1 kg of Oxygen per day, with about 0.8 of it recycled, it would be 1 kg of food, 4 kg of potable water with 0.8 of it recycled, and the rest used for washing, and 26 kilograms of wash water with 0.9 of it reclaimed. [4]

Accordingly to the Mars Direct approach proposed by Robert Zubrin[5], option one would require about 180 days for the transfer from Earth to Mars and the same back from Mars to Earth, with about 550 days of staying on the surface of Mars. While the option two mechanisms are a bit different, for a crew that will arrive the first, arrival and departure transfer will be the same, but the staying period will extend more than twice - from 550 days to 1330 consecutive days. It is because the second crew will have a possibility to depart from Earth to Mars only on the next transfer window that will follow in about 780 days[6]. Therefore, to achieve a constant presence on the surface of Mars, the staying period for crew one and crew two would need to overlap, so crew one will need to wait for crew two arrival and departure back to Earth on the next window. Such a system will allow crew one and crew 2 (crew two and 3, etc.) to stay together for about 550 days before crew one departure. Then for crew 2, it will be 550 days with crew 1, 230 days alone, and another 550 days with crew 3.

In this way, a transient population on the surface of Mars can be achieved. However, for it to happen, humanity should understand the influence of the reduced gravity on the human body and how to fight its potentially harmful effects.

4 R. Zubrin, R. Wagner, "Case of Mars", 1997, p. 70
5 R. Zubrin," The Mars Direct Plan" , 282(3), 52–55, 2000
6 Sydney Do, Towards Earth Independence – Tradespace Exploration of Long-Duration Crewed Mars Surface System Architecture, 2016 p.54

SITE SELECTION

After the definition of the mission's architecture, reasons, and tasks, it becomes clearer which exact characteristics of the site to respect and their hierarchy. In most cases, they follow general rules based on safety requirements and common sense. However, the final site location can vary dramatically depending on the functions, main reasons of the mission, type of the settlement or base, type of the chosen structure, etc.

Main Criteria

While each specific function and task of the mission will dictate more detailed characteristics for the site, there are more general criteria that those sites should follow.

Scientific Interest

Each of the locations on Mars possesses some scientific interest starting from the basic one as an experimental site for the techniques and methods for building a human settlement and following with a search for signatures of ancient life. The second one has become a primary reason for previous robotic missions to Mars and will probably be a driving force for future crewed exploration missions.

The site's scientific characteristics are mainly of two types: geological and astrobiological[1]. In the case of geological, features of the landscape as the meteorite impact sites, ancient glaciers, or ice covers, can reveal the history of the early solar system and the history of the Mars formation. On the other hand, astrobiological features of the site can disclose the secrets of the origin of life.

It is possible to assume that scientific tasks that will be important for a crew mission to Mars will be the same tasks defined for previous robotic missions such as Curiosity or Perseverance. One can explore an environment that appears to have once been capable of supporting life as we know it or sustaining pre-biological processes leading to the origin of life. For example, it could be ancient river deltas or underwater volcanic features. It could also be a deep ice sheet under the polar caps that still can store valuable information about life traces and the history of climate formation on Mars[2].

Search for biosignatures can be another scientific orienteer that will define a site's preferability. In this case, the site location should accommodate a wide array of habitable environments and biotas that can differ dramatically from what we find here on Earth. An essential role of the environment that is valuable from a scientific point of view is its potential for preserving biosignatures[3].

Mars contains many mysteries about the history of its formation and climate change, and many geologically interesting features can collect information about it. Therefore, the future settlement site should have several different geological characteristics that will allow a proper investigation on topics of potential for past or present life, water presence, crater records and ages of Mars, igneous processes, surface-atmosphere interactions, chemical and mineralogical composition of the crust, tectonic history and present activity, determination of processes of regolith formation, crustal magnetization, and impact effects on the Martian crust[4].

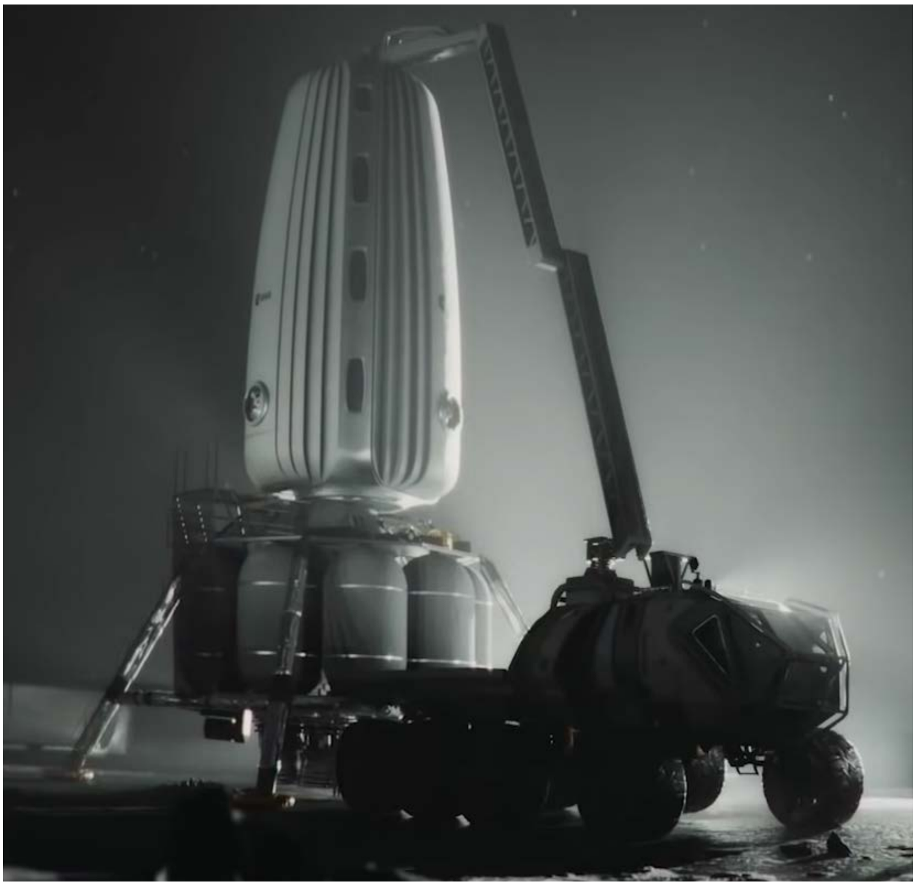
1 J.F. Mustard, Report of the Mars 2020 Science Definition Team, 2013, p. 16

2 J.F. Mustard, Report of the Mars 2020 Science Definition Team, 2013, p. 16

3 J.F. Mustard, Report of the Mars 2020 Science Definition Team, 2013, p. 16

4 International Space University, ACCESS Mars Assessing Cave Capabilities Establishing Specific Solutions, 2009, p. 32

Safe Landing Conditions



The capabilities of different Earth-Mars transport systems dictate a set of engineering constraints on the safety of the landing site and the quality of the surface mission after landing, which is a crucial requirement for the crewed mission to Mars. Several factors can play a critical role in the safety of the landing site, which will determine the applicability of one potential settlement site.

One could be elevation and atmosphere - the big difference in atmospheric pressure accordingly to Martian seasons will significantly influence the ability of the parachute system or an entry profile of the spacecraft (depending on the landing approach and type of the spacecraft) to slow it down efficiently.

Another parameter that plays an essential role is safe landing conditions: simply a slope of the landing site can trick the spacecraft's automatic landing system, which will cause accuracy and safety problems and can cause an increase in loads during the landing.

Such parameters as rocks size and density, the reflectivity of the surface, etc. influence the landing conditions: rocks can damage the landing gear, not reflective enough surface will trick the radar, and dusty ground could not bear the load of the spacecraft standing on it[5].

5 M. P. Golombek, Selection of the Mars Exploration Rover landing sites, 2003 p.6

Habitability

As soon as the spacecraft arrives on Mars's surface, it will need to charge its batteries to function and protect the crew and the crucial parts of the spacecraft during the night. The most probable leading resource of electricity for the spacecraft, for a crew, and the source for the research base during the starting period will be deployable solar panels. Therefore, proper solar irradiance for the site will be a crucial parameter. Of course, using portable nuclear reactors will expand the area of the possible site locations. However, this energy source is very complex to reproduce, costly to construct and deliver, and therefore limited in use.

A base supplied only by solar power needs to be located between the 10° South and 10° North latitudes because, in this case, the solar panels will receive enough energy to support the station[6].

Water and hydrogen availability is another factor that will be important for choosing the site, not only for a necessary supply of drinkable water but also for fuel, energy production, and manufacturing. That means the potential site will probably be located in the northern hemisphere. There are no sizeable permanent ice reservoirs south of 75° Northern latitude, but it will also be possible to find ice deposits covered with about 1 m soil and dust until 40° of North latitude[7]. Some regions as, such as Terra Sabaea, around the Elysium volcanoes, and the northwest of Terra Sirenum ice concentrations (about 18% of ice) still can be found, even if their locations are close to the planet equator with the closest one of 2° North latitude[8].

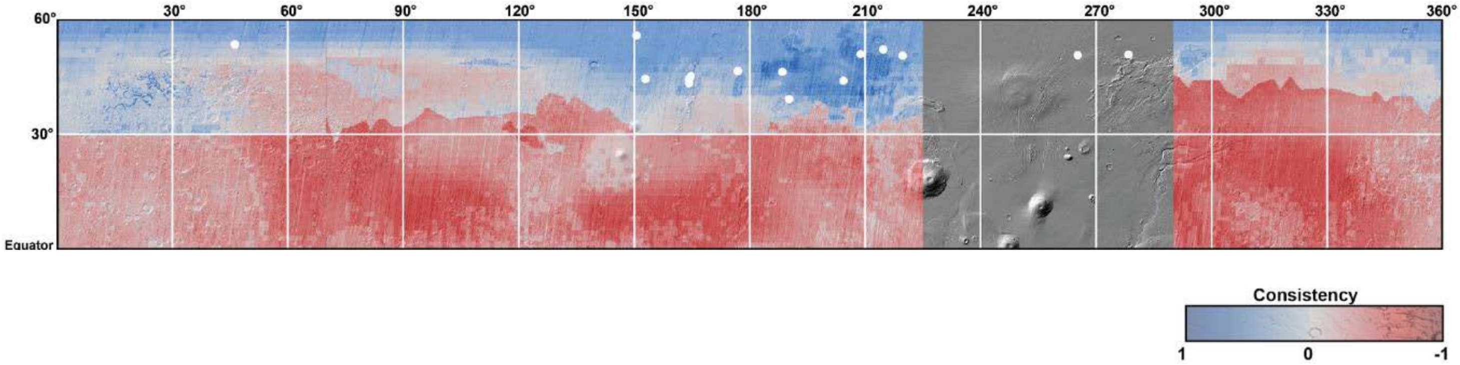
The potential site also needs to support some manufacturing activities, as the Earth-independence is necessary for a sustainable presence on Mars. For that to be accomplished number of the resources, including water, should be available in the approximate vicinity.

Different terrain features not only possess a scientific interest, but they also can partially protect future Martian astronauts from the extreme conditions that are present on Mars. Most discussed are lava tubes, as they support substantial protection from solar and cosmic radiation, meteorites, and dust storms. But it also encompasses some additional risks connected to the cave instability (skylights are one of the representations of it). However, it can be controlled mainly through appropriate training, prior research, and site assessment. Another risk involved with using the Martian caves is the danger during extra vehicular activity (EVA), when astronauts can get into trouble due to unstable ground conditions or rugged terrain surrounding the entrance of the lava tube.

6 M. P. Golombek, Selection of the Mars Exploration Rover landing sites, 2003 p.6

7 R. Zubrin, R. Wagner, "Case of Mars", 1997 p. 125

8 M. Nazari-Sharabian, Water on Mars—A Literature Review, 2020 p.12



Graphical Representation

It is possible to assume that the Northern hemisphere of Mars is more suitable for any human base because it has several advantages: more humid conditions, which means that it has a more significant amount of water in the atmosphere and soil, it has lesser temperature swings in comparison with Southern hemisphere, because of the highly inclined elliptical orbit of the Mars, and it has lesser amount of the dust storms as they form mainly in the southern hemisphere. Therefore, the Northern hemisphere is

Water availability map

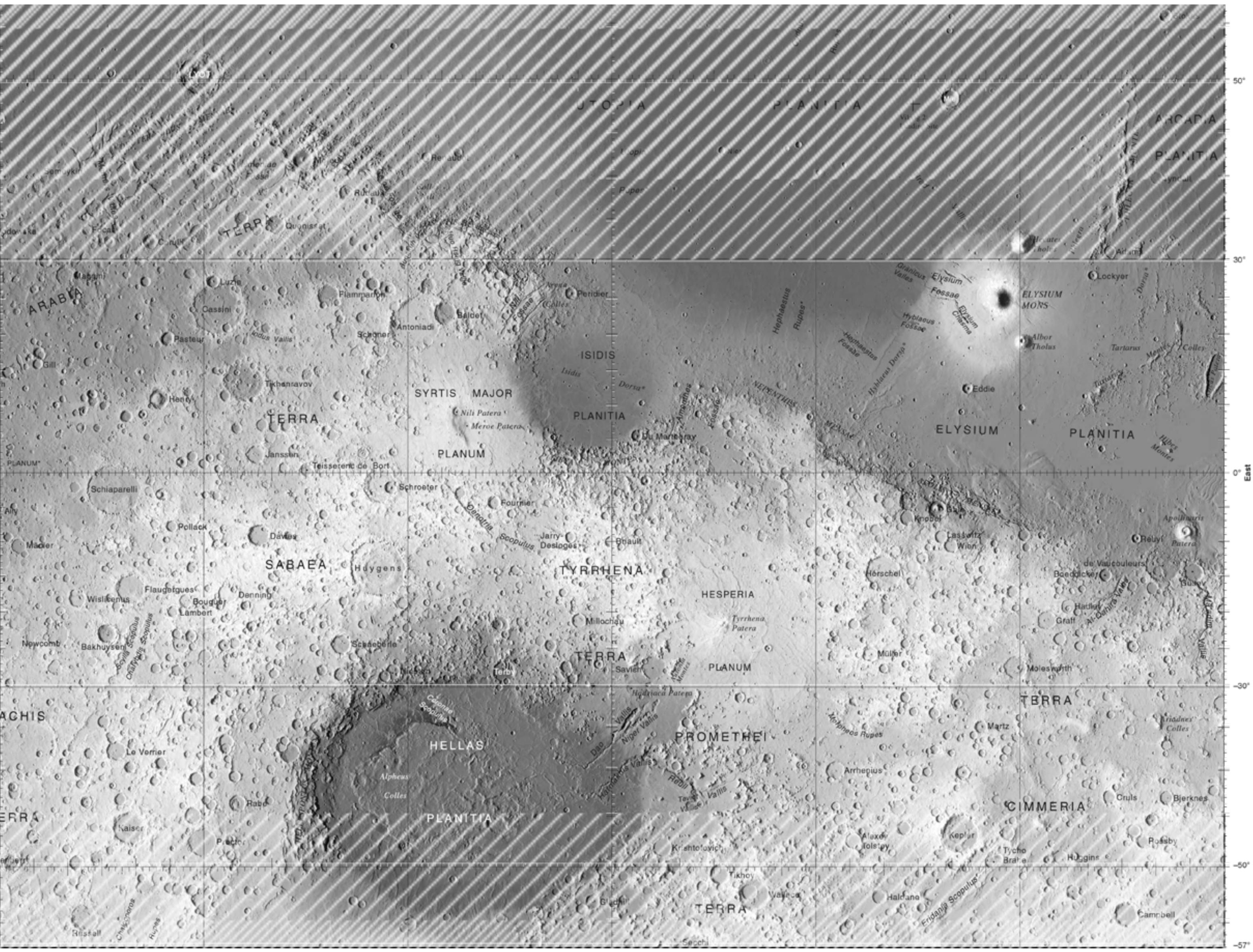
where it should be looked at if we are choosing the settlement site.

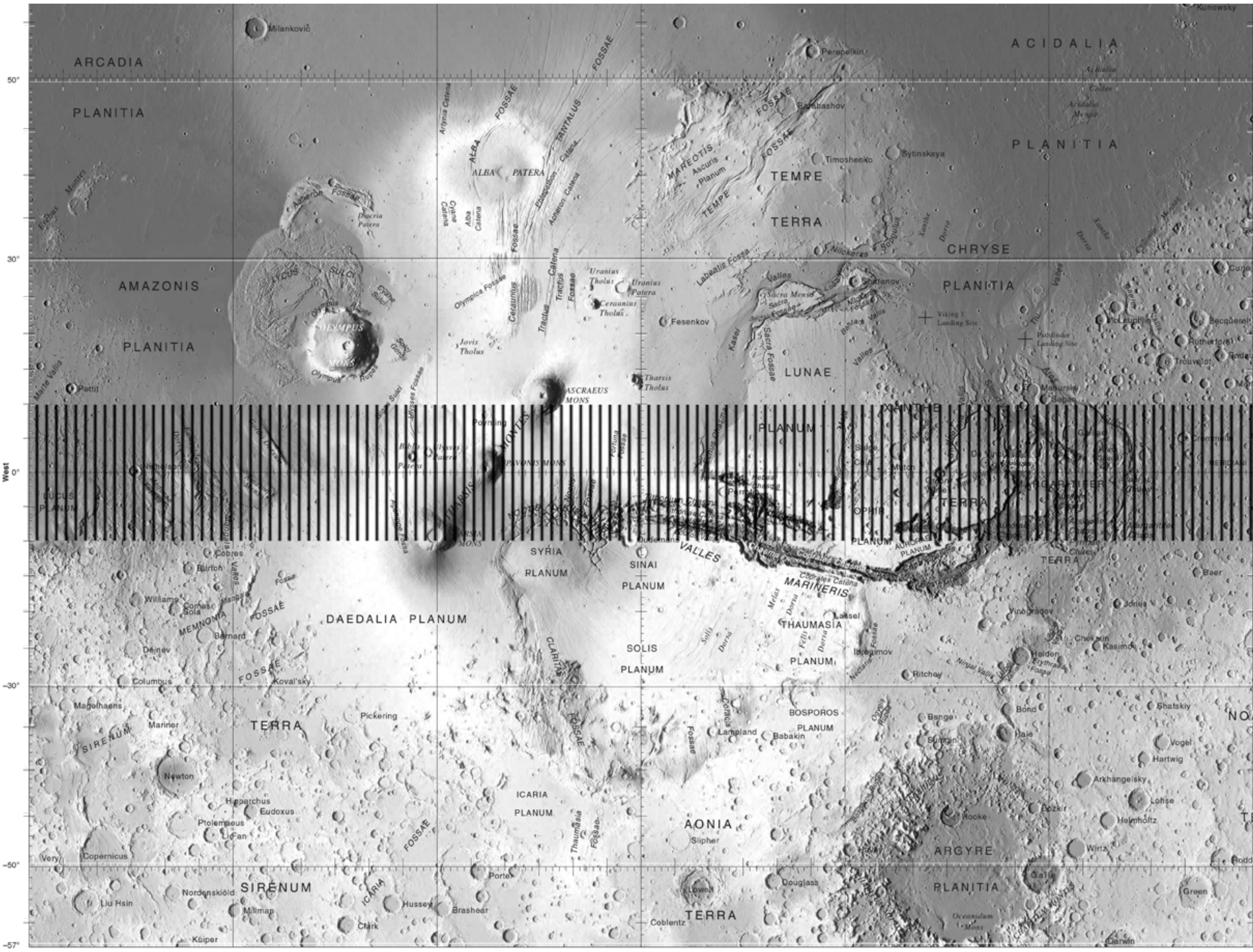
To understand better areas that are more suitable for a future Mars settlement, several criteria that have a bigger priority and that can be assessed on a planetary scale need to be established. If we look at safe landing conditions, it is a local characteristic of the landing site. The same can be said of scientific interest - it is more likely that some local features will possess more scientific valuable data than a whole region. The availability of natural resources is a feature of each particular site. While we already know the general composition of the soil and atmosphere, the study of the concrete parameters of a definite region cover only the outer soil layers.

At the same time, the available amount of water in the soil and atmosphere is very well studied[9]. The same can be said of solar irradiance[10] - considering the atmosphere density, visibility, and distance to the sun - it is possible to predict approximate solar radioactivity on a specific site. And those parameters are crucial for a sustainable Martian settlement to exist. It is possible to predict the approximate region or latitude of the potential site that will satisfy those two parameters. Its local features distinguish which one will be more suitable for the rest of the parameters.

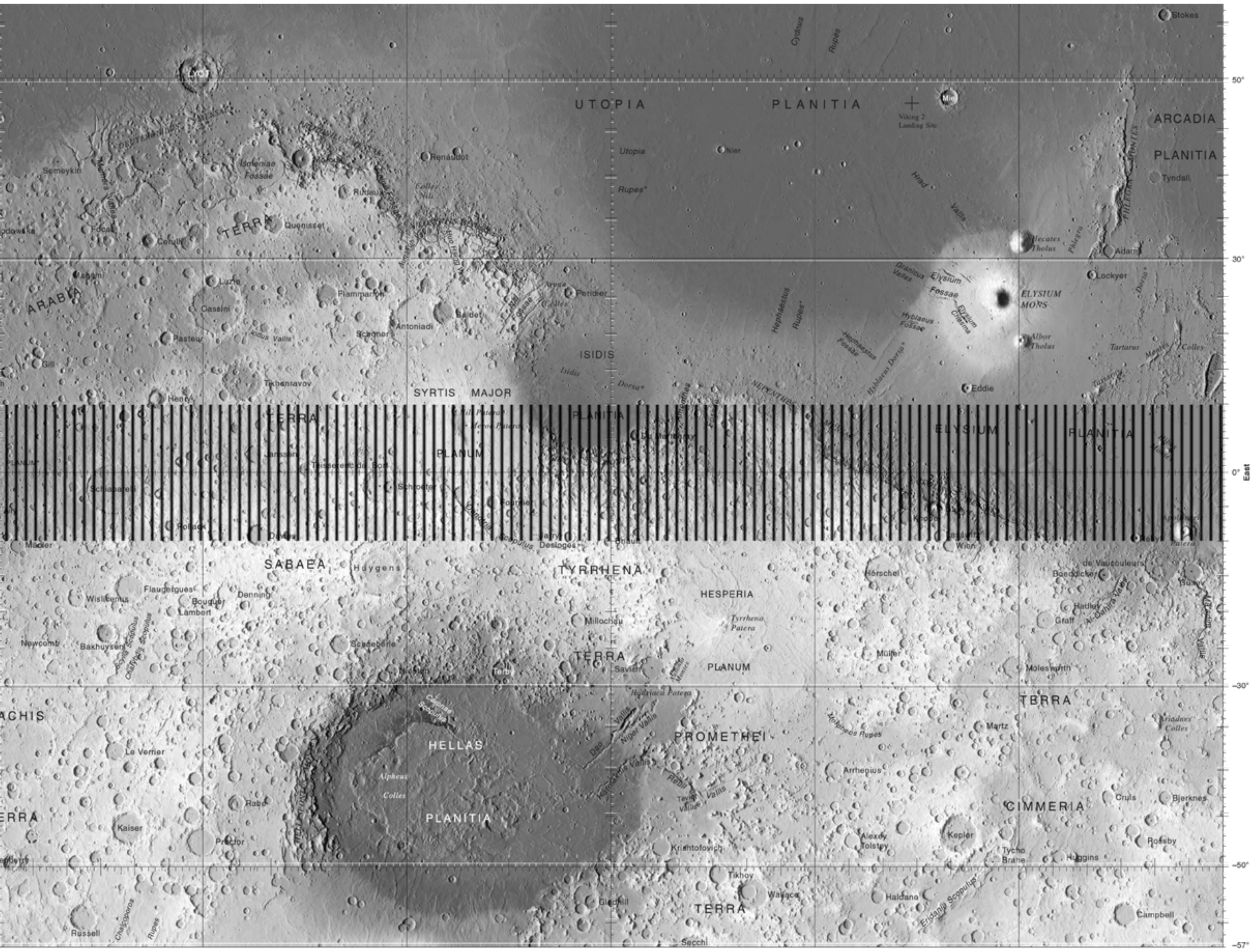
9 R. Zubrin, R. Wagner, "Case of Mars", 1997 p. 125

10 M. P. Golombek, Selection of the Mars Exploration Rover landing sites, 2003 p.6





Solar irradiance map



UTOPIA
PLANITIA
Viking 2 Landing Site
ARCADIA
PLANITIA
Stokes
Lyot
Mie
Renaudot
Utopia
Rupes
Semeykin
Ismeniae Fossae
Rudaux
Colles Nili
TERRA
Quenisset
Cerulli
Hecates Tholus
Adams
Tyndall
Lockyer
ARABIA
Cassini
Flammarion
Peridier
Antoniadi
Baldet
Pasteur
ELYSIUM MONS
Elysium Fossae
Albor Tholus
Hephaestus Rupes
Hephaestus Fossae
Tartarus
ISIDIS
Tikhonravov
Henry
Eddie
SYRTIS MAJOR
TERRA
PLANUM
PLANITIA
ELYSIUM
PLANITIA
Janssen
Schiaparelli
Schroeter
Rotigaux
Maunder
Dawes
Wien
SABAEA
Huygens
TYRRHENA
Herschel
de Vaucouleurs
Boeddicker
Flaugergues
Wislicenus
Bouguer
Lambert
Denning
HESPERIA
Tyrrhena Patera
Millochau
Hartwig
Graff
Newcomb
Bakhuysen
Schaeberle
TERRA
PLANUM
Savich
Müller
Molesworth
TERRA
HELLAS
PROMETHEI
Le Verrier
Martz
Arrhenius
Alpheus Colles
PLANITIA
CIMMERIA
Crulls
Bjerknes
Rabe
Kaiser
Proctor
Kepler
Alexey Tolstoy
Tycho Brahe
Huggins
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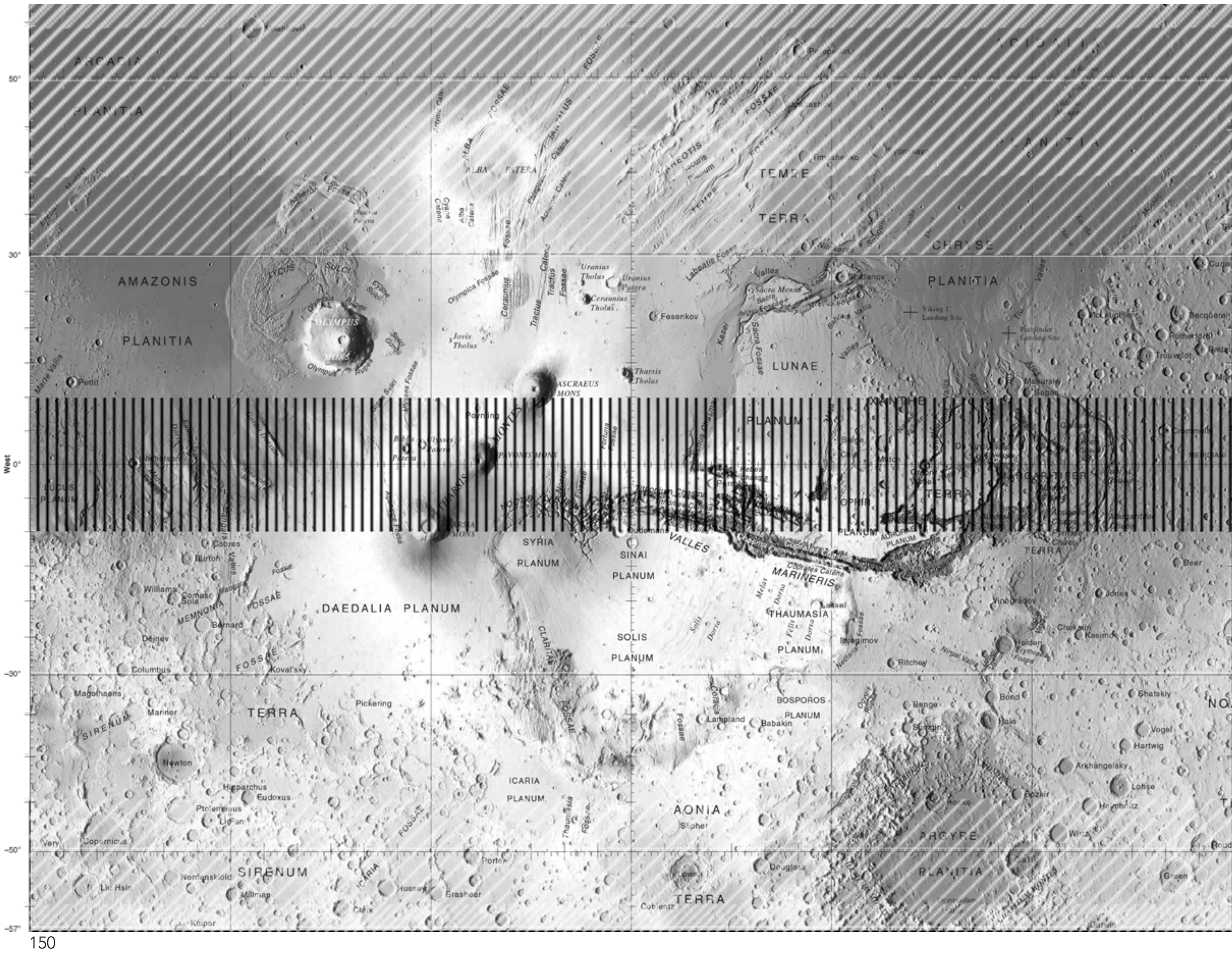
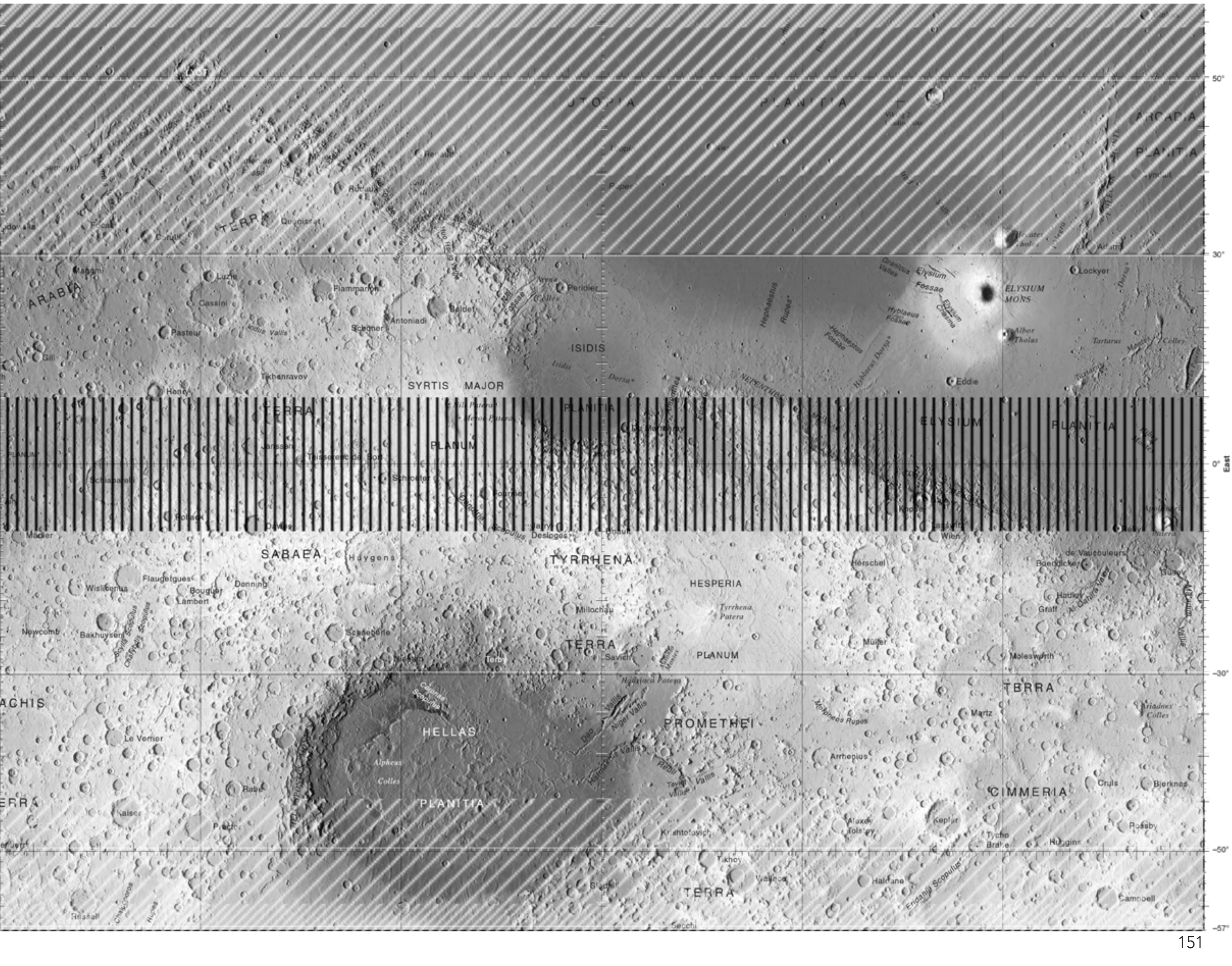
Solar irradiance and water availability map





UTOPIA
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Cassini
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ISIDIS
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SYRTIS MAJOR
PLANUM
ELYSIUM
MONS
Elysium Fossae
Albor Tholus
Eddie
Lockyer
ELYSIUM
PLANITIA
Hephaestus Rupes
Hephaestus Fossae
Hyblaeus Fossae
Antoniadi
Peridier
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Huygens
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Renaudot
Madler
Pollack
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East

List of the Sites

Regarding the scientific interest of the research site, it is vital to have a specialist vision, it is still valid to have a general understanding of the reasons behind one or another decision, but those decisions should be based on a deep knowledge of the topic. Therefore, the list of regions of interest listed below is supported by existing research.

With the water distribution and solar irradiance maps as a reference, it is possible to manage the given sites regarding their suitability for a crewed mission.

	Coordinates	Ice / Water availability	Terrain features / Caves	Science Interest (Geology)	Science Interest (Astrobiology)
Olympus Mons Northern flank	18°39°N 226°12°E	It has been speculated that the detachment along the weak layers was aided by the presence of high-pressure water in the sediment pore spaces	An enormous shield volcano with a height of over 21.9 km[1]	The mountain may still be volcanically active, though in a very quiescent and episodic fashion[2]	Potential springs or seeps around the volcano would offer exciting possibilities for detecting microbial life.[3]
Terra Sirenum	39.7°S 150°W	Concentric crater fill, like lobate debris aprons and lineated valley fill, is believed to be ice-rich.[4]	Terra Sirenum is a large region in the southern hemisphere of the planet, an upland area notable for massive cratering. A low area in Terra Sirenum is believed to have once held a lake.[5]	The Mars Global Surveyor (MGS) discovered magnetic stripes in the crust of Mars, especially in the Phaethontis and Eridania quadrangles (Terra Cimmeria and Terra Sirenum)[6]	Evidence of deposits of chloride based minerals, This suggests that near-surface water was widespread in early Martian history, which has implications for the possible existence of Martian life.[7]
Alba Mons	40.5°N 250.4°E	High potential for shallow subsurface ice	Alba Mons is notable for the remarkable length, diversity, and crisp appearance of its lava flows, [8]area with high concentration of lava tubes	Boundary of volcanic terrain and Northern Plains, Alba's well-preserved lava flows and faults provide an excellent photogeologic record of the volcano's evolution.[9]	Potential for organic molecules/cells preserved in ice (

1 J. B. Plescia, "Morphometric Properties of Martian Volcanoes". J. Geophys. Res. 109 (E3): E03003, 2004
2 L. A. Soderblom, J.F. Bell, "Exploration of the Martian Surface: 1992–2007 in The Martian Surface: Composition, Mineralogy, and Physical Properties", Cambridge University Press: Cambridge, UK, 2008, p. 15
3 McGovern, P.J. (2010). Olympus Mons: A Primary Target for Martian Biology. Astrobiology Science Conference, LPI, Abstract #5633.
4 J. Levy, "Concentric crater fill in Utopia Planitia: History and interaction between glacial "brain terrain" and periglacial processes". Icarus: 202. 462-476, 2009
5 R. Irwin, "Geomorphology of Ma'adim Vallis, Mars and associated paleolake basins", J. Geophys. Res. 109(E12), 2002
6 N. Barlow, "Mars: An Introduction to its Interior, Surface and Atmosphere", Cambridge University Press, 2008
7 "NASA Mission Finds New Clues to Guide Search for Life on Mars". Jet Propulsion Laboratory. 2008-03-20. Retrieved on 30.05.2022
8 M. H. Carr, R. Greeley, K. R. Blasius, J. E. Guest, J. B. Murray, "Some Martian Volcanic Features as Viewed From the Viking Orbiters". J. Geophys. Res. 82 (28): 3985–4015, 1977
9 K. L. Tanaka, "Tectonic history of the Alba Patera–Ceraunius Fossae Region of Mars". Lunar. Planet. Sci. Conf. 20: 515–523, 1990

Elysium Fossae	24.8°N 213.7°W	Possible subsurface ice remnents	Yes - identifed lava tubes	Extensive anicent fluvial activity	Scientists are excited about finding hydrated minerals such as sulfates and clays on Mars because they are usually formed in the presence of water. Places that contain clays and/or other hydrated minerals would be good places to look for evidence of life.[10]
Gusev Crater	14.5°S 175.4°E	Evidence of small amounts of briny (salty) water,[11] Thin dust cover contains a small amount of chemically bound water.	The crater is about 166 kilometers in diameter and formed approximately three to four billion years ago.	at first the region proved disappointing in its lack of available bedrock for study on the flat lava plains of the crater	It is believed that Gusev crater may have held a lake long ago, but it has since been covered by igneous materials.[12]
Jezero Crater	18.38°N 77.58°E	Unknown	Besides having a delta, the crater shows point bars and inverted channels.[13]	From a study of the delta and channels, it was concluded that the lake inside the crater probably formed during a period in which there was continual surface runoff.	Clay minerals have been detected in and around the crater. Clays form in the presence of water, so this area probably once held water and maybe life in ancient times.[14]
Nili Fossae	22.57°N 76.8°E	Unknown potential for shallow ice	Volcanic area	Horst-graben structure, large area of exposed olivine	Methane plumes of unknown origin and potential for traces of life in water related minerals (carbonates and phylosilicates)
Margaritifer Terra	15°S 22.5°W	Unknown	The area reveals “chaos terrain”, outflow channels, and alluvial plains that are indicative of massive flooding. A region within the terra shows some of the highest valley network densities on the planet.	Some of the images from this region display layers. Many places on Mars show rocks arranged in layers.[15]	Holden and Eberswalde, craters in Margaritifer Terra, are thought to have formerly held lakes because they contain deltas and iron/magnesium smectite minerals which need water to form.
Mawrth Vallis	22.6°N 16.5°W		Channel formed by massive flooding	Presence of phyllosilicate (clay) minerals which form only if water is available	Potential for preserved biosignatures in the clay minerals
Melas Chasma	10.4°S 72.7°W	Possible subsurface ice and transient liquid water at depth	No lava tubes - unknown potential for dissolution/tectonic caves	Access to geological strata, evidence of water-cut channels, landslides	Potential for traces of life in water related minerals (sulphates and phylosilicates), strong indications of magma/water interactions likely conducive to hydrothermal activity and habitable conditions

10 “Target Zone: Nilosyrtis? - Mars Odyssey Mission THEMIS”. themis.asu.edu. Retrieved on 30.05.2022

11 “Aqueous processes at Gusev crater inferred from physical properties of rocks and soils along the Spirit traverse”. AGU. Archived from the original on 2012-02-04. Retrieved on 30.05.2022

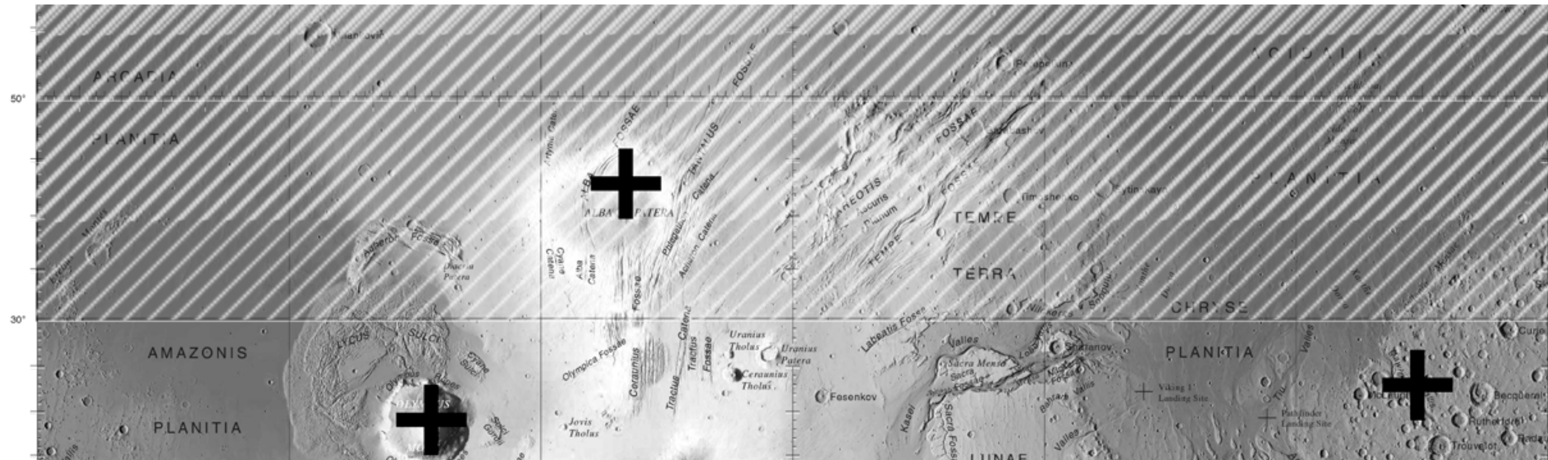
12 R. V. Morris,S. W. Ruff, R. Gellert, D. W. Ming, R. E. Arvidson, B. C. Clark, D. C. Golden, K. Siebach, t“Identification of Carbonate-Rich Outcrops on Mars by the Spirit Rover”. Science. 329 (5990): 421–4, 2010

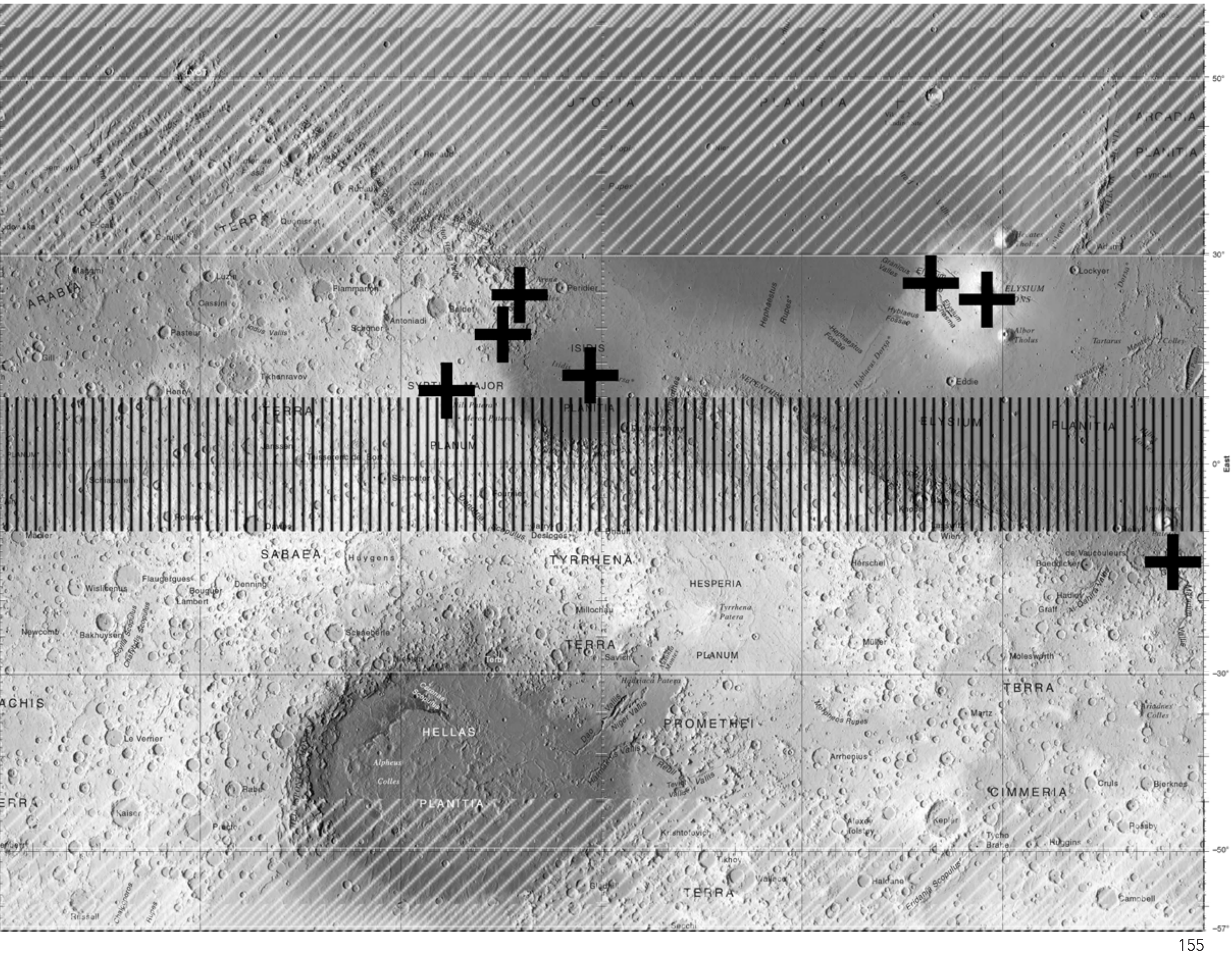
13 T. Goudge, “Stratigraphy and Evolution of Delta Channel Deposits, Jezero Crater Mars”. Lunar and Planetary Science 48 (2017), 2017

14 J. Bibring, “Global mineralogical and aqueous Mars history derived from OMEGA/Mars Express data”. Science. 312 (5772): 400–404, 2006

15 J. Grotzinger, R. Milliken, “Sedimentary Geology of Mars”, SEPM, 2012

Solar irradiance and water availability map with the potential sites indication

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Antoniadi
Peridier
Lockyer
Eddie
Huygens
Herschel
Millochau
Schiaparelli
Flaugergues
Wislicenus
Newcomb
Bakhuysen
Le Verrier
Molesworth
Arrhenius
Martz
Kepler
Cruls
Bjerknes
Campbell
Tycho Brahe
Huggins
Rossby
Krasnotov
Halfane
Terby
Savich
de Vaucouleurs
Boeddicker
Graff
Müller
Tyrrhena Patera
Hadriaca Patera
Alpheus Colles
Albor Tholus
Hephaestus Rupes
Amphitrites
Hyblaeus Fossae
Denning
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CONCEPT DEFINITION

How to create a human (-istic) environment on Mars?

This question is trying to address a core issue of architecture. Before creating a human environment, one should know or imagine what a human environment is? For example, a cave, palm leaves shed, wild and diverse natural habitat, social contacts, fast and always in rush city, homemade cake, etc. It is a pretty complex and abstract question, it is not a topic of this thesis, and many architects and philosophers were trying to answer it, including Christopher Alexander. The point of this question is not to have a proper and defined answer, but the attitude towards sensitive design, towards a partial understanding of what the human mind and body need.

How to create an artificial environment that will express the diversity and freedom that we have moving through nowadays city or town?

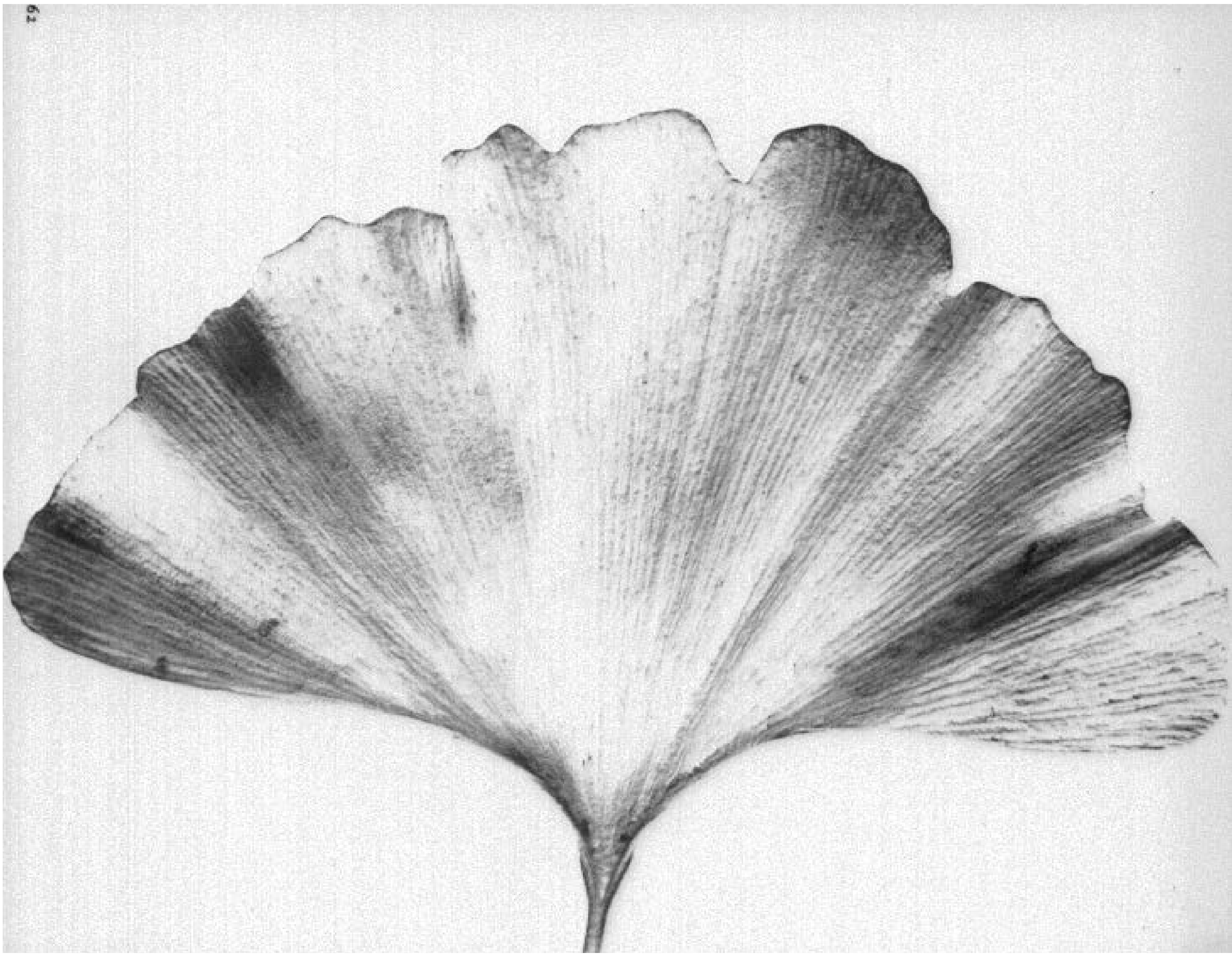
If one wants to think about Mars the same way as we think about the urban environment on Earth, it is the wrong way to go. But, it is possible to think about human beings that will stay on the Martian surface in terms of conditions that they are used feeling, seeing, and so on.

What would be Martian vernacular or Martian and human reference together?

There is already the answer to those questions: we (as humans) will be aliens on this planet. Therefore, we will need to bring a 'human' environment to Mars, but it will need to be adjusted and modified to suit Mars and the strict requirements for delivery.

What will an expression of life in a pristine environment look like?

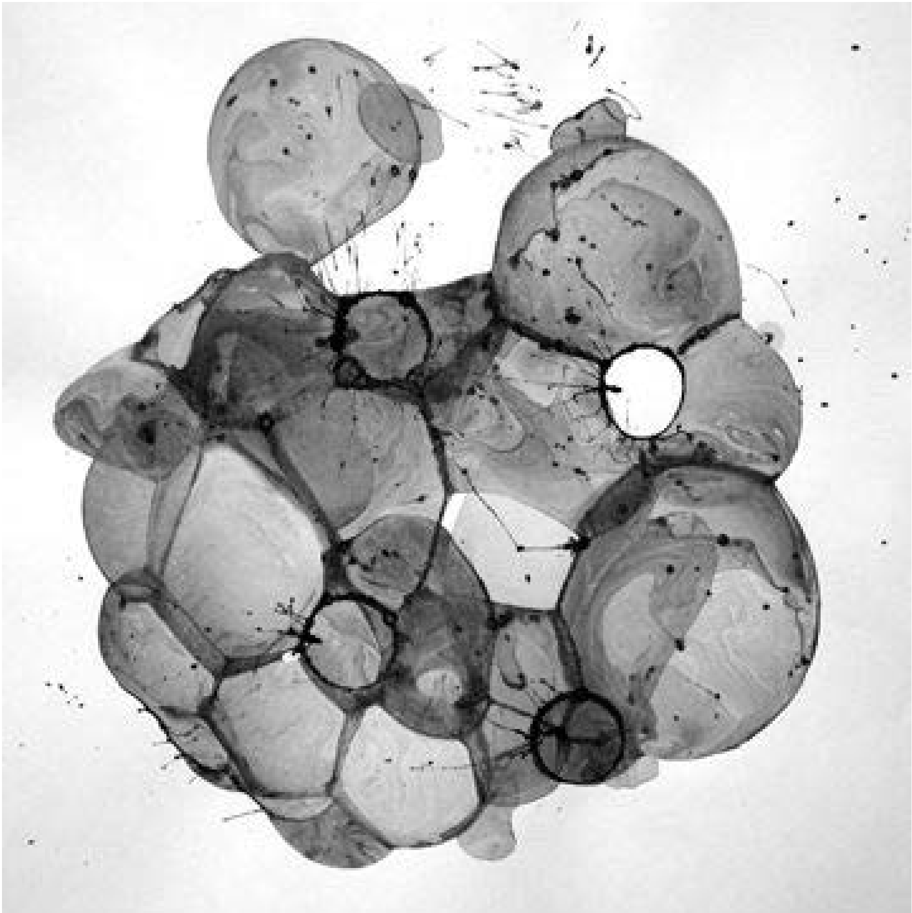
The Martian surface is an example of a natural and pristine environment that hasn't changed much for millions of years. A massive contrast with the ever-changing and full-of-life Earth. This contrast is what will be constituted by the human presence on Mars. We will bring (back) life to this lifeless (possibly not) planet. But how will it be expressed?



BUBBLE IDEA

This idea or concept answers the question of the support of diversity, the one familiar to the human being used to the city environment.

What if we imagine an environment created like a soap bubble, or maybe a better example would be the chemical reaction of the Mentos candies thrown into a Cola bottle. What if we could imagine a small amount of reactive substance that will react with the environment or another substance and quickly create an enclosed, pressurized space.



Bubble drawings

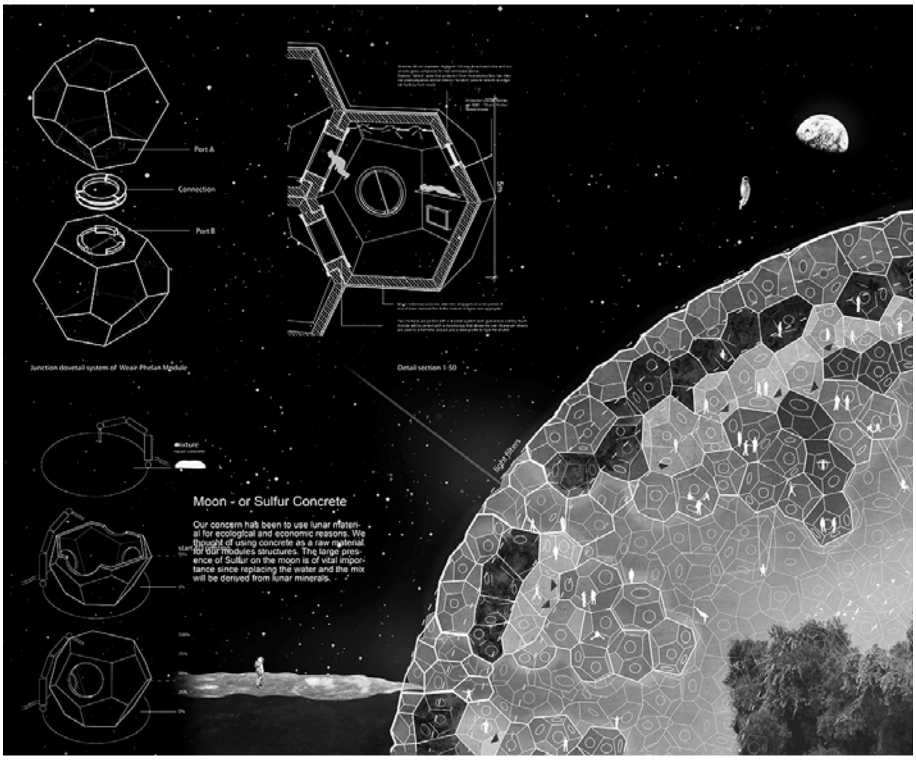
Charlotte X. C. Sullivan

Coca Cola e Mentos contro il Coronavirus

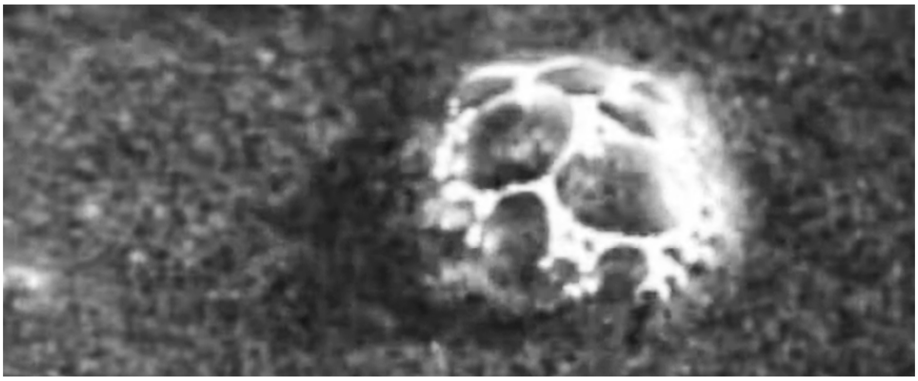
Rosa Zagni, May 18, 2020

This method would allow to fill in different spaces, whether a Martian lava tube or dunes of the Martian desert. It would be possible to inhabit spaces of different volumes.

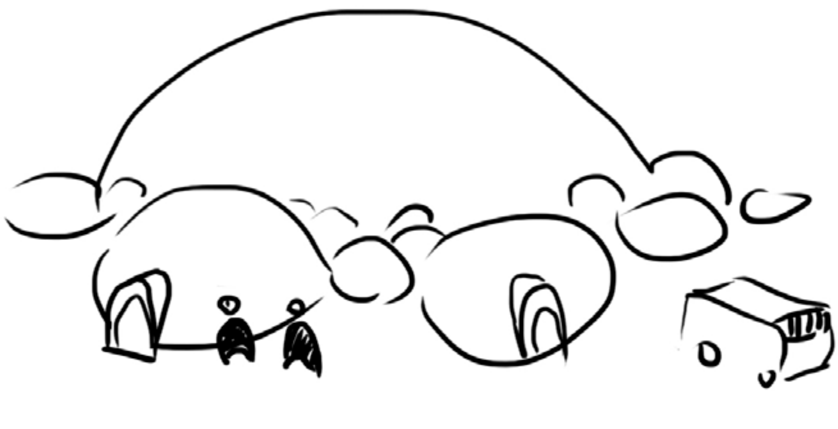
And in the end, it would create a space constellation similar to the Voronoi grid.



Such a way of constructing a Martian habitat can support the creation of the enclosed space. However, this enclosure cannot be a load-bearing structure (depends on the final material of the outer layer, of course, but it is doubted that it would be possible). Therefore it will need some interior structure that will support floors and all the equipment and people needed. Also, if there is a need for some vertical constellation, it will need to have a separate load-bearing structure.

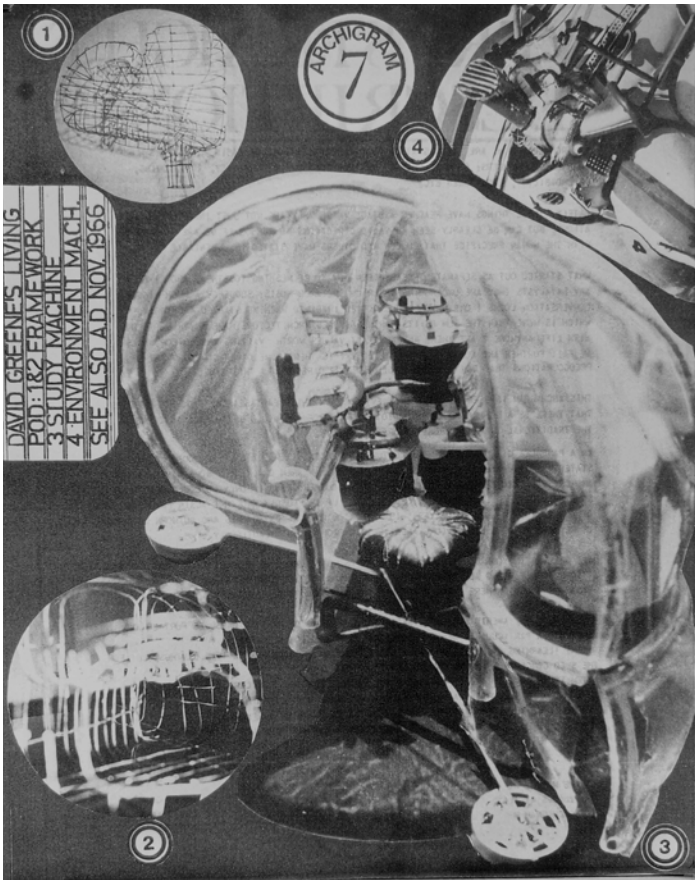


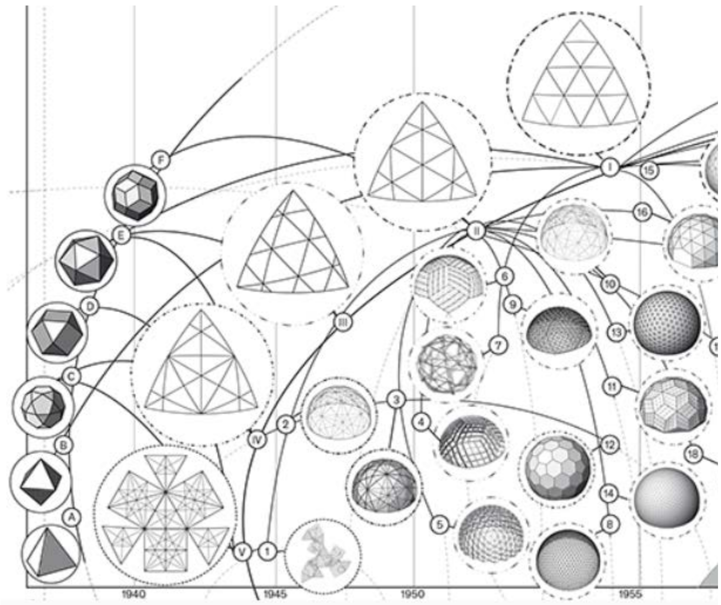
The final material of the shell should be robust enough to withstand all the environmental dangers that Mars possesses. But, simultaneously, it should not be brittle to resist the tension forces of the pressurized space.



Due to the novelty of the idea and disassociation of the bubble as a fragile and transient event with the notion of the house or inhabited space, no particular reference or example were found. It could be Archigram's experimentations[1] with the inflatable architecture or Buckminster Fuller's contribution to geodesic domes[2] as examples. However, those ideas dealt with prefabricated shells or membranes that then were inflated or constructed in the dome-like structure.

Therefore, to explore the idea of the inhabitable space formation through the process of chemical reaction, indirect references were used[3].





1 "Davide Green's Living Pod", Archigram 7 Magazine, 1966
2 D. Lopez Perez "R. Buckminster Fuller Pattern Thinking", 2021
3 C. Clark, "Physics of Giant Soap Bubbles: Emory scientists burst a secret of fluid mechanics that may help the flow of oil through pipes", 2020, Retrieved on 12.07.2022 at: news.emory.edu/features/2020/01/physics-of-bubbles/#article

upper Archigram 7 p. 16

middle Spherical Atlas by D. Lopez Perez

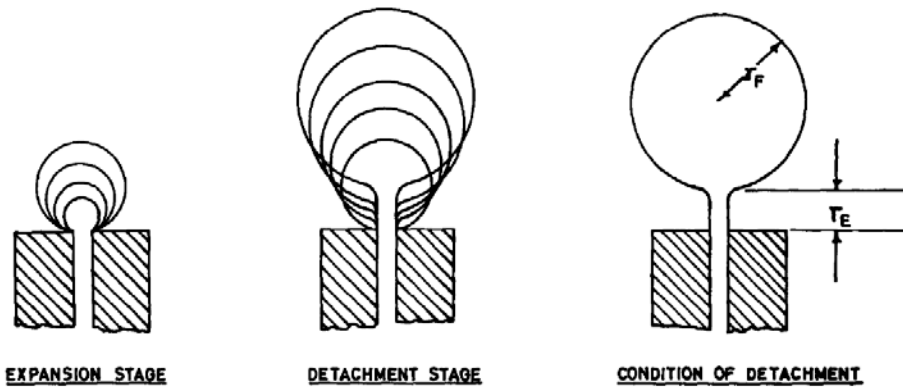
bottom Emory physicist J. Burton experiments with giant soap bubble

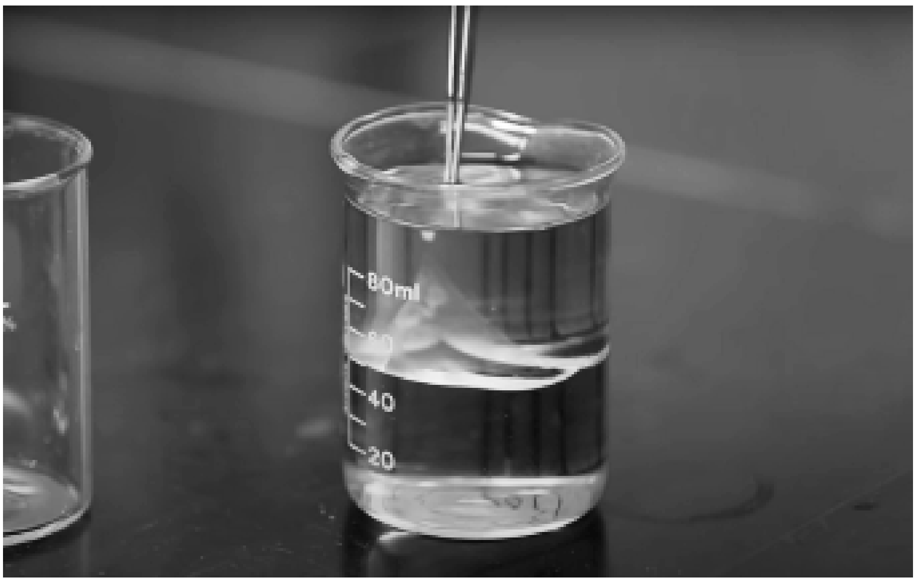
Accordingly to the physics of bubble formation, they follow the so-called Plateau's Law, making the sum of the surfaces of the merged bubbles as tiny as possible [4].

Therefore, each soap bubble constellation follows particular geometric rules that can predict its formation.

At the same time, the power and frequency of the airflow determine the form and dimension of the bubble or a bubble's cluster[5].

These rules area explaining the surface tension of water, but on the surface of Mars, liquid water cannot sustain for a long time. Therefore, a different solution should be applied. For example, synthetic polymer like nylon and, more specifically, its membrane formed during the polymerization process[6] can serve as a substrate for water surface tension. But it will need an additional heat source in the Martian conditions.





upper *Soap bubble cluster*

middle *Bubble formation*

bottom *Nylon polymerization*

4 R. I. Saye, J. A. Sethian, "Multiscale Modeling of Membrane Rearrangement, Drainage, and Rupture in Evolving Foams". Science, 340(6133), 2013, 720–724

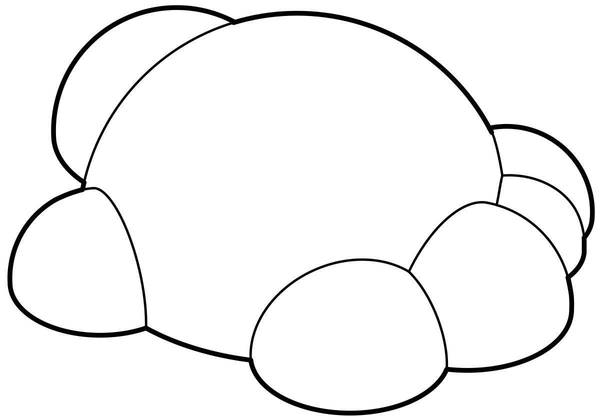
5 S. Ramakrishnan, R. Kumar, N.R. Kuloor, "Studies in bubble formation—I bubble formation under constant flow conditions", Chemical Engineering Science, Volume 24, Issue 4, 1969, P. 731-747,

6 S. Ramakrishnan, R. Kumar, N.R. Kuloor, "Studies in bubble formation—I bubble formation under constant flow conditions", Chemical Engineering Science, Volume 24, Issue 4, 1969, P. 731-747,

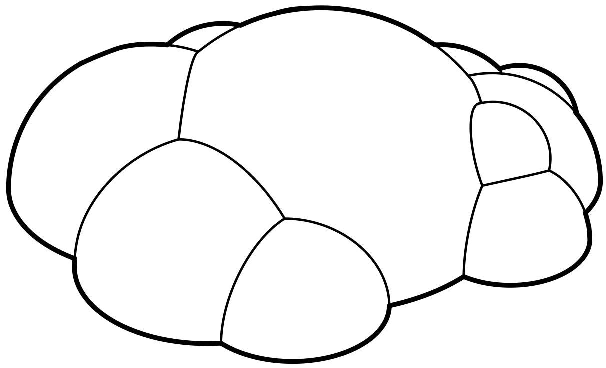
RANDOMNESS

Questioning the notion of a designed order Bubble idea gives a degree of freedom and variety in the space division. However, even if the concept also predicts a planned approach toward bubble creation, when all ingredients are well calculated and sorted to create a bubble or cluster of bubbles of desirable shape and dimensions. There will always be a degree of uncertainty and variety due to the explosive character of the process.

This way, it is possible to create a diversity of enclosed spaces that will create an exciting environment. That can be more familiar to people that are used to the variety of the full of life streets of the human city or wilderness of nature.

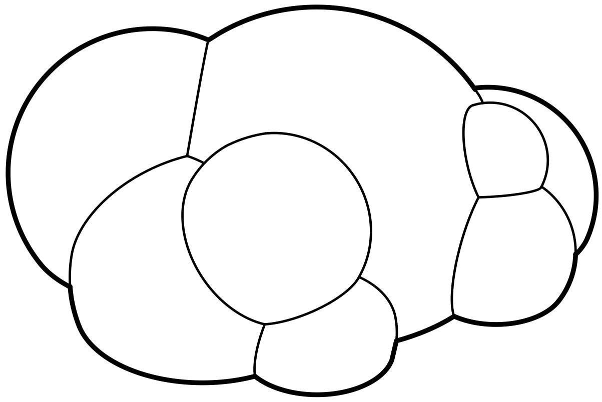


OPTION 1



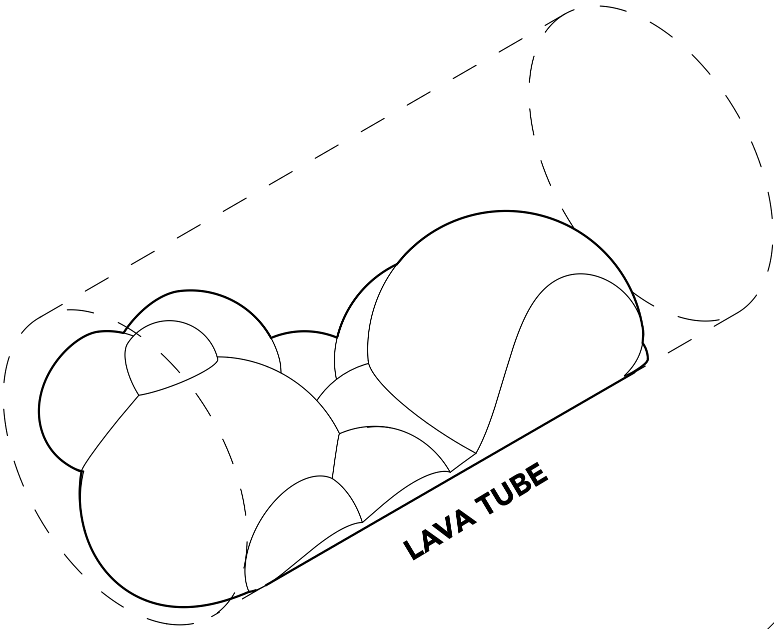
OPTION 2

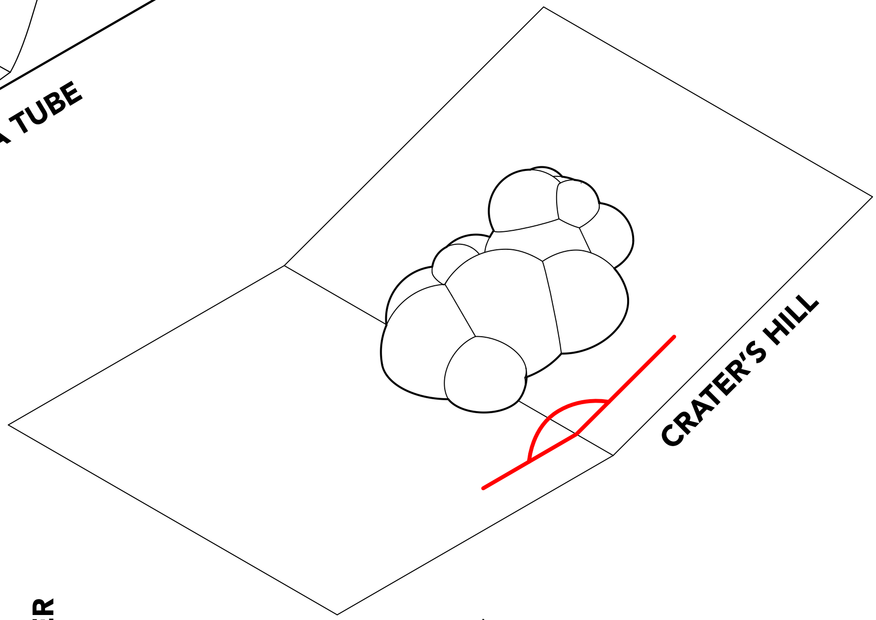
OPTION N

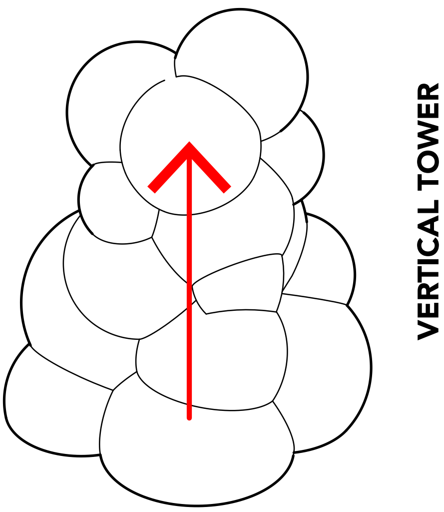


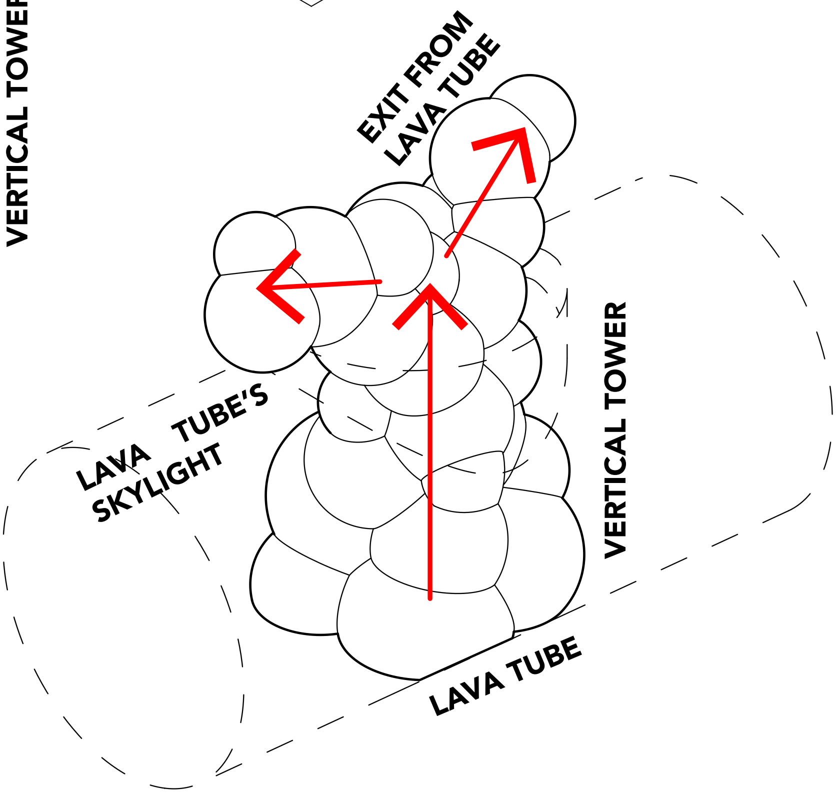
SPACE FILLER

Bubble Idea is also a way to create enclosed, pressurized space that adapts to different environmental conditions. Would it be a lava tube, the hills of the crater or just the ever-changing face of dunes, a constellation of bubbles can adapt to the given landscape.









CONSTRUCTION TECHNIQUE

If we look more closely at the example of the reaction between Mentos and Soda, we can see that liquid in the bottle is only a substrate for the Carbon Dioxide and the surface of the Mentos candy in this reaction. The outer surface of the foam is a soda that encloses tiny bubbles of the CO2 released during the process. So, the reaction is created by the interaction of the Mentos itself with the CO2 dissolved in the Soda, while the liquid serves as the material for the outer shell. [7]

It is possible to create a similar reaction using other reagents. For example, it could be Citric Acid and Sodium Bicarbonate [8] or any different reaction that, in the end, would create a cloud of gas that will inflate the bubble.

The reaction itself will need to happen in a substrate, liquid, or rigid that will serve as the material for the outer shell of the bubble. It can be a polymer, but for it to expand, it will need a higher temperature than is available on the surface of Mars. So the reaction should be exothermic (producing heat during the process).

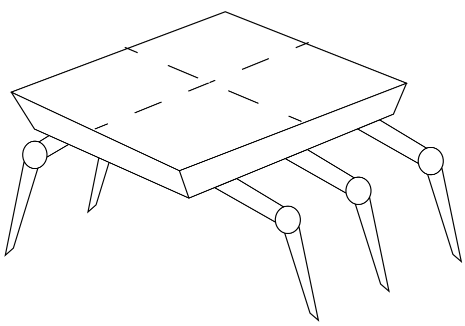
Afterward, the material should stabilize itself.

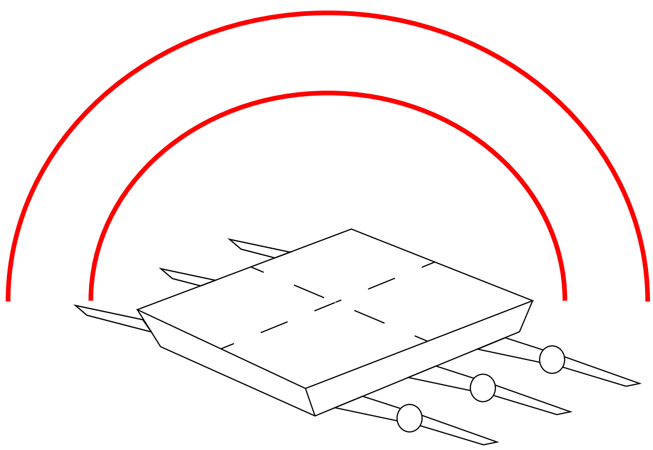
One of the possible applications for it in the Martian environment would be using walking drones that will be able to crawl in hard-reaching environments such as lava tubes or on top of another bubble.

It can contain inside Martian Polymeric Soda that will serve as one of the reagents and at the same time as a substrate, and also a critical quantity of the Martian 'Mentos' that will react with Soda after triggering the start mechanism. After 'Mentos' are realized, those kamikaze drones will explode during the reaction.

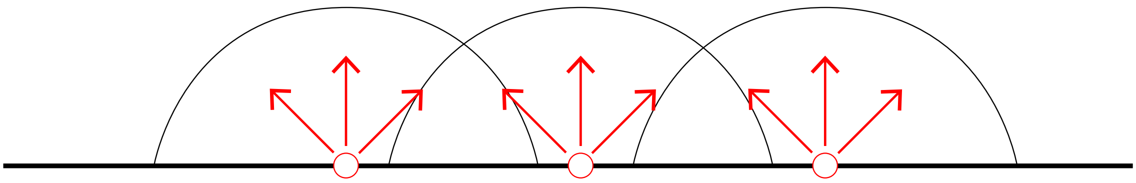
7 Lucy Bell-Young, 2021, 'Why Do Mentos React with Coca-Cola' accessed on 01.07.2022 on: www.reagent.co.uk/why-do-mentos-react-with-coca-cola/

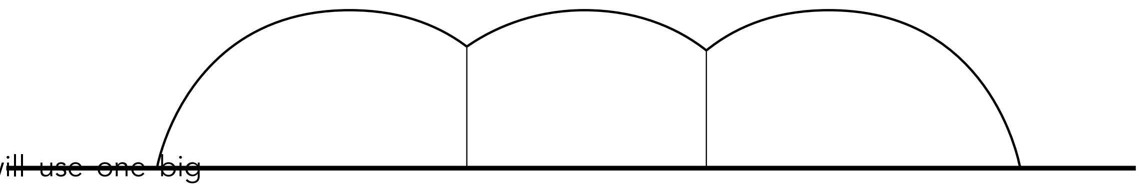
8 Webb, Penelope; Sumini, Valentina; Golan, Amos; Ishii, Hiroshi (2019). [ACM Press Extended Abstracts of the 2019 CHI Conference - Glasgow, Scotland Uk (2019.05.04-2019.05.09)] Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems - CHI EA '19 - Auto-Inflatables. , (), 1–6.



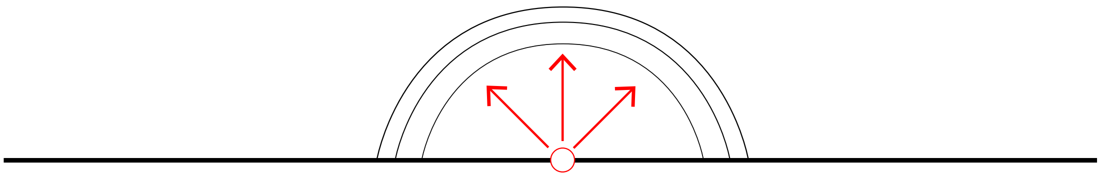


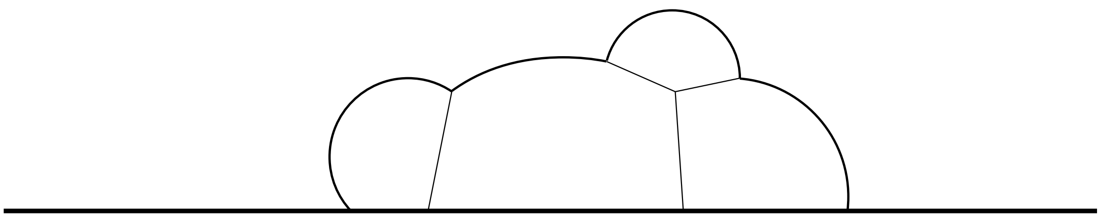
There are few hypothetical possible applications of this technique. One of the options would use several drones that, after the release of "Mentos," will create separate bubbles each. If triggered simultaneously, it can create a vertical wall between bubbles.



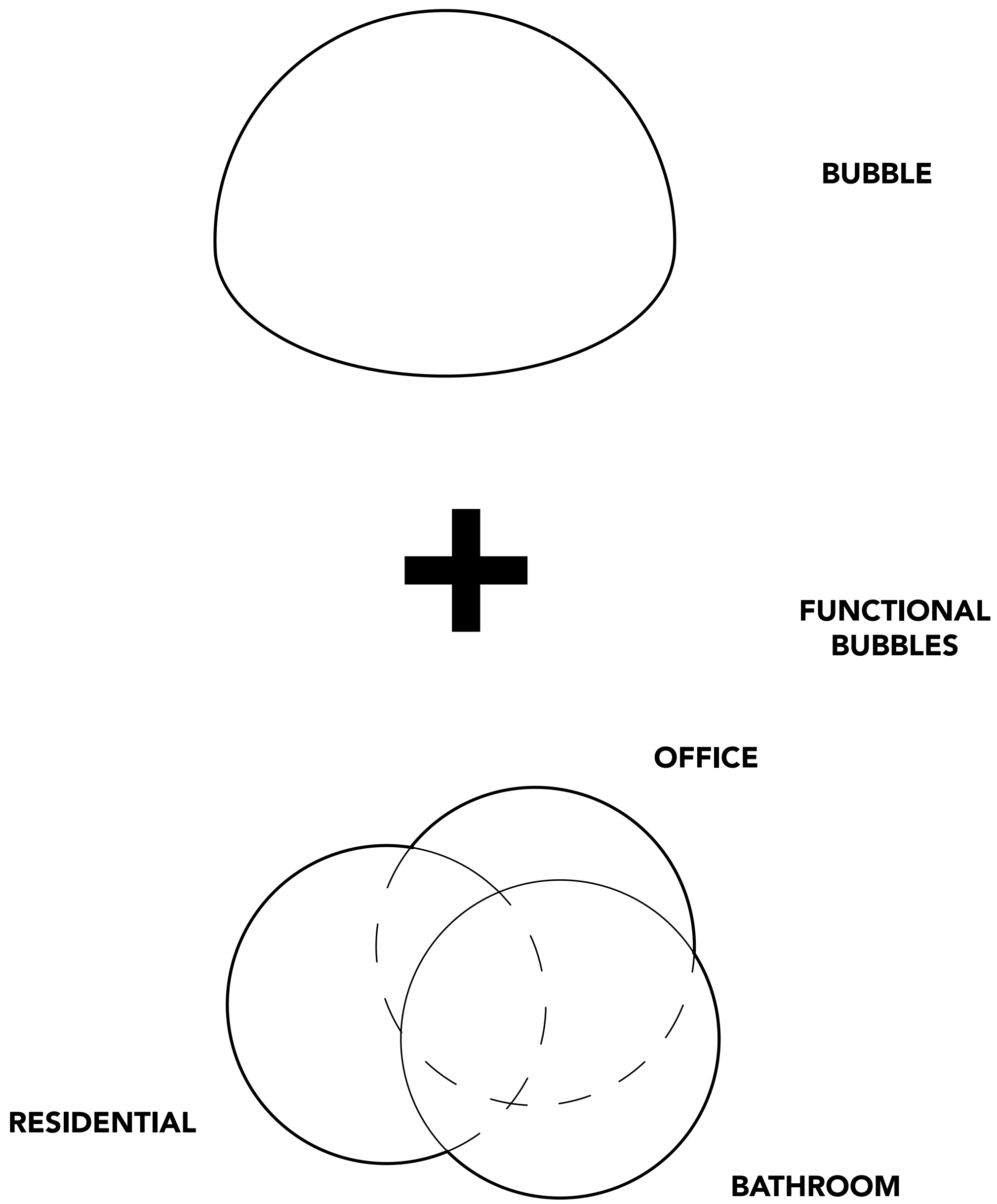


Another option will use one big kamikaze drone that will create not one bubble but a constellation with random enclosed space that will need to be discovered and inhabited accordingly to the form and dimensions of the given bubble.



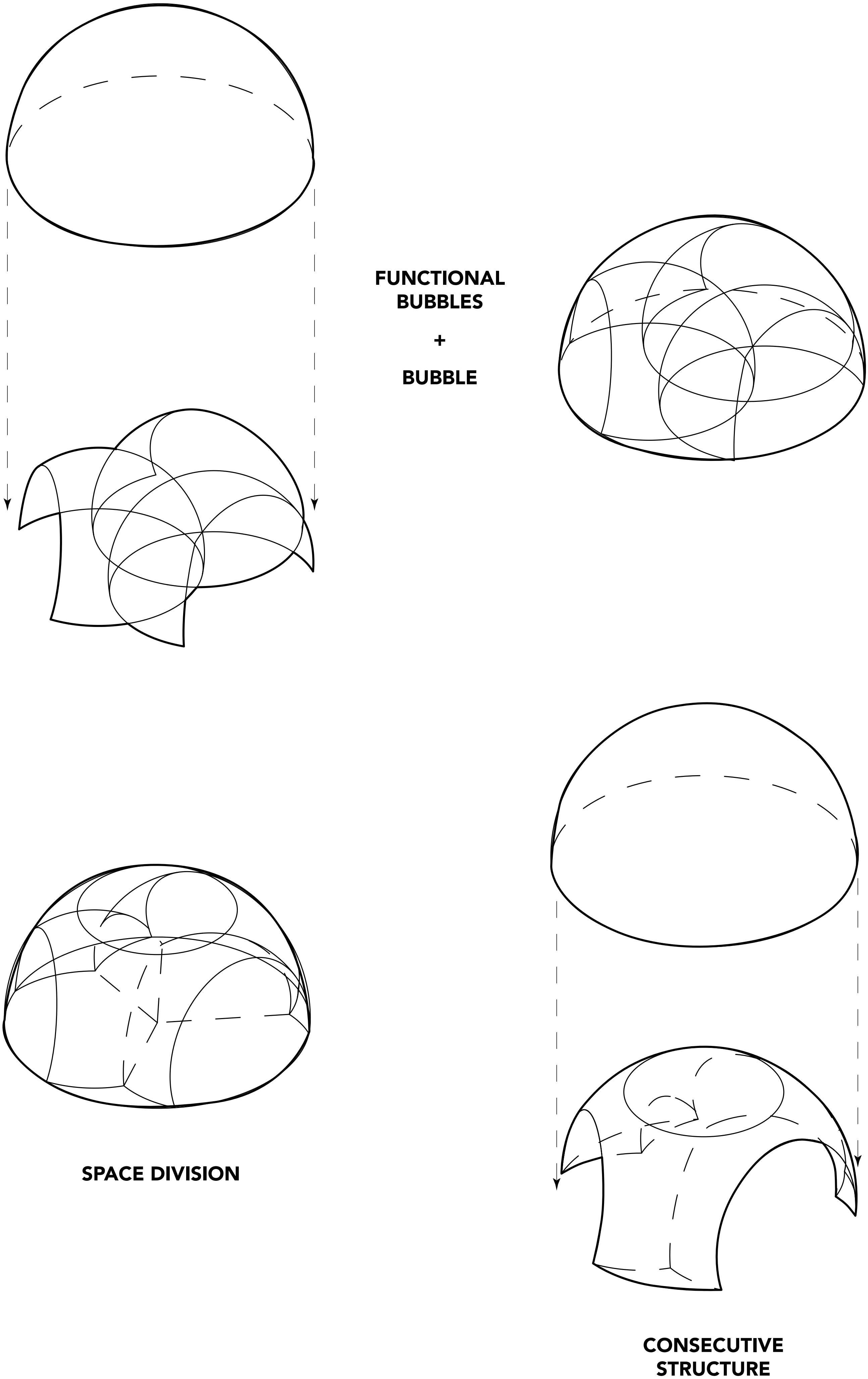


SPACE DIVISION

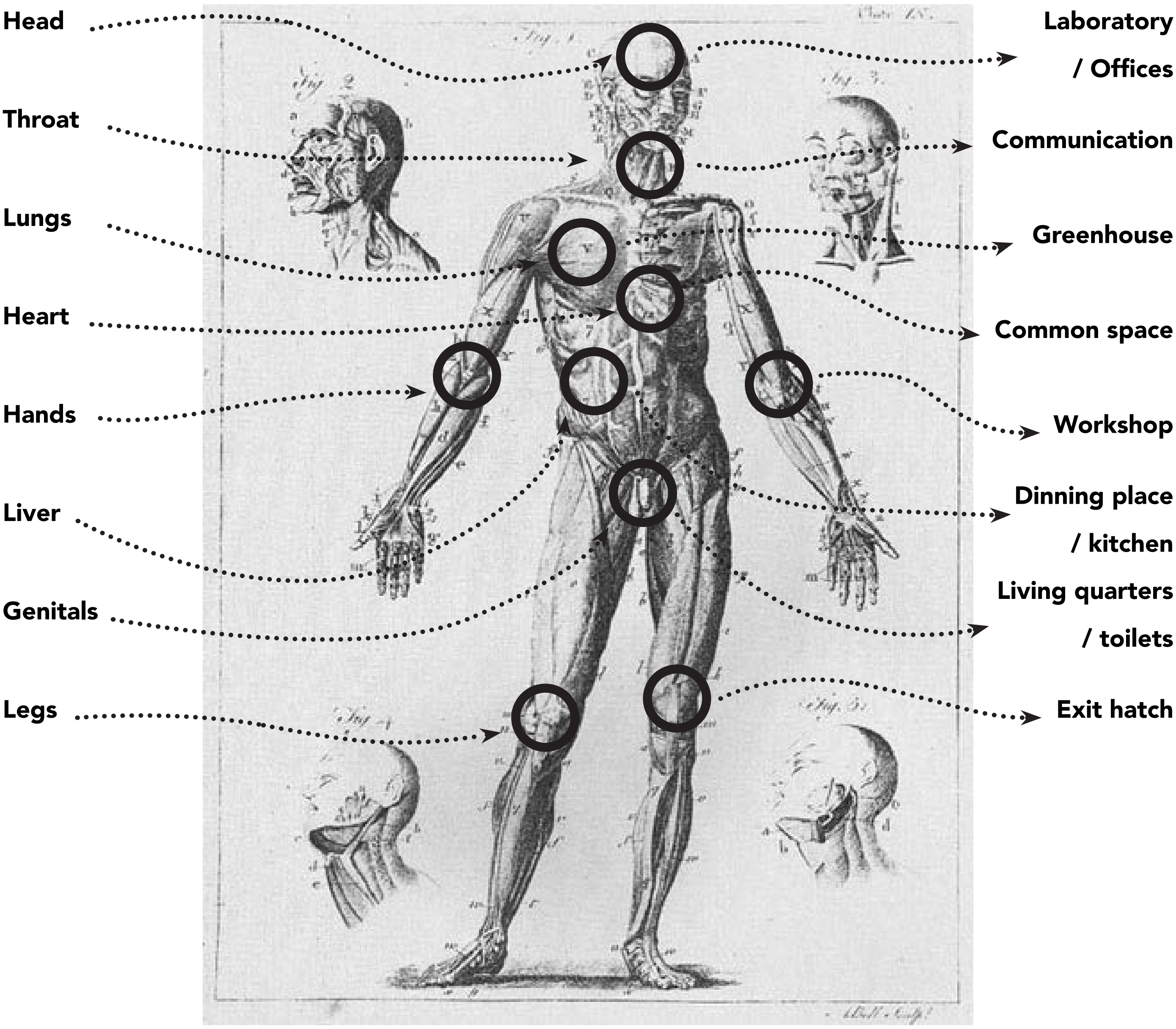


A dome-like space without defined dimensions and particular form will need an adaptable space division that can be automatized and applied to different rooms.

The space division concept uses the same idea of bubbles but now to define a sphere for particular activity inside the already formed cluster.


FUNCTIONAL BUBBLES
+
BUBBLE
SPACE DIVISION
CONSECUTIVE STRUCTURE

HUMAN REFERENCE



Martian human settlement will be isolated from the Earth's supply chain, so having to rely only on a delivered with crew resources or, ideally, totally self-sustain.

Reminding the self-sustained organism analog of which can be a human body.

GROWING AN INTERIOR

The safe and warm interior of the Martian habitat will be the principal place where the future astronauts will live.

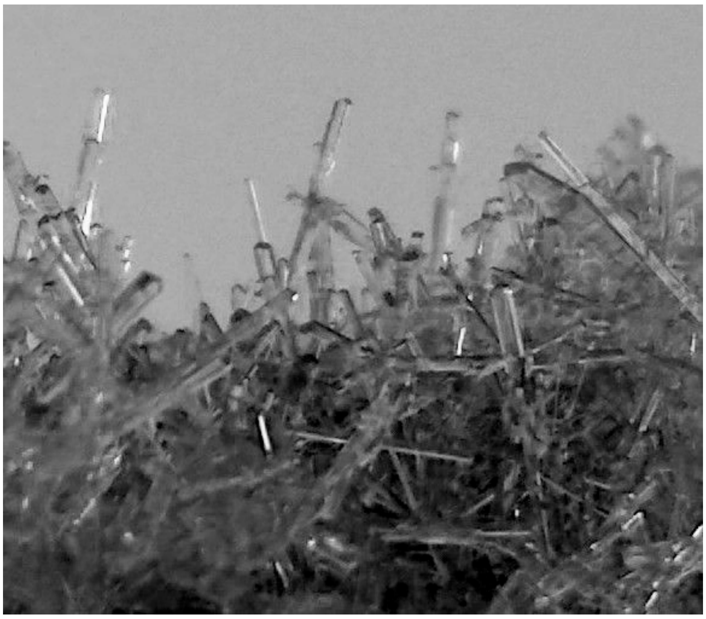
The question is how to create a human environment expressing chaotic human nature and not sterile hospital-like rooms.

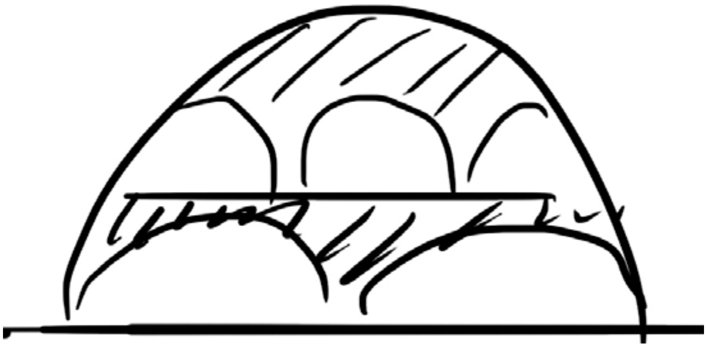
What material and technique would support such an environment and, simultaneously, be simple enough to maintain and less sensitive to the laboratory conditions.

It could be related to the crystal growing when the elements (carbon, for example) are absorbed from the environment into a crystal-like structure.

Another option could be using mushrooms or bamboo as a building material, naturally growing but led by artificial intelligence and robots that it controls.

The question would be the use of it in the laboratory, where the environment should be clean from any sign of the Earth's life.



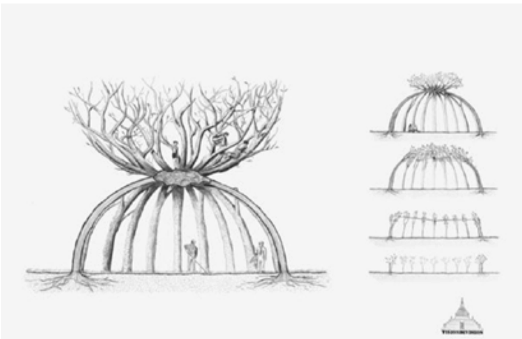


STRUCTURE

The structure of the interior spaces adopts the idea of growing it from the local soil resources with needed additives and nutrition. Then, after the system is developed and carefully led into its form by automated machines, nutrition can be gradually taken away to consolidate the grown structure.

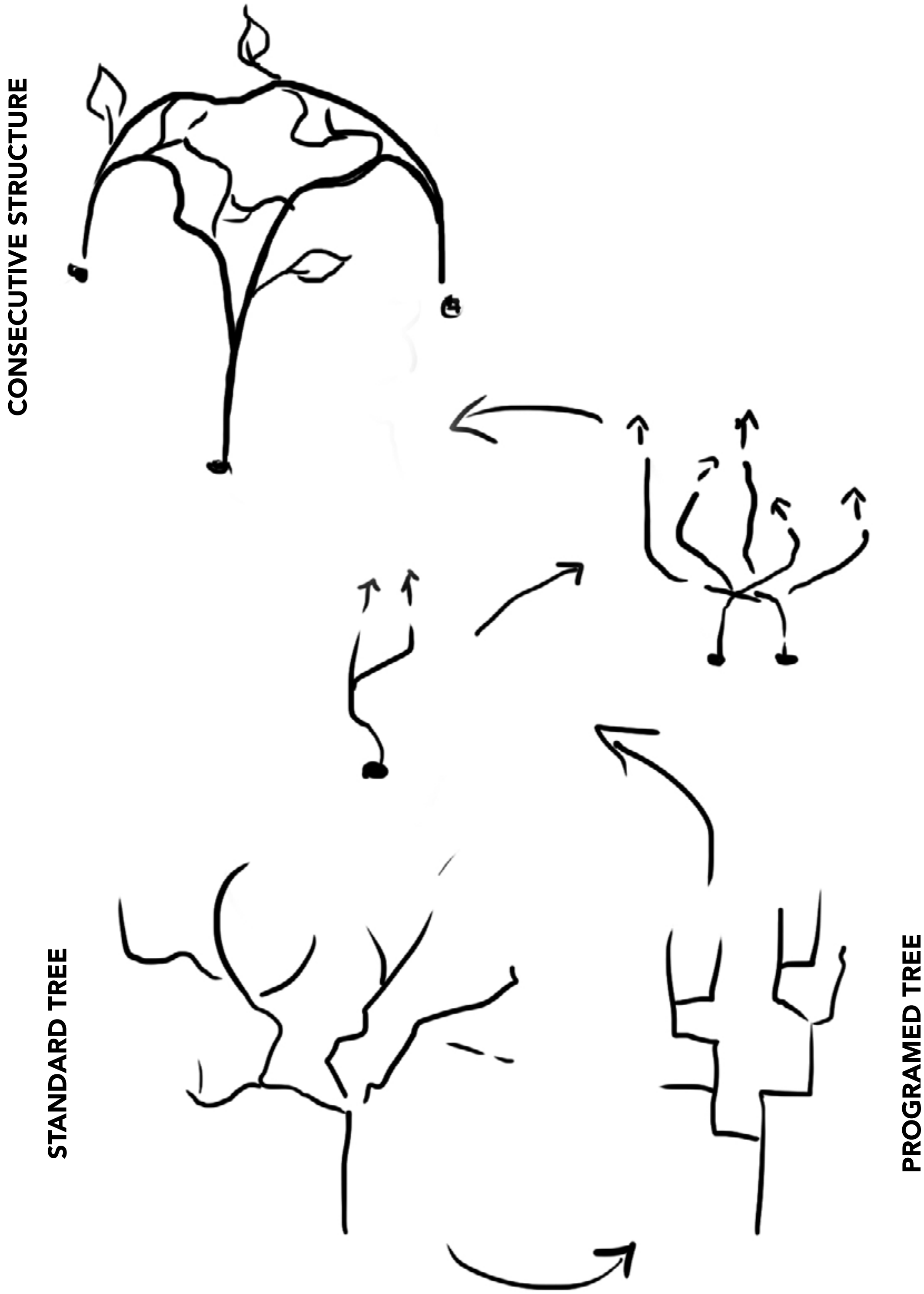
Then the space between branches and around open walls can be filled with substrate infected by mycelium, creating a proper insulation layer. Then after reaching its desirable thickness, mycelium should be consolidated as well [9].

9 Vallas, Thomas; Courard, Luc (2017). Using nature in architecture: Building a living house with mycelium and trees. Frontiers of Architectural Research, S2095263517300353–.

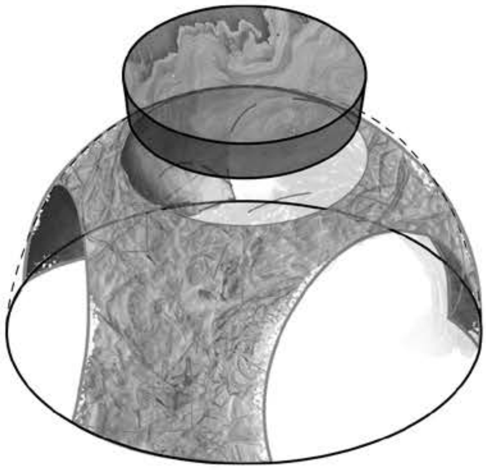


This way, the proper In-Situ Resource Utilization will be achieved, decreasing the delivery mass significantly. It also will contribute to the bibliophile and diversity of the habitat spaces, potentially reducing psychological stress due to isolation and confinement.

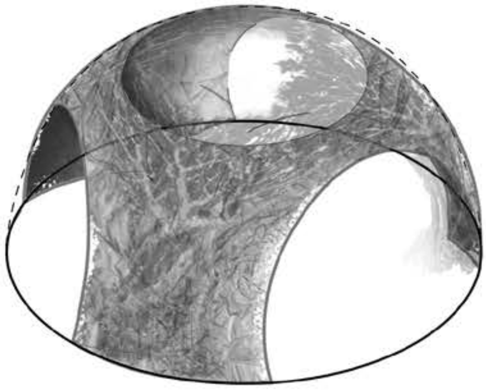
The question here would be how to create a good base or substrate from which the tree structure will grow and how to protect the inflated bubble from the potential damage from the tree's root system or mycelium growth.



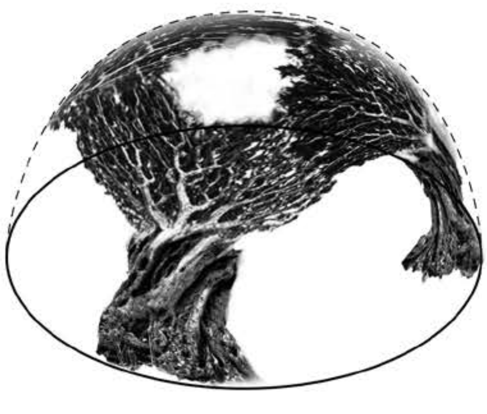
TREES PROGRAMING



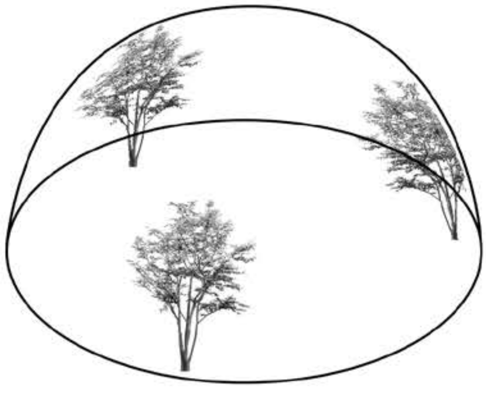
ALGAE SOLAR WELL?



MYCELIUM INTEGRATION



STRUCTURE STABILIZATION

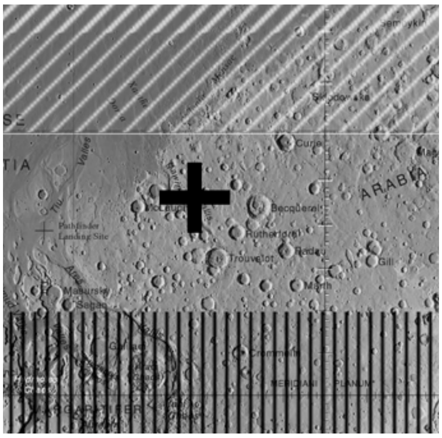


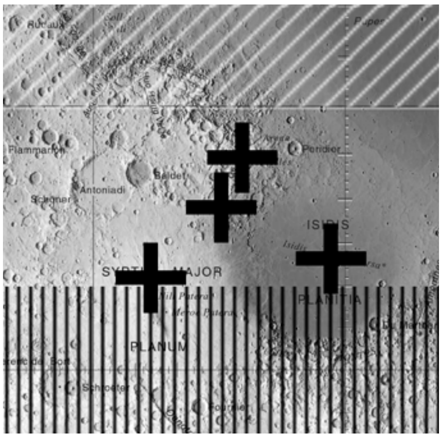
TREES PLANTING

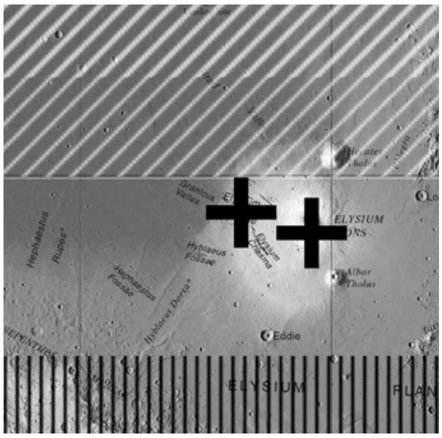
PROJECT DEVELOPMENT

From the list of possible sites for a potential human outpost on Mars, three candidates have the most potential to support human activities and have significant research potential. But to finally decide the most appropriate one, the main reason and target for the mission should be defined. As for a research purpose, the site with the most potential should be chosen. For example, a Jezero crater, where now the Mars 2020 mission landed with the Perseverance rover, or it could be Mavrth Vallis, with the extensive reserve of clay and sediment materials, has the potential for a search for life purpose.

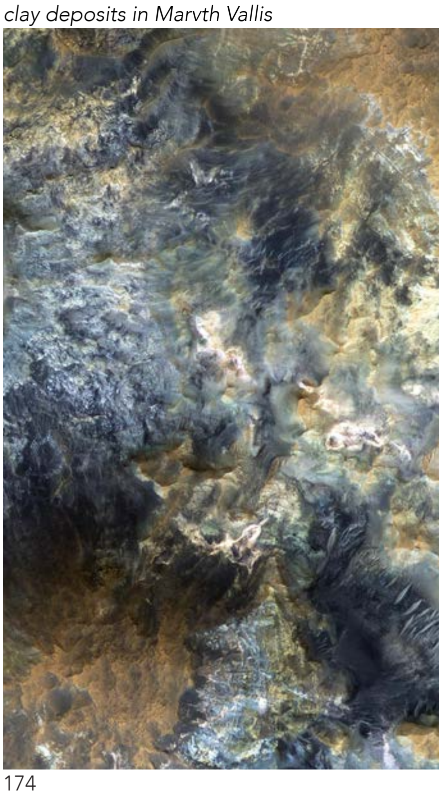
While the Elysium Fossae propose good conditions for developing the human outpost in terms of water ice and lava tube availability, it is a more modest site compared to the other two regarding research potential. Additionally, despite an extensive area and rich volcanic landscape, it seems to be isolated from other potentially interesting sites in proximity. Simultaneously, the rich volcanic landscape that makes it distinctive from other candidates makes it more dangerous for a landing.



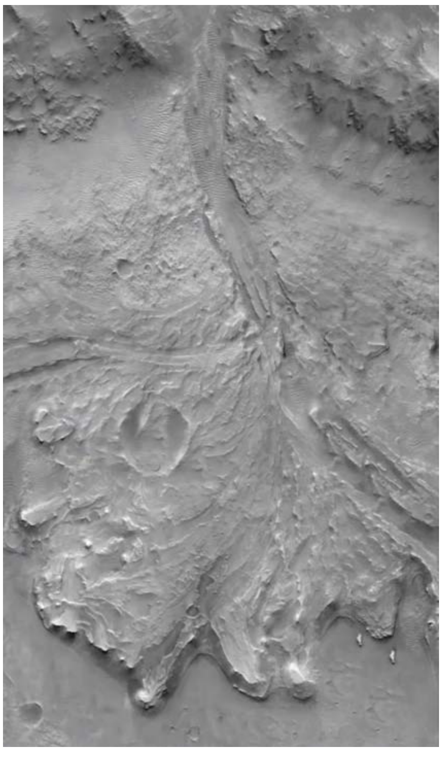




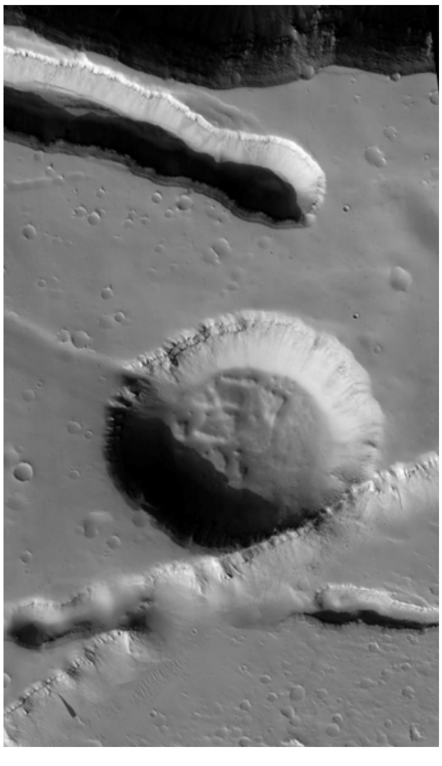
Extensive colorful variety of the clay deposits in Marvth Vallis

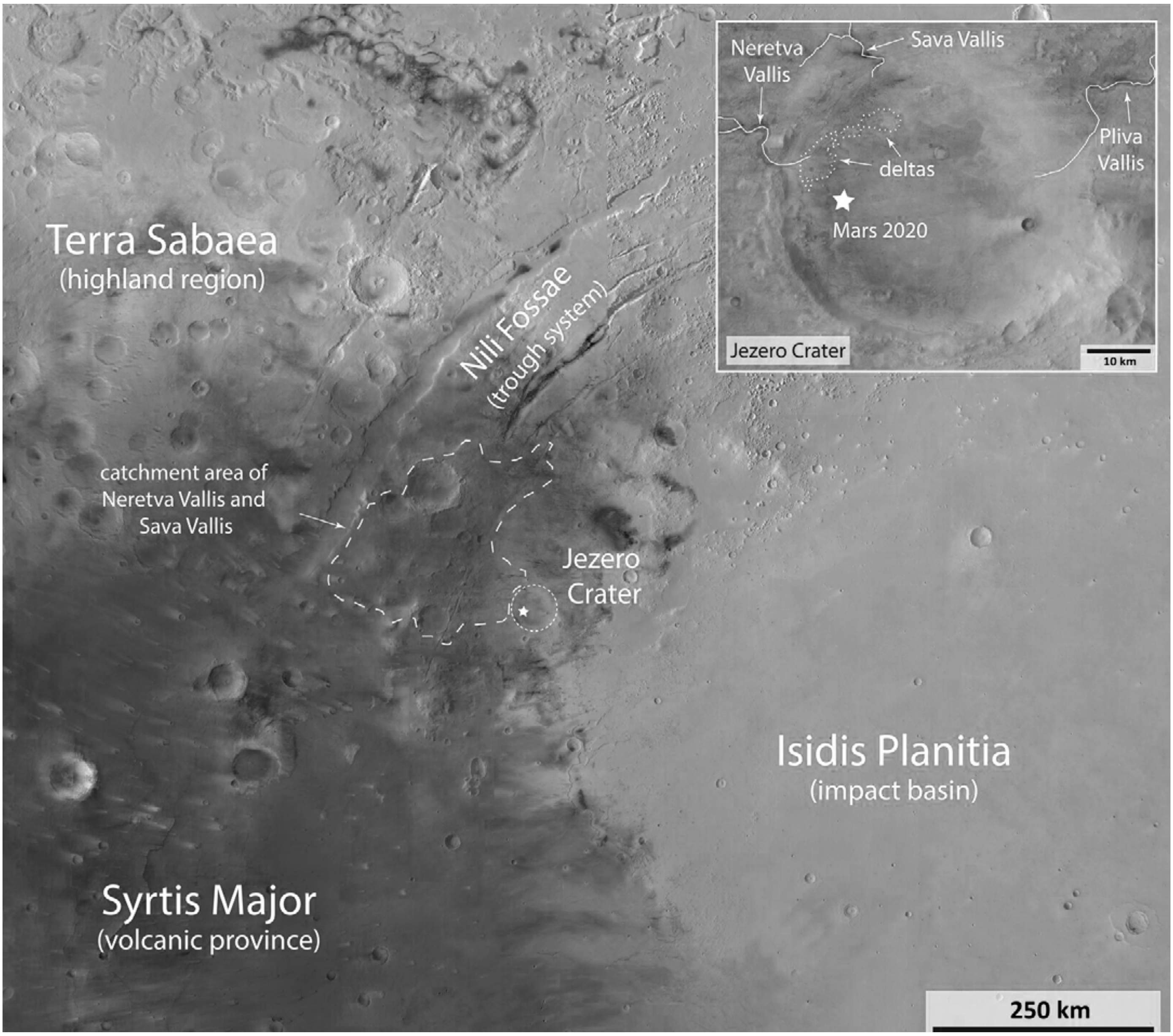


Big river delta on the hills of Jazero Crater (Mars 2020 landing site)



Volcanic and erosion landscape features of Ellysium Fossae





Jazero Crater in Context

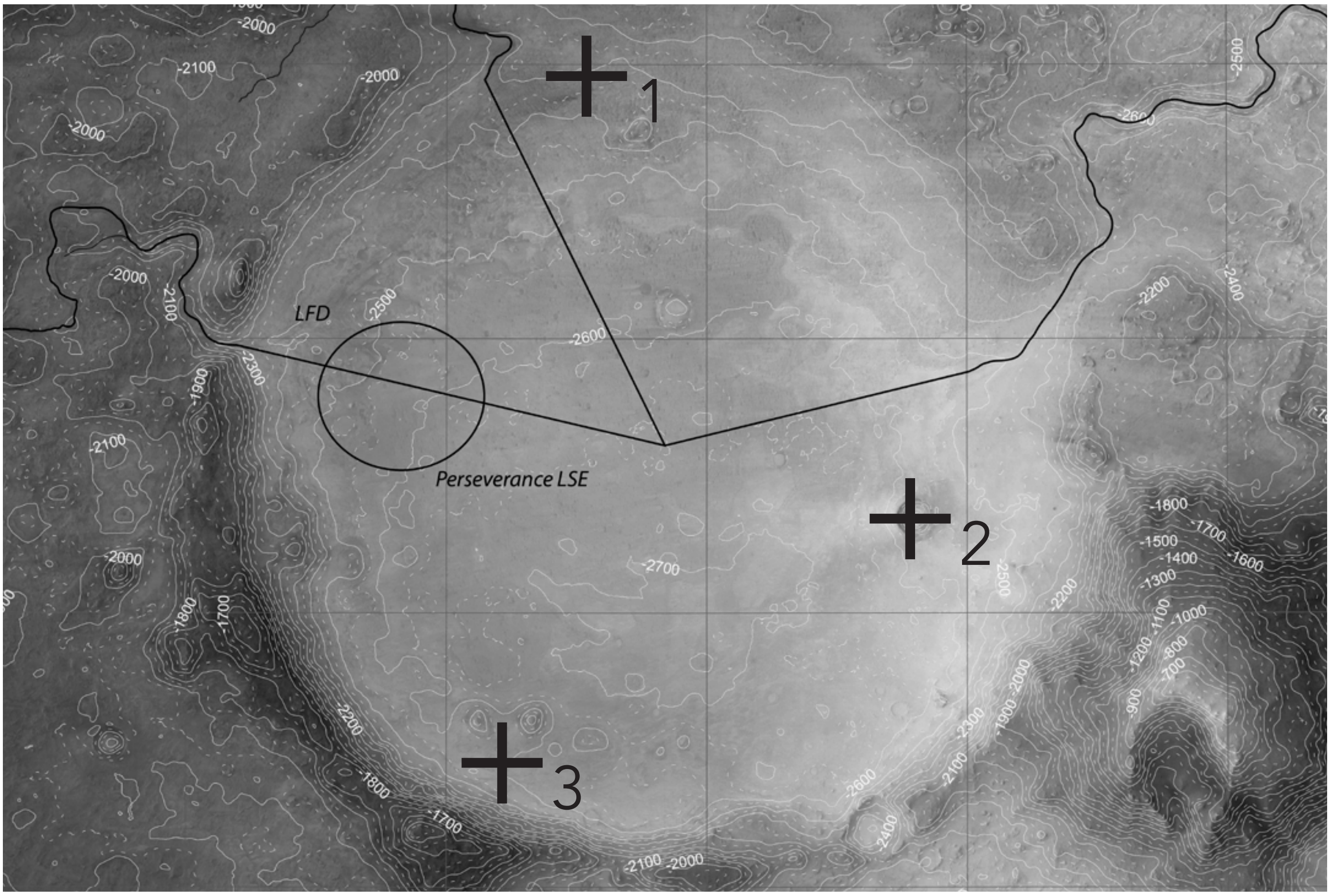
The decision for a Jezero Crater to be a Perseverance landing site had several advantages over other options[10]. As for the potential human outpost site, it has a particular advantage in the context where the crater is situated. In South West, it is a giant volcanic area with the potential for a lava tube to be found for geological research. Jezero is also between the highlands of Terra Sabaea and the basin of Isidis Planitia, which allows studying different contexts and exploring the planet's history from various perspectives.

All distances between mentioned area exceed 400 km, which makes it accessible only for multi-day expeditions. Therefore, a proper mobility infrastructure becomes a priority for the outpost.

The decision of the Jezero crater for a site for a human outpost, in the context of the thesis, was chosen because of the extensive availability of the research material, landscape photos, and analysis.

But it does not mean that other potential sites are less valuable. On the contrary, the chosen location seems more suitable for the study.

10 "Jezero Crater through the Eyes of the Mars Express" The European Space Agency, esa.int, 16.02.2021, Retrieved on 11.07.2021 at: www.esa.int/Science_Exploration/Space_Science/Mars_Express/Jezero_crater_through_the_eyes_of_Mars_Express



Site 1 has a hill of about 2km on its South side, while also being sited between the northern ridge of the crater makes it optimal in terms of the wind speed and dust contamination. At the same time, the vicinity of the ancient river delta makes it more plausible for research opportunities.

2nd site is inside an impact crater, protecting it from all sides by the hills of the crater. But the unstable conditions of the crater ridge make it undesirable from a mobility support point of view.

The 3rd site is situated in the southwest part of the crater, it is well protected from any wind by the southern flank of the Jezero crater and mild hills in the North of the site. However, it is blocked and isolated by the steep crater ridge making it less comfortable for outgoing expeditions.

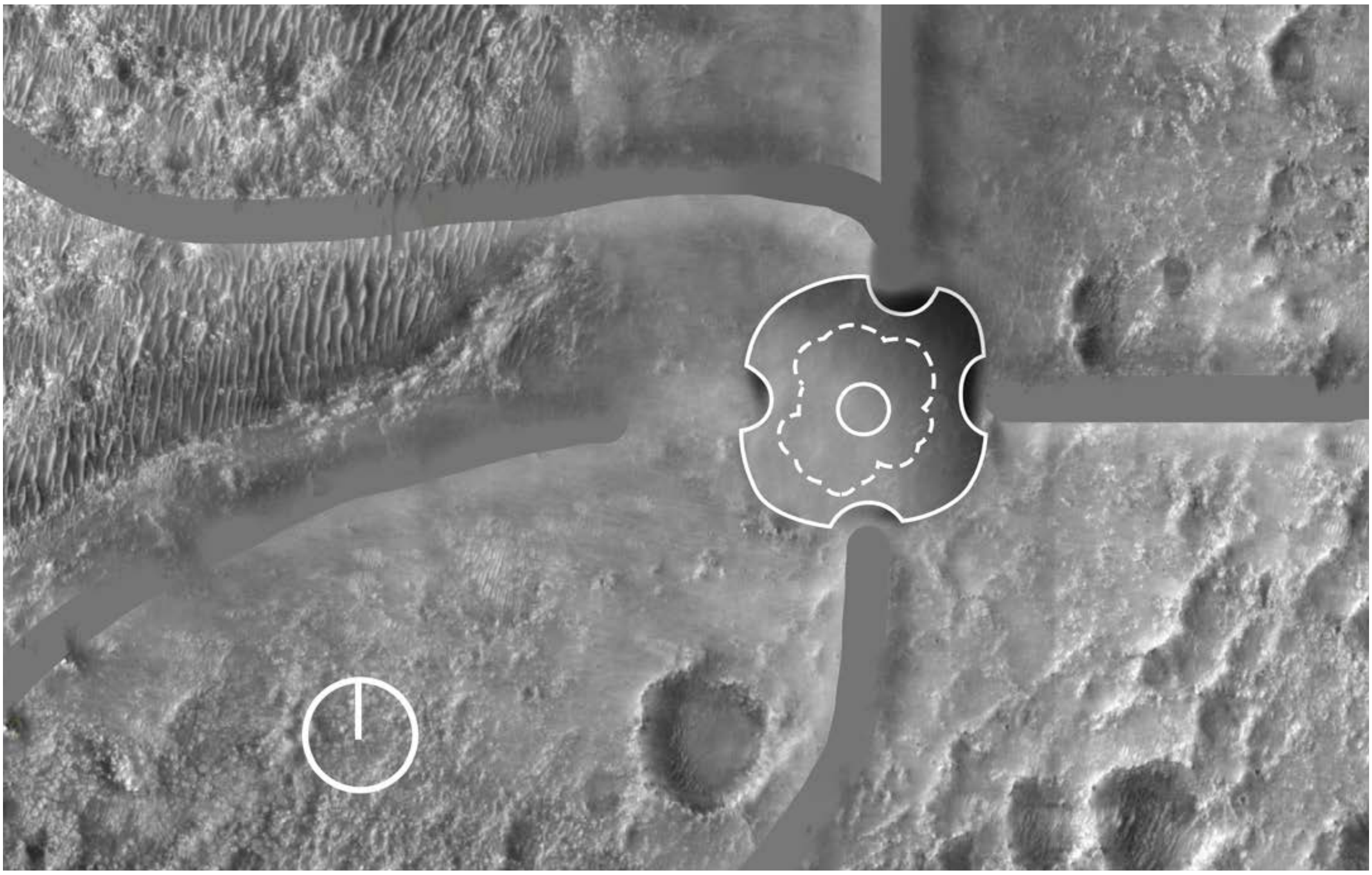
Jezero crater features rough terrain with steep hills on the southwest ridge, a primarily flat (relatively) basin, and a mild North East flank.

Because of the predominant SE and NW winds[11], those directions will need additional protection from dust contamination and dust storms. Unfortunately, few sites in the basin of the Jezero crater can offer such protection by the landscape features.

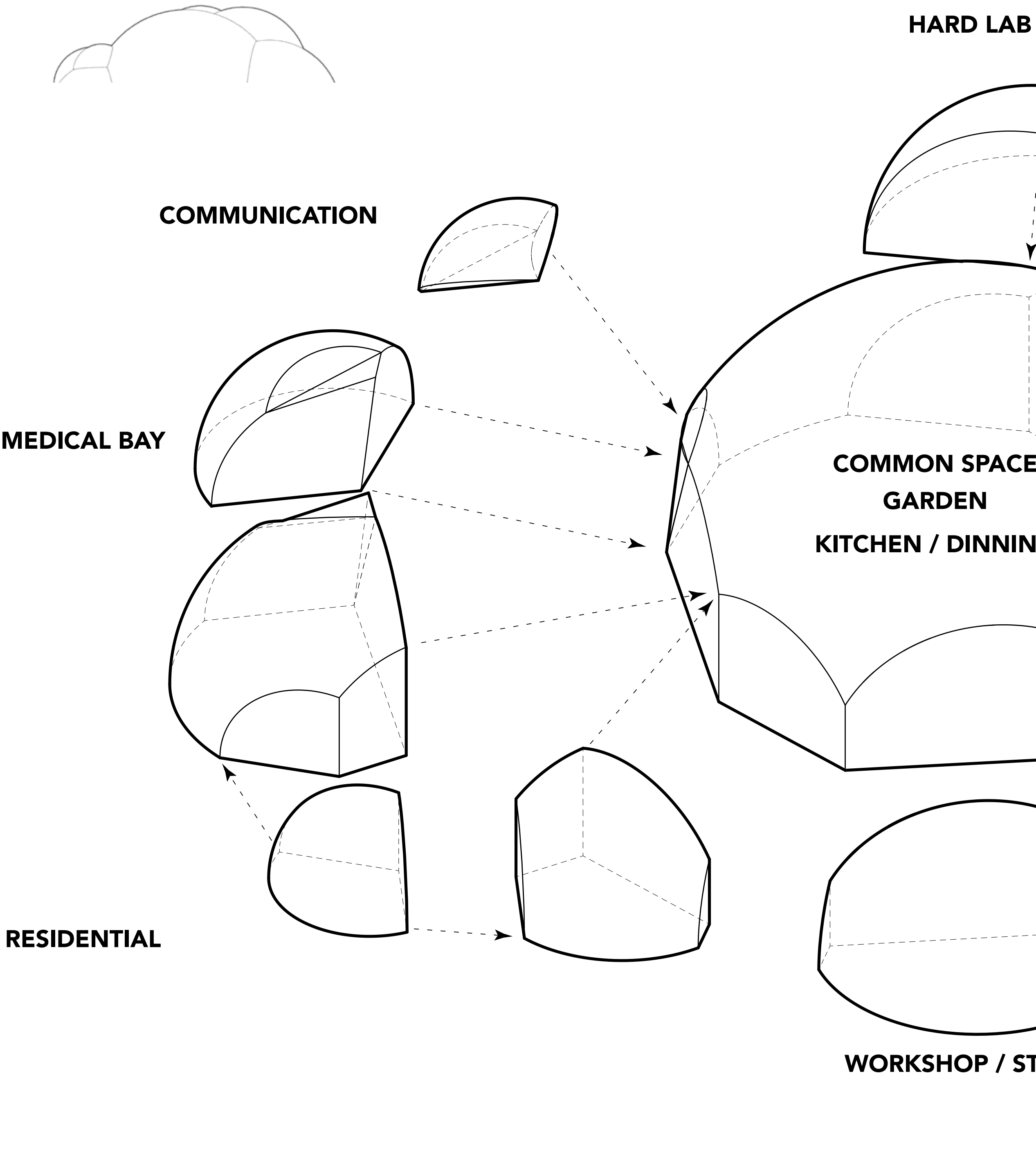
11 J. Pla-García, S. C. R. Rafkin; G. M. Martinez; Á. Vicente-Retortillo, C. E. Newman, H. Savijärvi, M. de la Torre, J. A. Rodriguez-Manfredi, F. Gómez, A. Molina, D. Viúdez-Moreiras, Ari-Matti Harri, "Meteorological Predictions for Mars 2020 Perseverance Rover Landing Site at Jezero Crater", Space Science Review, 2020

Therefore, site n1 would be a good option for the potential human outpost site. However, the habitat should be far from the southern hill to eliminate any possible obstruction to the rocket landing.

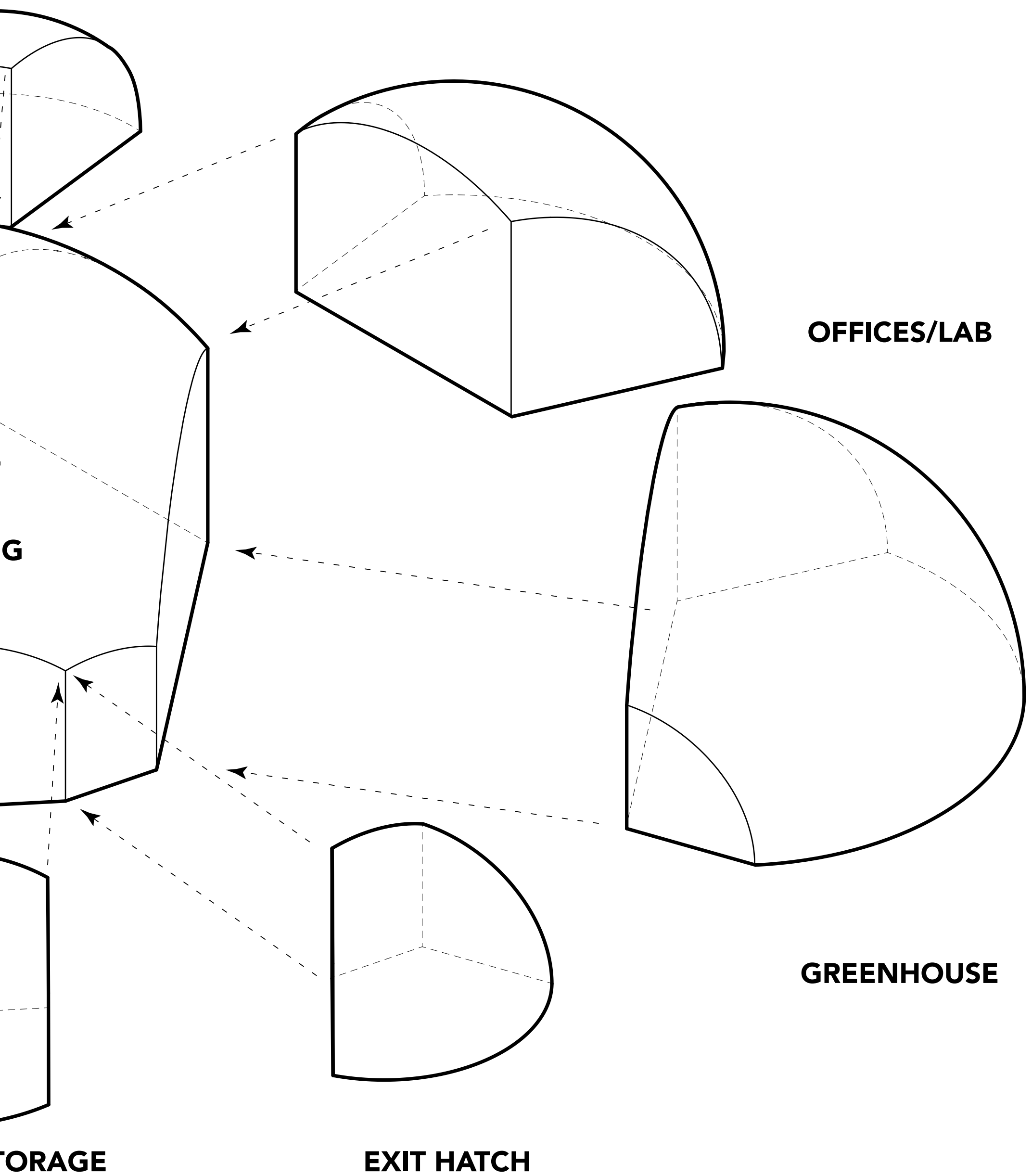
Master Plan



FUNCTIONS

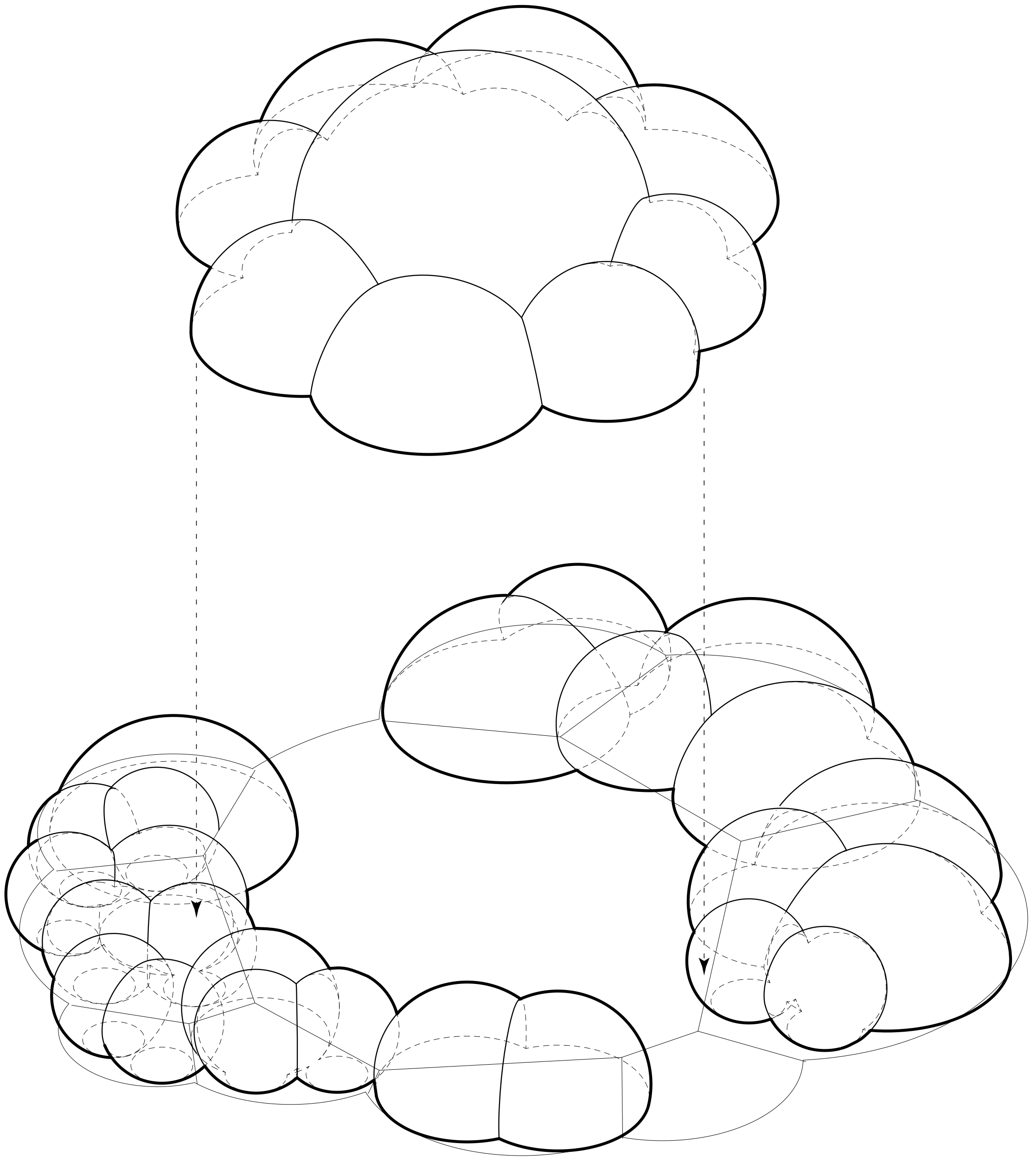


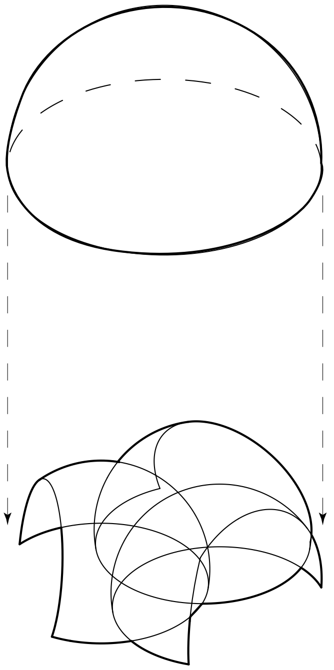
HARD LAB
COMMUNICATION
MEDICAL BAY
COMMON SPACE
GARDEN
KITCHEN / DINNIN
RESIDENTIAL
WORKSHOP / ST


OFFICES/LAB
G
GREENHOUSE
TORAGE
EXIT HATCH

SPACE DIVISION

Following the idea of the space division expressed previously, the habitat environment is shown as a more complex task but simultaneously creates interesting and various spaces.

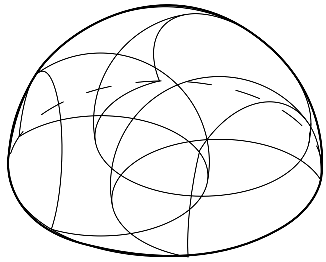


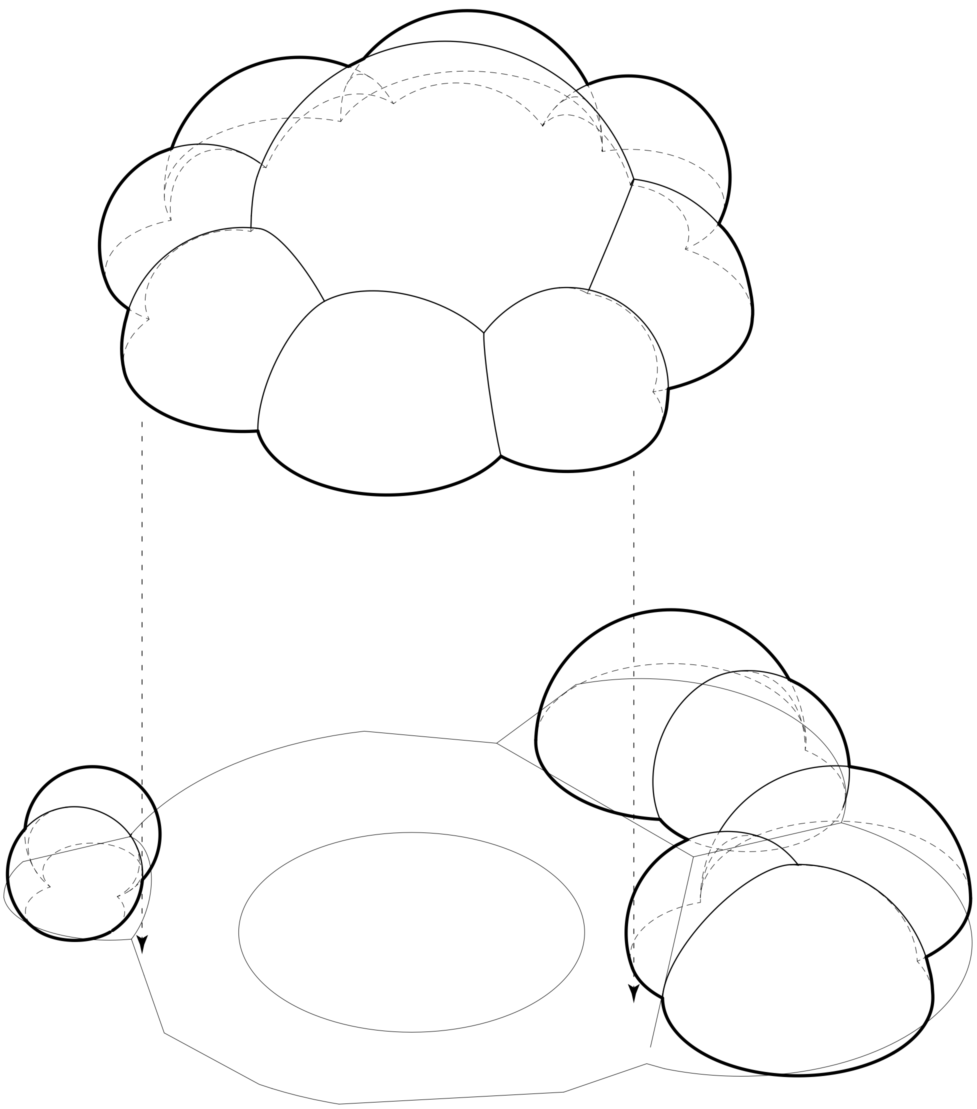


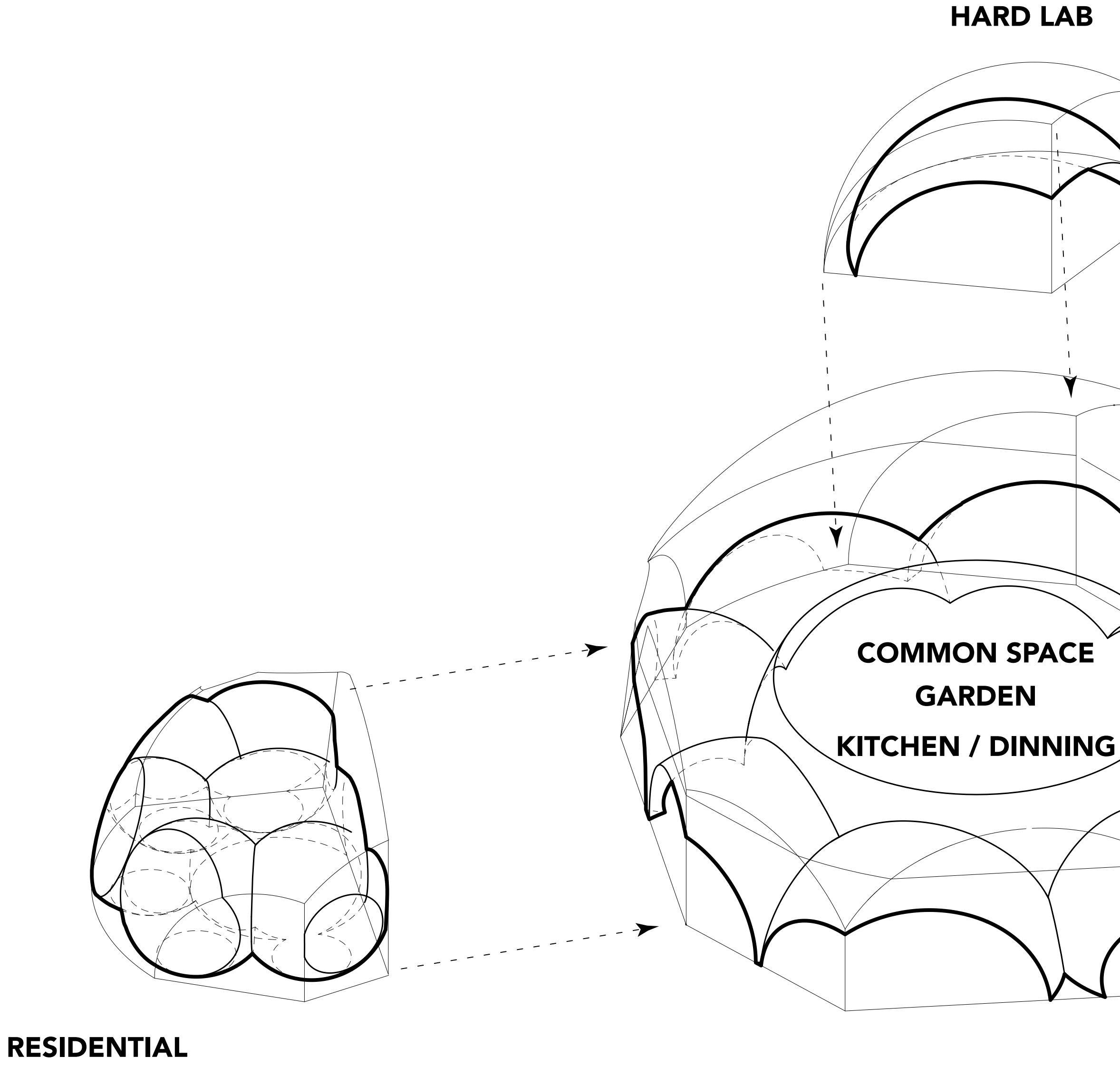
FUNCTIONAL BUBBLES

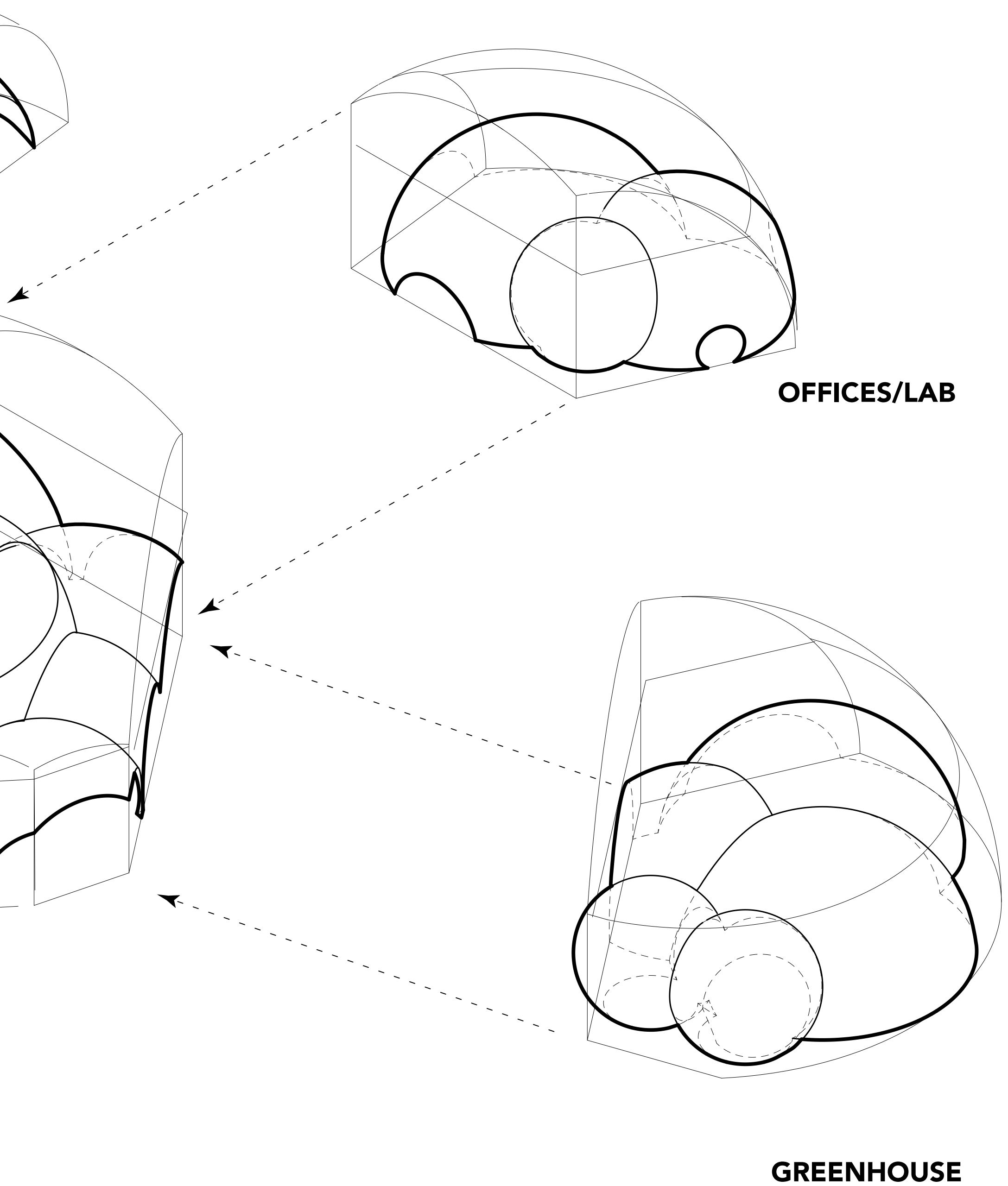
+

BUBBLE

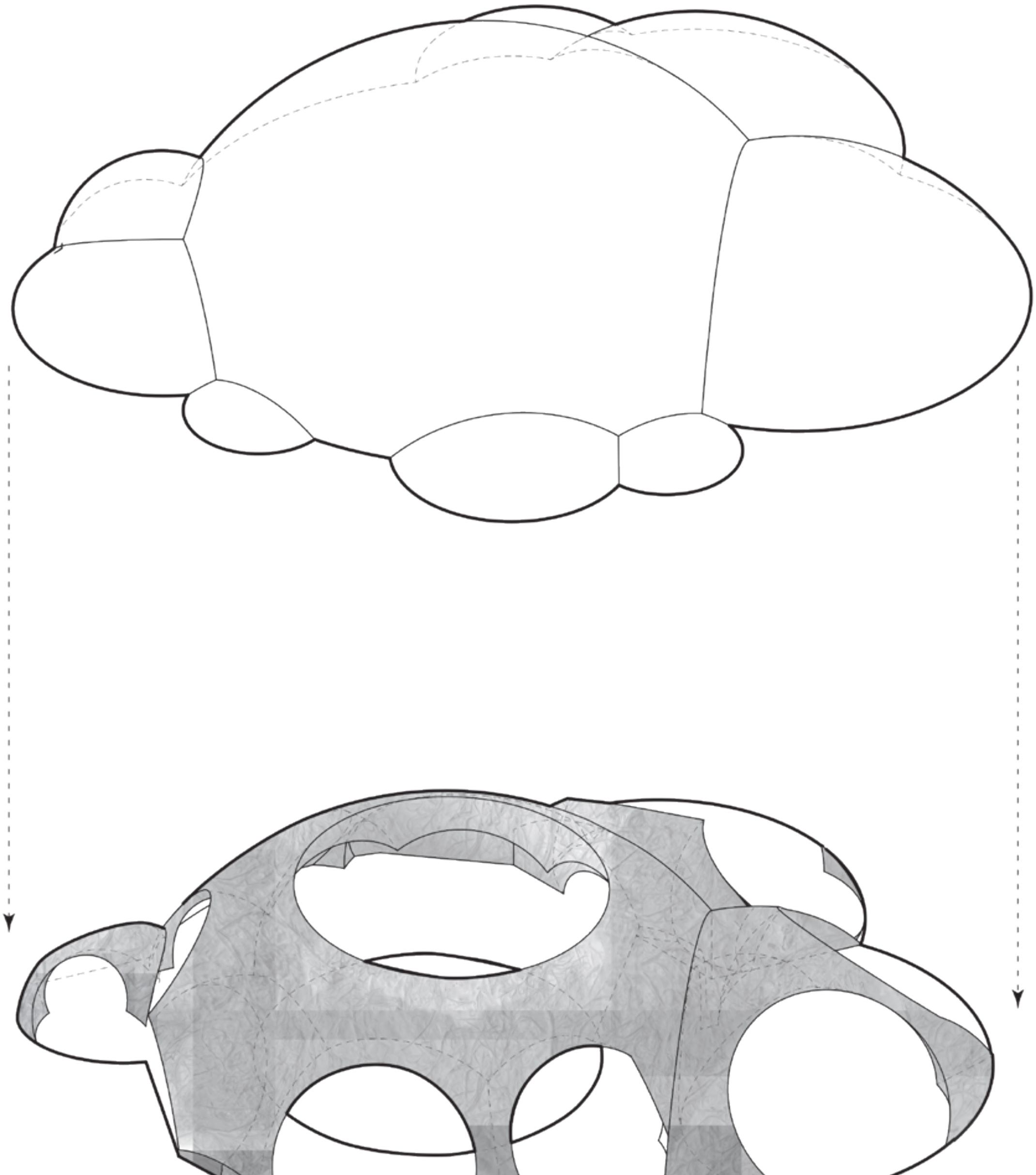


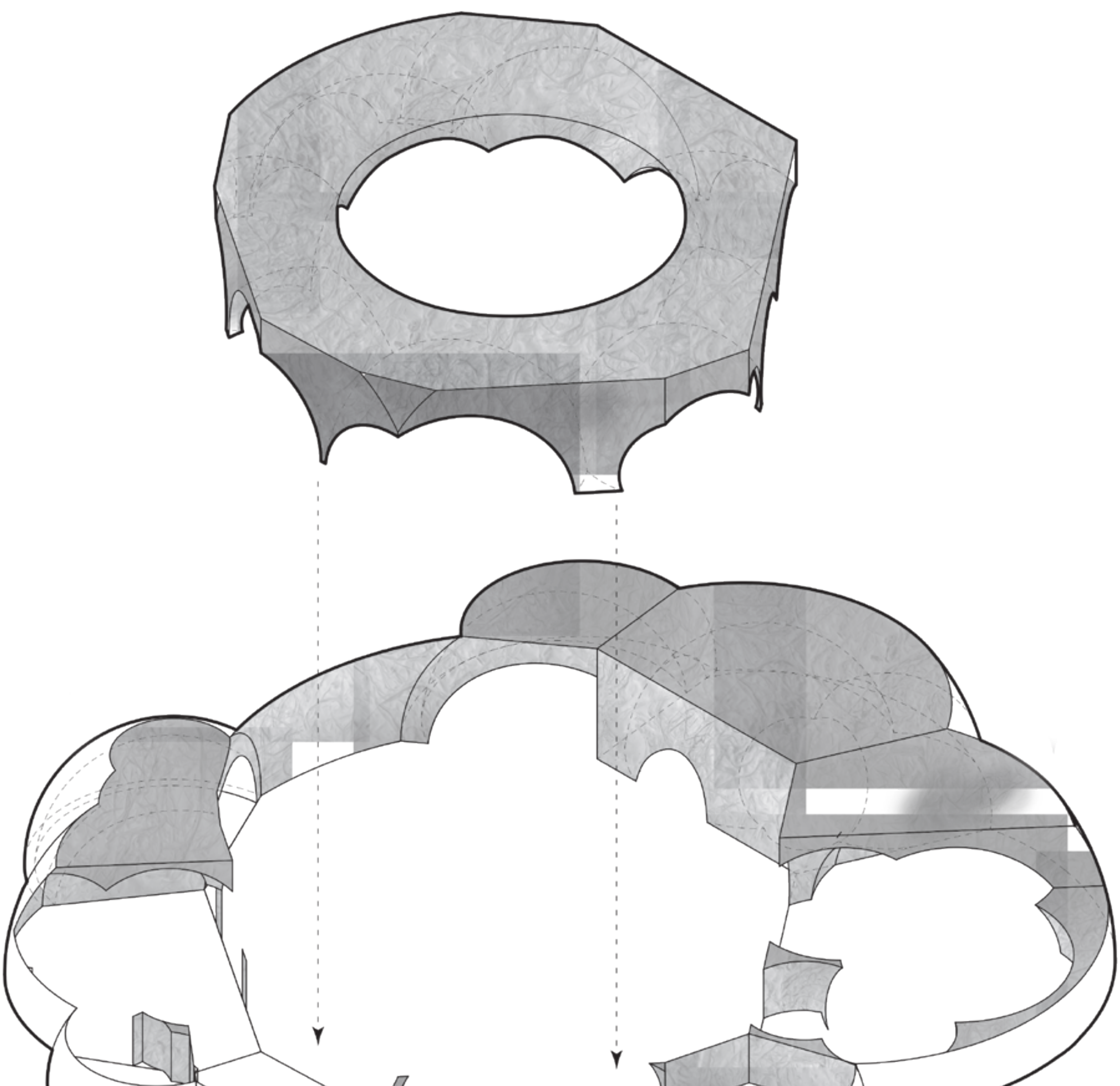



HARD LAB
COMMON SPACE
GARDEN
KITCHEN / DINNING
RESIDENTIAL

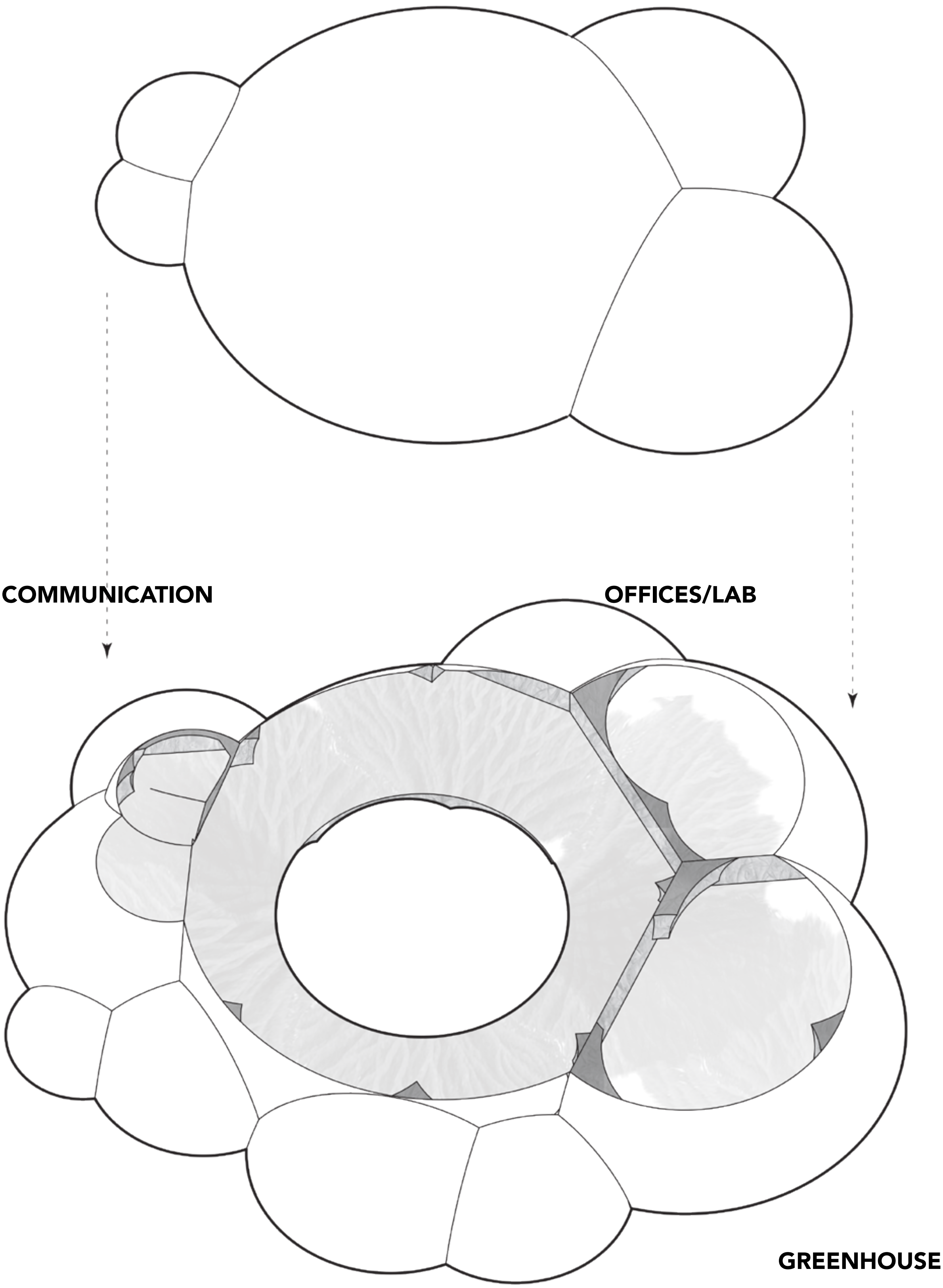

OFFICES/LAB
GREENHOUSE

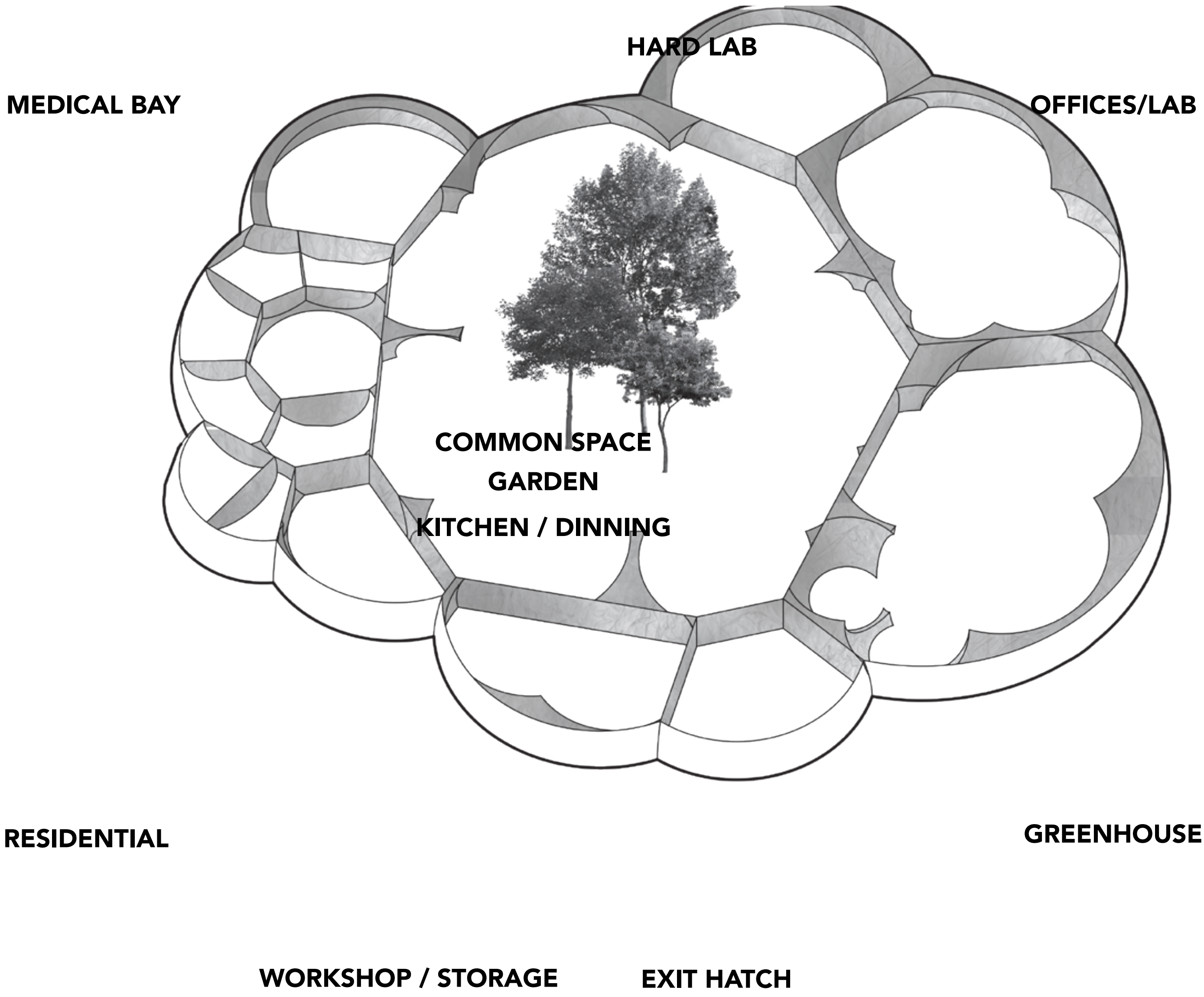
STRUCTURE





FUNCTIONS




HARD LAB
MEDICAL BAY
OFFICES/LAB
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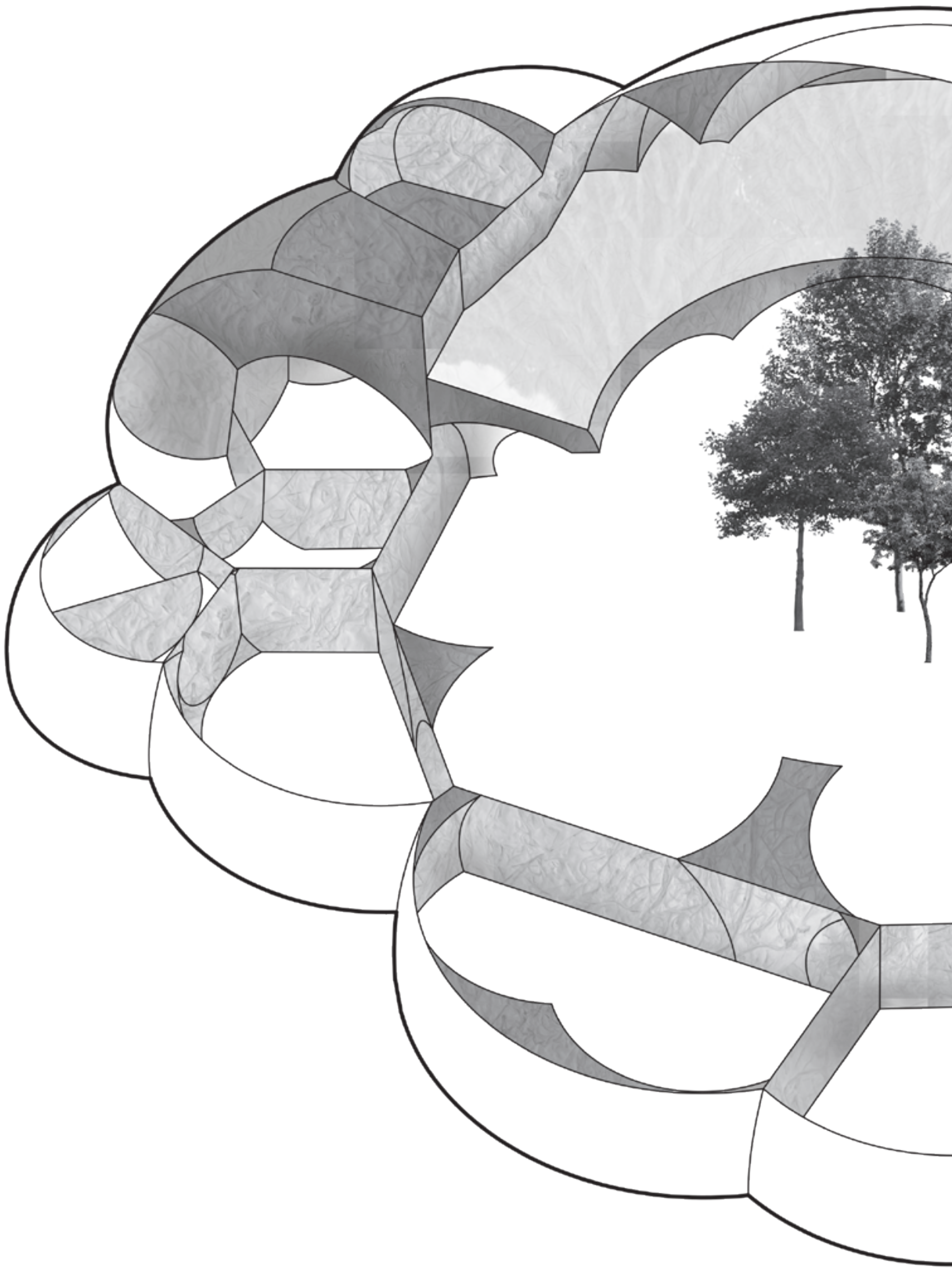
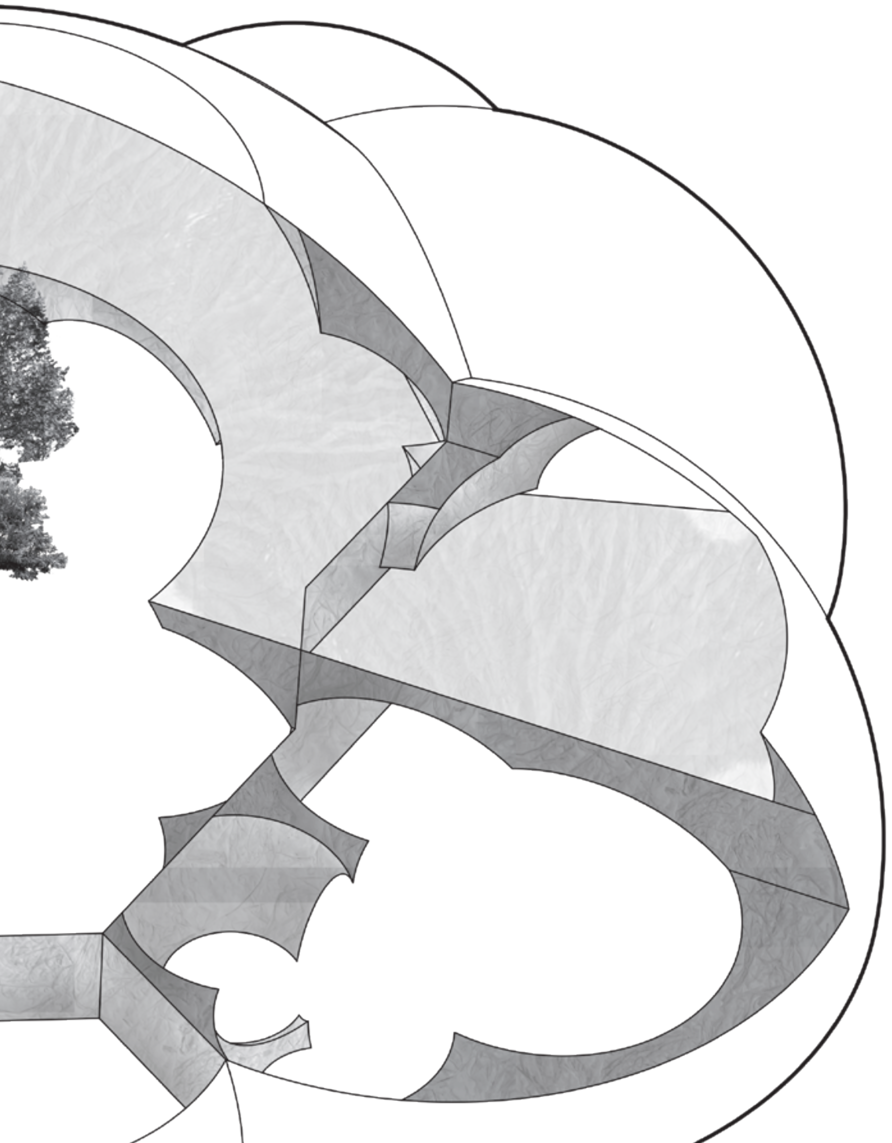
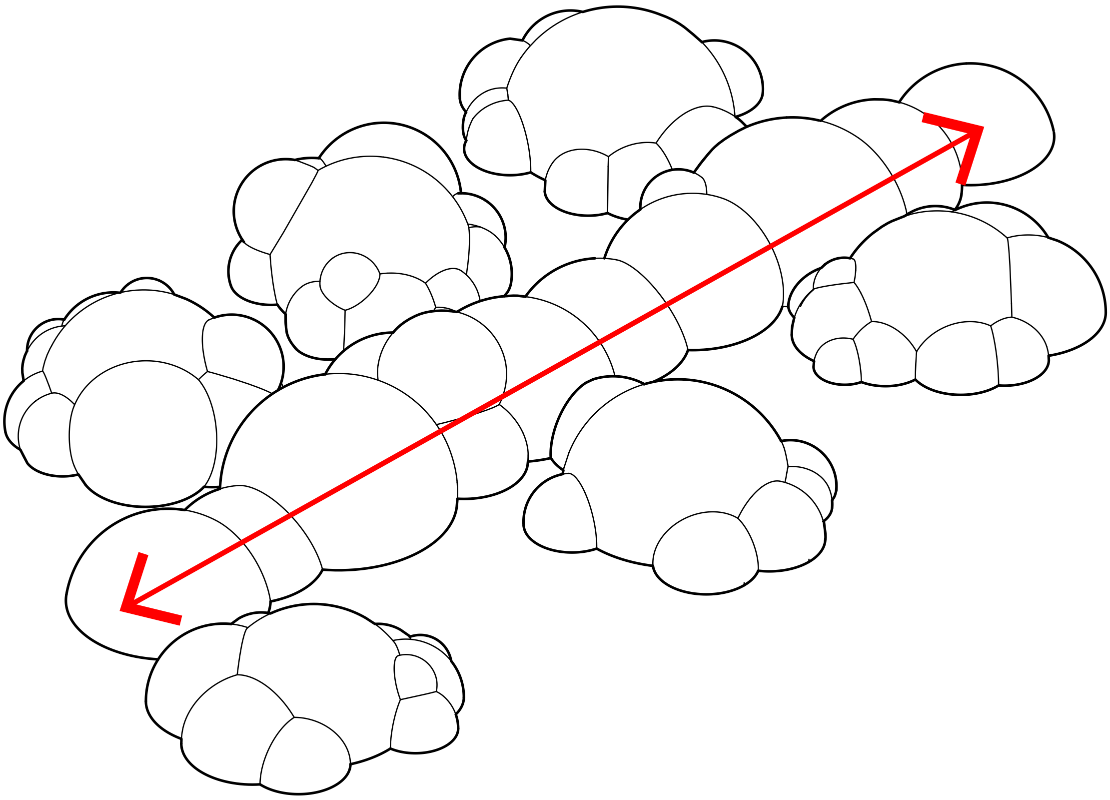
GARDEN
KITCHEN / DINNING
RESIDENTIAL
GREENHOUSE
WORKSHOP / STORAGE
EXIT HATCH





EXPANSION

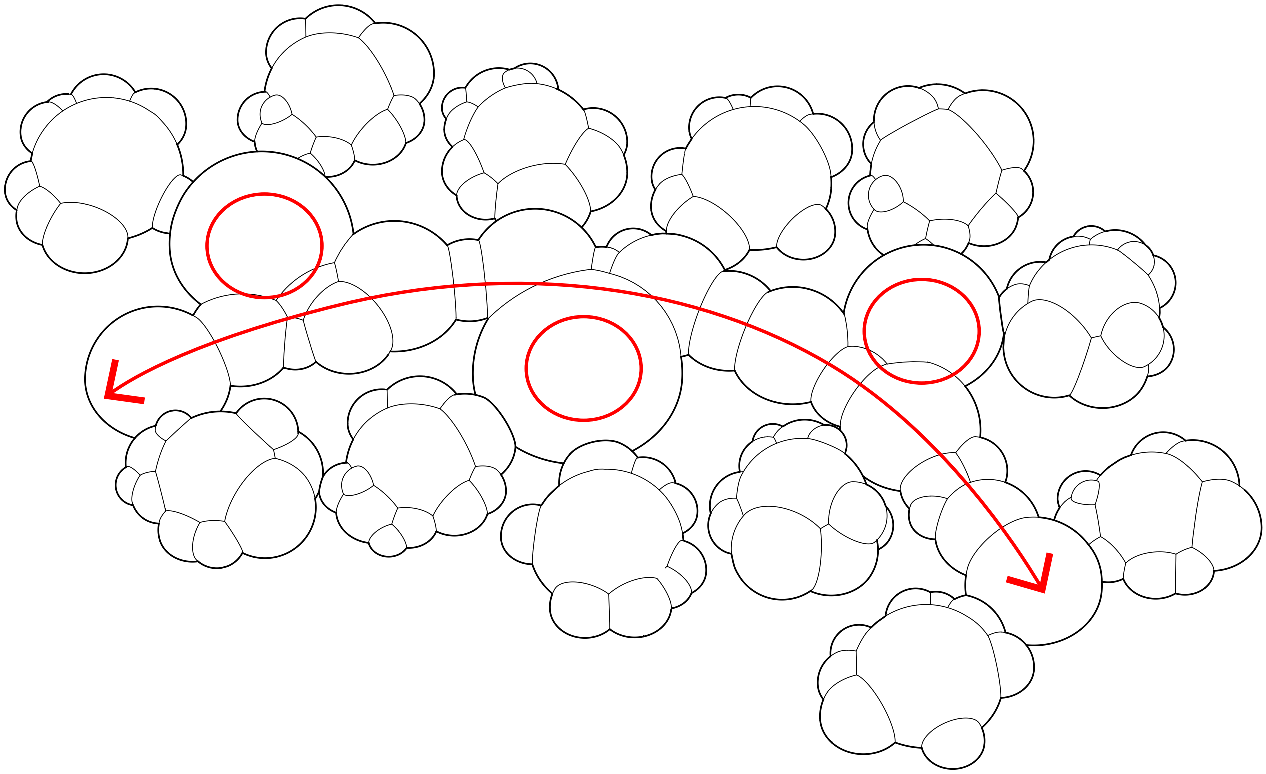
OPTION 1



There are a few possible ways this system can create even more prominent constellations and clusters of habitats that will generate small research settlements.

One option is using more regular distribution of habitats across the line, a corridor, or a street.

OPTION 2



Another option adopts a more complex solution for a bigger number of inhabitants. On the main street, many public centers are created for everyday activities and gatherings—functioning similarly to piazzas in the city.

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