LUNAR LIGHT HOUSE

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BACTERIAL NANO-CELLULOSE APPLICATION IN THE RADIATION SHIELDING ARCHITECTURE

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ABSTRACT

The Lunar Light House project was developed to provide a novel system of protection against cosmic radiation specifically for a surface Lunar base. It's main target was to find a technical solution which would allow for more freedom in shaping the base structure and also potentially for introducing natural sun light.

At the time of developing this project, there seldom were any ideas as to how to protect ourselfes from radiation on Lunar bases. The shielding could not be brought from Earth because it would mean a lot of additional weight. That is why a reliable In-Situ Resource Utilisation method seemed to be the only option. When it comes to Lunar bases regolith – a loose layer of soil – could be used as a protective shield.

Lunar regolith had very good properties for this purpose, but on the other hand, covering the structures with it would diminish the flexibility of shaping the building. The other idea was to dig in the ground or to look for already existing caves. For example, recently big lava tubes were discovered on the Moon. From the radiation protection perspective this solution presented itself as very efficient, however it did not make introducing natural sun light possible.
That is why a different solution had to be found. One that would use regolith as material and allow to shape the base freely at the

same time, while not making the payload too heavy. A new idea had been developed while researching. With the use of synthetic biology or bacterias to 3d print and grow, a support structure for the regolith could be created in-situ. The protective shell against radiation could take more various shapes and allow for more freedom in design.

The base had to consist of two structure systems. The first one was needed to ensure life support - a tight structure, able to hold pressure, temperature etc. There was no known way as to how to produce such a structure In-situ and thus the project proposed bringing inflatable components from Earth. Torus-shaped modules could be stacked vertically, one on top of another, creating a habitat for the crew with all of the necessary functions, laboratories, greenhouses, workshops etc. The other structure, the main focus of the project, would work as a shell for the pressurised modules. It's primary purpose was to ensure passive radiation shielding.

For that an In-Situ grown bacterial nano-cellulose was used. It was a light solid substance that had exceptional strength characteristics. It was lightweight, stiffer than Kevlar R , electrically conductive and non-toxic. It had very high tensile strength - 8 times that of steel. Also, or maybe above all, it might have been translucent, which was a great asset when considering the introduction of natural light to the habitat.

Together with the lunar regolith, nano-cellulose membranes would create a composite system, based on the soil reinforcement principles. Inclusion of sheets within the soil mass would stabilise unstable slopes and help to retain the soil on steep slopes and under crest loads. Additionally, to ensure lateral stabilisation, nano-cellulose reinforcement was designed as a continuous surface, climbing in a form of a spiral along the whole structure, instead of being divided into separate layers. Thanks to that, Lunar Light House could be built tall and stable without the use of as much material.

The base would be localised on the rim of Shackleton Crater, on the lunar south pole. What made it a good potential site for the lunar base is that the crater stayed in shadow almost all the time. This meant that ice could be found there. Despite the fact that the crater is dark and cold the crater rim itself is located at the 'peak of eternal light', with a sun light present for almost 90% of the time. This location possibly provided both ice and sunlight which made it an optimal choice.

The Lunar Light House project proposed a novel way of using already existing systems and materials, bringing new qualities and possibilities. First, one tower would be built and with time the site would become a moon village. The height of the structures built on the Moon would overcome the obstacles created by dust floating above the surface raised by the vehicles' engines and mechanical works. Additionally, with a site in the peak of eternal light and with the nano-cellulose membrane placed all along the structure, the sun light would gradually pass inside, having its climax on top of the structure. To keep the crew in the best health, there had to be an artificial light system to simulate day-night cycle on Earth inside the habitat. However, on the last floors of the base there was a transparent module placed, on the level where there was no dust anymore. The density of cellulose layers there was the biggest and due to the height, sun light would shine on the top all the time.

Yearning for family and friends left on earth would be an impactful psychological discomfort for astronauts. The transparent module on top of the base would make watching the home planet possible. This would provide a reassurance that home is still there and would have a soothing effect on astronauts' nerves.

Translucent nano-cellulose not only would transmit light to the base but also light up itself, making the top of the base clearly visible from the outside. During external activities the base would become for astronauts what a Light House was for sailors.

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INTRODUCTION

1 | SPACE ARCHITECTURE

The theory and practice of designing and building
inhabited environments in outer space

Nowadays architecture is a very broad term. It used to be clear: architects design buildings, but now architecture can be understood in many different ways and developed in multiple directions. Aesthetics, shapes and forms as we find them in contemporary buildings have reached impressive levels of mastery and can represent, in themselves, a goal to architecture. However architecture is not merely about designing buildings.

In fact, recently the word 'architecture' became commonly used in many different industries that have nothing to do with buildings; computer science, software development, aerospace to name a few. Brent Sherwood, Chair of AIAA Space Architecture Technical Committee wrote that the term architecture 'adequately captures the act and product of grasping and manipulating a complex design problem characterised by thousands of parts, mutually conflicting requirements, diverse specialties and the wilful creation of order out of chaos'

What is the most important to me as an architect, is the quest to find new concepts answering people's needs and overcoming technological and natural constraints. If one takes those constraints into consideration, combining aesthetics, practicality and a good living experience becomes a challenging task. This is exceptionally true when it comes to dealing with outer space - the most extreme environment we know, with a variety of obstacles such as different gravity levels, lack of air, extreme temperatures, deadly radiation, hardscrabble, lack of material resources, vast distances and psychological remoteness.

There are multiple adverse circumstances both on Earth and in outer space, to which people are constantly learning to adapt. There is no doubt that exploring space is dangerous, thus minimizing the risk of mission failure is critical to the future of manned exploration of the Solar System. The duty of a space architect and in fact every architect, is to know how to protect the health and safety of people and respond to present and future global challenges. Being one of them allows me to take part in an expedition to discover where we, as a civilisation, can go.

RESEARCH

2 | SPACE RADIATION

One of the biggest challenges when it comes to space architecture is to protect humans and mechanisms from the harmful cosmic radiation.

Thanks to the magneto-sphere, people on Earth and astronauts in the low Earth orbit are protected from the harmful effects of the radiation. The situation dramatically changes when leaving the earth and the risk increases with the length of the space travel.

COSMIC AND SOLAR RADIATION

There are two main types of solar radiation; Galactic Cosmic Rays (GCR) and Solar Particle Events (SPE).

Galactic Cosmic Rays originate from the interstellar space and reach every single object that occurs on their way, similarly to the light. They are highly charged, energetic atomic nuclei and protons of corpuscular nature. They travel at a very high speed along straight lines. GCR are modulated by a solar wind in 12 years solar cycle, oscillating from more intense to less intense, but are eternally present.

Solar Particle Events, unlike the GCR, are isolated events. SPE are mostly protons, they emerge from coronal mass ejections from the sun and are very hard to predict.

1. Artistic impression of cosmic rays entering Earth's atmosphere. (Credit: Asimmetrie/Infn).

Source: https://cds.cern.ch/record/1345733

HAZARDS

Longer exposure to the space radiation might be very harmful to humans. Exposure to heavy ions causes unique damage to biomolecules. There is no research proving it, however it is estimated that heavy ions can be much more damaging to DNA then terrestrial forms of radiation. They can tear through DNA molecules, splitting them or damaging the code. The damaged DNA can cause cancer or other diseases.

For now, most of the predictions are based on studies on atomic bomb survivors, but it is a completely different type of radiation.

Eyes
High dose can trigger cataracts months later

Thyroid
Hormone glands vulnerable to cancer. Radioactive iodine build up in thyroid.

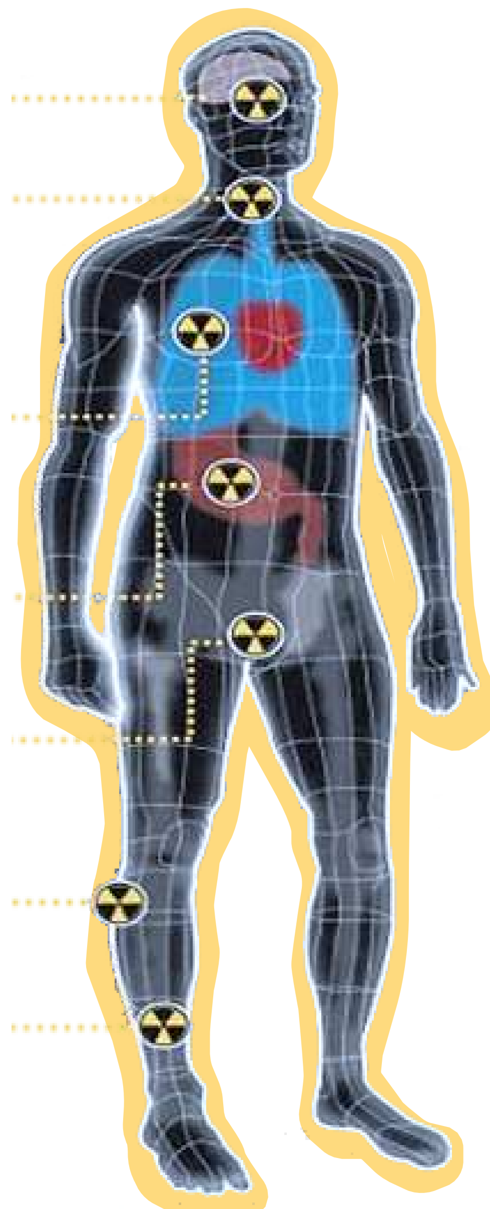
Lungs
Vunerable to DNA damage when radioactive materials is breathed in.

Stomach
Vunerable if radioactive material is swallowed.

Reproductiove Organs
High dose can cause sterility.

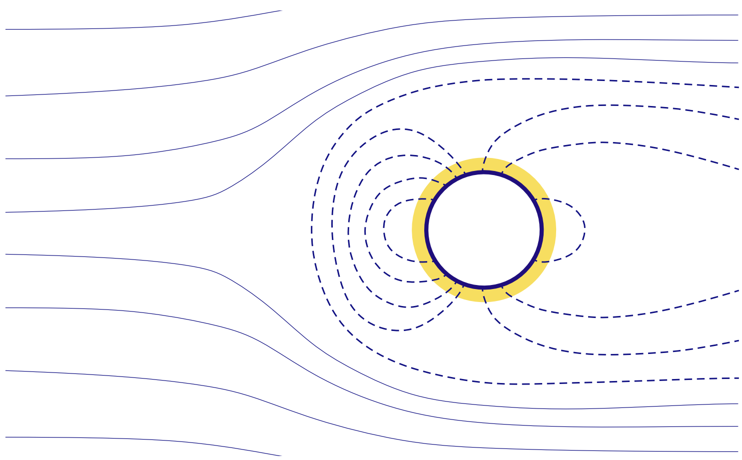
Skin
High doses cause redness and burning.

Bone Marrow
Produces red and white blood cells. Radioation can lead to leukaemia and other immune system diseases.



WHAT PROTECTS US ON EARTH?

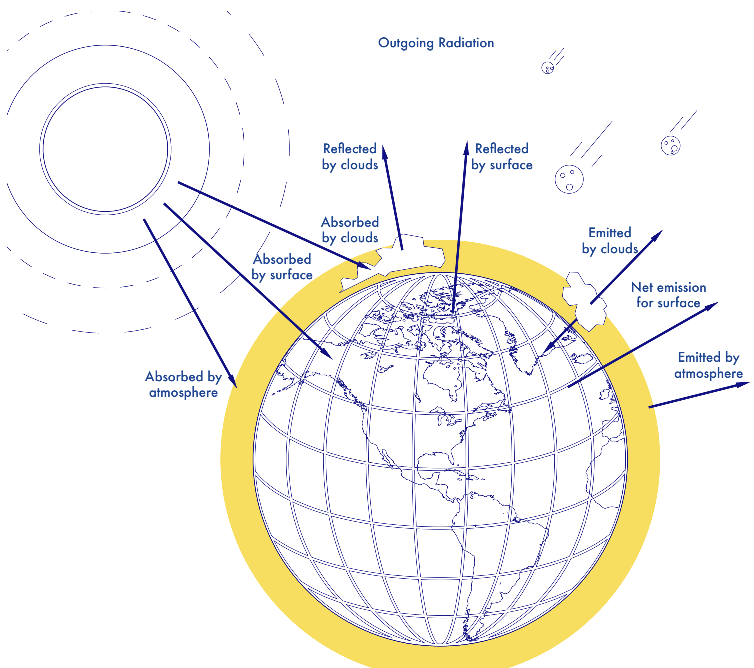
MAGNETIC FIELD



Earth provides us with natural protection against radiation - the magnetic field. It is generated by electric currents on the Earth's liquid iron core and extends far into space, shielding the planet from 99.9 % of harmful radiation.

2.
Earth's Magnetic Field
Source: http://m.esa.int/Our_Activities/Space_Science/Cluster/Earth_s_magnetic_field_provides_vital_protection

ATMOSPHERE



Space radiation is also efficiently absorbed by the Earth's atmosphere. This additional protection is equal to that of a 1 meter thick metal slab. Particles of the primary cosmic radiation undergo interactions in the atmosphere creating atmospheric showers.

3. Earth's Atmosphere, Ozone Layer
source: https://www.earth.com/news/dangerous-threat-ozone-layer/

RADIATION PROTECTION IN SPACE

There is no natural protection against radiation in outer space, so space travels and extraterrestrial habitats are heavily impacted. For short duration missions (like Apollo) space radiation provides minimal risk, however long exposure increases the risk of cancer. The Moon has almost no atmosphere and a very weak magnetic fields. To protect the astronauts a proper shielding ought to be ensured throughout the duration of the mission.

There are multiple mitigation strategies to protect astronauts from space radiation:

1. FORECASTING AND DETECTION

Within the solar system, cosmic ray fluxes are lower during periods of strong solar activity. Inter-planetary travel may take place during solar maximum to minimise the average dose of radiation. However, this idea doesn't work for planetary missions, where people would stay for a longer period of time.

2. RADIOBIOLOGY AND BIOLOGICAL COUNTER MEASURES

In other words, giving astronauts medication. It would lead to a personal risk assessment capability and enable early detection and prognostic monitoring.

3. PASSIVE RADIATION

Already used in space travels is the use of shielding materials and configuration optimisation. Optimal placement of shielding materials can significantly reduce the radiation risk.

MATERIALS

Different shielding materials may lower the effects of cosmic radiation, but also, some types of those materials can increase the secondary radiation, which should also be avoided. Shielding materials are more effective for Solar Particle Events than for the GCR environment.

Materials used for the radiation shielding:

- Kevlar
- Hydrogen-rich plastics
- Liquid hydrogen (fuel) gives good shielding, while pro ceeding relatively low levels of secondary radiation.
- Water, which is necessary anyway, to sustain life. It's hydrogen content is high and has very good properties when it comes to radiation protection.
- Electromagnetic fields, to mimic the Earth's mag netic protection. NASA has been working on this idea, but so far without any promising results.
- International Space Station (ISS) is constructed out of aluminium walls, which protect the crew, but it probably wouldn't work in deep space, due to the higher energy of the particles.

The biggest impediment is that bringing any kind of shielding from the Earth increases the payload of the space craft, which is one of major issues in long duration flights. The goal is to absolutely minimise the payload. That is why focus is put on In-Situ Resource Utilisation (ISRU) which is a method of making use of materials found on the landing spot.

3 | THE MOON

Presumably, the Moon was formed after a really large meteorite collided with Earth around 4.5 billion years ago.

The moon is the fifth largest moon in the solar system. It is our natural satellite, which by moderating the Earth's wobble on its axis makes Earth a more habitable planet. It is responsible for a relatively stable climate and a tidal rhythm that has guided humans for thousands of years. It remains in a synchronous rotation with Earth. It makes a complete orbit around Earth in 27 Earth days.

The Moon is an ideal test bed to try all the technologies and operations before they will be adapted for further travel, to Mars and beyond. From there we can send missions into deep space. Most of the challenges given by environmental conditions on Mars will be even bigger on the Moon; thin and weak atmosphere, extreme temperatures, weaker gravity.

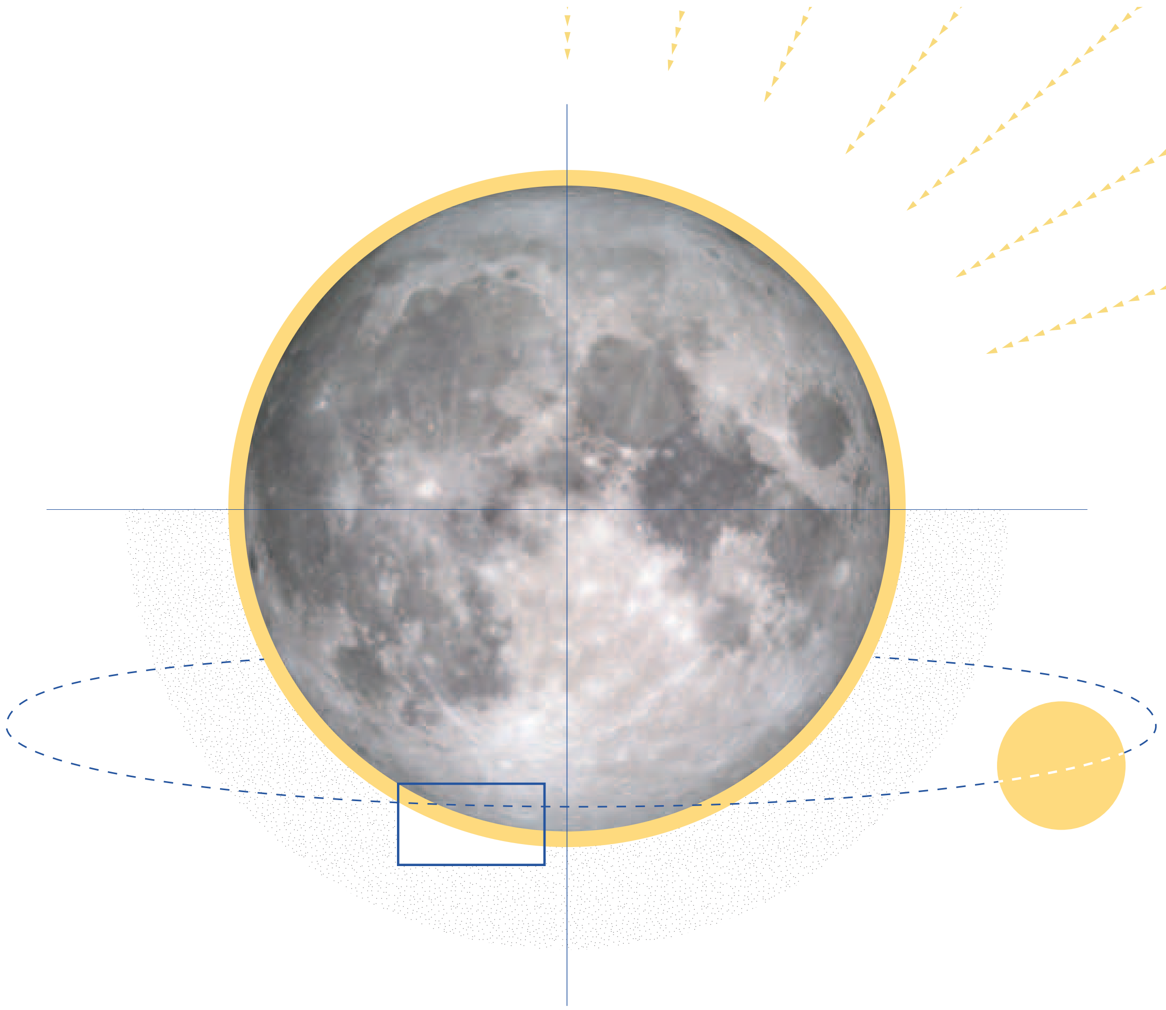
We currently have means of getting there and our technology is sufficiently advanced to sustain life in space. Thus, when the ISS will have finished its service, the next step will be to build a base on the Moon. Conditions on the Moon will make mastering multiple technologies such as regolith 3d printing and growing bacterias possible.

CHARACTERISTIC

Moon does not have any protection from the solar and cosmic radiation and is constantly being stricken by asteroids, meteoroids and comets. Hence it has so many craters.
The key factors influencing structural designs of habitats on the Moon are:

- One-sixth terrestrial gravity.
- High internal air pressure (to maintain human-breathable atmosphere).
- Radiation shielding (from the Sun and other cos mic rays).
- Micrometeorite shielding.
- Hard vacuum effects on building materials (i.e. out gassing).
- Lunar dust contamination. Dust on the Moon is an abrasive fine powder that sticks to everything.
- Severe temperature gradients.

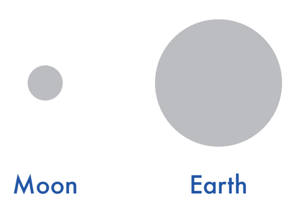
4.
4 sides of the Moon,
source:
http://lunarnetworks.blogspot.com/2010/10/lroc-lunar-north-pole.html



Distance from the Earth	357,200 km
Athmospheric Pressure :	0am (almost vacuum)
Temperature:	-233.15 C to +122.85 C
Magnetic Field:	1/100 of Earth's
Gravity:	0.16g
Threats:	Gamma radiation, Solar flares

27% diameter

60% density



SITE

Self-sustaining lunar outpost needs energy, water and shelter. These resources need to be renewable or exist in immense quantities in order to be considered useful by the lunar outpost.

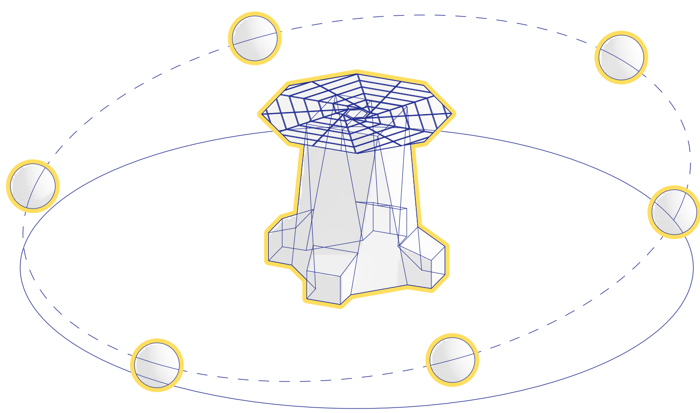
Changes in temperature on the lunar surface may cause the contraction and expansion of materials and thus materials might change their dimensions. To allow materials to be used for a longer duration, saving money and time, locations with the smallest temperature variations should be chosen for a lunar outpost. Due to the moon's spin axis, which is less than 2 degrees relative to its orbital plan, the inside of many low-points on the surface of the Moon never see light. Those regions are very cold and permanently dark. That is why there is a big possibility of the presence of water in the form of ice, which is a crucial element for survival.

5.
View of the Lunar Module at Tranquility Base. Image taken by Astronaut Neil A. Armstrong during the Apollo 11 Mission. Armstrongs shadow is visible in foreground. Sun angle is Medium. Tilt direction is Northwest NW.

source: https://commons.wikimedia.org/wiki/File:Apollo_11_Mission_image_-_Lunar_Module_at_Tranquility_Base_(6962456597).jpg

Credit: NASA

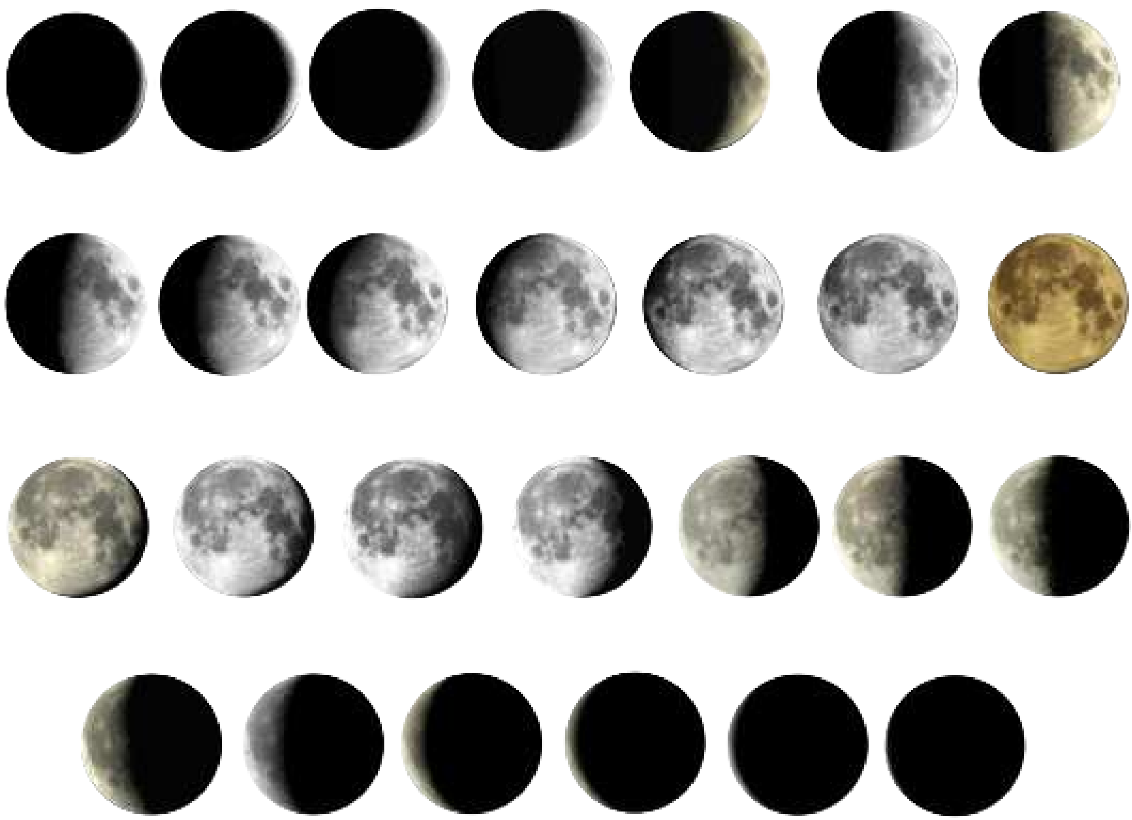
PEAK OF ETERNAL LIGHT



On the Moon here are certain spots which stay illuminated nearly constantly, colloquially called 'peaks of eternal light'. Presence of sunlight gives them little temperature variation over time, comparing to other regions. The variation is estimated to be between -50 to 10 degrees Celsius. Also, the nearly constant illumination is ideal for collecting solar energy and the permanent darkness is necessary for the possibility of ice being present.

On both of the Moon's poles these regions exists. Therefore both are seriously considered as possible starting locations for the Lunar Outpost.

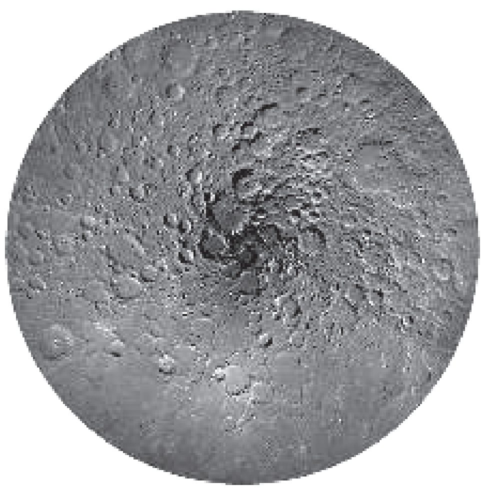
6.
Moon Phases
source: https://www.moongiant.com/phase/today/

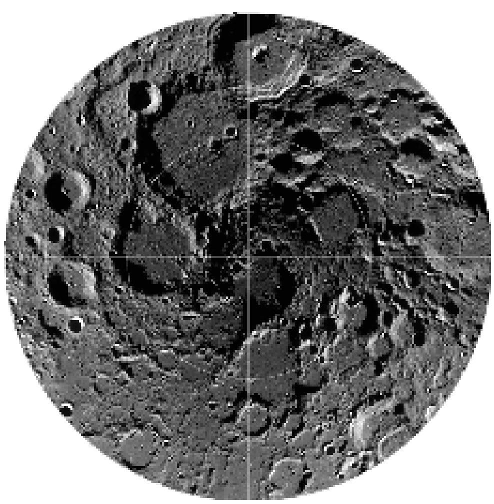


NORTH POLE LOCATIONS

Peary Crater, Hermite Crater, Rozhdestvensky Crater

Along the northern rim of the Peary Crater there is a region that sees nearly continuous sunlight during a lunar summer day.



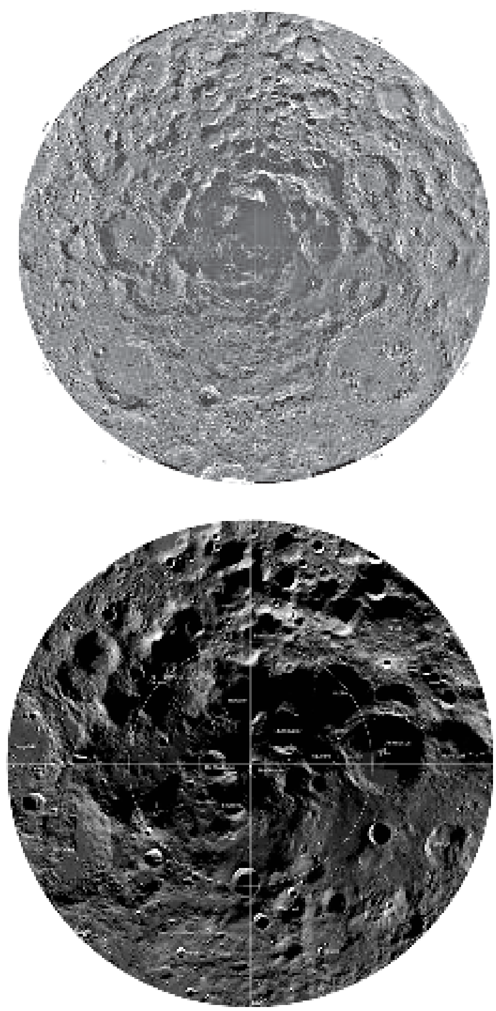


7. 8.
Lunar north pole.
NASA/GSFC/Arizona State University
https://cosmosmagazine.com/space/volcanoes-nudged-moon-its-axis

Summer at the lunar north pole. Some regions regions are perpetually dark and very, very cold. – NASA/GSFC/Arizona State University
https://cosmosmagazine.com/space/volcanoes-nudged-moon-its-axis 9.
Peary Crater
NASA/GSFC/Arizona State University

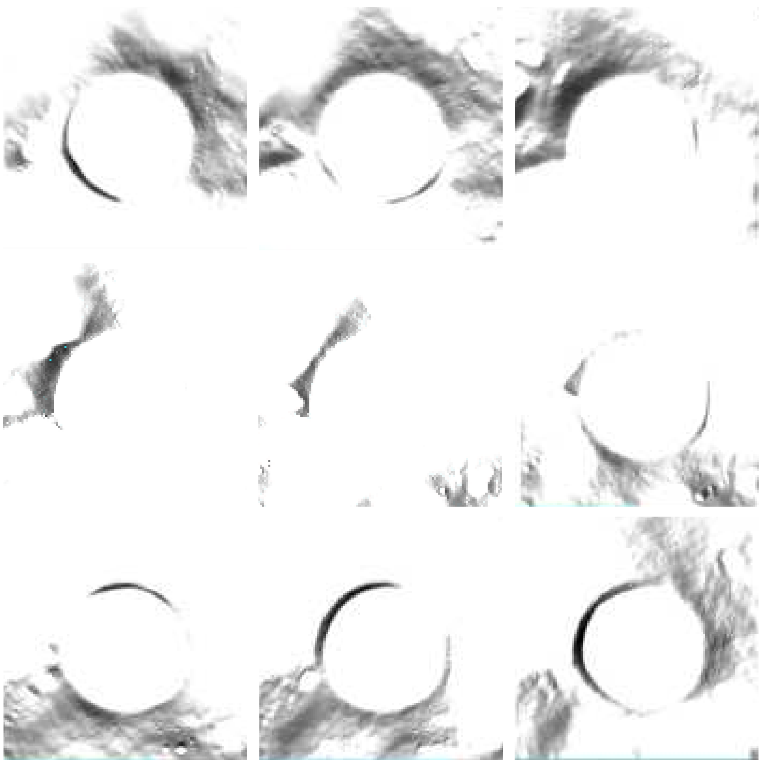
SOUTH POLE LOCATIONS

Shackleton Crater



10.11
Moon South Pole

SCHACKLETON CRATER



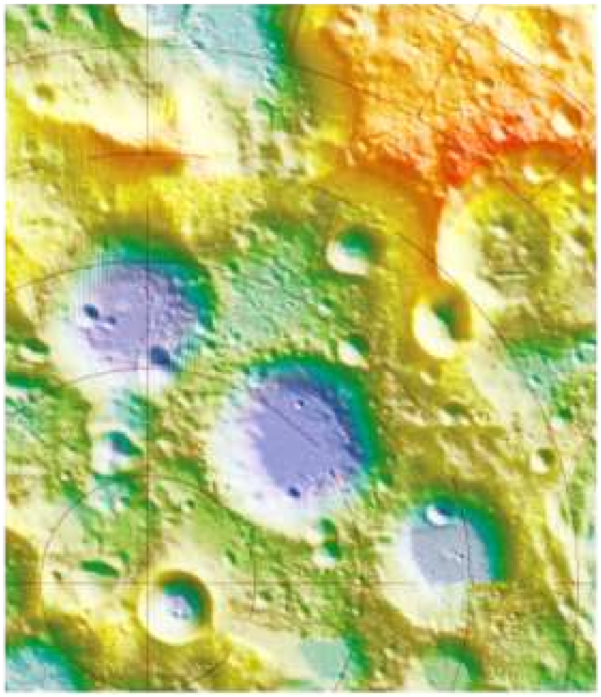
12. The Peak of Eternal Light
source: https://www.youtube.com/watch?v=dXr2auGOxus&t=273s

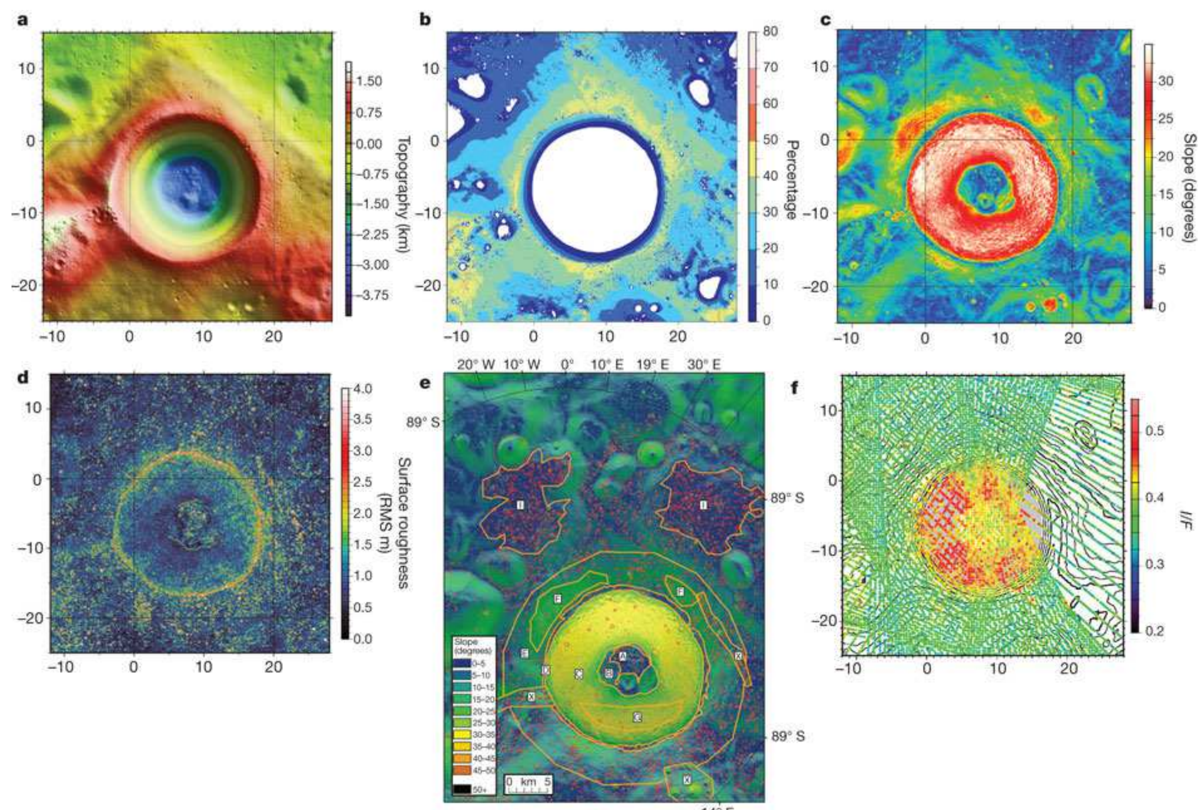
13.
a, Topography in km; b, percentage of time illuminated; c, 10-m baseline slopes in degrees; d, surface roughness shown as RMS residual in m; e, locations of crater counts used to determine relative ages; and f, zero-phase

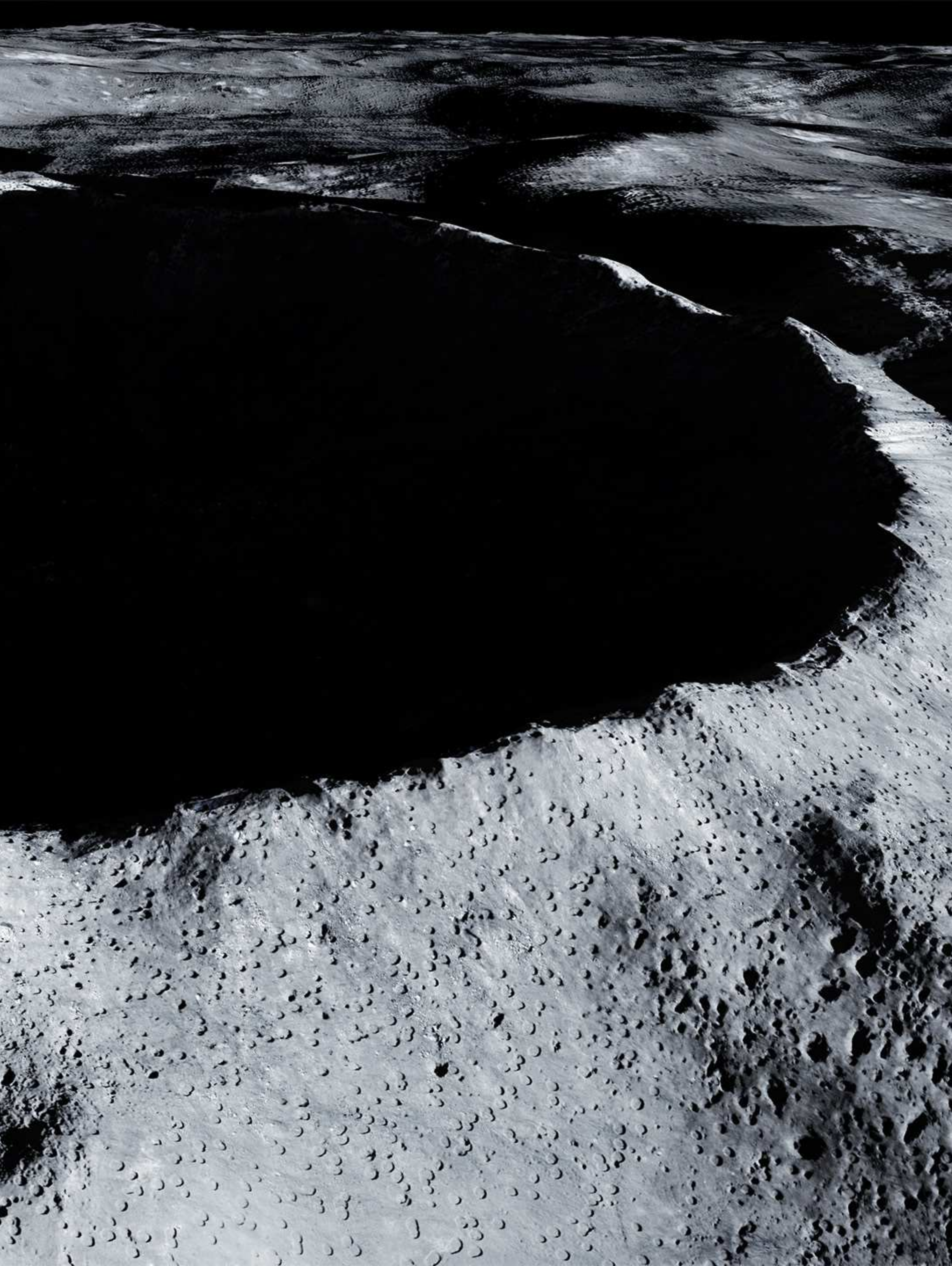
source: http://www.nature.com/nature/journal/v486/n7403/full/nature11216.html?WT.ec_id=NATURE-20120621

14.
Shackleton Crater
source: https://m.esa.int/spaceinimages/Images/2017/01/Shackleton_Crater, copyright: Jorge Mañes Rubio. Spatial design & visualisation in collaboration with DITISHOE http://ditishoe.com/

Thanks to it's characteristics, the Shackleton Crater is one of the most relevant locations for a lunar base. The crater stays in shadow almost all the time and that makes it a good potential site for the lunar base, due to the possible presence of the ice. Crater rim on the other hand is a site with sun light present for almost 90% of the time. It was chosen for the location for the Lunar Light House, being one of the 'peaks of eternal light'.




a
b
c
d
e
f
Topography (km)
1.50
0.75
0.00
−0.75
−1.50
−2.25
−3.00
−3.75
Percentage
80
70
60
50
40
30
20
10
0
Slope (degrees)
30
25
20
15
10
5
0
Surface roughness
(RMS m)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
20° W
10° W
0°
10° E
19° E
30° E
89° S
14° E
Slope
(degrees)
0–5
5–10
10–15
15–20
20–25
25–30
30–35
35–40
40–45
45–50
50+
0 km 5
I/F
0.5
0.4
0.3
0.2
−10
0
10
20
−20

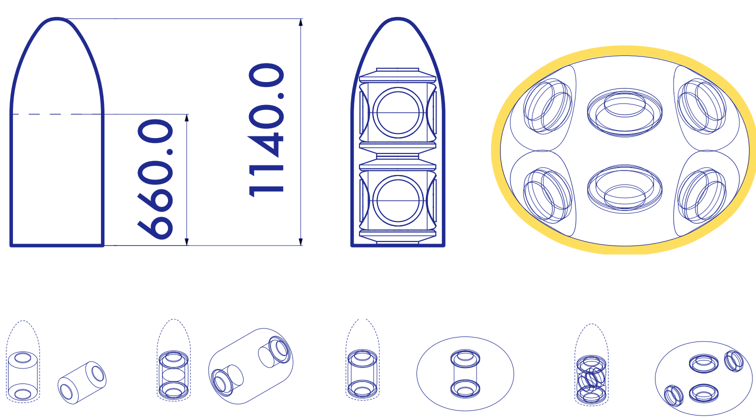


PAYLOAD

Payload is the carrying capacity of a rocket. It is usually measured in terms of weight and it is the main cost defining element when it comes to space travels. The transport of building supplies from Earth to the Moon would be too costly. That is why space agencies and private companies are working on In-situ resources utilisation (ISRU) to minimise the payloads. Future colonist will be required to mine minerals, water and even oxygen out of the soil and use it to manufacture bases and radiation protection for the habitats. Also, due to the payload restrictions the pressurised modules of the base should be self-deployable.

FALCON HEAVY

This partially reusable super heavy-lift launch vehicle designed and manufactured by SpaceX has the highest payload capacity of any currently operational launching vehicle and has the fourth-highest capacity of any rocket ever built, trailing the American Saturn V, the Soviet Energia, and the never-successful Soviet N1. The launch costs 90 mln USD.



15.
Falcon Heavy launch, source: http://staging.aiaa.org/uploadedImages/Industry_News/Falcon-HEAVY-SpaceX-1-AP-Purchased.png?_


SPACEX

SPACEX

FACTORS WHEN DESIGNING FOR THE MOON

1. SAFETY

Human safety and minimization of risk to “acceptable” levels, this concerns for example structural robustness, reliability of systems and redundancy

2. EMERGENCY SCENARIOS

Back-up and exit strategies in case of any kind of emergency

3. EASE AND OPTIMISATION OF MANUFACTURE, ASSEMBLY AND OPERATION

Keeping maintenance of crew and robotic assistants low and providing configurations that are flexible

4. USE OF LOCAL MATERIALS (ISRU)

5. LOGISTICS

Refers mainly to assembly and the when, how and what kind of material and elements
will be delivered and constructed

6. MATERIAL PROCESSING, AUTOMATION, ROBOTICS, TELE-OPERATION

It is assumed that most material processes are automated or at least tele-operated processes conducted by robots

7. SURFACE TRANSPORTATION

Exploration by humans requires different kinds of surface transportation, either non-pressurized or pressurized vehicles

source: RegoLight, Structural Summary, Scenario Options

ERGONOMY IN 1/6 G

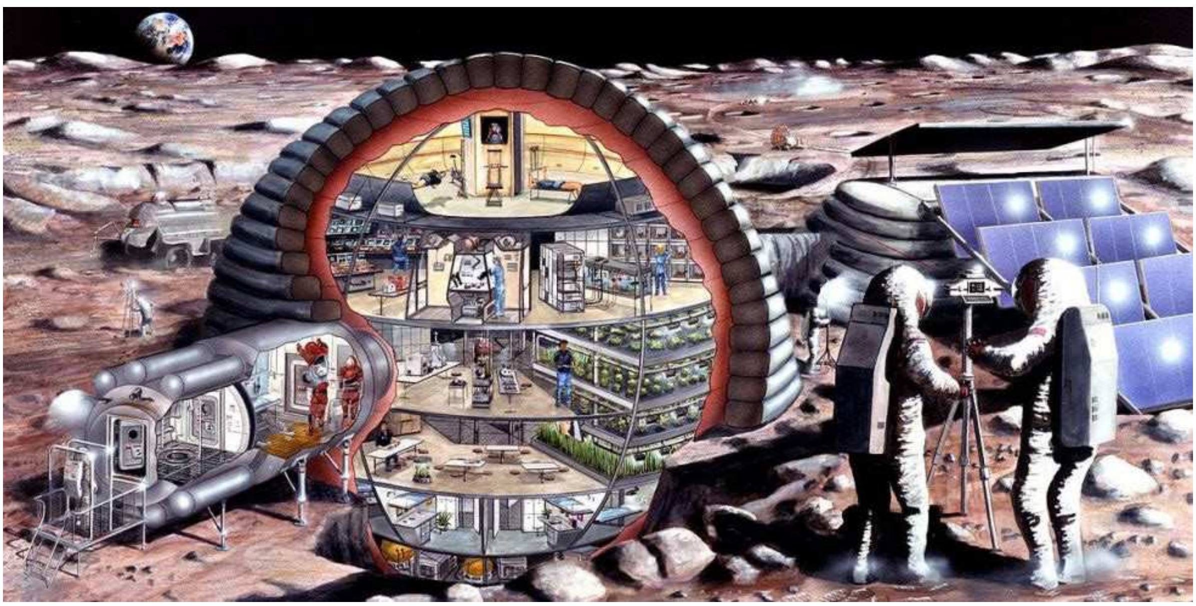
The architectural effect of partial gravity on crew locomotion remains not fully understood. Video of Apollo astronauts moving is misleading for understanding it because the suits of that era were pneumatically stiff.

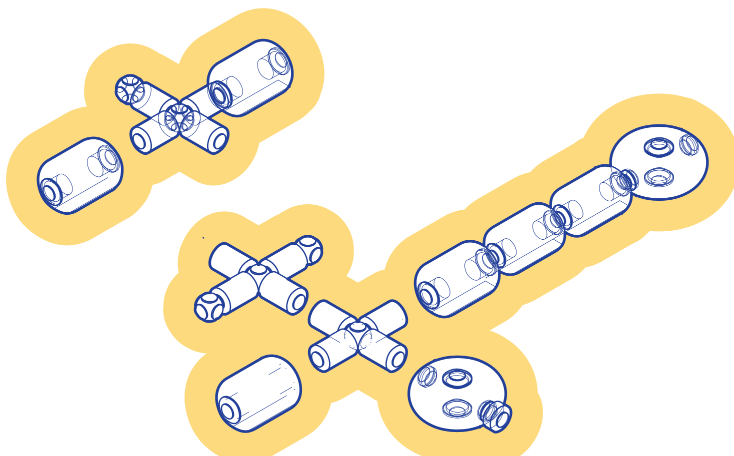
16.
Walking on the Moon- https://www.youtube.com/watch?v=aQX9KOCS7MA

LUNAR HABITAT CONCEPTS

The lunar environment consists of a hard vacuum so in order to enable humans to live there, it requires highly pressurised structures. The lunar surface is dominated by electrically charged dust grains and is exposed to harmful solar and cosmic radiation and to impact with micrometeorites. Therefore, the whole base needs to be protected.

17.
One of the first lunar base concepts.
A lunar base for six to twelve people, built into an inflatable spherical habitat. Proportions of interior volume devoted to different systems equipment is relatively accurate. The heaviest equipment such as for environmental control, and areas in which the crew spends the most time, such as their personal sleep quarters are lowest in the habitat. Work areas for lunar sample analysis, for hydroponics, and even for small animals are located in the middle areas. The top deck in this view is a running track on which the sloped surface permits the crew member to use centripetal force rather than gravity to permit running in 1/6 G.
Concept: NASA (1989)



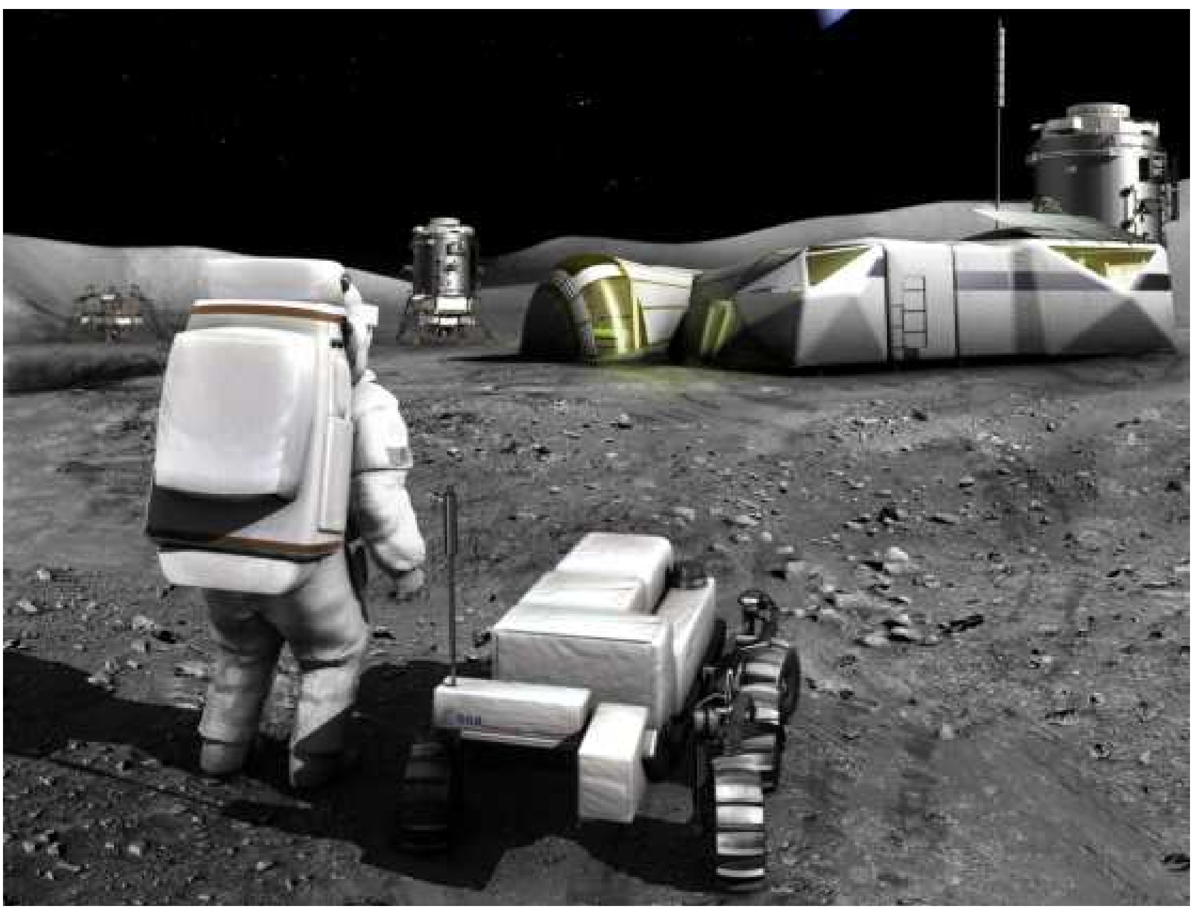


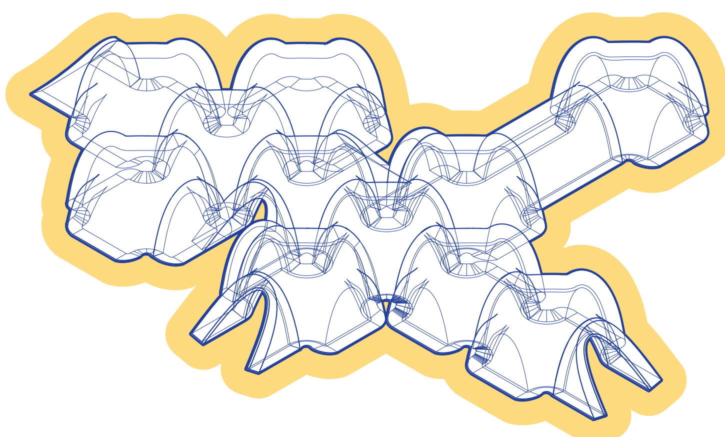
RIGID MODULES

This method uses existing technology and may be one of the most feasible concepts of starting a Moon base. International Space Station (ISS) consist of separate modules put together, and every single one of them has its own radiation protection. A base like this can be built on the surface of the Moon. It requires bringing all of the rigid modules form the Earth. Also the radiation and micrometeorites protection given in this example may turn out not to be enough for long duration missions.

18.
International Space Station
source: http://spaceflight101.com/iss/iss-reboost-and-mbsu-transfer/

19.
Auror Moon Base
Copyright ESA - AOES Medialab, source: https://www.esa.int/spaceinimages/Images/2006/02/Aurora_Moon_base_artist_s_view



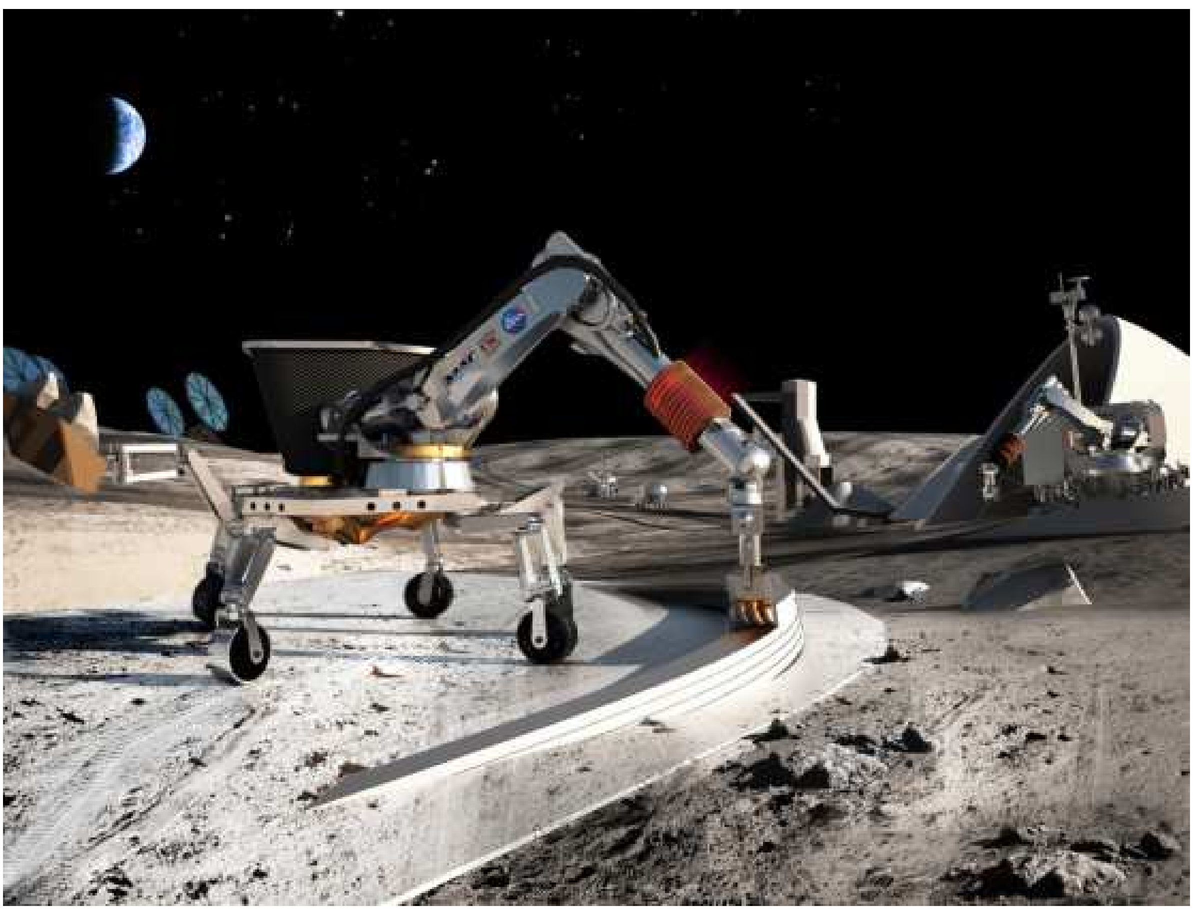


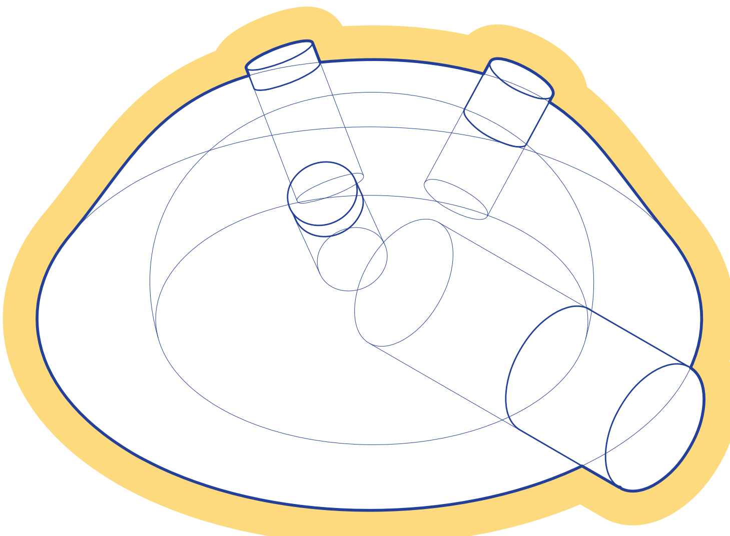
SOLAR SINTERED REGOLITH

This method is predicated on the use of 3D printing to build infrastructure and protective shells from lunar soil using the Sun as the only source of energy. The idea might be generally called Regolith Additive Construction (RAC). Contour crafting, similar to Sinterhab is based on robots which sinters the regolith to construct necessary lunar infrastructure. Solar crafting also uses robots and balloon gantry system which sinters regolith.

20. 3D Printed LunarBase Sinterhab,
source: http://markadesign.se/portfolio-item/sinterhab-lunar-base/

21.
Robotic construction of Lunar and Martian infrastructure using 3D printing. Credit: Contour Crafting,
source: https://phys.org/news/2016-05-moon-base-easyjust.html

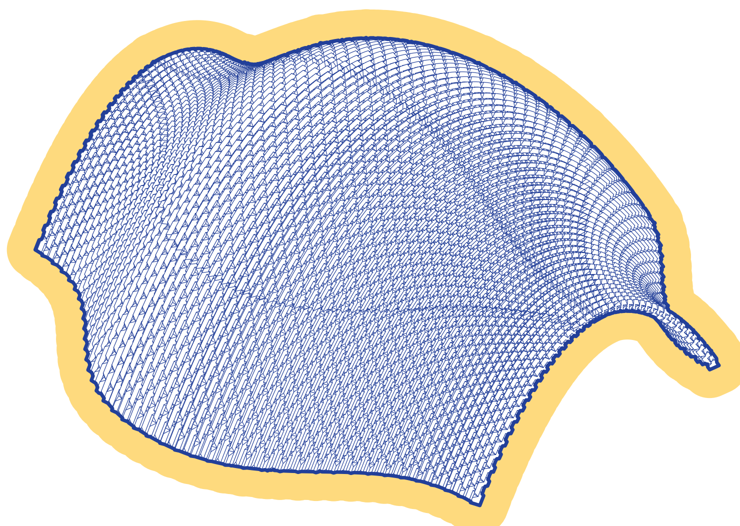




REGOLITH 3D PRINTING ON TOP OF INFLATABLE STRUCTURE

Use of a single multi-purpose robot with for example a D-shape 3D printer for building the lunar habitat. The robot has a regolith scoop on one end which excavates the loose regolith and poures it around the dome to build the protective shell.

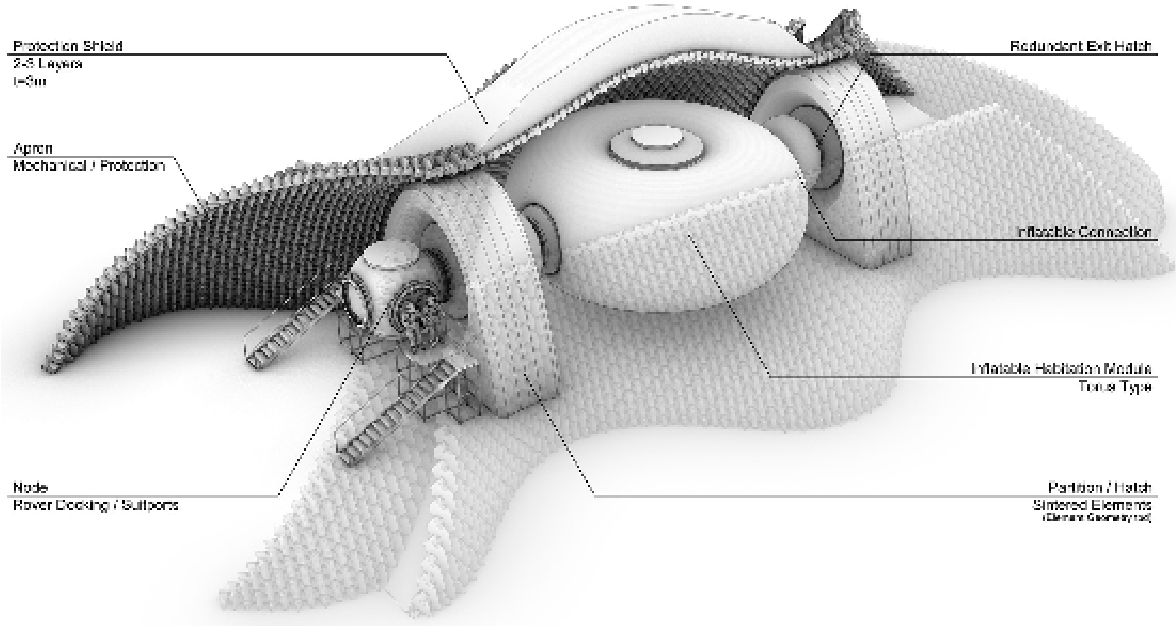
22. 23.
Multi-dome lunar base being constructed, based on the 3D printing concept. Once assembled, the inflated domes are covered with a layer of 3D-printed lunar regolith by robots to help protect the occupants against space radiation and micrometeoroids (ESA/Foster + Partners)

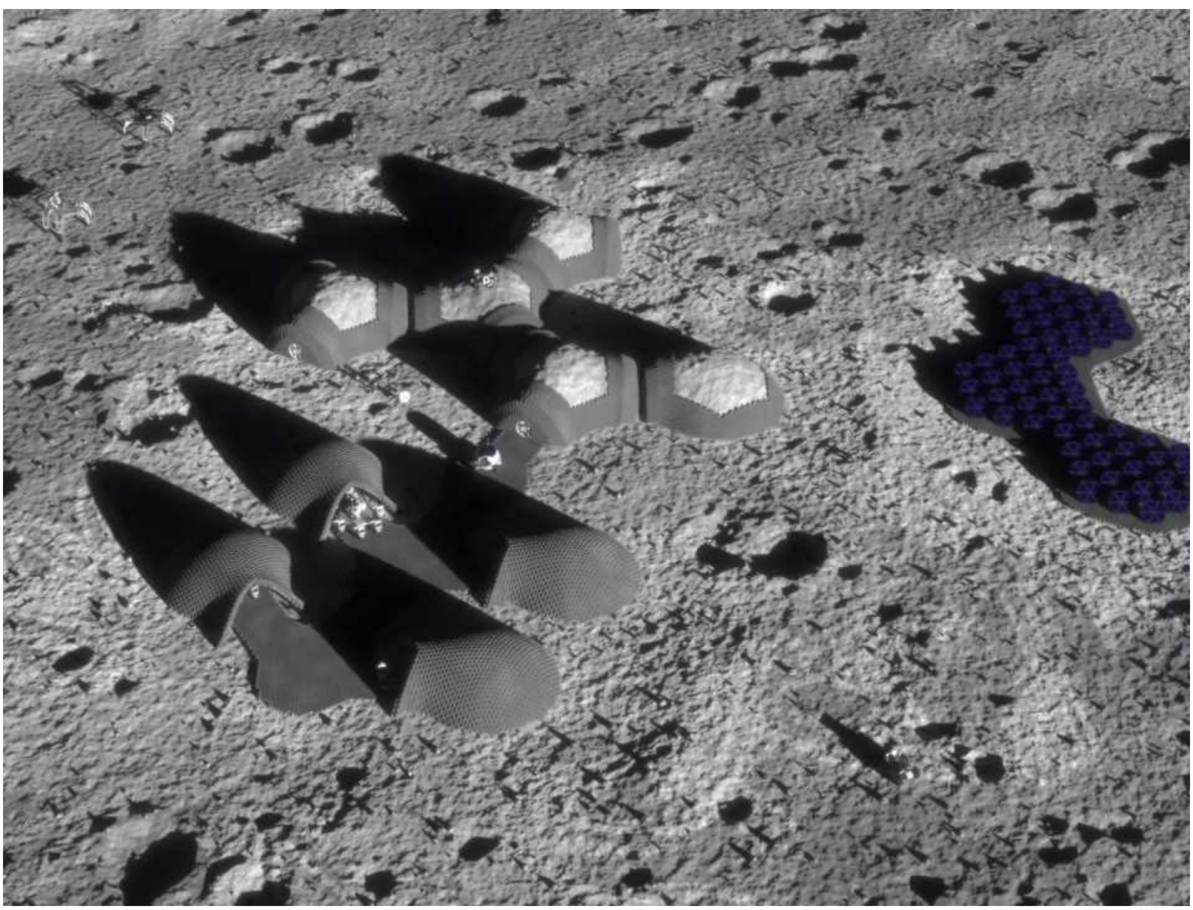


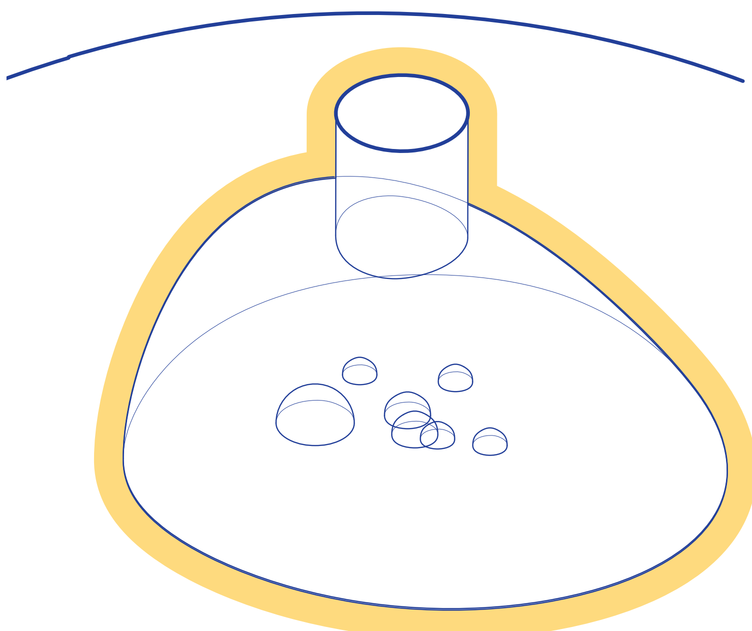
SOLAR SINTERED BRICKS

The RegoLight project. Solar sintering of regolith bricks is currently at TRL3 , being able to build a regolith 'brick' in a laboratory set-up with a moving table in a solar furnace. Based on the mechanical properties of solar sintered regolith, architectural scenarios and applications are developed while taking into account the benefits of additive layer manufacturing and novel construction concepts for lunar gravity.

24. 25.
Regolight Project
source: http://regolight.eu/


Protection Shield
2-3 Layers
Apron
Mechanical / Protection
Node
Rover Docking / Suitports
Redundant Exit Hatch
Inflatable Connection
Inflatable Habitation Module
Torus Type
Partition / Hatch
Sintered Elements





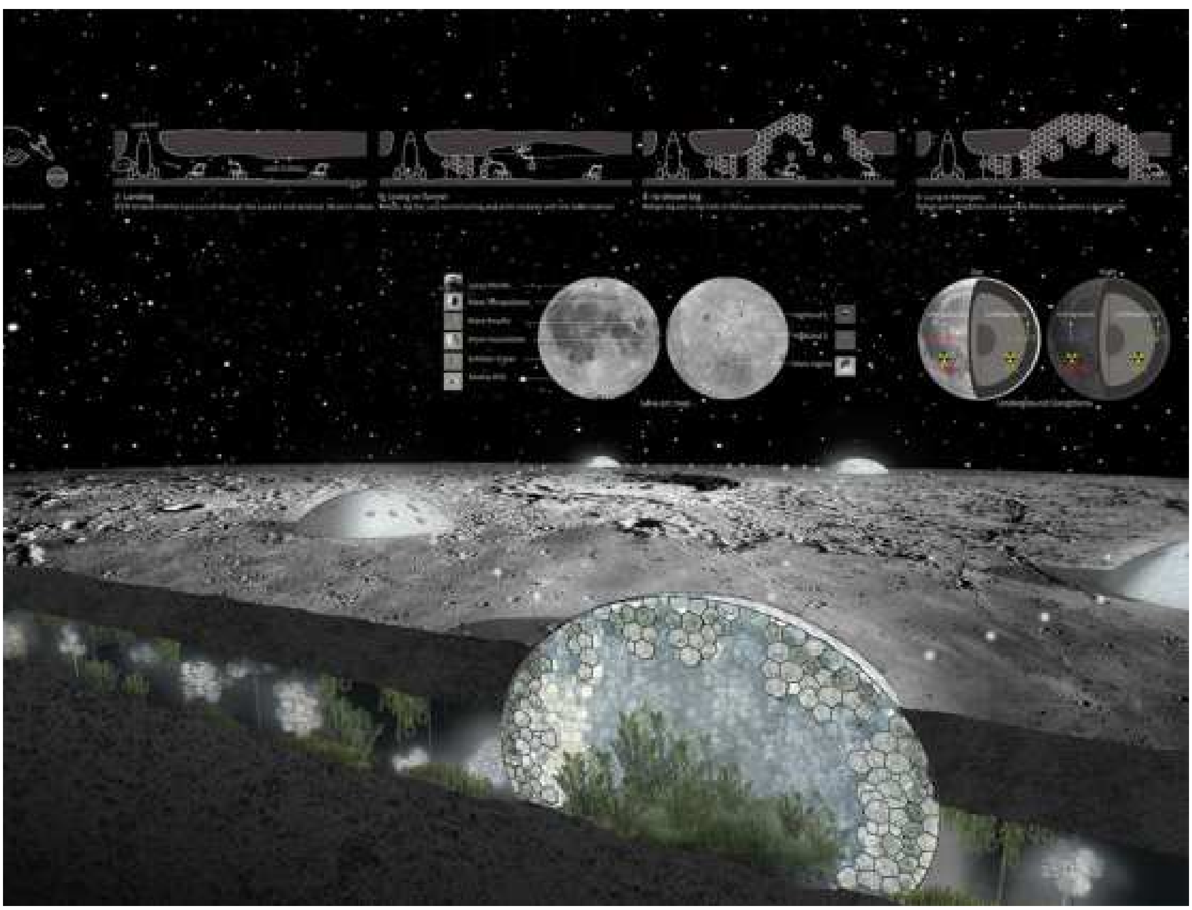
UNDERGROUND LAVA TUBES

Recently lava tubes were discovered under the surface of the Moon and it brought a range of new ideas for the lunar bases. Using natural cavern systems would have many benefits, principally that minimal construction would be required. Underground habitats would be probably the safest and ensure the biggest radiation protection, however it would mean 'returning to the caves'. It might be necessary to look for ground options anyways, to support subterranean habitats.

26.
Lunar Lava Tube Base,
source: https://www.sciencealert.com/scientists-discover-lava-tubes-leading-moon-polar-ice-water

27.
Modulpia,
source: Eleven Magazine,
https://www.eleven-magazine.com/?entrants=modulpia-ec2312


XARC

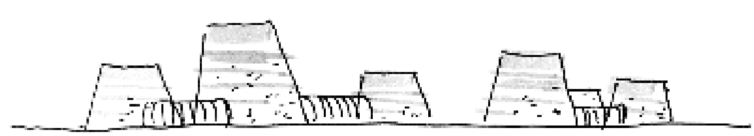


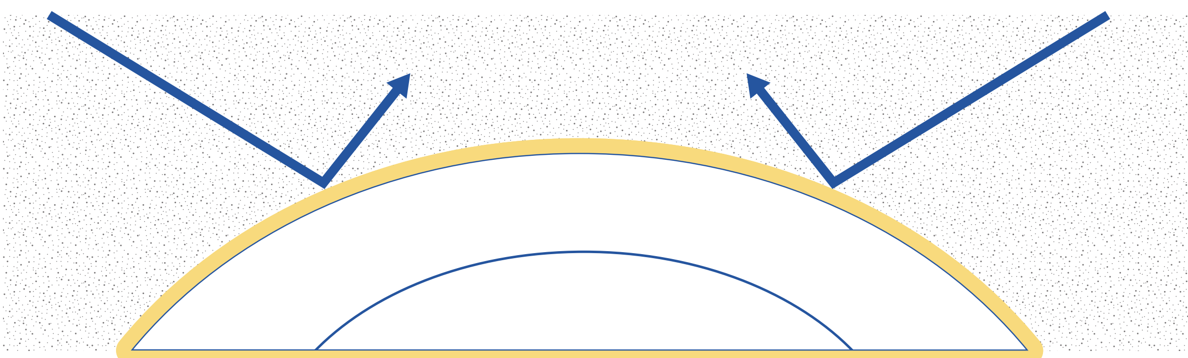
CONCEPT

4 | IDEA

The Lunar Light House project is driven by the need to develop a novel system of protection against cosmic radiation for the 'surface' Lunar base, which would allow for more freedom in shaping the base structure and also potentially allow for introduction of natural sun light to the structure.

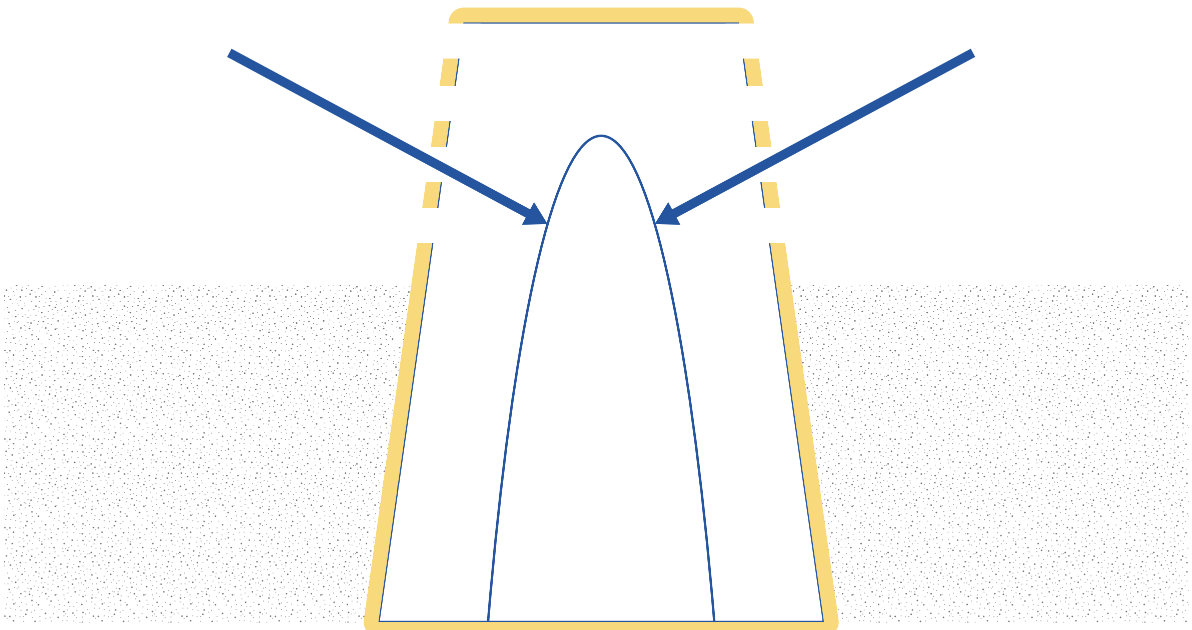
The challenge of the Lunar Light House project is to propose a use of already existing systems and materials in a novel way that would bring new qualities and possibilities.





FLAT REGOLITH MOUND

NO SUN - LIGHT



TALL STRUCTURE,
ABOVE THE DUST POLLUTION

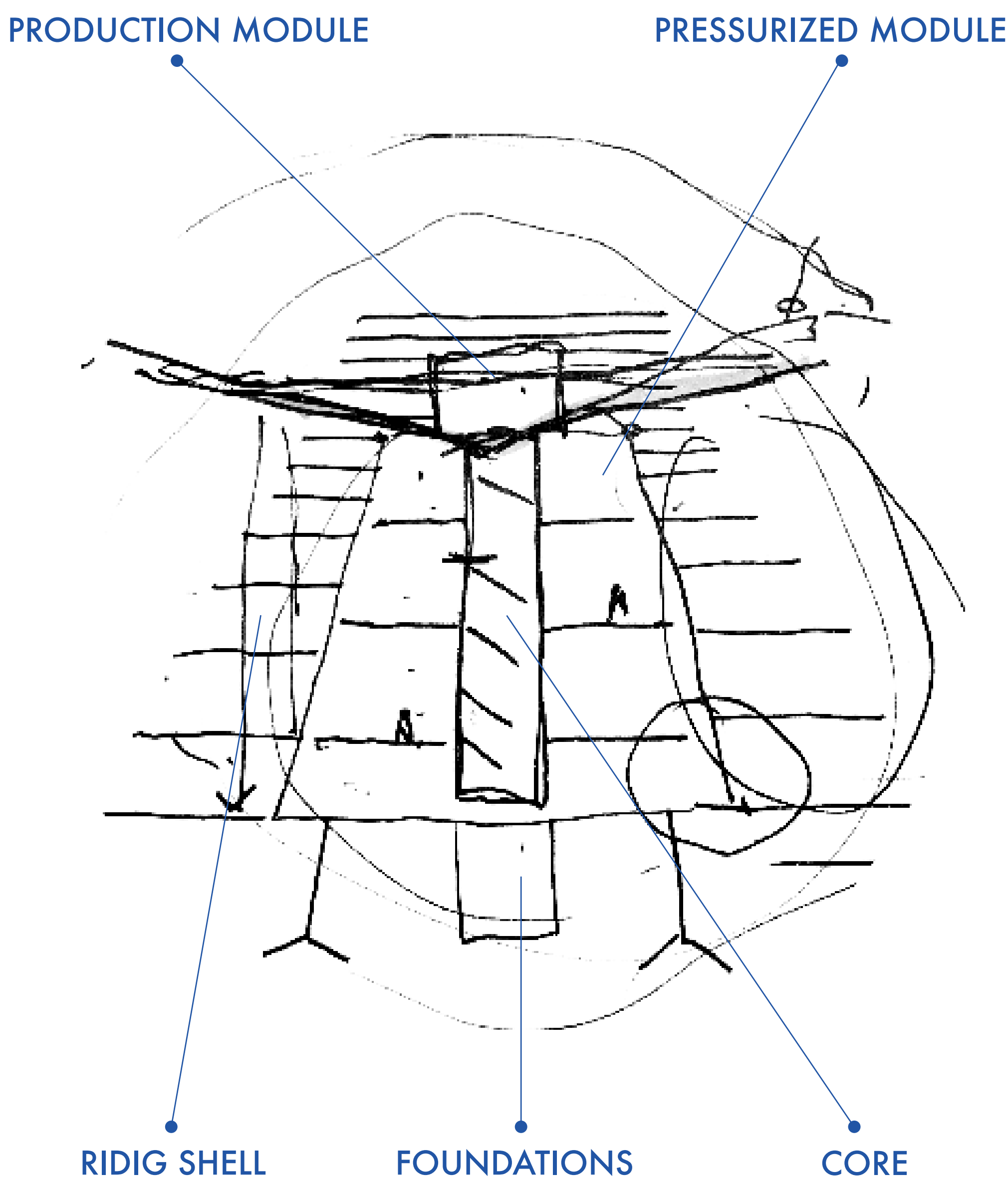
NATURAL SUN - LIGHT

FREEDOM OF SHAPE

SUN - LIGHT

SELF - ASSEMBLY

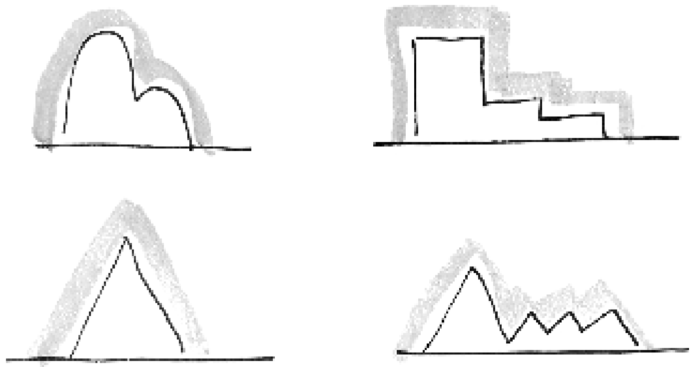
BASE MODULE

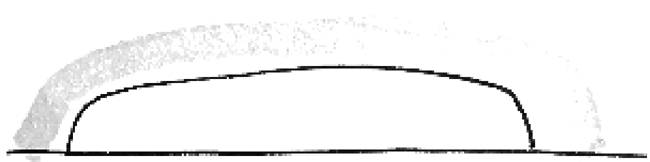

PRODUCTION MODULE
PRESSURIZED MODULE
RIDIG SHELL
FOUNDATIONS
CORE

FREEDOM OF SHAPE

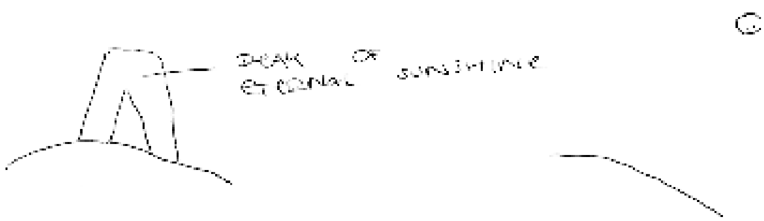
The project proposes an idea of building on the surface of the moon. The main idea standing behind the project and development of the base is to create a structural system that would make building on the Moon more flexible compared to the 'traditional' concepts of designing for a lunar surface.

Tall structure built on a Moon would overcome the obstacles given by the dust, floating above the surface, raised by the engines and mechanical works.





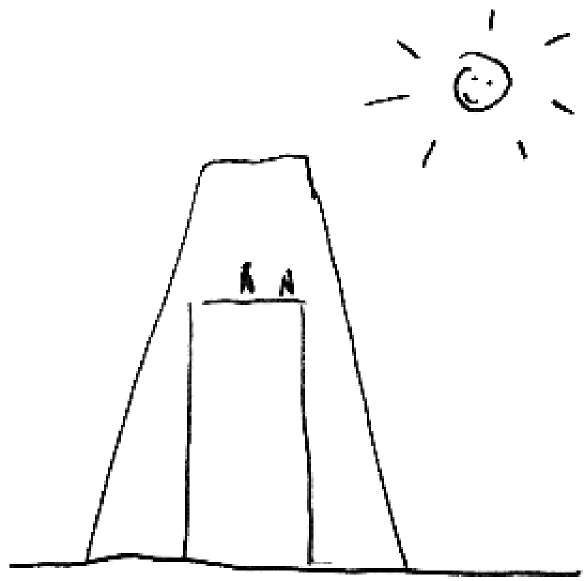
SUN - LIGHT



A lot of lunar base concepts are proposing to bury the base under the ground or cover it fully with the regolith layer, this however makes creating windows hardly possible. Therefore, designing such a habitat involves taking into the account the problem of how to mitigate claustrophobia. NASA Johnson Space Center investigates the strategies for compensation for the lack of outside views, like flat panel monitors working as a virtual windows or upper-surface penetrations for optic-fibre light source.

Speaking with a few astronauts that have spent some time on the International Space Station or shuttles, I verified that it is a very important issue indeed. What astronauts like the most, and that is as far as I know an opinion shared by all of them, is to spend their spare time watching the view from the cupola, the ISS window. It is very important from the psychological point of view. Doing my field research, gathering information, the first thing I was told was that the base should have any kind of 'windows'.

On the other hand, from purely technical point of view, placing windows is hard because of the protective aspects and engineers are willing to avoid that. With Lunar Light House I am trying to resolve this issue, introducing a novel system, that would allow for the daylight to pass into the base structure, without any losses on protective capabilities.

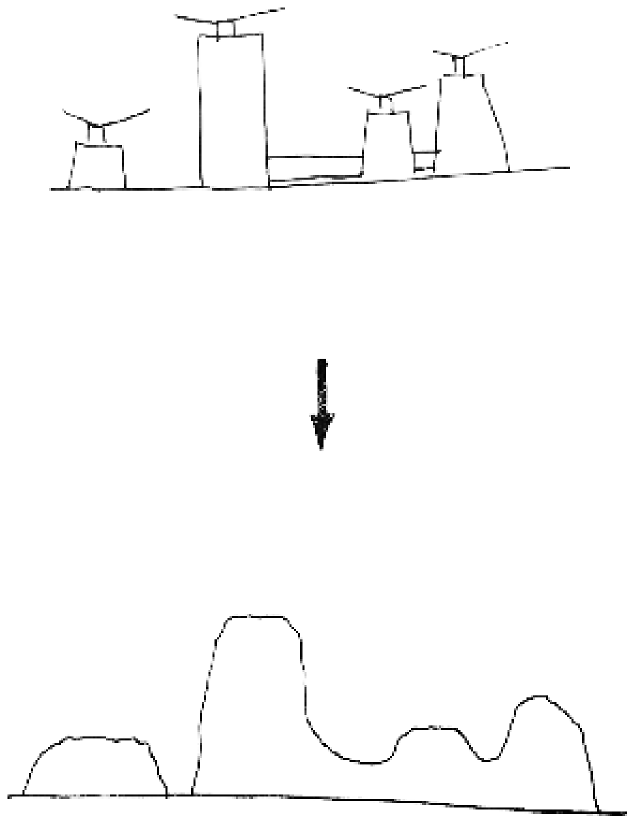


With a site in the peak of eternal light and a translucent nano-cellulose membrane, which works as a light fibre, placed all along the structure, the sun light can gradually pass inside, having its climax on the top of the structure. On every floor, in the corridors and open areas there would be a diffuse light coming from the outside. However in most of the closed rooms artificial light must be simulated, to ensure healthy day-night cycle for the crew. Yet, on the last floor of the base a transparent module could be placed. For on the level where there is no dust anymore, the density of the cellulose layers is the biggest and, due to the height, light shines all the time. It would allow astronauts to see the view a little bit and get some natural light as well. Translucent nano-cellulose not only would transmit light to the base but also light up itself, making the top of the base clearly visible from the outside. During external activities the base would become for astronauts what a light house was for sailors.

SELF - ASSEMBLY

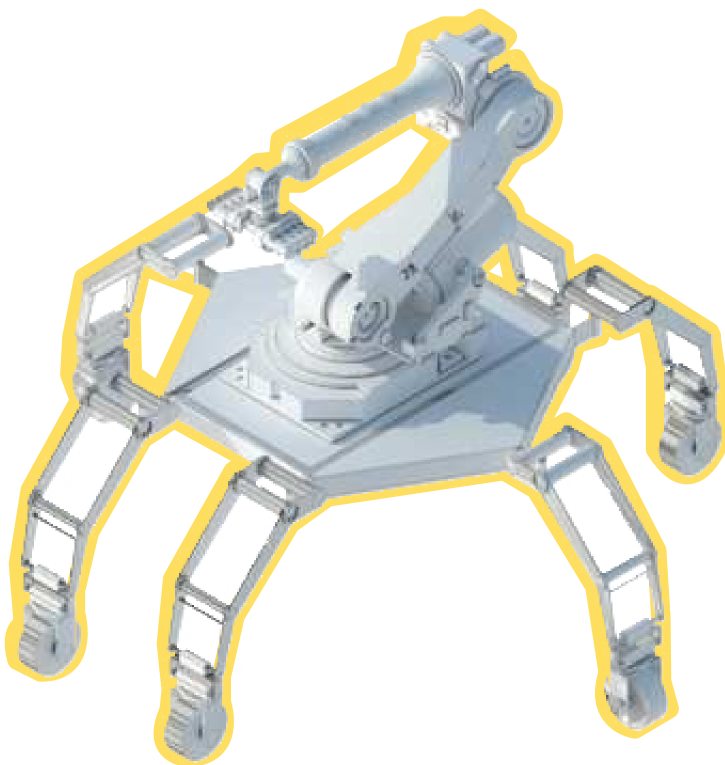
Important aspects of the project is it's self assembly and construction autonomy. There would be no manned operation needed to fully establish the base. The inflatable modules and the production module deploy automatically and the production of the cellulose starts. In order to gather and assemble regolith layers additional robots (for example ATHLETE) would be needed. They can work all the time, while the cellulose layers are being produced, so the regolith would be ready to put on place, with every 'layer' of the cellulose which is ready.

Since the base modules are build vertically, it requires minimum site preparation and ground manipulation to start construction.



The whole base is assembling autonomously. Each module has capabilties to 'grow' the shell strucutre around it. Also the connections between modules are solved in a way, that they wouldn't need any additional system to ensure radiation protection.

ATHLETE



All-Terrain Hex-Limbed Extra-Terrestrial Explorer

28.
Two ATHLETE rovers traverse the desert terrain adjacent to Dumont Dunes, CA. Task: ATHLETE: Rough and Steep Terrain Lunar Surface Mobility

29. ATHLETE with a Hab module on the top (NASA)


SPTM
UNIT A

5 | MATERIALS

Due to the payload restrictions local materials should be used where and when possible. To achieve inexpensive construction, as much ISRU must be applied as possible.

In the end, the base should be self-sustainable, requiring virtually no additional resources from Earth. All amenities and necessary facilities ought to be fabricated from local materials derived from mining or gathering.

Building materials may be prone to damage. On the lunar surface they would be exposed to a vacuum, severe temperature variations, radiation, micrometeorite impacts, high outward forces from pressurized structures. It all must be taken under consideration when choosing the right materials.

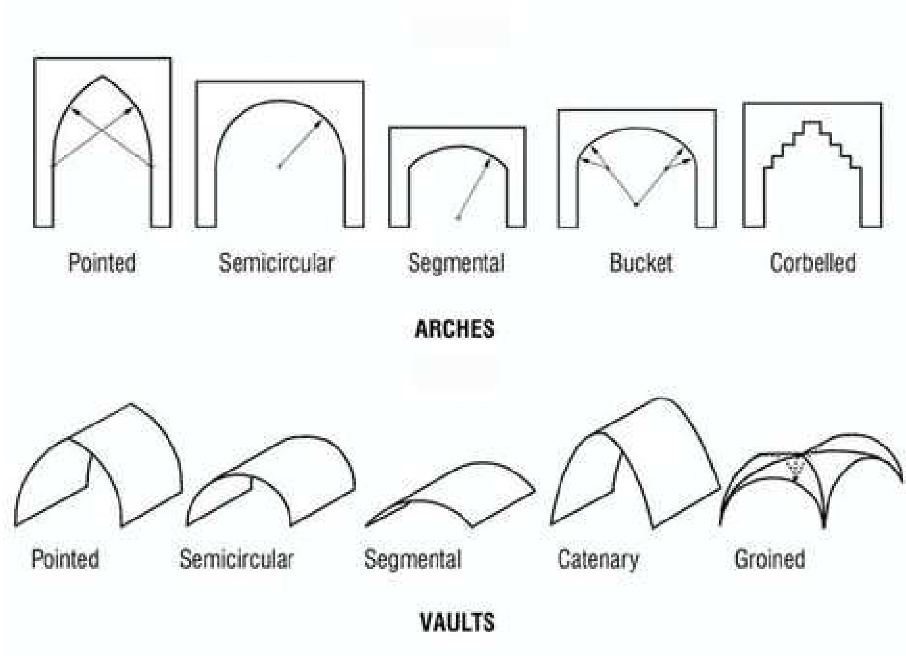
VERNACULAR ARCHITECTURE

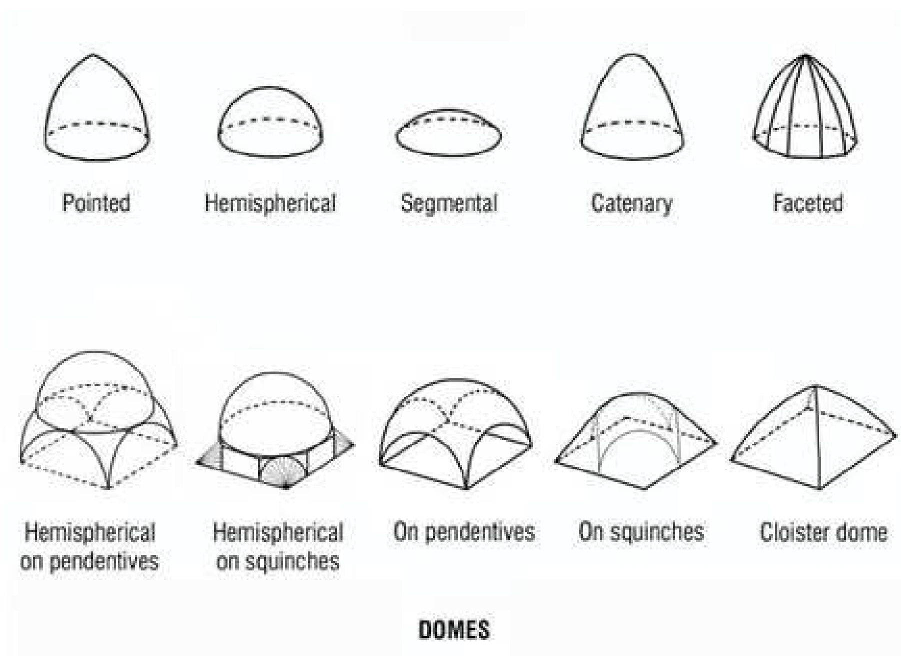
In Situ Resource Utilization (ISRU) is a very old concept that has shaped cultures and buildings over centuries. Nowadays, the high degree of infrastructre and logistics has made us forget about the value of local resources. However, this value is reastablishing as a technology for human planetary exploration.

41.
Basic typology of arches and vaults

42.
Basic typology of domes

source: http://www.earth-auroville.com/vaulted_structures_introduction_en.php

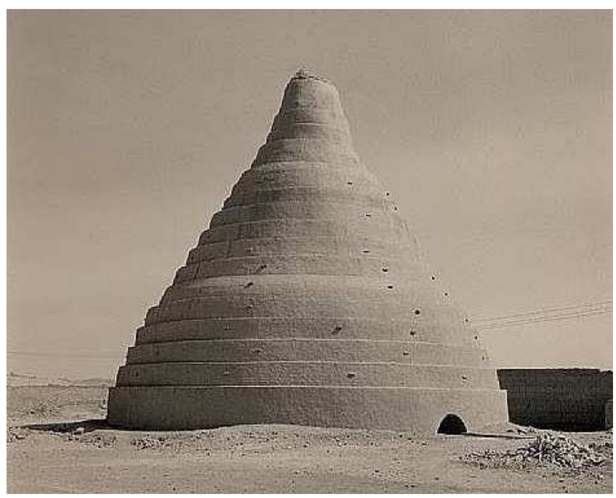

Pointed
Semicircular
Segmental
Bucket
Corbelled
ARCHES
Pointed
Semicircular
Segmental
Catenary
Groined
VAULTS


Pointed
Hemispherical
Segmental
Catenary
Faceted
Hemispherical on pendentives
Hemispherical on squinches
On pendentives
On squinches
Cloister dome
DOMES

43.
Burning Man Architecture
source: https://www.dwell.com/article/16-otherworldly-photos-of-burning-man-architecture-0b30ba0a/6359935255297622016

44.
Clochans on Dingle Peninsula, Kerry, Ireland,
source: https://en.wikipedia.org/wiki/Cloch%C3%A1n#/media/File:Dingle_beehive_hut.JPG

45.
Igloo
https://www.arch2o.com/wp-content/uploads/2017/10/igloo-against-blue-sky.jpg



46. http://www.academia.edu/30984939/Vernacular_Architecture_of_Southern_Italy

47. 48. https://dome.mit.edu/bitstream/handle/1721.3/55058/145281_cp.jpg?sequence=1

49. Ancient Ice House, Iran. Photo by Lynn Davis (b.1944) https://it.pinterest.com/pin/501377371000534022/

REGOLITH

Lunar regolith is the loose layer of dusty, powdery, charcoal-grey soil on the surface of the Moon. It is electrically charged, abrasive and is a bad heat conductor. Almost the entire lunar surface is covered by it and in most cases (80%) the lunar regolith is homogeneous to depth of 10cm.

Most of the regolith found on an even, plain surface has a bearing capacity of 25-55kPa. However this capacity is lower on steep slopes and on crater rims.

30.
Apollo 11 Lunar Module Pilot Buzz Aldrin's bootprint. Aldrin photographed this bootprint about an hour into their lunar extra-vehicular activity on July 20, 1969, as part of investigations into the soil mechanics of the lunar surface.

Source: https://en.wikipedia.org/wiki/File:Apollo_11_bootprint.jpg

Due to the lack of the natural weathering process on the Moon the lunar regolith is sharp and jagged. There was no process waring down its shape edges after the meteoroids impacts created all the particles.

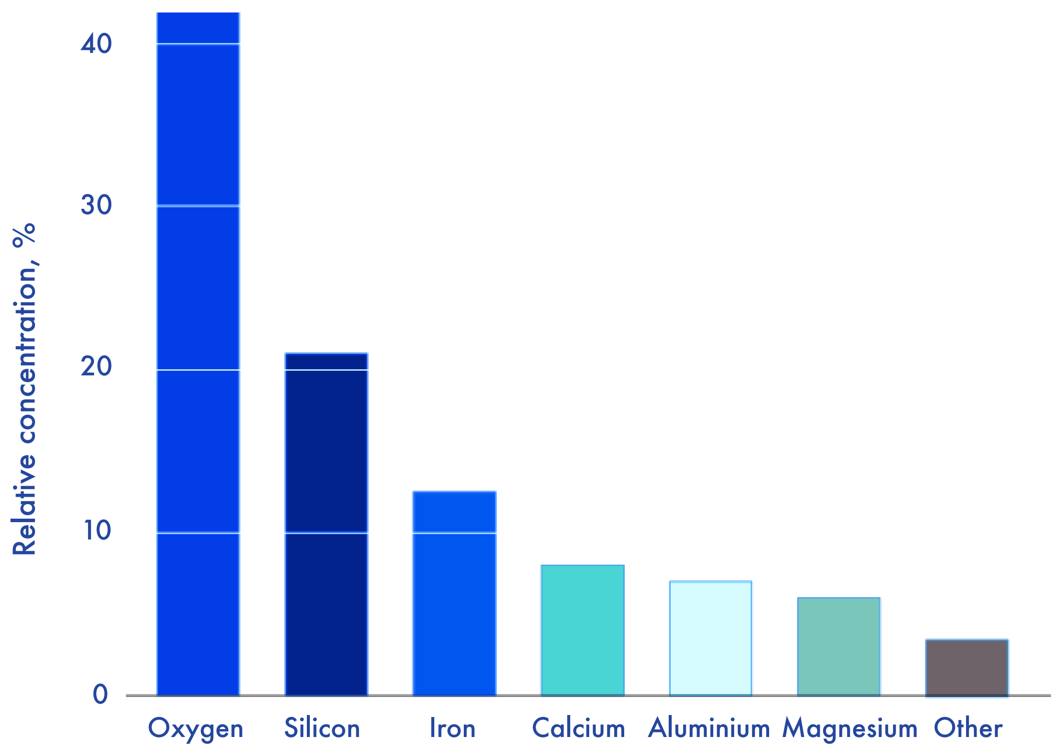
It can be used to cover parts of habitats to ensure protection against radiation for the base. According to studies, a regolith thickness of 2-3 meters is required to protect the human body from the hazardous radiation.

A lot of the concepts for the lunar bases assume that the regolith shell structures covers inflatable modules. This solution does not allow for a lot of freedom in shaping the structure. Double-curved morphology of inflatable structures, covered with the regolith tends to shed loose regolith coverings.

The biggest challenge is to construct the shell using optimal geometry. At this moment none of the previous approaches work sufficiently enough.

32.
Composition of the Lunar Soil

Source: https://en.wikipedia.org/wiki/Regolith



COMPOSITION OF THE LUNAR SOIL

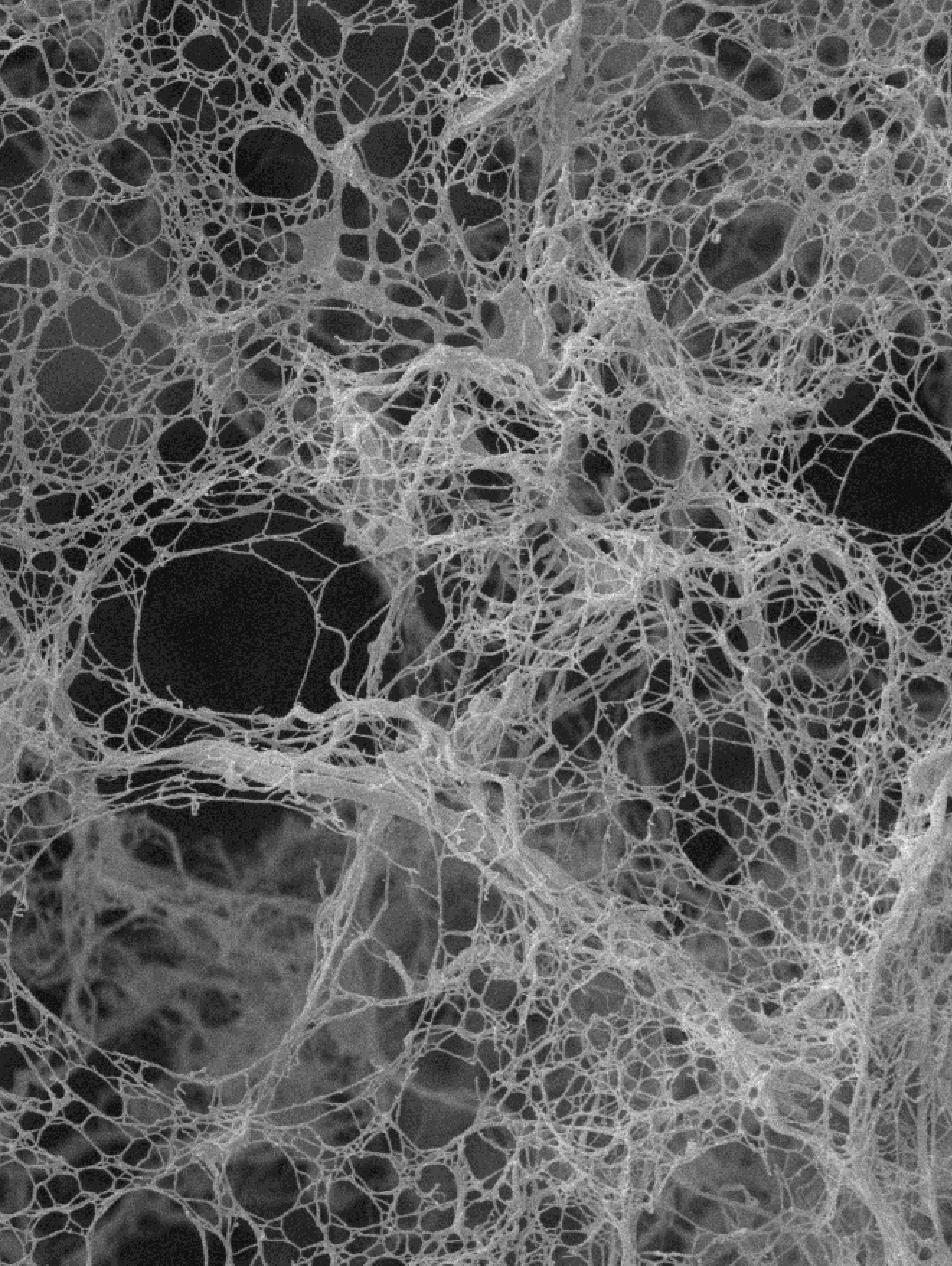
CELLULOSE

Cellulose is the main structural fibre of the plant kingdom and the most abundant, biodegradable and renewable polymeric material on Earth. It is very cheap, allows for functional versatility, hence it has various applications.

Cellulose is a polysaccharide composed of a few hundred to many thousands of monosaccharide molecules of D-glucose linked together by glycosidic bonds. Cellulose molecules combine with each other by means of hydrogen bonds to form large aggregates

Cellulose material is held together by the formation of numerous hydrogen bonds. The cellulose micro fibrils are oriented at 10-30 degrees from the main longitudinal axis of the fibre, which results in high tensile strength of the fibre in this direction. The elastic modulus is controlled by the amount of the cellulose in the fibres as well as by the angles between them. The elastic modulus raises when the content of cellulose increases and that of micro fibril decreases. Cellulose and it's derivatives are colourless, biodegradable and return to the natural carbon cycle by simple rotting. They are not toxic to living organisms, including humans. They are a good candidate for the replacement of non-renewable fossil-based products.

32.
Nanofibrillated Cellulose (NFC) which is sometimes also called as Cellulose nanofibril (CNF) is encompassed by Nanocelluloses alongside with Bacterial nanocellulose (BNC), Nanocrystalline cellulose (NCC).
Source: https://nanografi.com/blog/nanofibrillated-cellulose-also-known-as-cellulose-nanofibril/

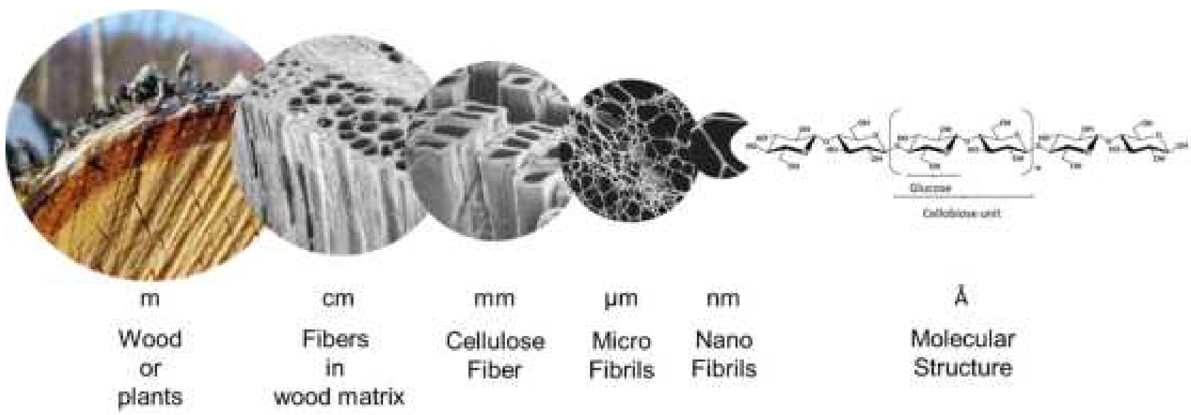


NANO-CELLULOSE

Cellulose nano fibres (CNF), micro fibrillated cellulose (MFC), nano-crystalline cellulose (NCC or CNC) or bacterial cellulose, all are nano-structured cellulose which might be generally called nano-cellulose. Nano-cellulose is a cellulosic material extracted from plants, animals or bacteria, in which at least one of the dimensions of a building block (fiber or crystal) is in the nanometer range. The main source of extraction is wood-pulp, it's also derived from cotton, flax, hemp, potato tuber, sugar beet, rice husk, algae and marine invertebrate animals - tunicates.

Nano-cellulose is a light solid substance and has exceptional strength characteristics. It possesses the property of specific kinds of liquids or gels that are generally thick in normal conditions. It is lightweight, stiffer than Kevlar®, electrically conductive, non-toxic and gas impermeable. It is highly absorbent when used as a basis for aerogels or foams. It has very high tensile strength - 8 times that of steel. But above all, nano-cellulose in crystalline form might be translucent, which is a great asset when considering the introduction of natural light to the habitat. It was already tested on Kombucha Multimicrobial Cellulose-Forming, on the surface of the ISS, with a conclusion that biofilm-forming microbial communities can survive in harsh environments. They display greatly increased resistance to physical and chemical adverse conditions. It is considered as an alternative to carbon fibre and glass fibre for some applications.

33.
Fibers in wood matrix, Herbert Sixta, Handbook of pULS, 1, 59, 2006
https://weidmannfibertechnology.com/what-is-mfc/


Glucose
Cellobiose unit
m
Wood or plants
cm
Fibers in wood matrix
mm
Cellulose Fiber
µm
Micro Fibrils
nm
Nano Fibrils
Å
Molecular Structure

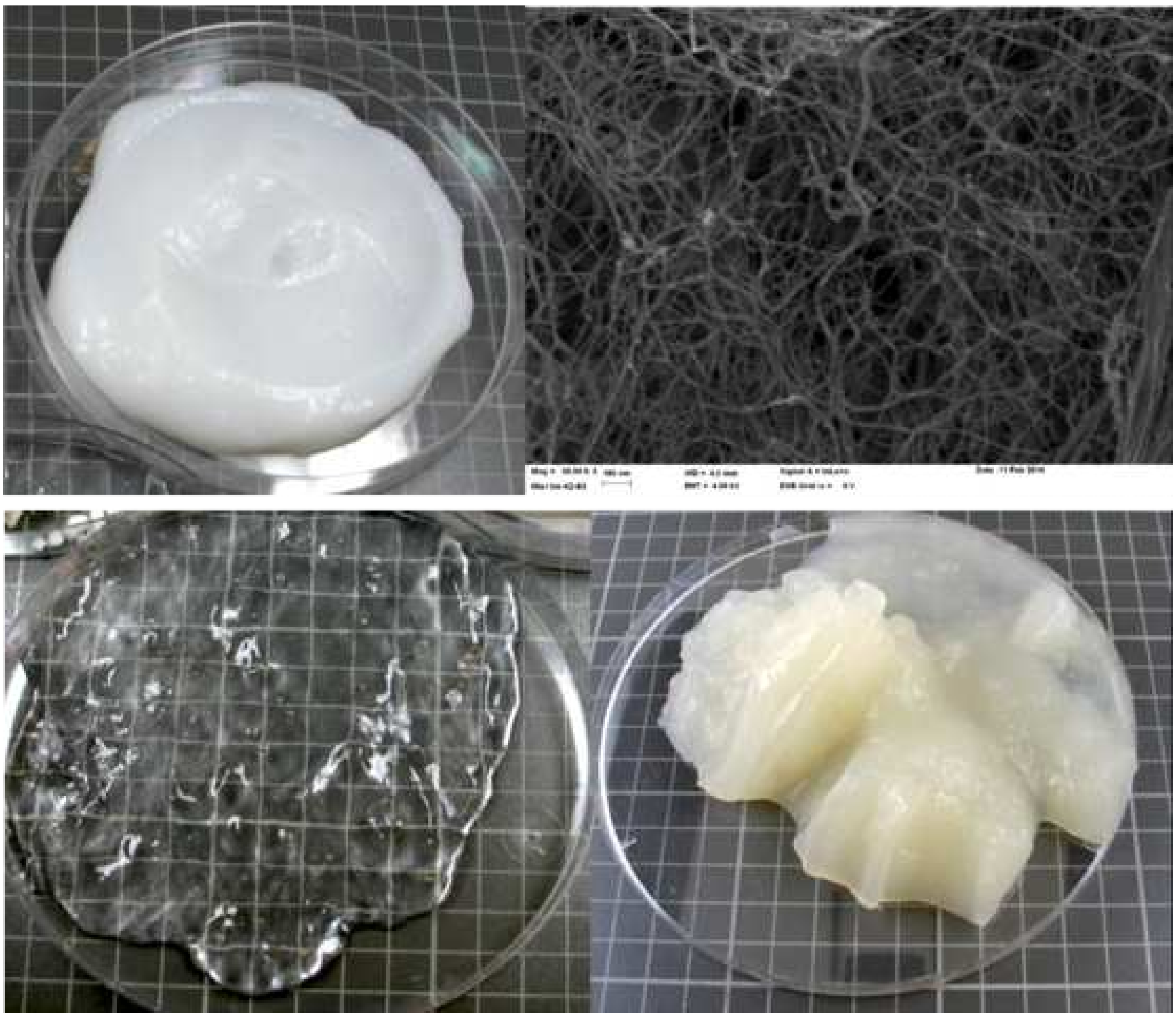
Cellulose nanomaterials can be divided into:

- Cellulose nanocrystals (CNC) also known as nanocrystalline cellulose (NCC). It has an elongated rod-like shape, generally with diameter in the range of 5-30 nm and length of 100–500 nm (from plant source), from tunicate anad algae source the lenght of 100 nm to several micrometers. The high crystallinity of the structure limits the flexibility compared to CNF.

- Cellulose nanofibrils (CNF), other name used is: cellulose microfibrils (CMF) or nanofibrillar cellulose. It's made of streched bundles of elementary nanofibrils build from alternating crystalline and amorphous cellulose domains, it has a width of 20–100 nm and a length of 500–2000 nm

- bacterial cellulose (BC). Most popular bacterial species is Acetobacter xylinum and Gluconacetobacter xylinum, the advantage of this nanocellulose is high chemical purity as compared to extracted from plants, BC structure consists nanofibers networks, generally with diameter in the range of 20-100 nm and length up to micrometer size.

34. Upper left: Cellulose nanofibril gel produced by Masuko grinding.(Image source: Tiina Pöhler, et al., VTT (2010)
Upper right: Scanning Electron microscope (SEM) image of cellulose nanofibrils. Scale: 100 nm (Image source: VTT).
Cellulose nanofibrils produced by TEMPO mediated oxidation (left) and carboxymethylation as the pre-treatment. (Source: Tiina Pöhler, et al., VTT (2010))



Nanocellulose materials can be preparation by using following processes:

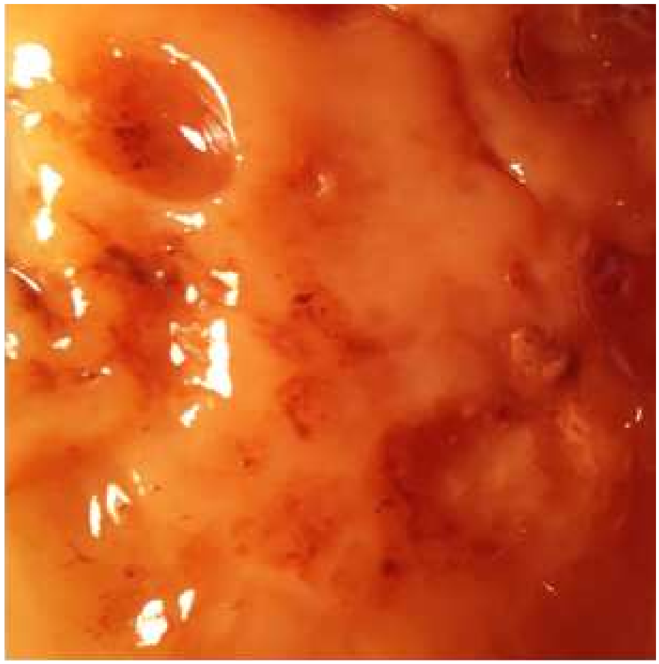
- chemical (acid and basic hydrolysis, TEMPO-mediated oxidation), these are basic and often used methods for preparation of CNC

- mechanical (grinding, high-pressure homogenization - very popular method for laboratory and large-scale production of CNF by an application of a high-pressure homogenizer at 50–200 MPa, microfludization, cryocrushing also known as freezer milling when the moisted cellulose biomass is frozen in liquid nitrogen and then crushed, high-intensity ultrasonication - in this process the aqueous cellulose solution is treatment by ultrasonic energy, steam explosion method as a cellulose biomass pre-treatment process, electrospinning - most effective method for producing micro and nanofibers from cellulose solution using an electric field)
- biotechnology (using bacteria and enzymes)

For high process efficiency and material quality, in the production cycle of nano-cellulose is usually used a combination of chemical mechanical and biotechnology methods.

35. 36.
Material grown on Kombucha membranes (KM), as secondary product from beverage production by fermentation of tea broth with symbiotic culture of bacteria and yeast (SCOBY), by purification, separation, and mechanical treatment it can result in Cellulose Nanofibrils. To purify KM NaOH should be used.

Source: http://www.mdpi.com/2073-4360/9/8/374



+ NaOH

GROWING CELLULOSE

At University of Texas scientists investigated genes from the family of bacteria that produce vinegar and Kombucha tea to produce nano-cellulose. Before, nano-cellulose had been produced by delaminating cellulosic fibres in high-pressure homogenisers. Now, nano-cellulose made by bacteria is easily produced and is high in purity.

Bacterias which are producing nano-cellulose (cyanobacteria/ blue-algae, vinegar making bacteria, SCOBY - symbiotic culture of bacteria and yeast) are photosynthetic bacterias.

It means that unlike the other bacterias, they are capable of producing their own food by photosynthesis process. The nutrients are synthesized from carbon dioxide and water using sunlight as chemical energy.

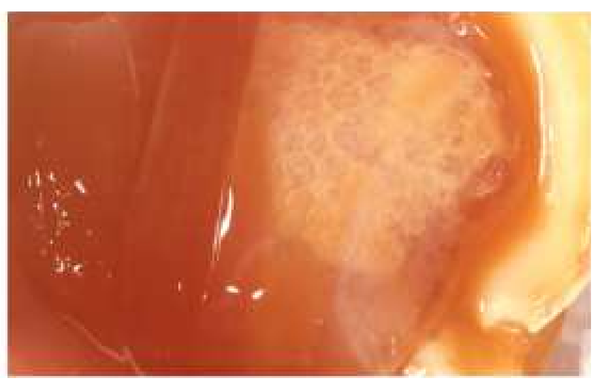
$$H_2O + CO_2 + \text{sun light} = \text{sugar} + O_2$$

Also it could be easy to harvest, since cyanobacteria had the potential to release nano-cellulose directly into their surroundings.

The biofilm is thick enough to see with a naked eye, even though it is created by microorganisms.

37.
Fermentation of tea broth with symbiotic culture of bacteria and yeast (SCOBY).

38.
Kombucha Membranes



EXPOSE-R2 - KOMBUCHA EXPERIMENT

A study published in journal Proceedings of the National Academy of Sciences, showed that bacterial species from Kombucha tea can be manipulated into microscopic factories and are able to manufacture products made of bacterial cellulose on demand.

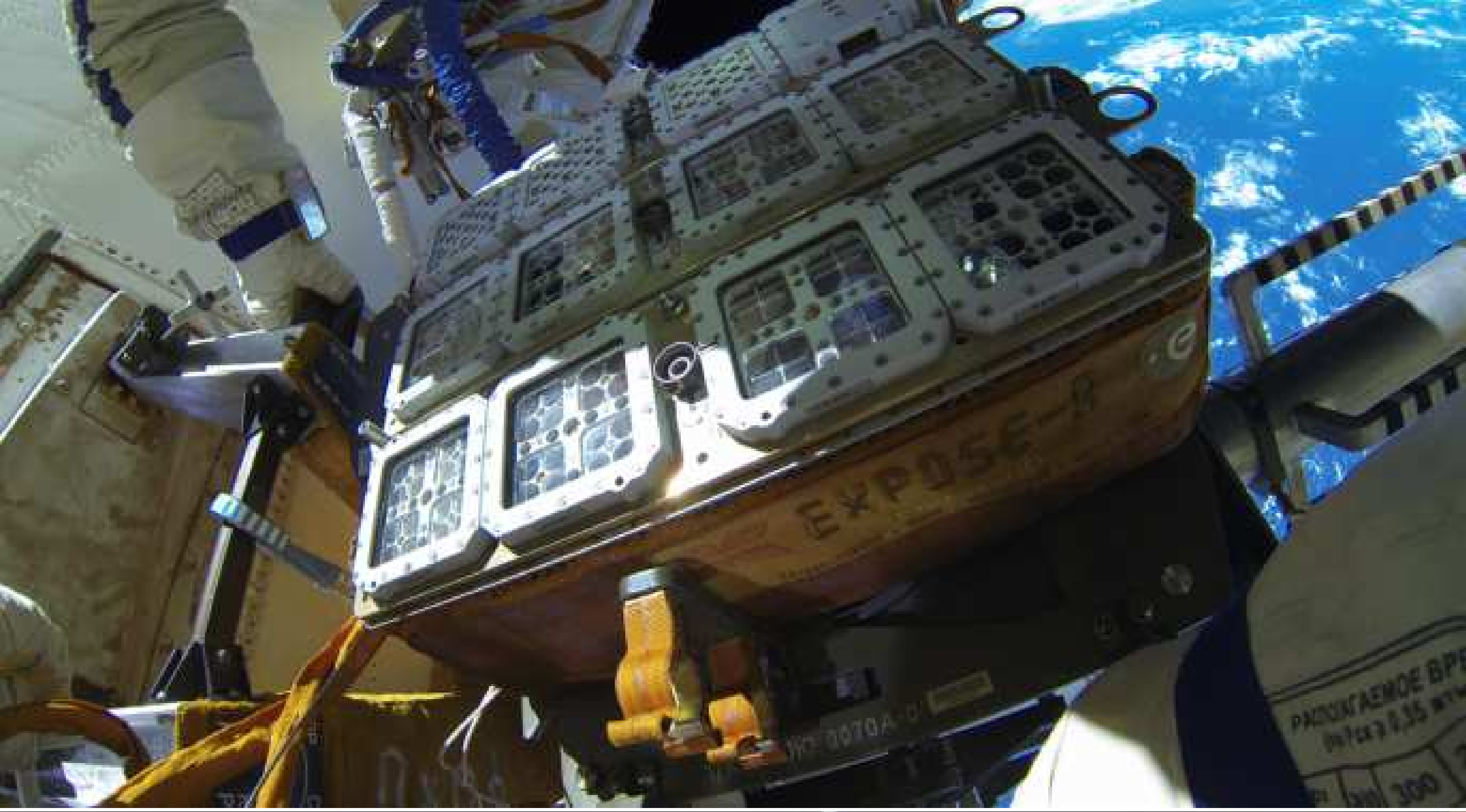
Tests on Earth have shown that multicellular biofilms in Kombucha cultures are very durable and will most probably survive a trip through space. After that, as a part of Biomex experiment, ESA sent a set of samples of the Kombucha-making organisms inside the Expose-R2 container to International Space Station. It was an 18-month trip in space to test how organisms and their molecular structure react to the combination of unfiltered solar light, cosmic radiation, vacuum and temperature changes found in space.

Kombucha cultures make a cellulose-based structure which protect themselves against harsh conditions. This way it can resist high temperatures and radiation.

Kombucha cultures are exceptionally robust when mixed with the moon dust, what was tested on the ground with the simulates. The cellulose absorbs minerals from the lunar soil, protecting the culture even better.

39.
The Expose-R2 facility on the International Space Station. As part of ESA's Expose-R2 project, 46 species of bacteria, fungi and arthropods are inside those containers as they spend 18 months bolted to the outside of the International Space Station. The vacuum of space is sucking out the water, oxygen and other gases in the samples. Their temperature can drop to –12°C as the Station passes through Earth's shadow, rising to 40°C at other times, and undergoing a similar process to the freeze-drying used to preserve foods. The Expose experiments are exploring the limits of terrestrial life, whether the organisms can survive in space and how the full blast of solar radiation is affecting accompanying chemicals.

40.
Spacewalking cosmonauts Alexander Skvortsov and Oleg Artemyev installed ESA's Expose-R2 facility on the outside of the Zvezda module on 18 August 2014, where it will stay for 18 months. Forty-six species of bacteria, fungi and arthropods are spending 18 months bolted to the outside of the International Space Station where the vacuum of space is sucking out the water, oxygen and other gases in the samples. Their temperature can drop to –12°C as the Station passes through Earth's shadow, rising to 40°C at other times, and undergoing a similar process to the freeze-drying used to preserve foods.


EXPOSE-R

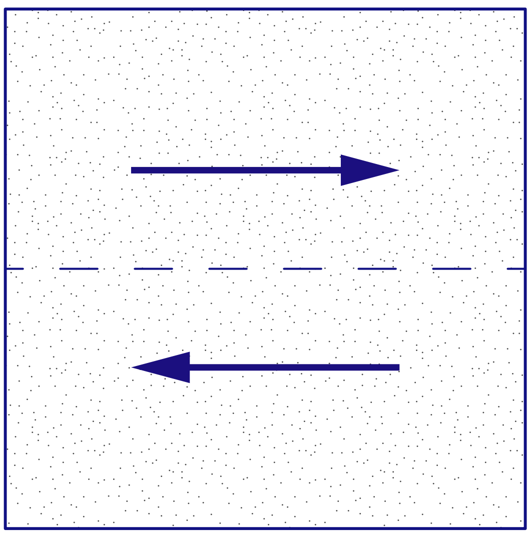

EXPOSE-R

6 | REINFORCE - MENT

Any kind of soil, weather it is sand, earth or lunar regolith, is not strong enough to act as a construction material itself. I propose using geotechnical engineering in order to make the use of regolith to build up a lunar base structure possible.

To achieve freedom in designing shape and to introduce natural light to the structure, in-situ grown nano-cellulose could be used. Together with the lunar regolith, nano-cellulose membranes would create a composite system, based on the soil reinforcement principles. It is a mechanical technique used to stabilize the soil structure. It can be conducted by the inclusion of short randomly distributed fibres or of continuous strips or sheets within the soil mass. It stabilises unstable slopes and helps to retain the soil on steep slopes and under crest loads. Additionally, to ensure lateral stabilisation, nano-cellulose reinforcement is designed as a continuous surface, climbing in the form of a spiral along the whole structure, instead of being divided into separate layers. Thanks to the use of nano-cellulose, Lunar Light House can be built tall and stay stable without using as much material.

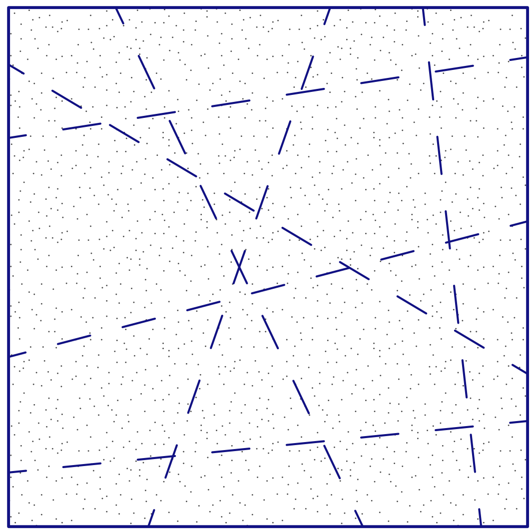
FRICTION FORCE

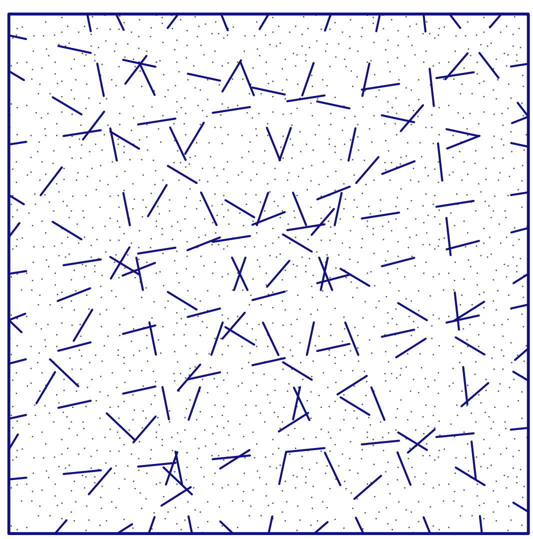


FRICTION FORCE = SHEAR STRENGHT

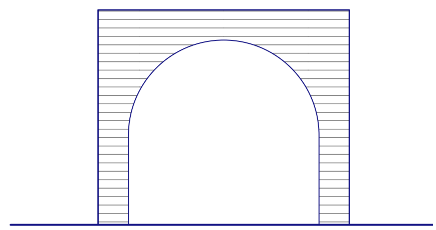
The reason why soils hold together is that they have high values of their coefficients of friction. Unlike steel which is held together by molecular bonding or concrete held by a binder, soil strength almost completely depends on internal friction between the soil particles themselves.

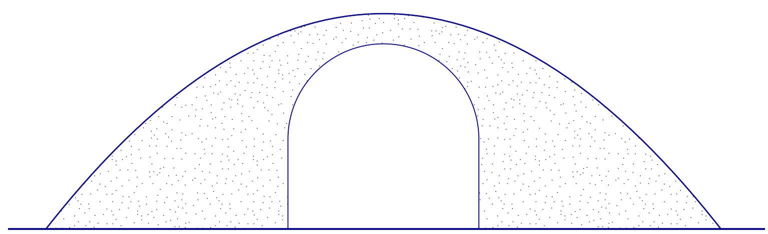
If we want to avoid sliding, the frictional force can be considered the shear strength. The more friction, the more strength against shearing. The shear strength of soil depends on the internal forces. But unlike other materials, soils have an infinite number of potential sliding planes all at once.






The angle of repose





The angle of repose, the steepest angle at which a soil can naturally rest. In other words, this is the slope at which the shear stresses within the soil due to its own weight are exactly equal to the shear strength caused by internal friction.

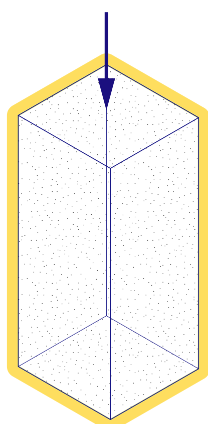
50.
Earthen structure takes about twice as much material than if you're using something that can stand vertically.

Source: http://practical.engineering/blog/2016/5/15/mechanically-stabilized-earth-aka-mse-reinforced-soil

REINFORCED REGOLITH

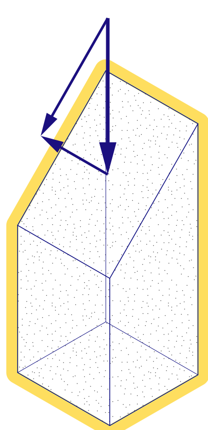
With a use of geo-synthetic material to reinforce the soil mass it is possible to build stable structure with smaller amount of the material used. Such a structure, in which tension in transferred to the soil reinforcement, relies on self-weight to resist the destabilising soil forces acting at the back of the reinforced soil zone. Structures constructed this way may be inclined steeper than 70 degrees from horizontal.

1



MORE NORMAL FORCE
= MORE SHEAR STRENGHT

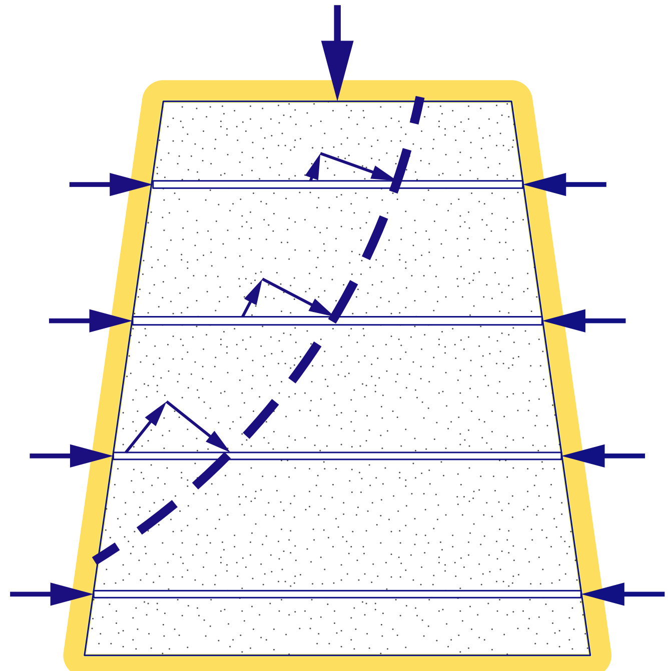
2



NORMAL COMPONENT
INCRESES SHEAR STRESS

PARALLEL COMPONENT
INCRESES SHEAR STRENGHT

3

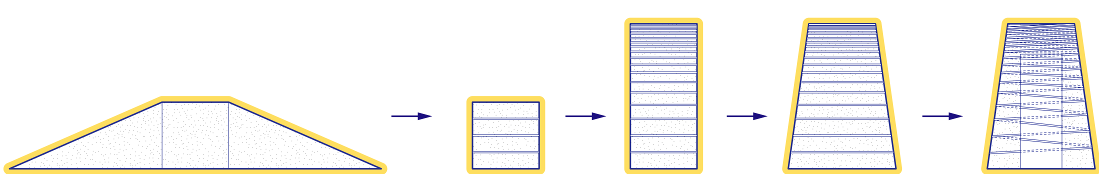


1. Horizontal plane - force is completely perpendicular, or normal, so it is increasing the shear strength of the soil.

2. Angled plane - the force is partly acting normal, increasing the strength, but it's also partly acting in parallel to the plane increasing the shear stress. The steeper the angle of the failure plane, the more the vertical force contributes to shear stress and the less it adds to the shear strength.

3. The tension in the reinforcement is generating confining pressure in the soil. This pressure acts perpendicularly to the failure planes, increasing the shear strength of the sand.

Source:http://practical.engineering/blog/2016/5/15/mechanically-stabilized-earth-aka-mse-reinforced-soil



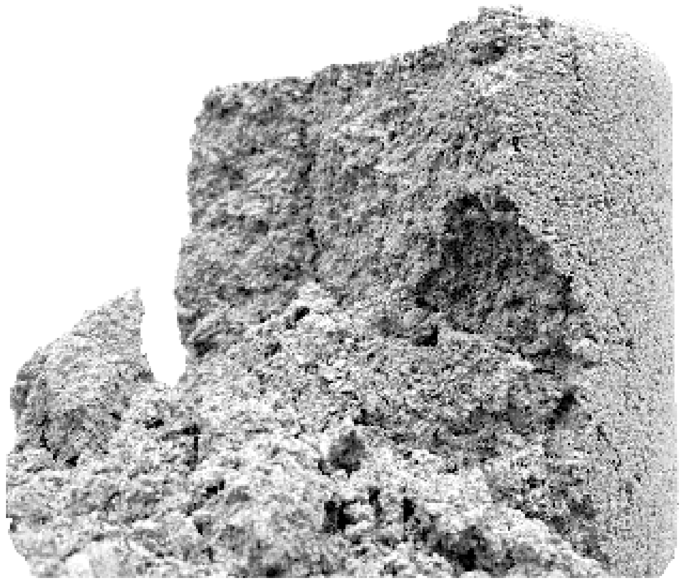
EXPERIMENTS

The reinforced regolith idea has been tested on the simple mould and the results were very promising.

The structure which did not have any reinforcement fell apart, even without any load. The structure with reinforcement layers made out of cellulose withstood given pressure, only with slight deformation, but no soil particles falling apart.

51.
Experiments with soil and cellulose membranes

52. 53.
Experiments with soil and cellulose membranes



REGOLITH WITHOUT REINFORCEMENT

REGOLITH WITH CELLULOSE REINFORCEMENT

7 | DEPLOYABLES

Payload optimisation of elements brought from Earth is crucial. Therefore, the use of deployable structure is very popular in space explorations. In my project I am using deployable structures for two different purposes.

The first are the inflatable modules, used to provide a pressurised space for the habitat. For now, we are hardly capable of producing tight modules in-situ, so they have to be brought form Earth.

The second is the cellulose membrane production module. The nano-cellulose has to have a big radius and thus a big structure is needed to be able to hold it and ensure a good growing environment. The structure would be too big to fit into the rocket, so it also has to be deployable.

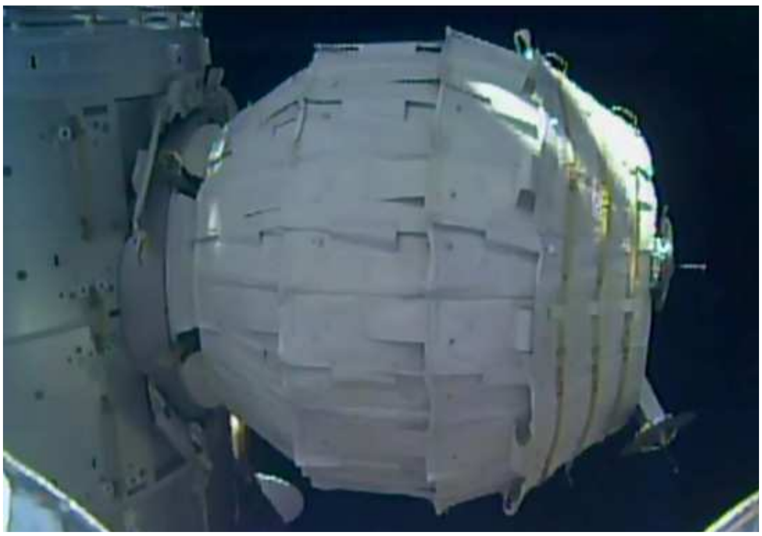
INFLATABLE STRUCTURES

Inflatable habitats are the most popular solution, they provide a lot of living area while being fairly lightweight. As the Moon has no atmosphere, any habitat would need to be pressurized to simulate the terrestrial atmosphere, to approximately 1 atmosphere or 101,325 kPa. Due to the high forces acting outwards, structural integrity of an inflatable has to be assured.

The most natural form of pneumatic structures is the sphere. Although it is possible for inflatable structure to take almost any shape (different forms can be forced by the cutting pattern of inelastic fabrics), they tend to take simple geometrical shapes and work the best when are close to a sphere, cylinder or a torus.

54.
Onishi Yasuaki inflates plastic volumes for granship window in Japan,
source: https://www.designboom.com/art/onishi-yasuaki-vertical-volume-granship-japan-04-05-2014/

SPHERE



55.
Bigelow Expandable Activity Module,
source: http://www.planetary.org/multimedia/space-images/spacecraft/beam-expansion-progress.html

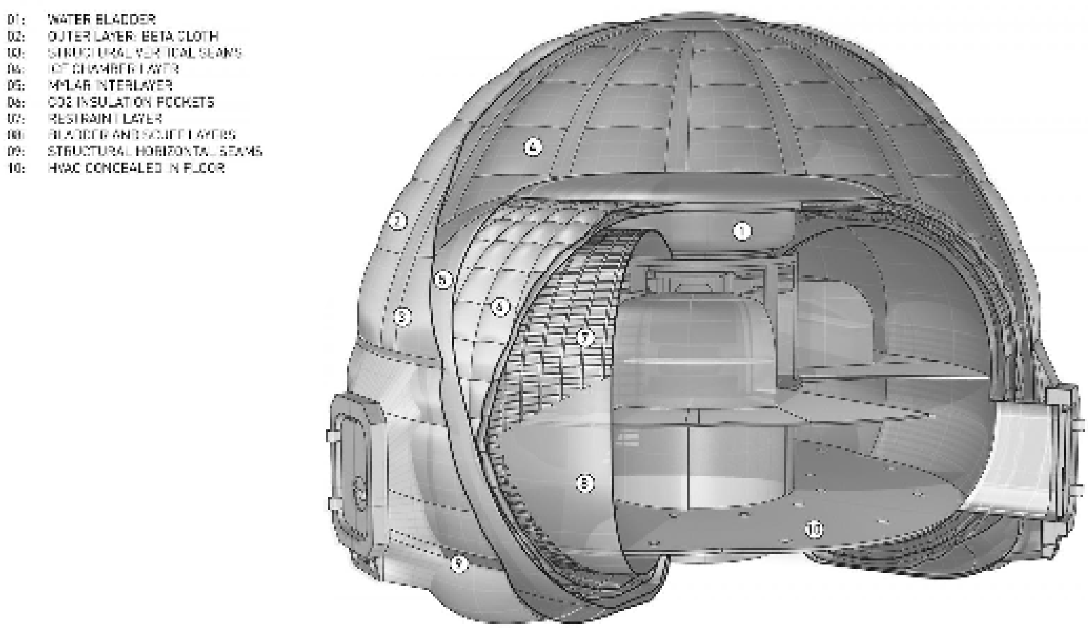
CYLINDER

56.
Olympus Space ,
source: http://www.olympusspace.com/

57.
Inflatable lunar habitat model at NASA's Langley Research Center in Hampton, VA (NASA/Sean Smith), source: https://www.nasa.gov/centers/langley/multimedia/image-0909-2007.html

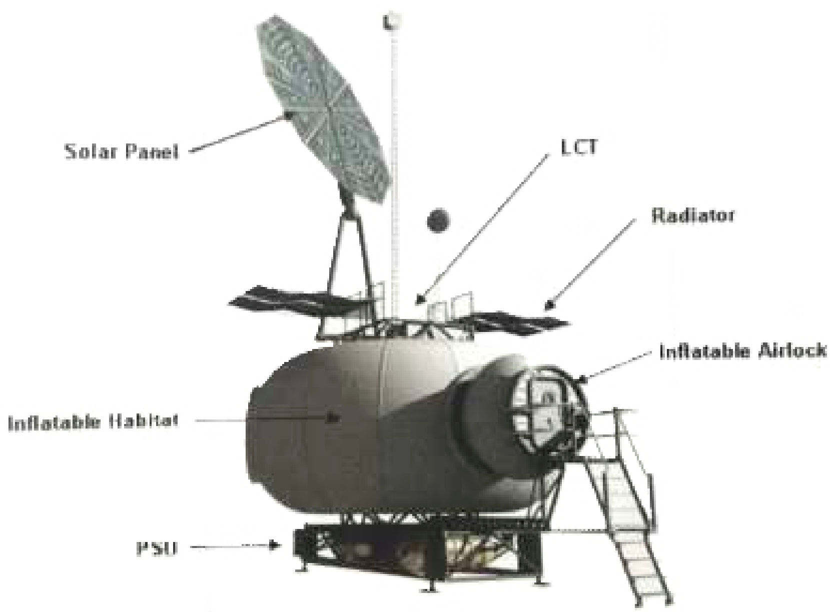
TORUS

58.
NASA Considered an Inflatable Donut for a Space Habitat
https://gizmodo.com/nasa-considered-an-inflatable-donut-for-a-space-habitat-1737138377



59.
NASA/Clouds AO/SEArch
https://www.nasa.gov/feature/langley/a-new-home-on-mars-nasa-langley-s-icy-concept-for-living-on-the-red-planet

INFLATED TORUS CONCEPT



60.
Inflated torus modules with external systems deployed. Mobile labolatory mode with ATHLETE carrying lab element for excursion science.

61.
Floor systems mechanism deploys as shell inflates, automatically positionin pre-integrated pretested hull penetrations.

source: Out of this world. The new field of space architecture
A. Scott Howe, Brent Sherwood, AIAA

ORIGAMI

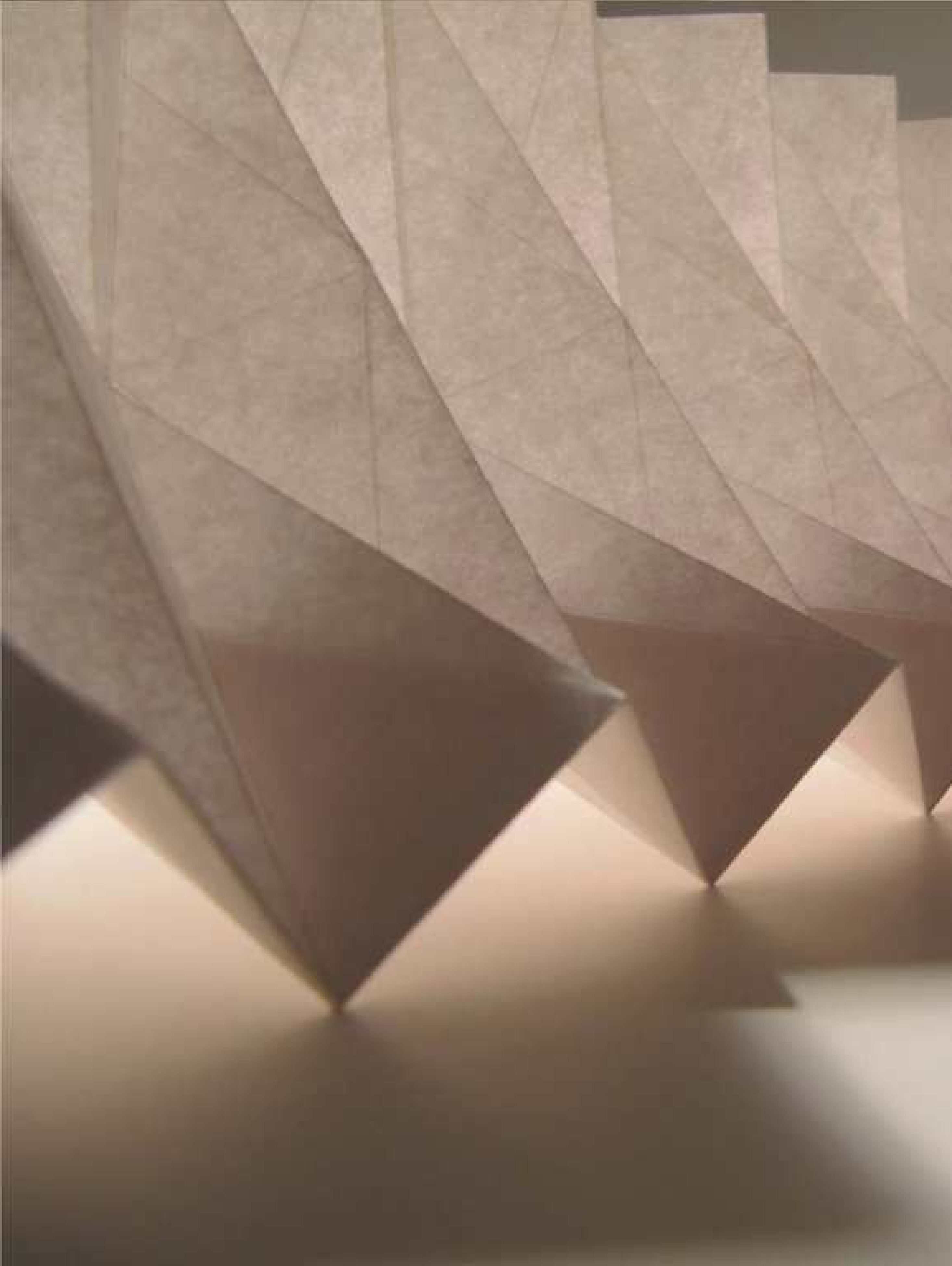
Origami is an ancient Japanese art of folding paper. The term "origami" comes from the Japanese words "ori" (to fold) and "kami" (paper). Traditionally, the art form utilises a single sheet of paper (no cuts permitted) that is then manipulated and folded.

Today, origami has transformed into more than just paper folding. American physicist, Robert Lang, inspired by working with origami objects in his free time, laid the foundation for computational origami using geometric mathematical formulas. Because of these advances in computers and mathematics, more complex geometric folding algorithms are allowed for endless possibilities of applications in the fields of science, technology, and engineering.

Folding is a great strategy when space is limited and can be used as a compactly stowed system that transforms into a 3D structure with variable functionality.

Common crease patterns seen in origami engineering are the Miura-ori, Yoshimura, and the Diagonal patterns.

62.
Origami foldings
source: https://catiniata.deviantart.com/art/Origami-Fold-07-411720248



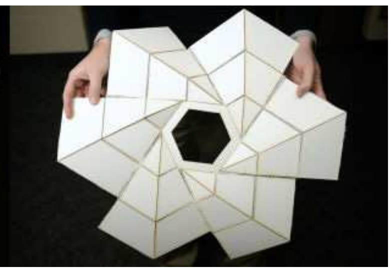
ORIGAMI IN ASTRONAUTICAL APPLICATIONS

Thanks to it's ability to compress and expand large object origami has a great potential in space research and exploration. Since getting things into space is costly, with origami it is possible to make things compact for launch and then deploy it. It could be especially appropriate for spacecraft applications where it is beneficial to deploy an object radially.

In space missions panels with simple folds already used, collapsing like a fan or an accordion. Recently the more intricate folds are being considered and investigated, that simplify the overall mechanical structure and make deployment easier.

63.
Some examples of origami designs at JPL. Engineers are exploring this ancient art form to create folding spacecraft. Image Credit: NASA/JPL-Caltech

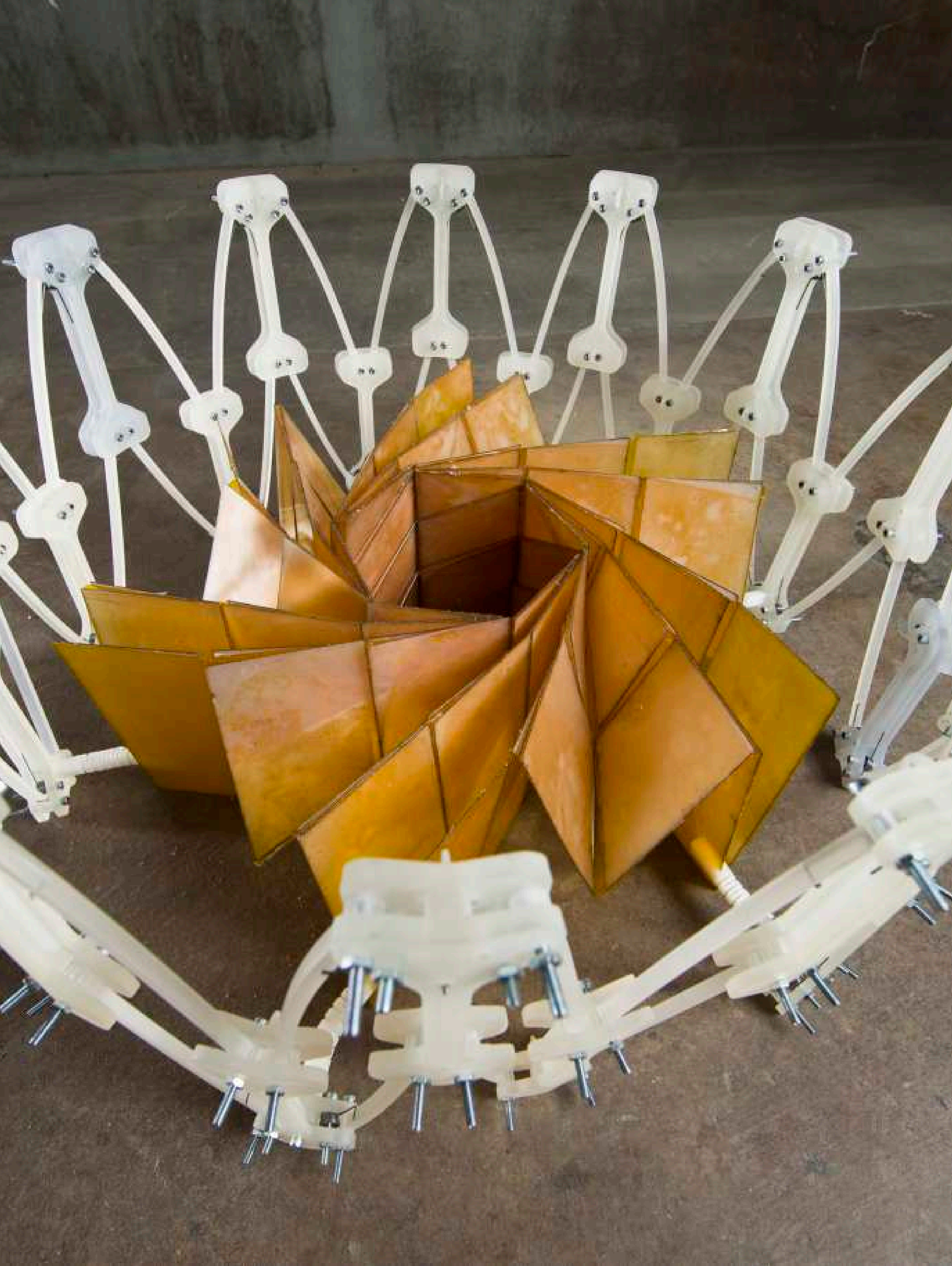
ORIGAMI INSPIRED SOLAR ARREY

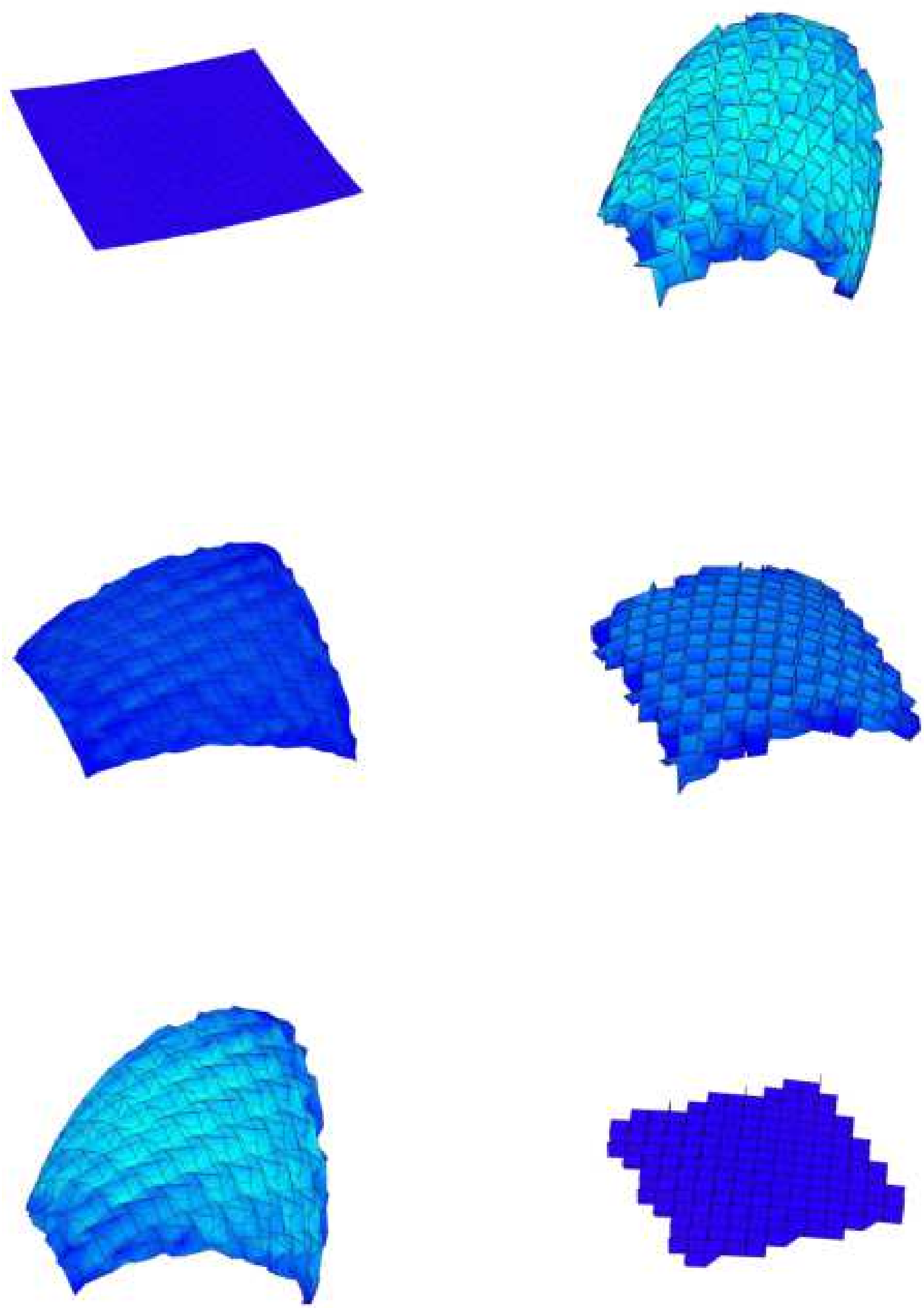
64. 65. 66.
A solar array that folds up to be 2.7 meters in diameter. Unfolded it becomes a structure of 25 meters across.

The design mimics flower with six sides with multiple layers of valleys and mountains that can be continuously added to increase the diameter. The height constraints of the stowed array do not limit the deployed diameter.

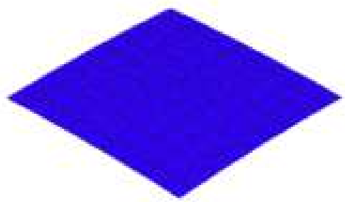
https://www.nasa.gov/jpl/news/origami-style-solar-power-20140814

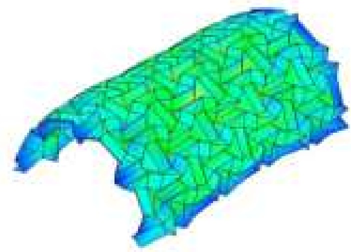


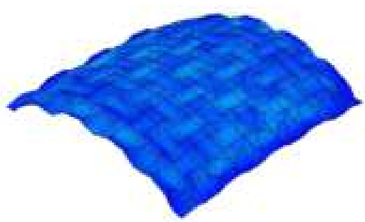
HUFFMAN EXTENDED BOX

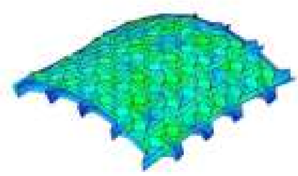


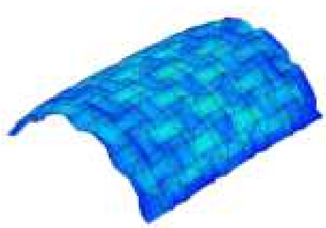
HUFFMAN EXTRUDED BOX

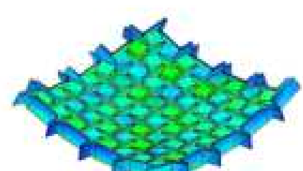




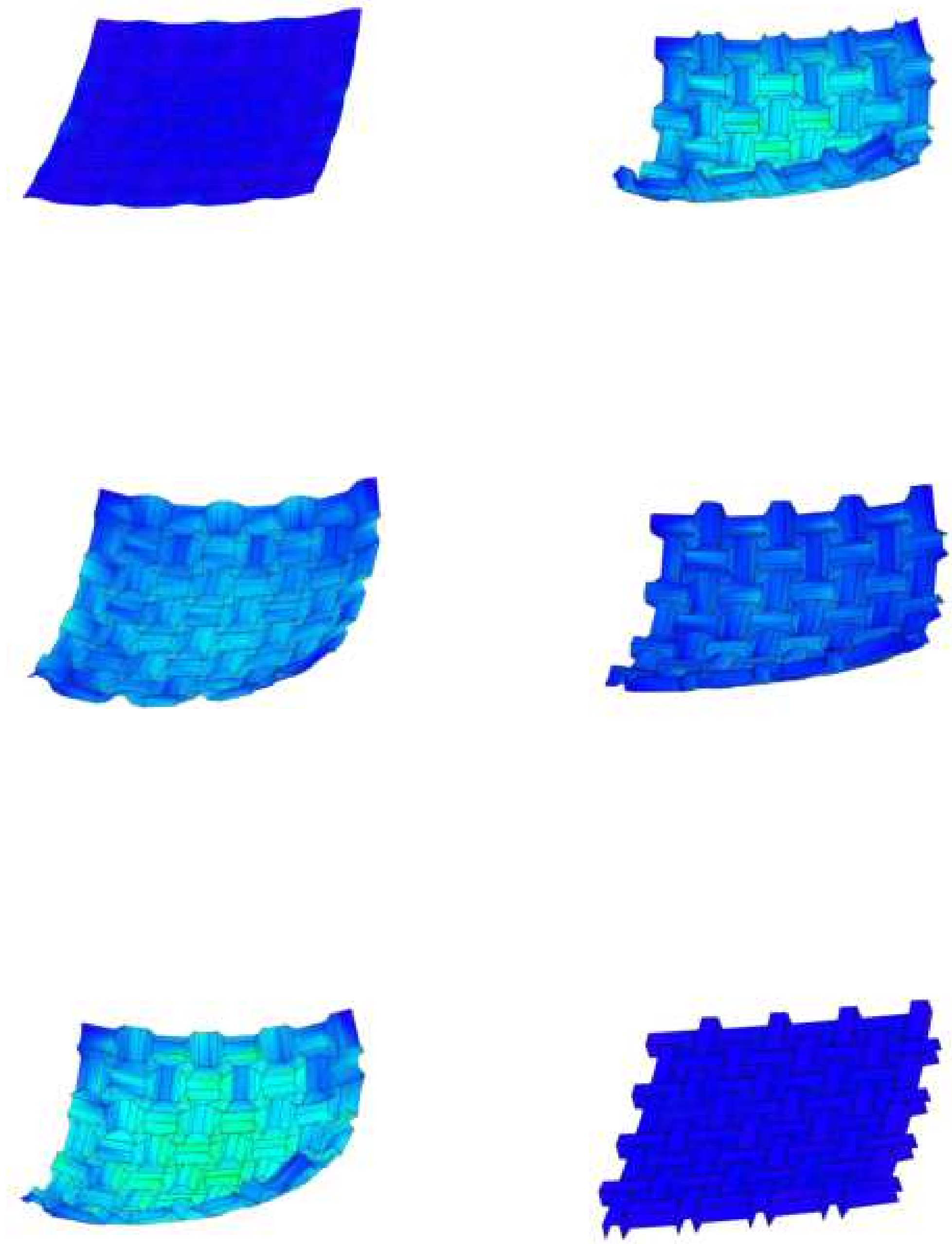




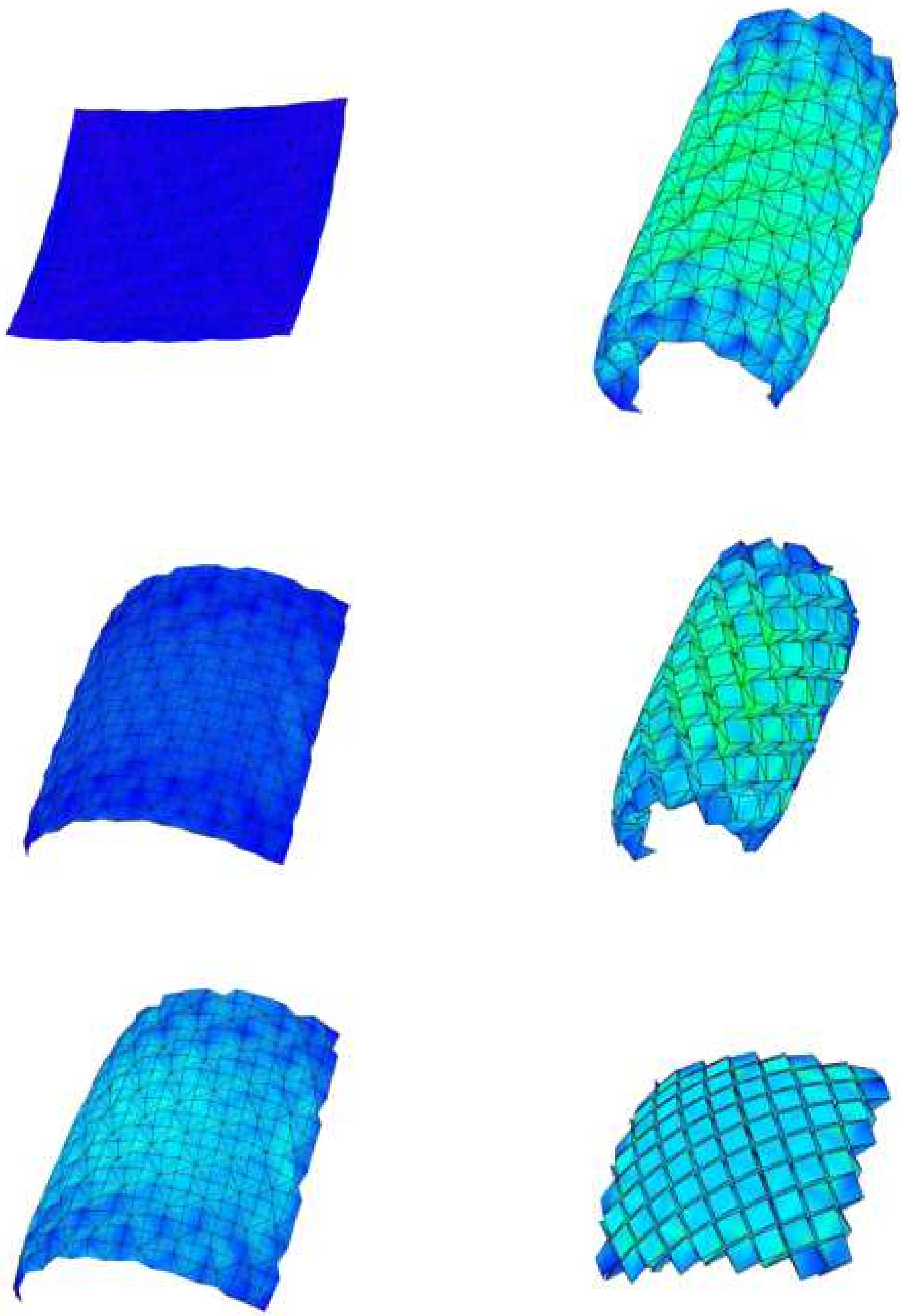




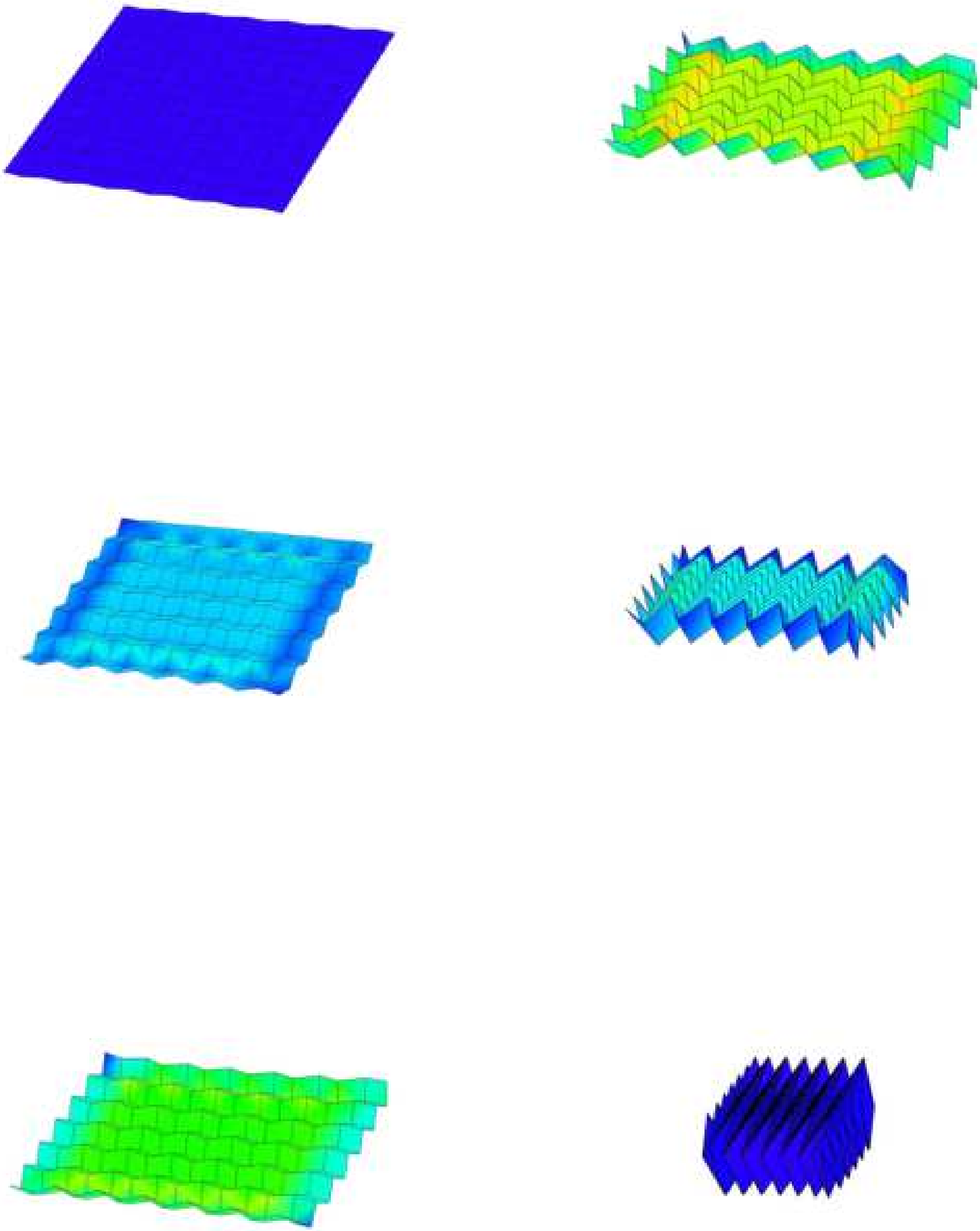
HUFFMAN RECT WEAVE



HUFFMAN WATERBOMBS



MIURA-ORI



MIURA-ORI

The Miura Ori, named after its inventor, Japanese astrophysicist Koryo Miuraquitem is a folding technique that allows for the compact format to open into a big sheets in one smooth motion. By developing a modified Miura pattern certain topographies can be generated.
This folding technique is a form of rigid origami. It means that the fold can be carried out by a continuous motion in which, at each step, each parallelogram is completely flat. This property allows for folding surfaces made of rigid materials.

68-71
Origami foldings generated by the origami software

http://www.tandfonline.com)

PROCESS

THE MOST
IMPORTANT STEPS
AND DESIGN
DECISIONS
ARE CIRCLED

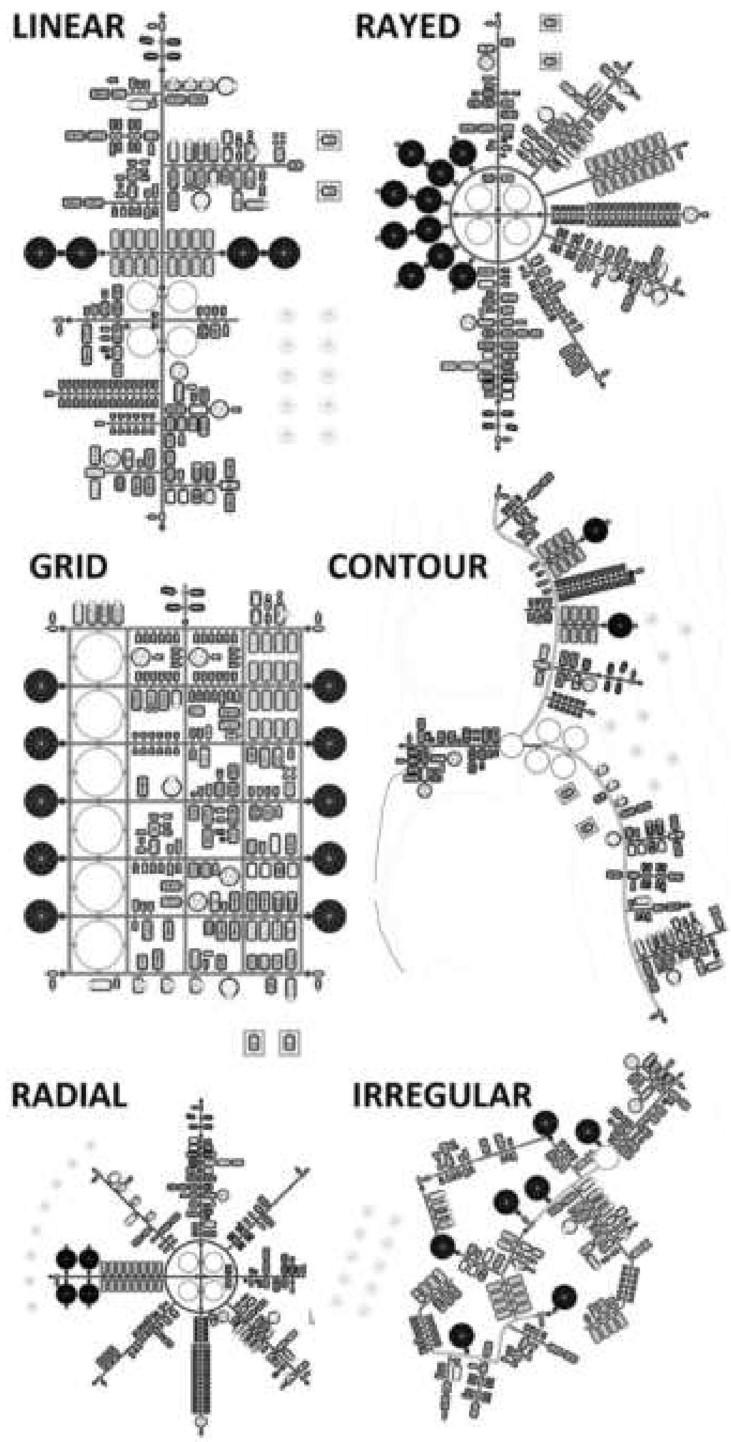
8 | SETTLEMENT

Large settlements in harsh environments require lots of precision in planning. Many specialists from a variety of disciplines will be working on different parts of such project. It is absolutely necessary for them to work together. Each discipline brings out new solutions and ways to look at a problem. In order to create the best possible outcome, engineers should work together simultaneously.

ARRANGEMENT AND LAYOUT

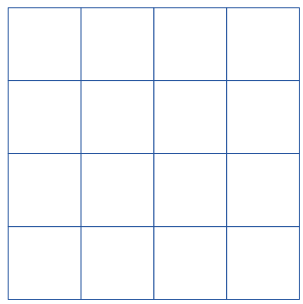
Lunar "city planning" will be another complex task and many module configurations must be considered.

There are a few main module configurations highlighted: Linear, Courtyard, Radial, Branching, Cluster, Rayed, Grid, Contour and Irregular.

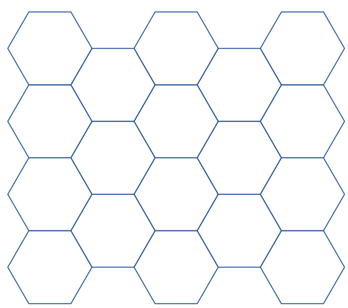


Examples of modular colony arrangements,
Architectural Design Principles for Extra-Terrestrial Habitatas, Acta Futura

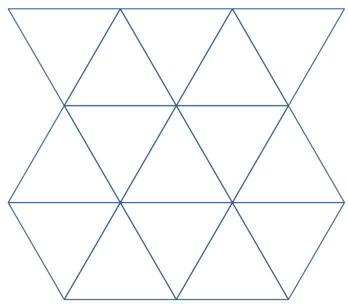
TYPES OF GRID



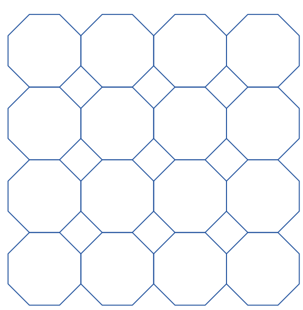
ORTHOGONAL GRID



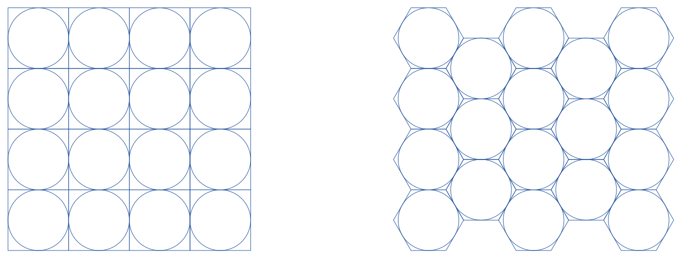
HEXAGONAL GRID



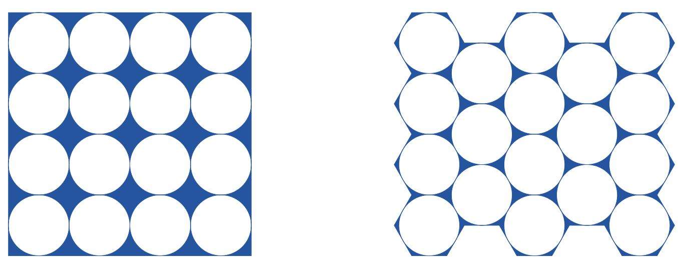
TRIANGULAR GRID



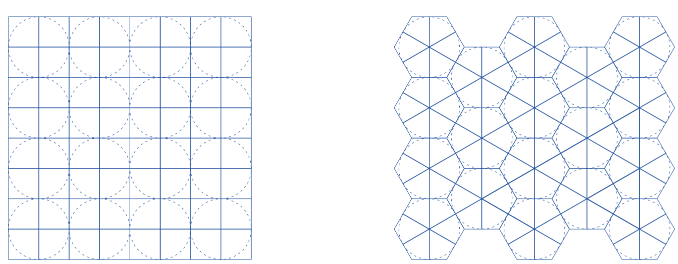
OCTAGONAL GRID



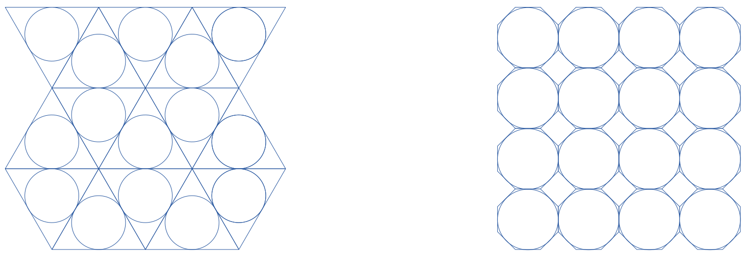
Spherical membrane on top - cellulose prouduction module



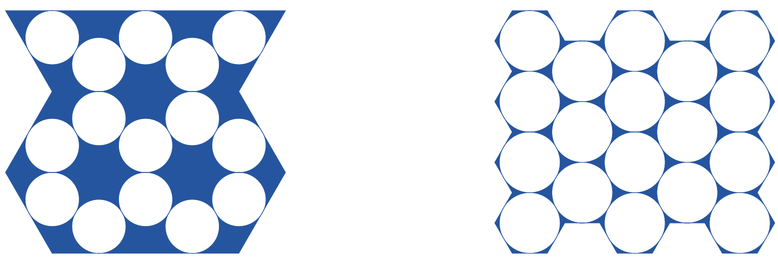
Negative spaces -
areas where the cellulose cannot be produced



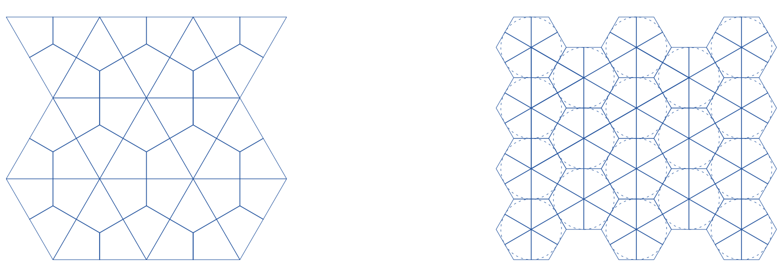
Connections between segments



Spherical membrane on top - cellulose prouduction module



Negative spaces -
areas where the cellulose cannot be produced

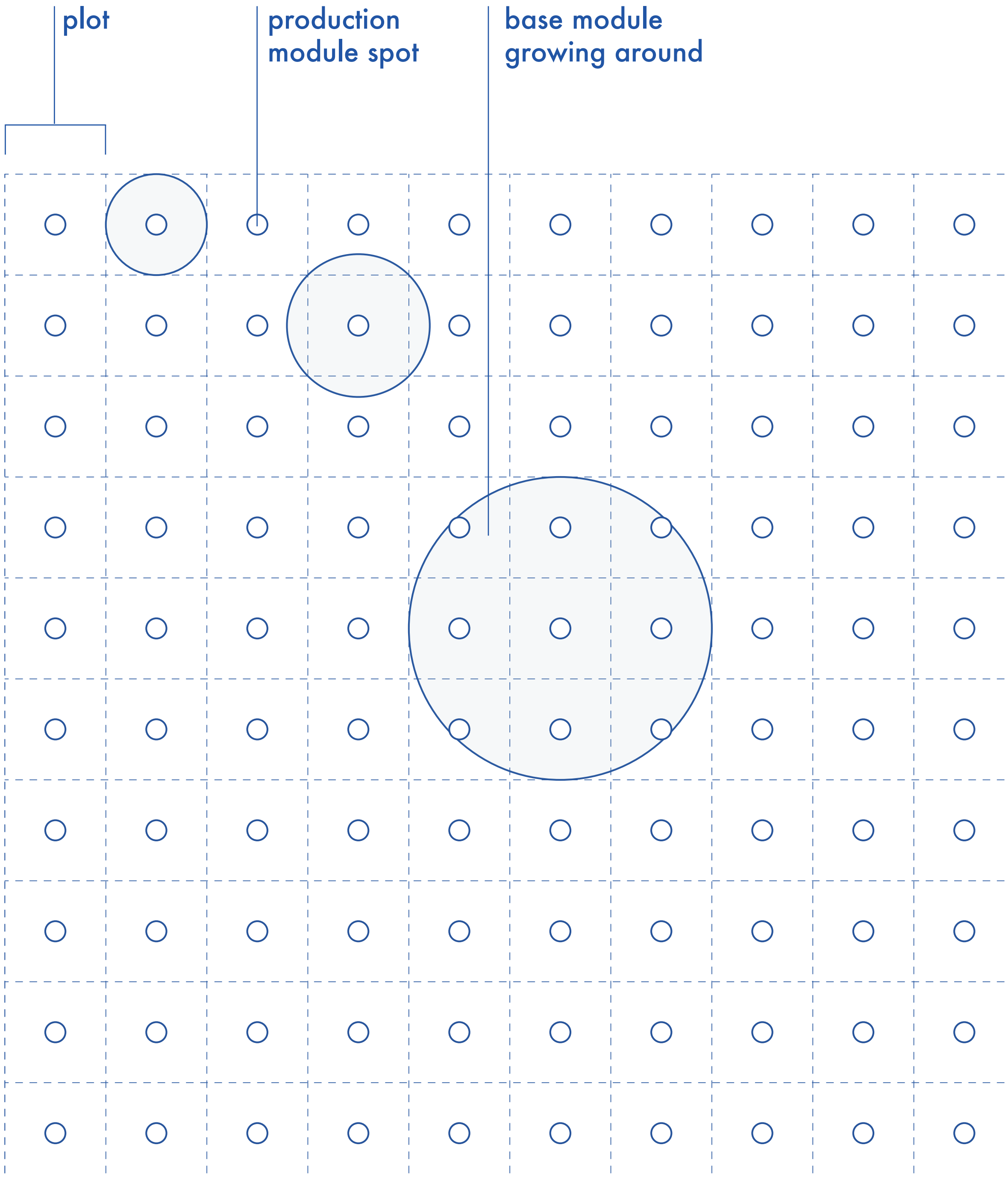


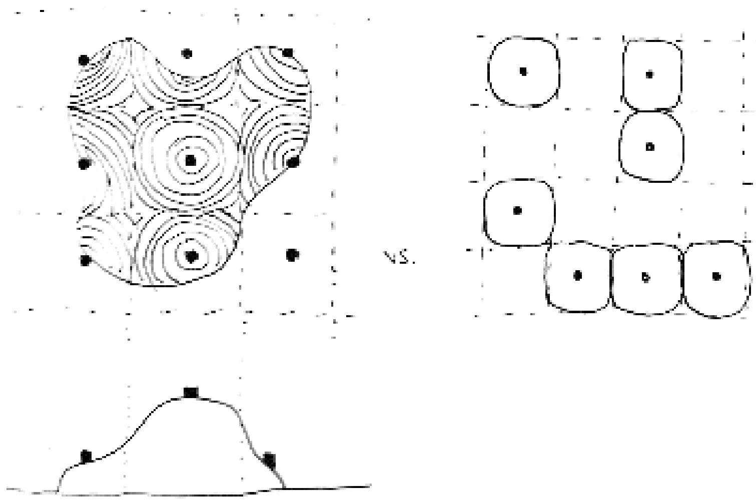
Connections between segments

ORTHOGONAL GRID

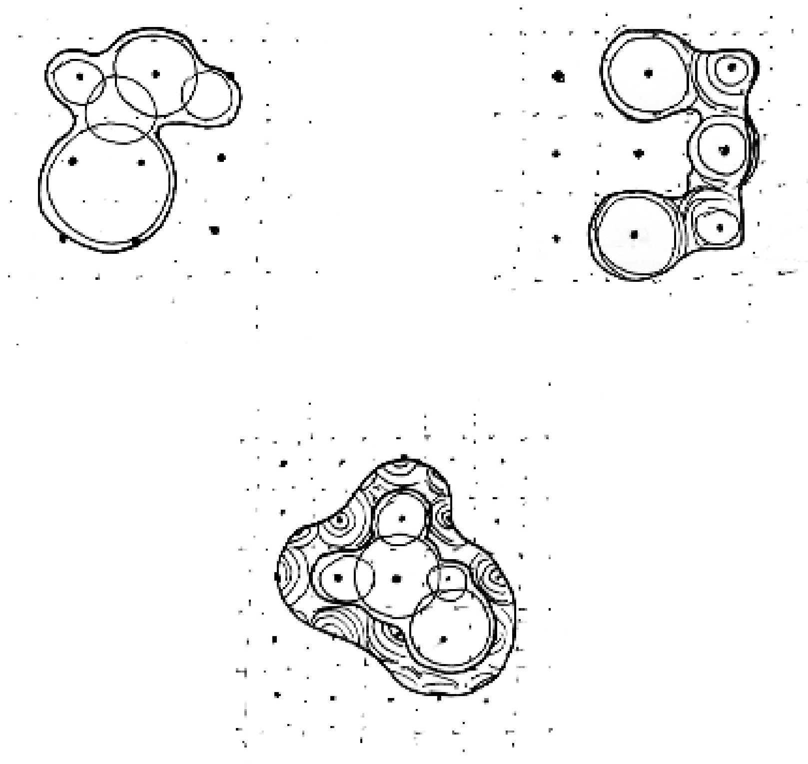
Orthogonal grid helps with robotic operations and navigation.

The whole base structure would be arranged on the orthogonal grid. The grid dictates the spots where the production module could be set (circles) and the base modules 'grow' around, following the pattern.


plot
production
module spot
base module
growing around

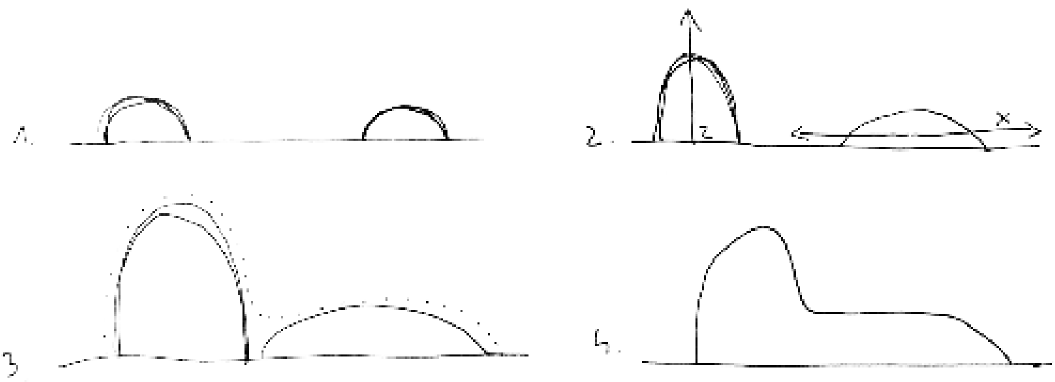


Testing the idea that shape of the whole base, or even each base module doesn't have to be same or follwoing any given boundaries.



Overall base structure merges together seperate base modules into one consistent structre. The way how the radiation shelter layers are assembled is dictated by the arrangement of the production modules, set on the grid.

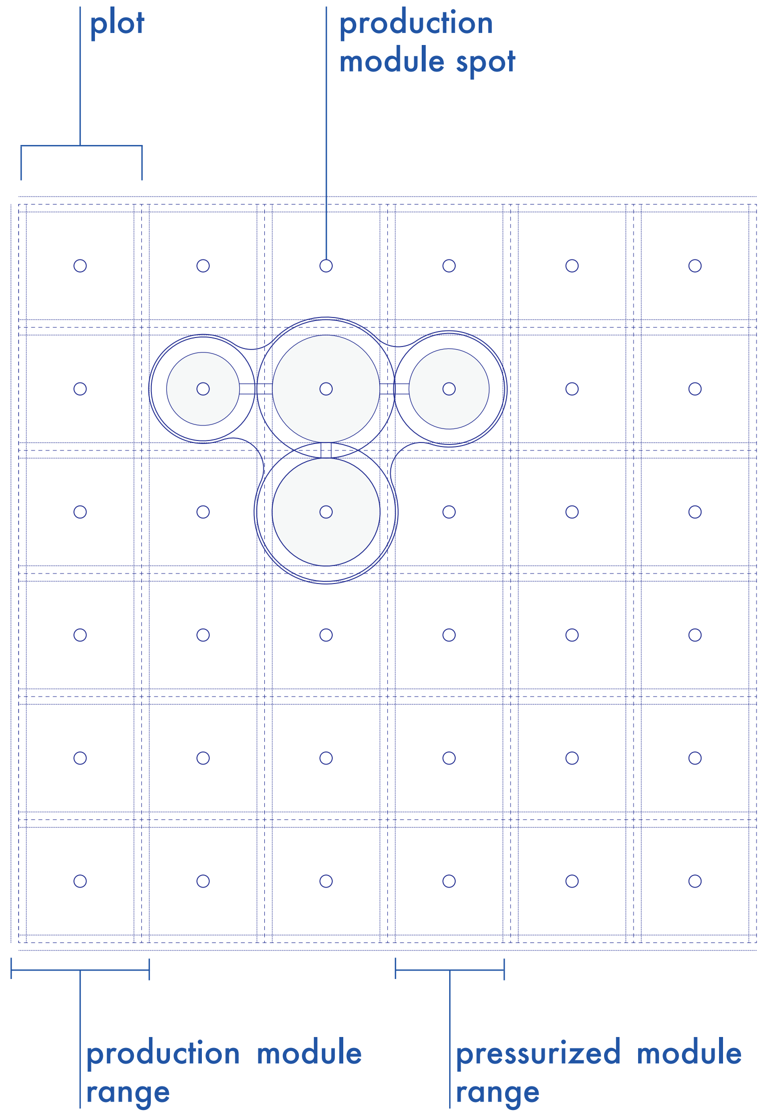
MERGING MODULES



How the base modules might be merged together, under one radiation protection shell.

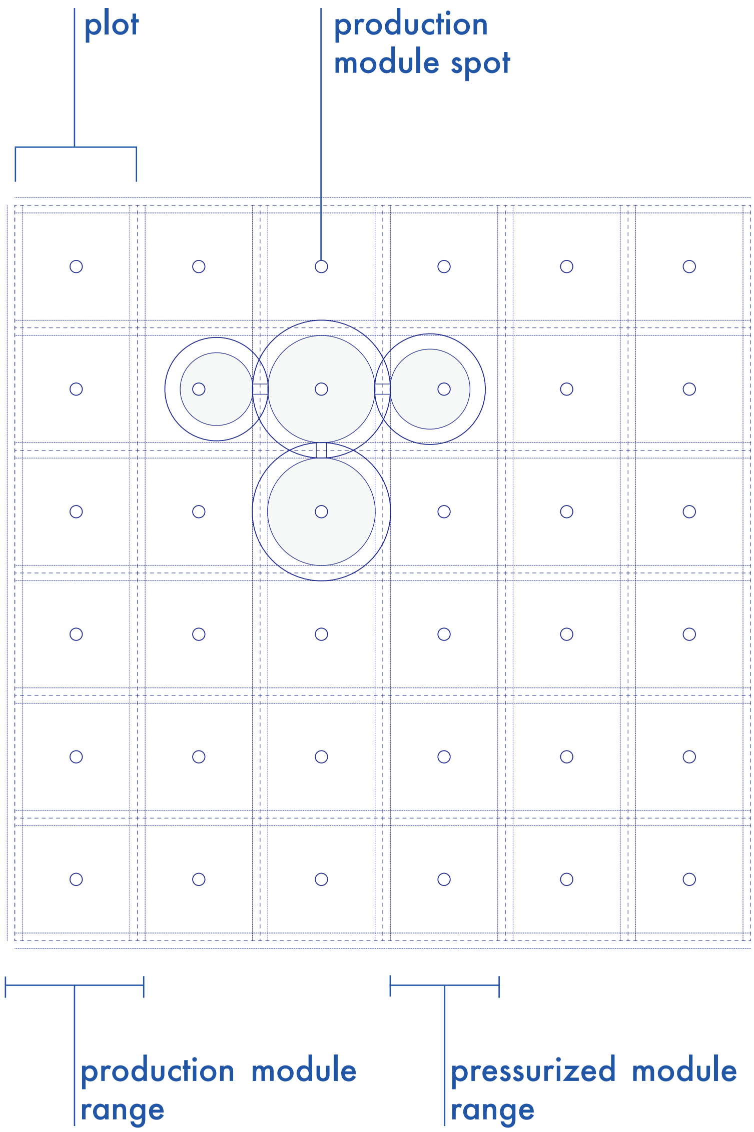
When two or more seperate pressurized module are connected, the rigid shell would have hums. It has to follow the shape of each of them.

OVERLAPPING / CENTRAL / PRESSURIZED MODULES IN ANY SIZE



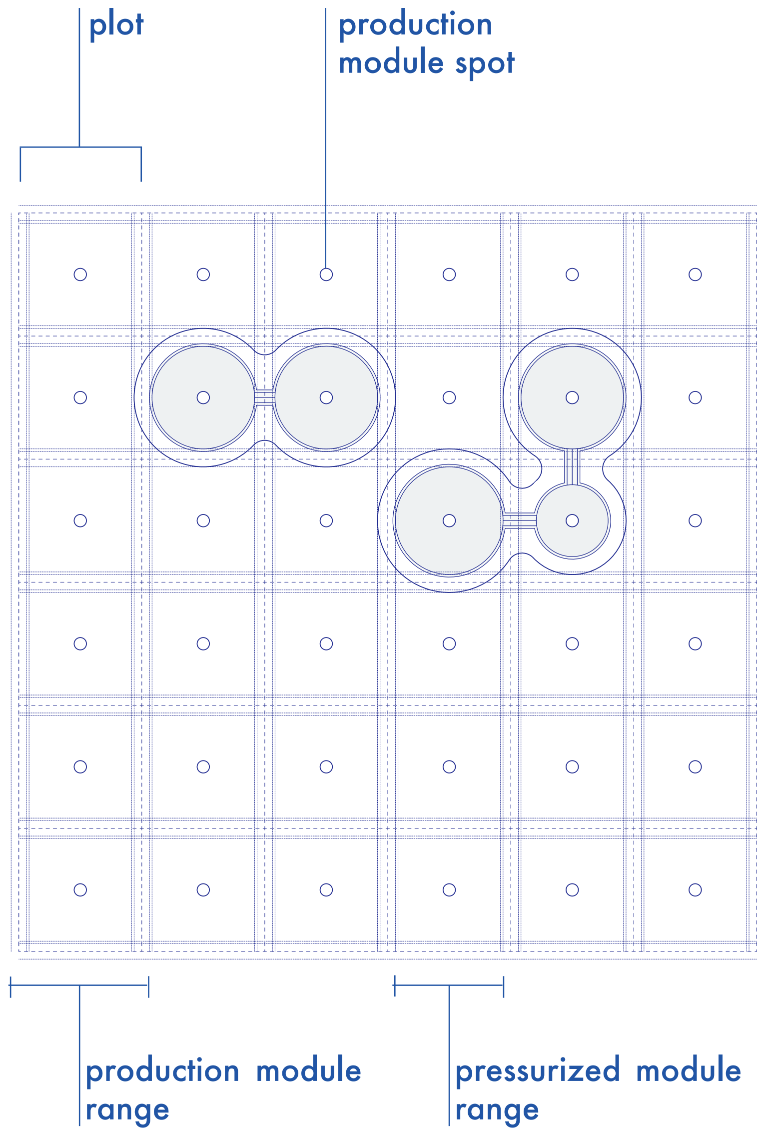
Production modules ranges are overlaping. Radiation protection shells would overlapp as well. It gives safe connections between seperate base modules.

OVERLAPPING / NOT CENTRAL / PRESSURIZED MODULES IN ANY SIZE



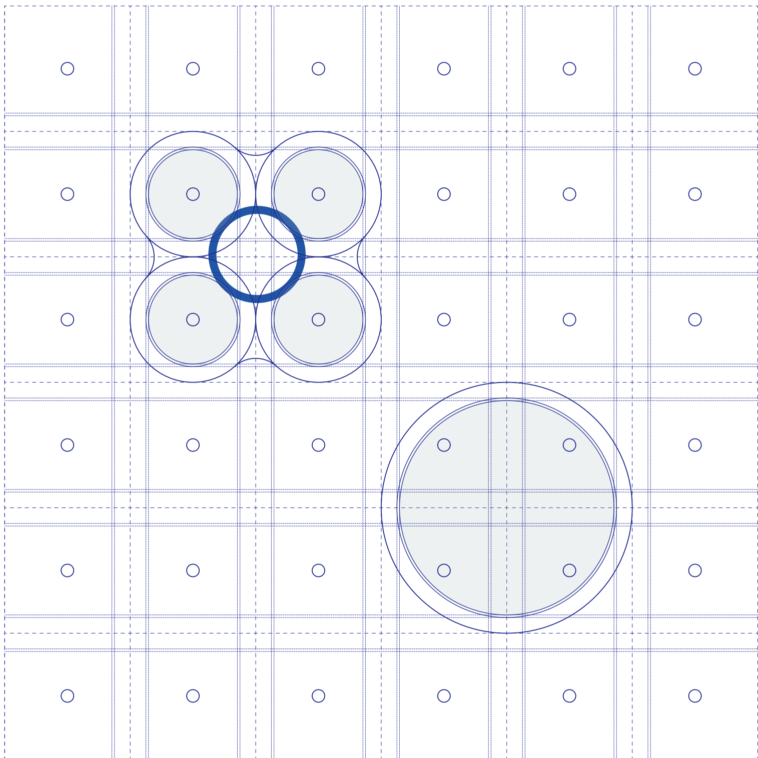
Production modules ranges are overlaping. Radiation protection shells would overlapp as well. It gives safe connections between seperate base modules. Base modules are not assembled centrally around the production modules. It brings difficulties in the constuction process.

OVERLAPPING / CENTRAL / PRESSURIZED MODULES HAVING MAX. SIZE



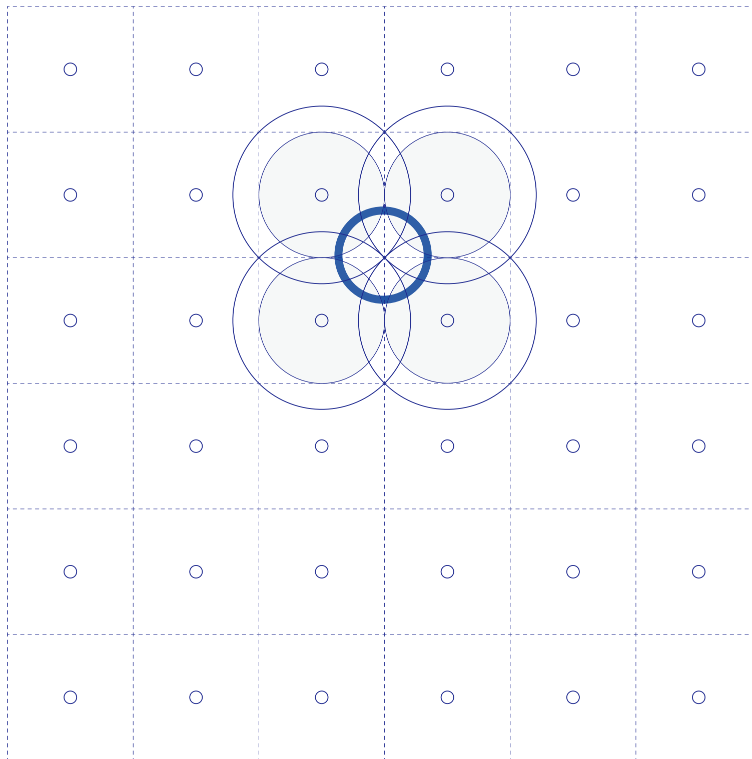
Production modules ranges are overlaping. Radiation protection shells would overlapp as well. It gives safe connections between seperate base modules. Pressurized modules having their maximus keeping the pattern given by the grid. The whole structure is easier to shape and organise.

MERGED MODULES / NOT OVERLAPPING

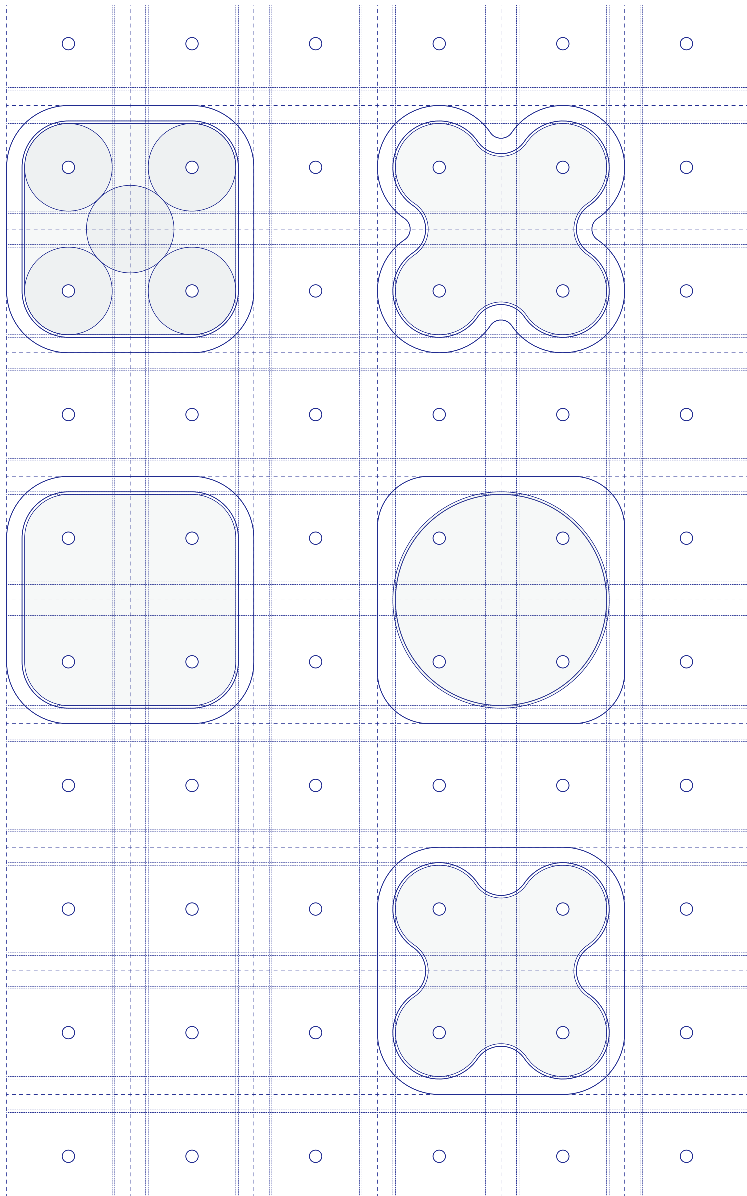


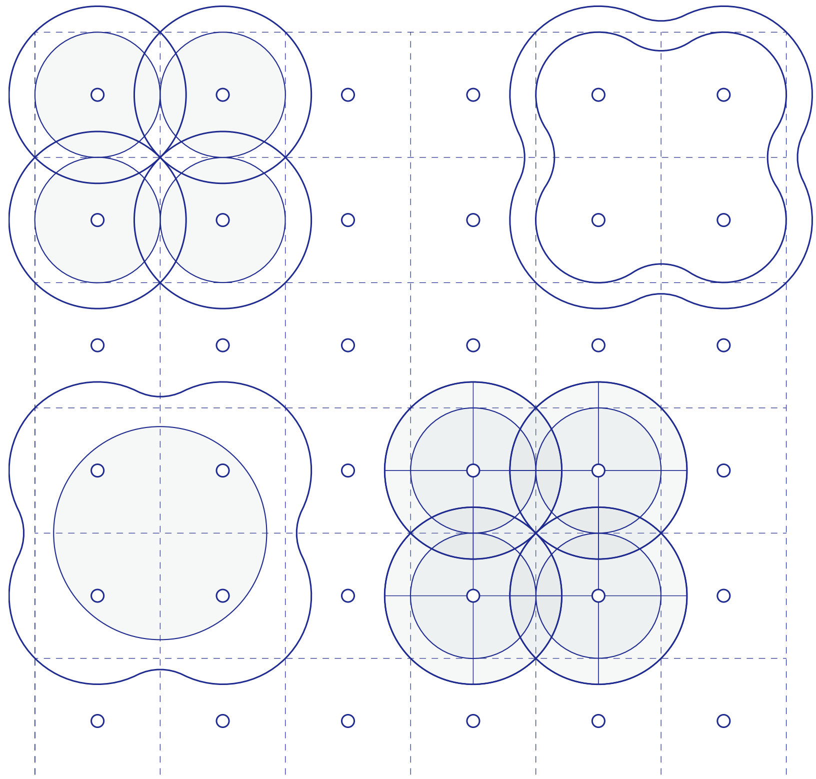
When willing to have few (4) seperate base modules under one common shell, working as one space, witout any connections, hatches etc, there are areas where rigid shell cannot be constructed.

MERGED MODULES / 'FULLY' OVERLAPPING



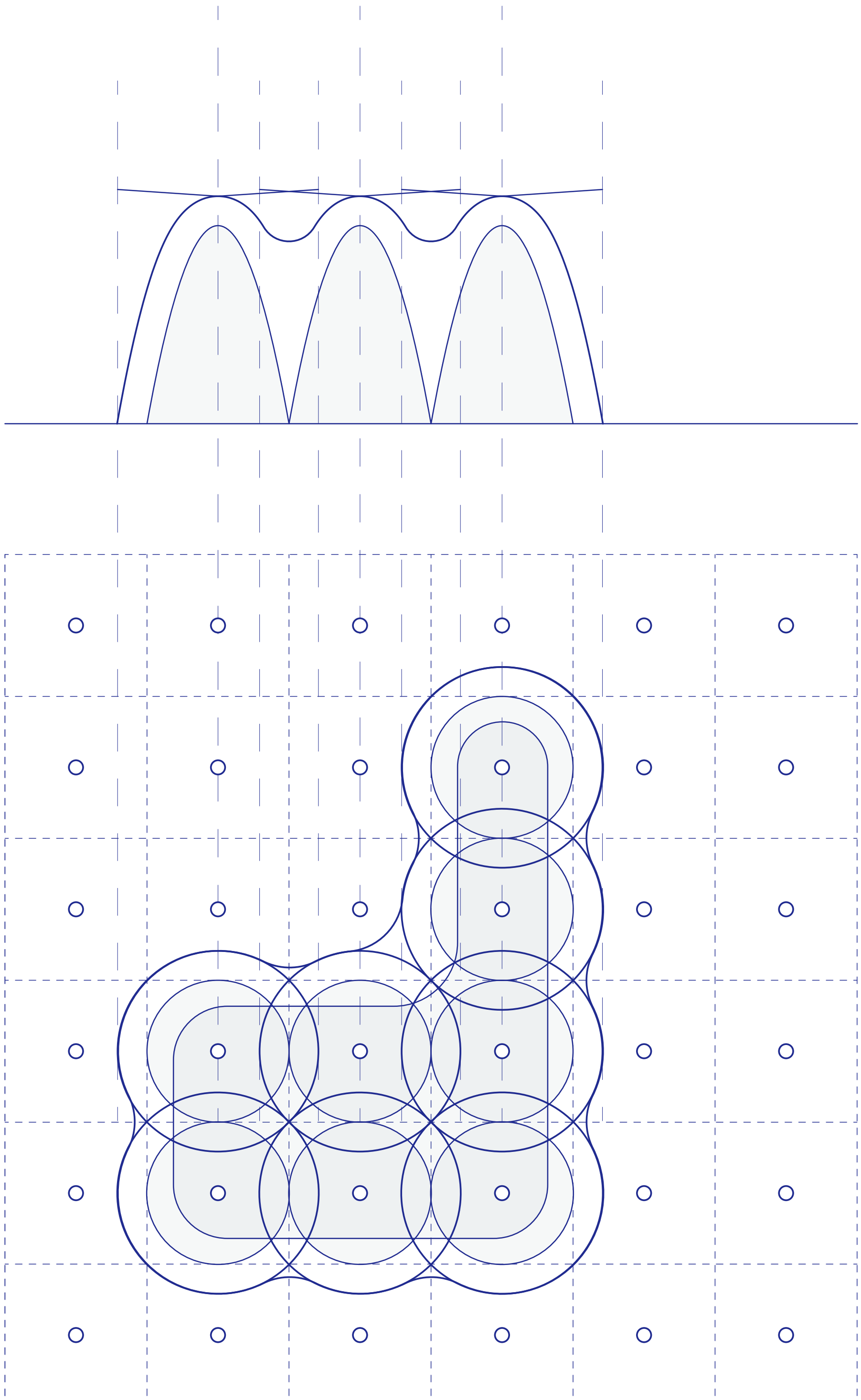
To ensure that in any plane ridig shell could be construcuted, the production modules ranges would have to overlap even more, creating spacefilling layout.

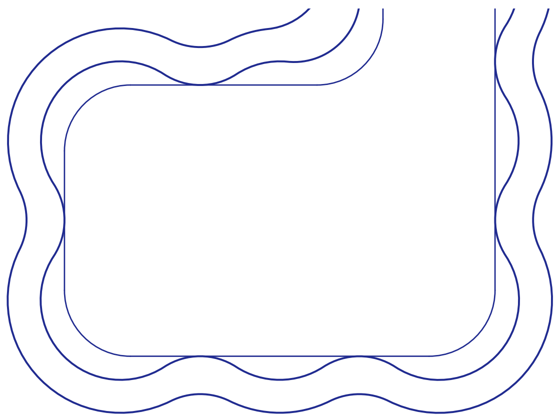




Variations on how rigid shell might be build around pressurized modules, when overlapping.

Pressurized modules here are not deploying from seperate cores. Modularity and ease of assembling is lost here. Thus, the concept is not developed further.



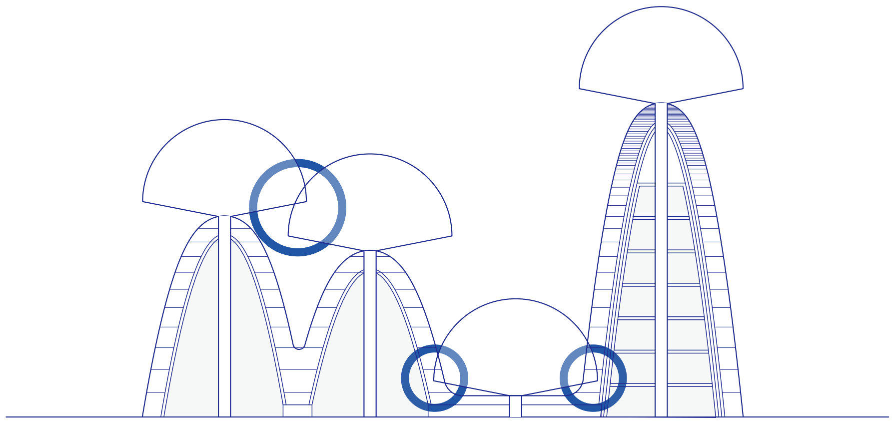


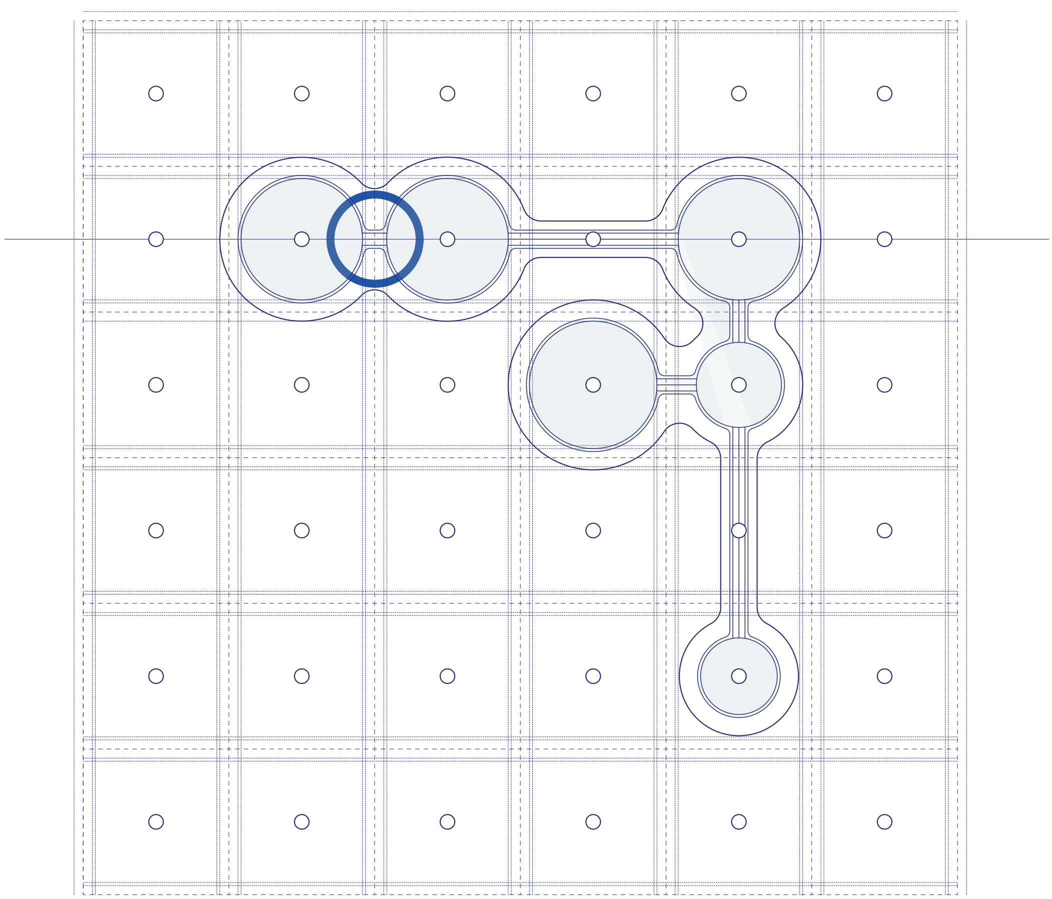
Variations on how rigid shell might be build around pressurized modules, when overlapping.

Pressurized modules here are not deploying from seperate cores. Modularity and ease of assembling is lost here. Thus, the concept is not developed further.

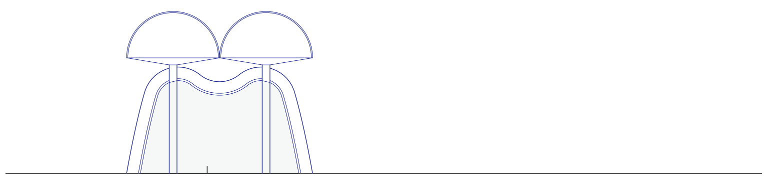
NOT OVERLAPPING

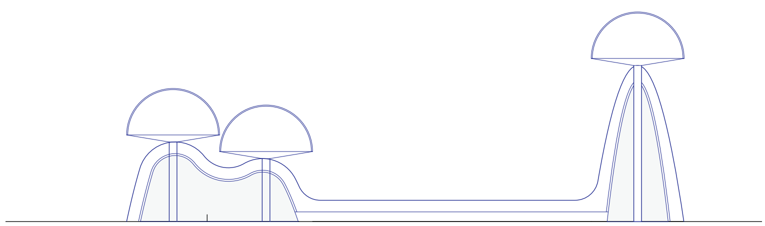
Connection looks good and safe on the plan. However, on thesection it is visible that overlapping production module randes causes difficulties.



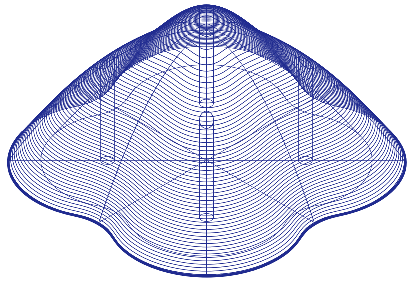


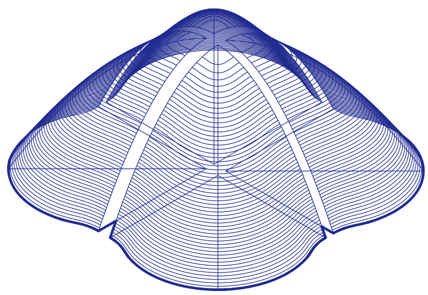
MERGING MODULES OBSTACLES

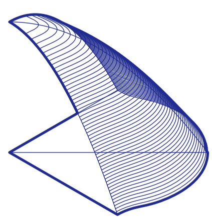


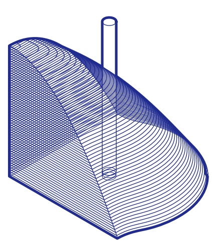


Merging seperate base modules under one strcutre, (when production modules are not overlapping) works on the section, but when it comes to 3Dmodel it is crlealy visible that the concept fails. Production modules would have to take shape other than round. It does not make sesne since it has to be covered with pressurized dome, to ensure required conditions for the cellulose growth.

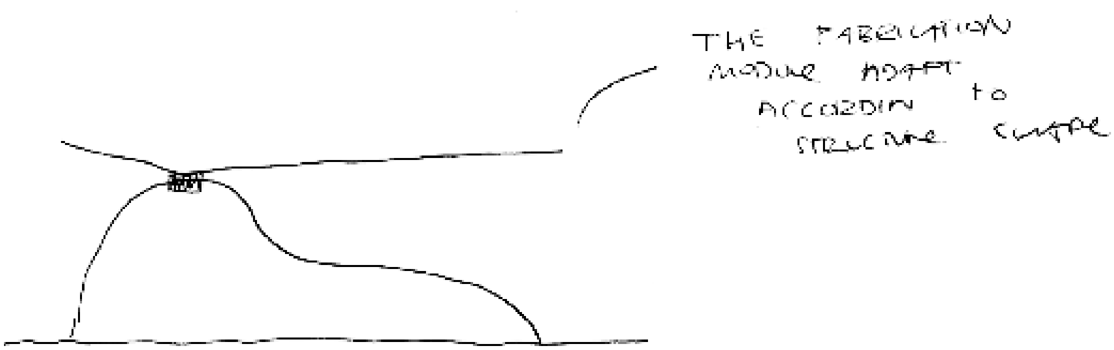


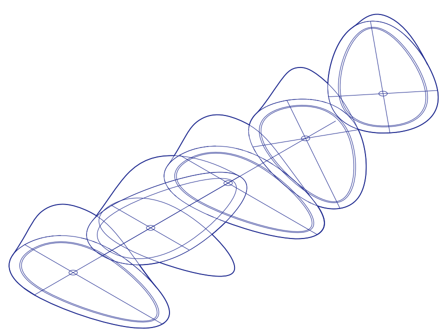




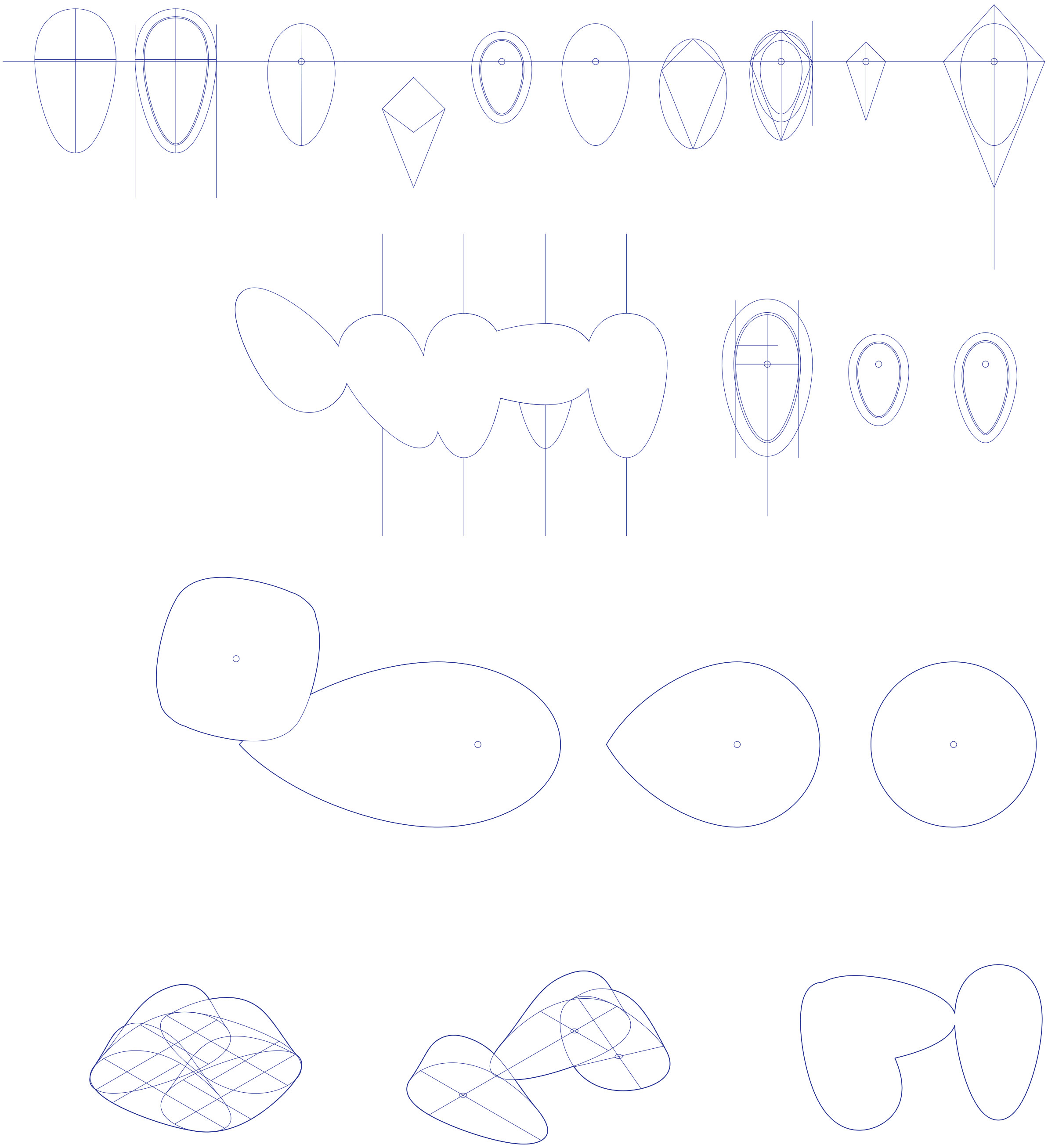


ELONGATED SHAPES



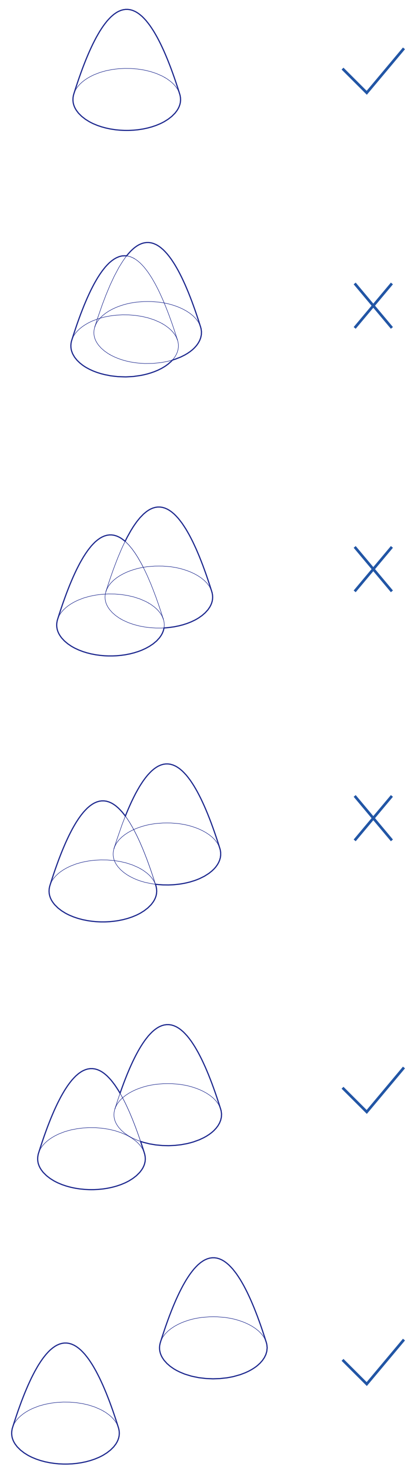


The other idea was instead of working on circles, work with elongated shapes. However all of the difficulties and obsticles were repeated here.

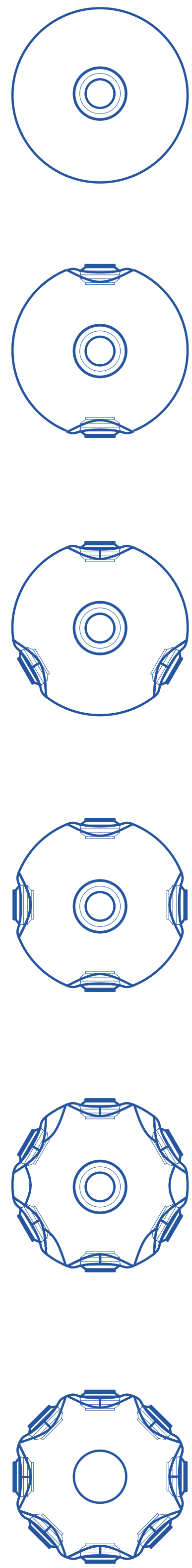


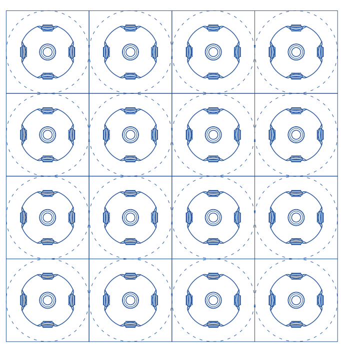
SEPERATE MODULES

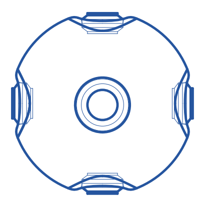
The base modules should keep seperated, connected by the hatches, but not merged together under on rigid shell. Each seperate pressurized module, deployed centrally from production module would 'grow' it's own radiation protection, which would eventually meet and create fully protected structure, but wouldn't overlap. This approach enhance the ease of construction, the system can be more universal and it also gives the possibility to constantly expand the base settlement, adding new base modules the the general layout, following the given pattern.

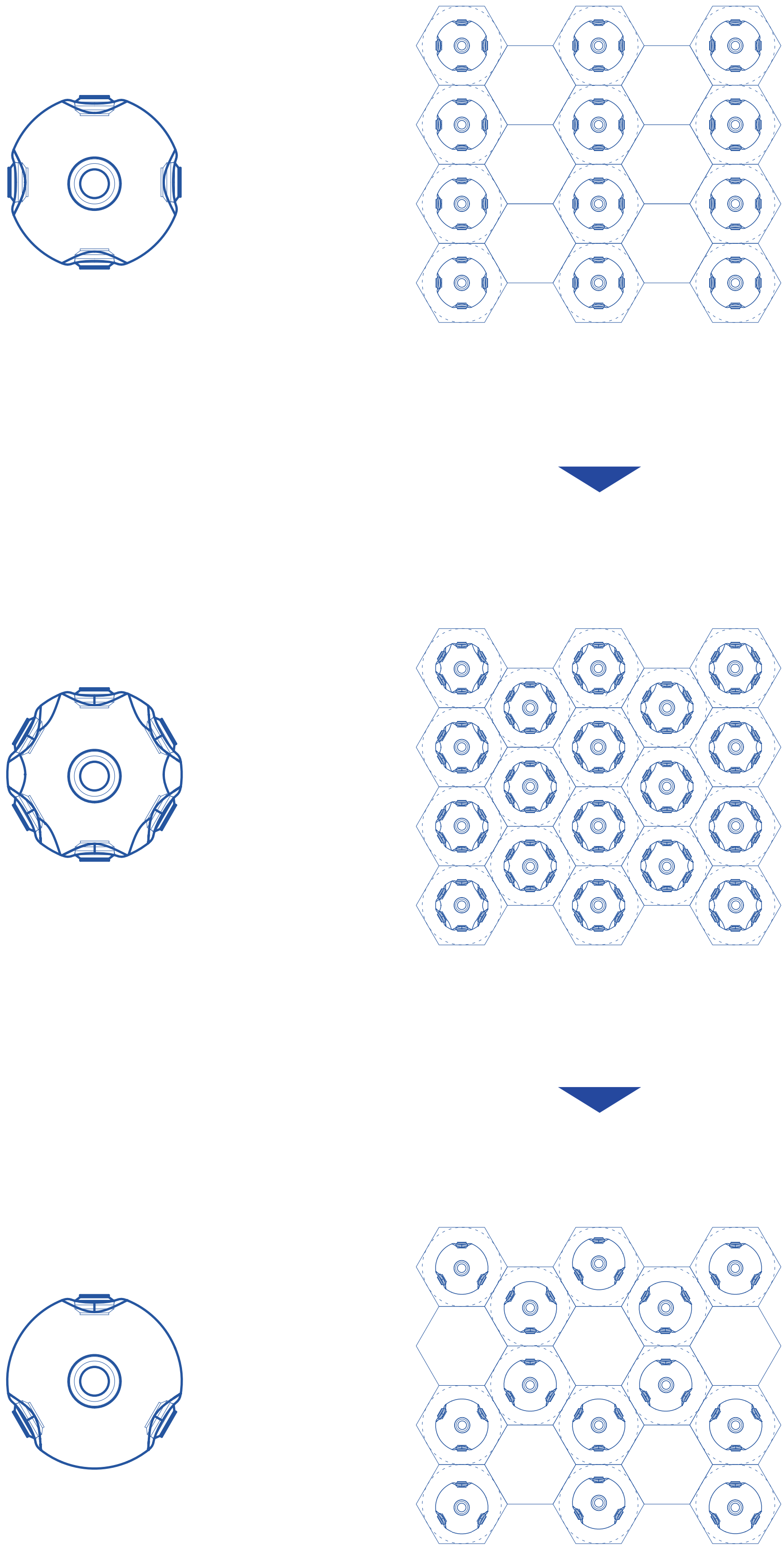


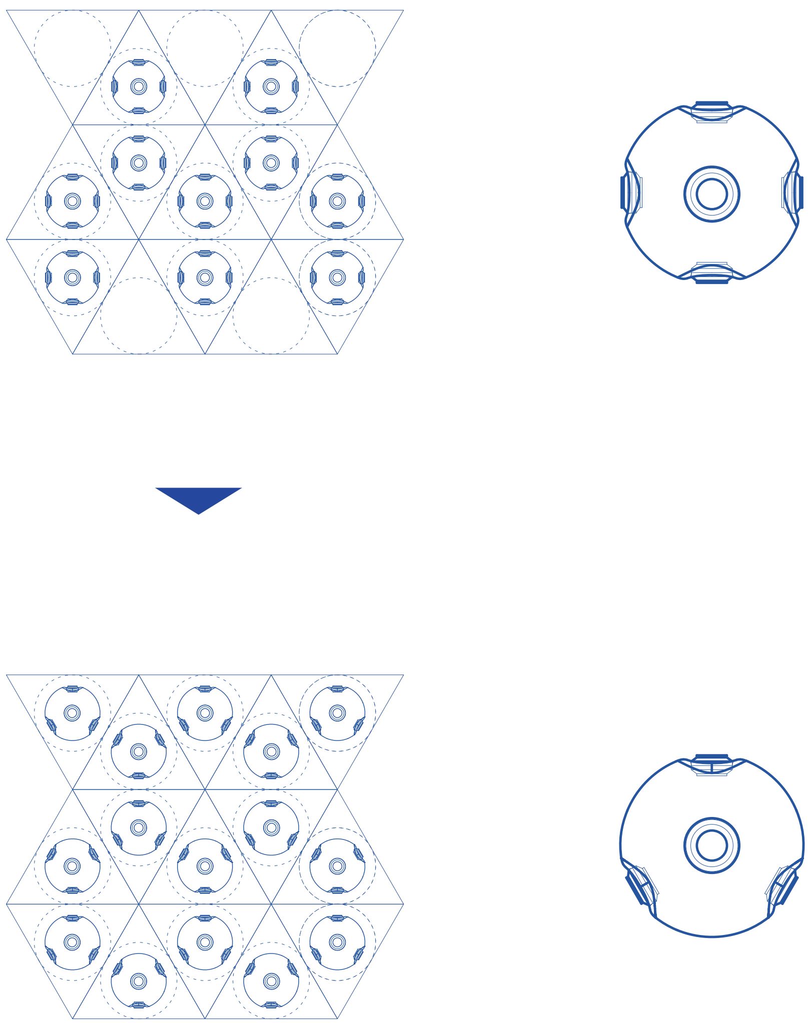
AIRLOCKS AND HATCHES



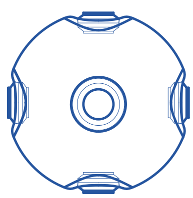


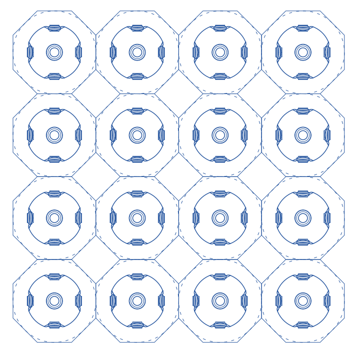




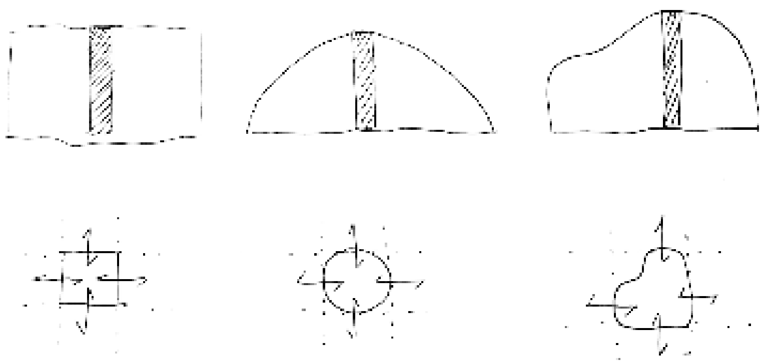


OCTAGONAL GRID
/ 4 AIRLOCS

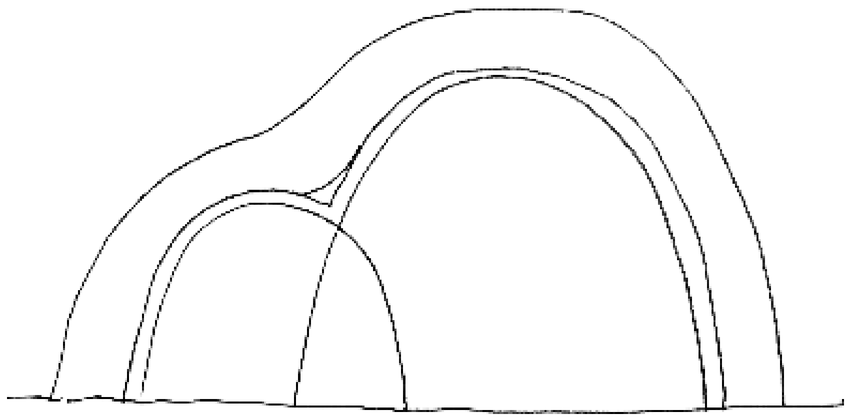


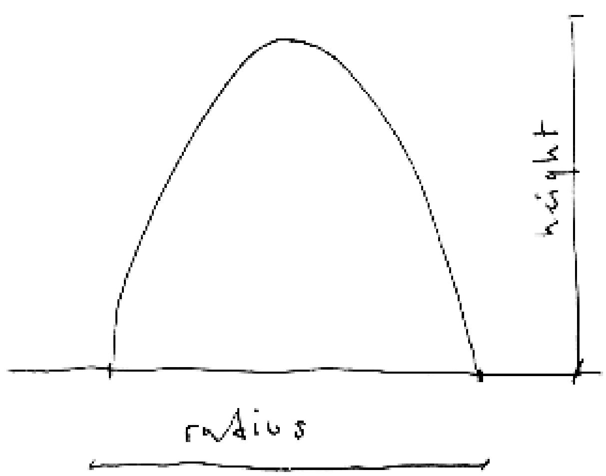


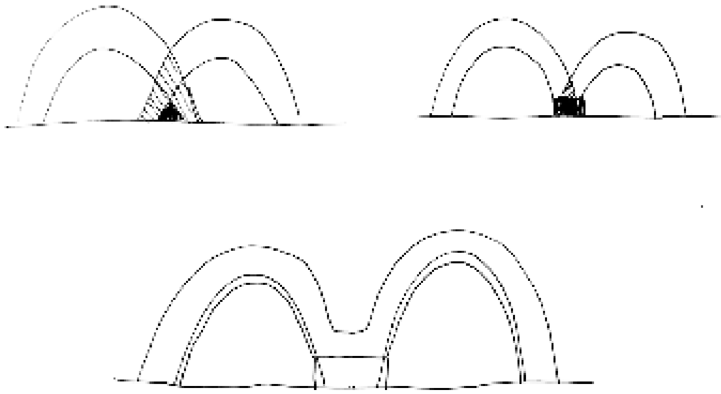
Octagonal grid works the best. Since octagon is the closest to the circle shape, it ensures the biggest area for the cellulose production. At the same time, when it comes to the number of connections between modules it uses same rule as in orthogonal grid, keeping 4 conncections between segements.



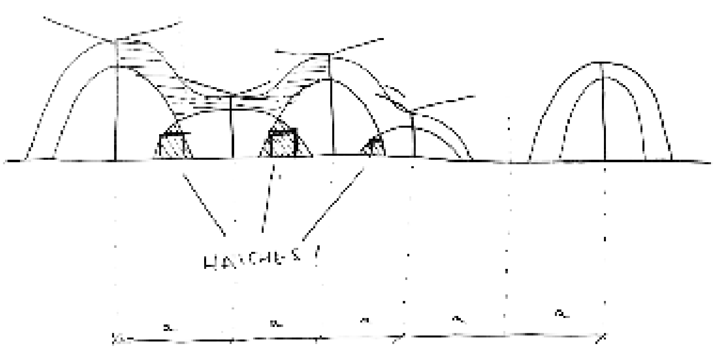
No matter what the size and shape of the base module is, it should always have 4 hatches ensured The number is 4 due to the layout set on the octagonal / orthogonal grid. Even if there is no further connection needed, the possibility to have one should be provided (for emergency reasosn or future develpment of the base).



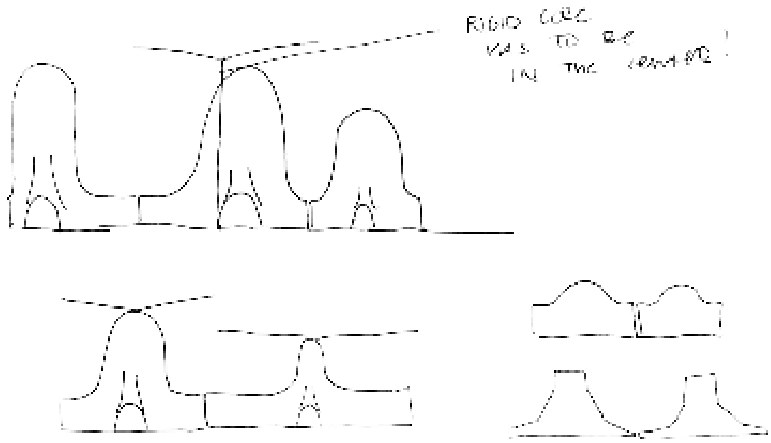

height
radius



'Fully' overlaping | Overlaping | Not overlaping (chosen)
Versions of creating radiation protection shell over the hatches. The connection between seperate module is a crucial part. It also has to be very good protected from the radiation.

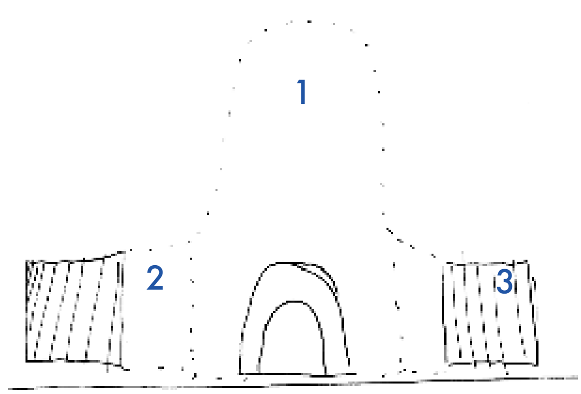


Hatches are also following the grid.

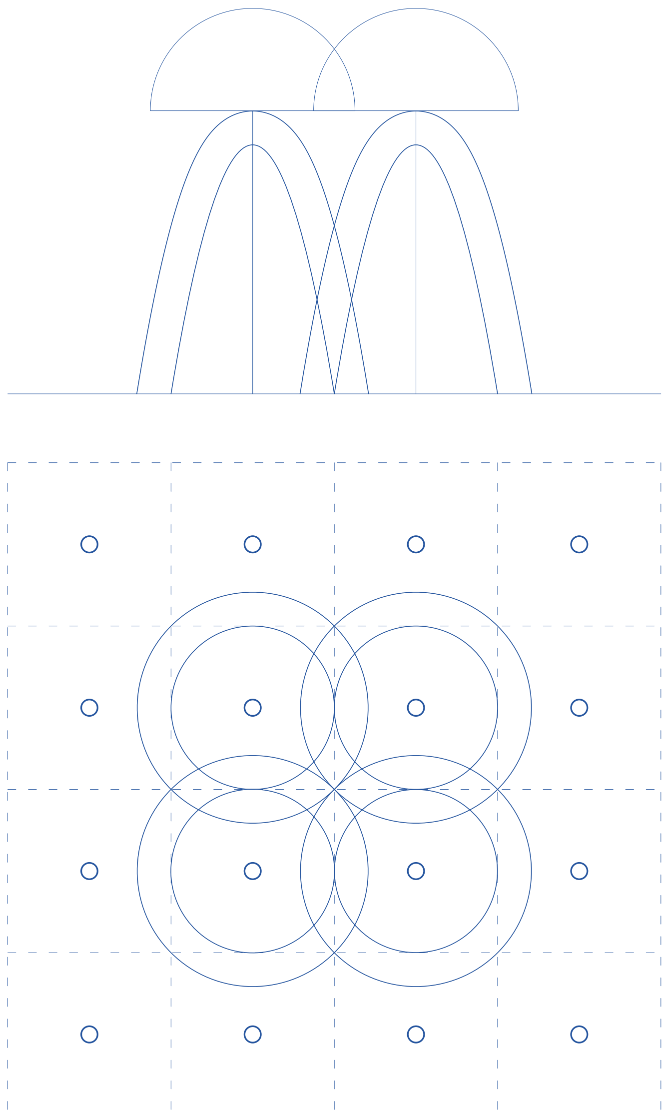


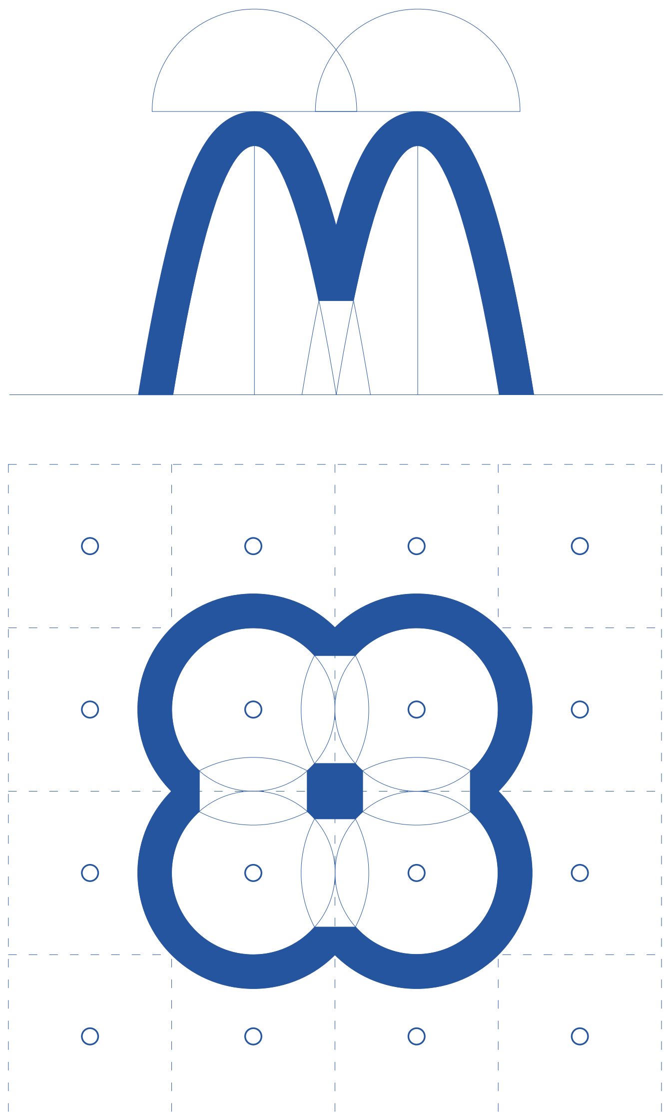
To ensure the best stuctural connection between seperate base modules the shape of the structure, followed by the rigid shell, should allow for smooth transition between pressurized module and hatch, corridor.

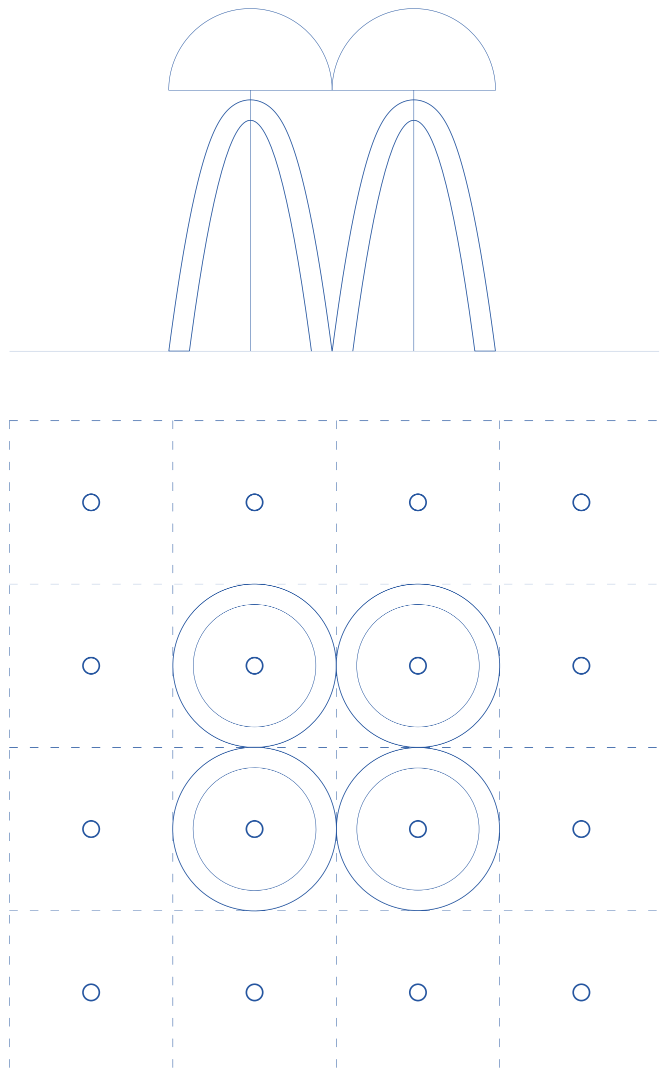
SMOOTH TRANSMISION BETWEEN MODULES

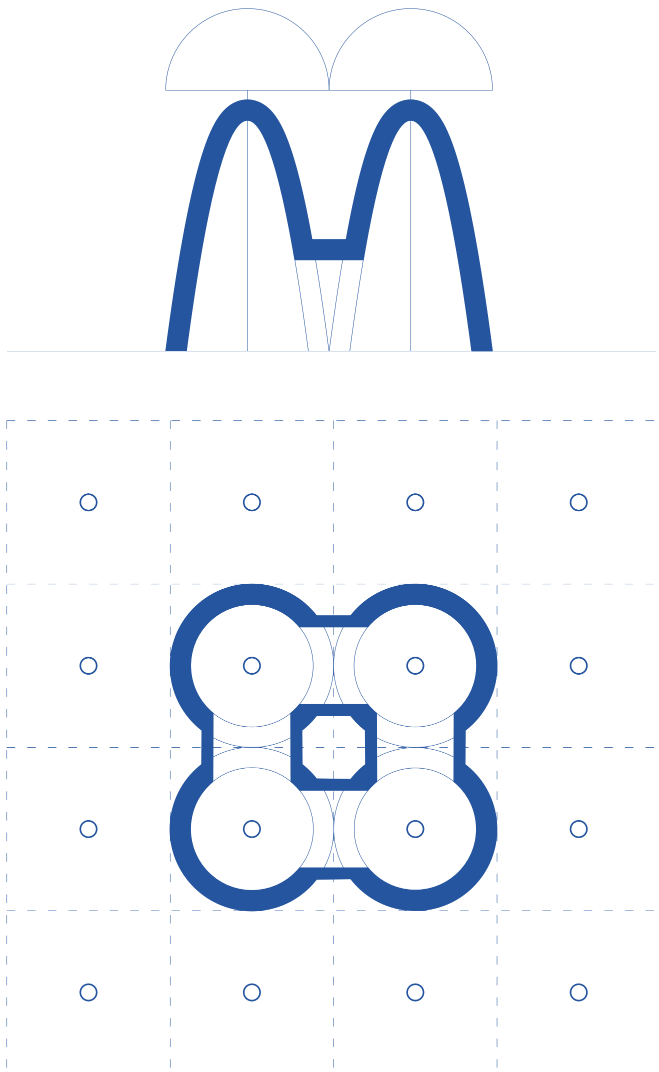


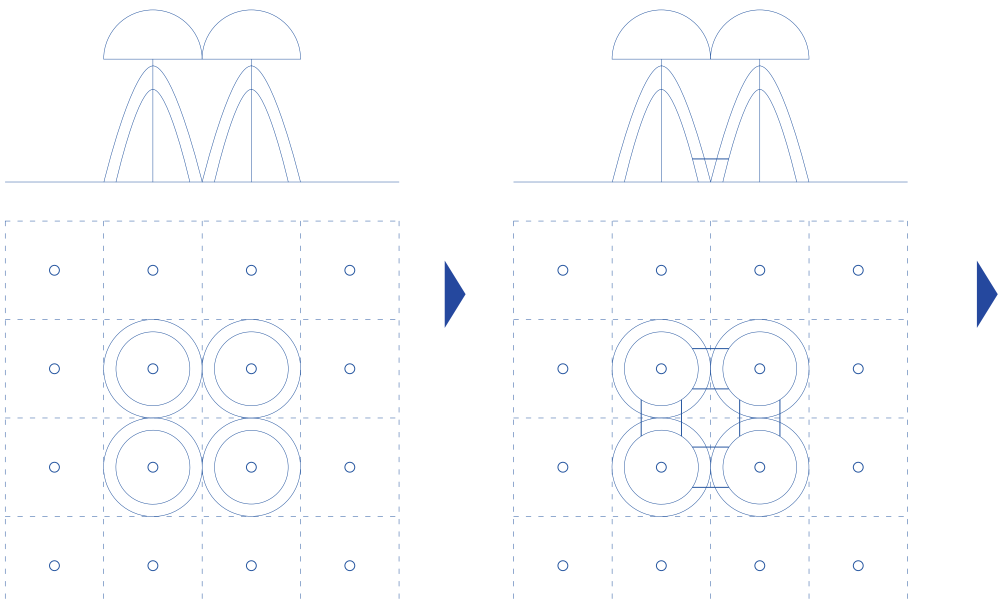
There would be 3 elements distingished in the structral shape; main part (1), transition part (2) and connection part (3)

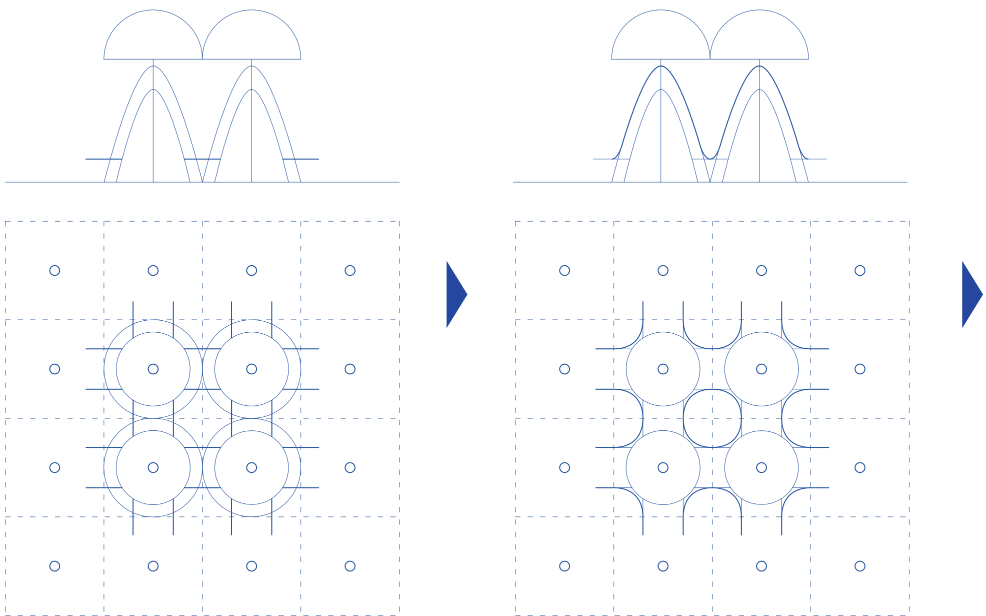


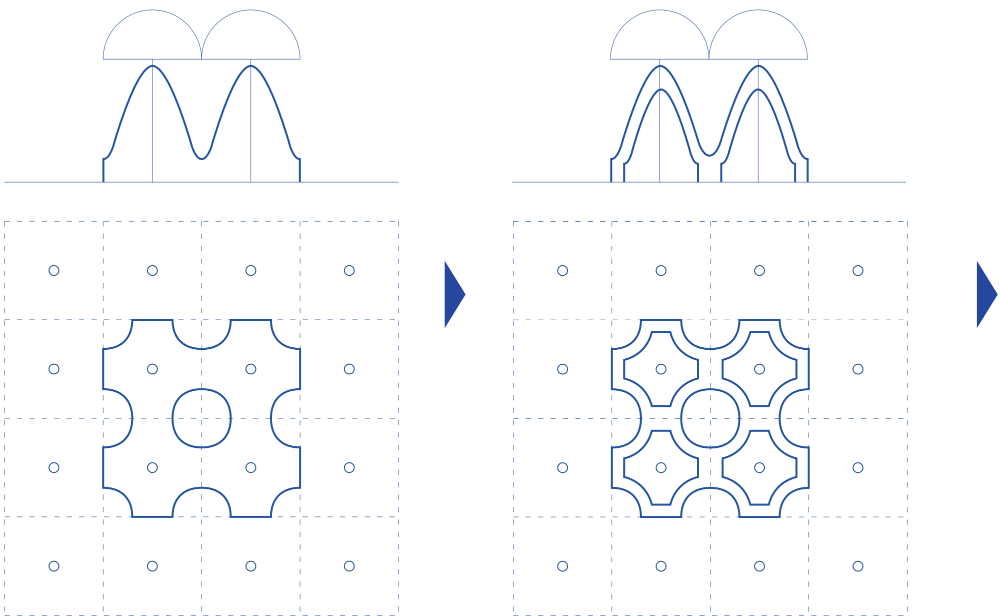


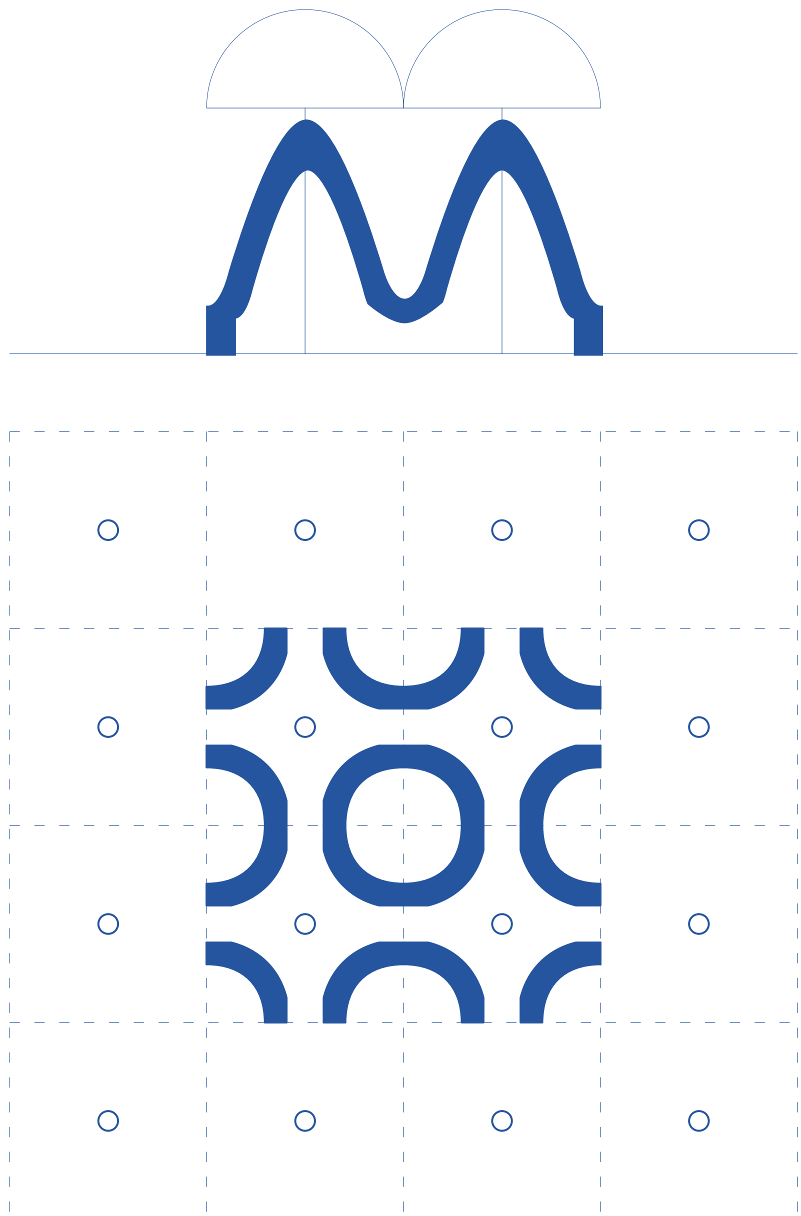


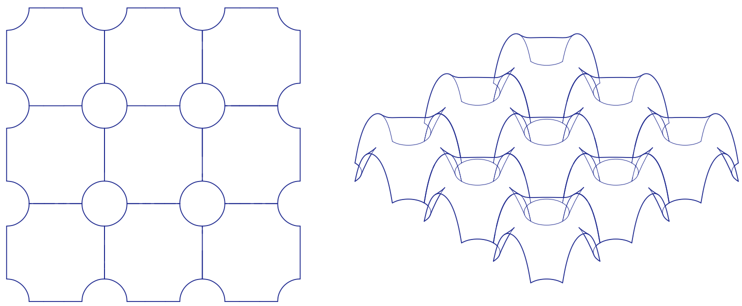




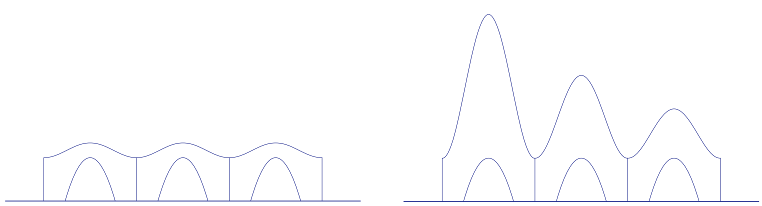






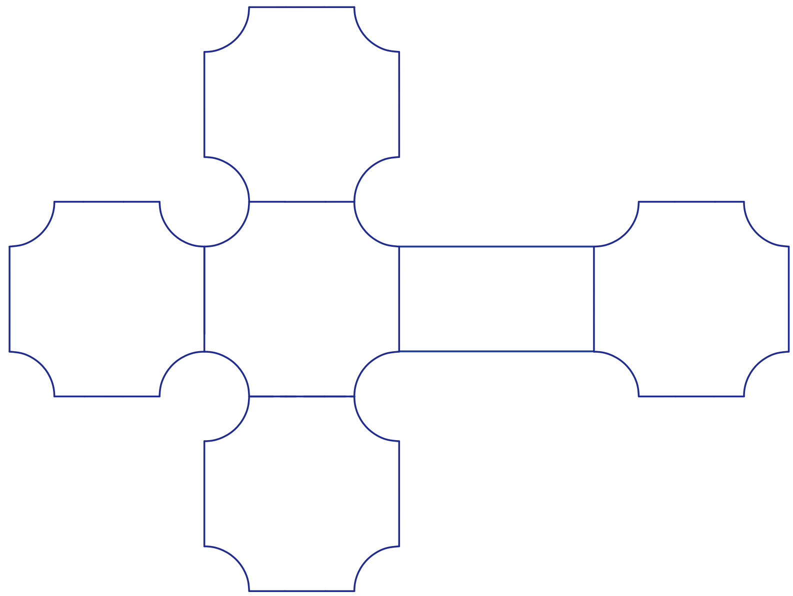


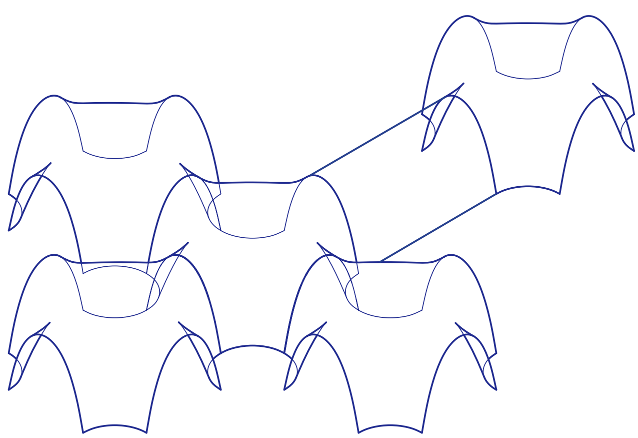
This kind of shapes, where the structure smoothfly turns changes between main and connection parts, work perfectly on the orthogonal grid arrangement. Also, the settlement could be easly expand, in any direction needed.



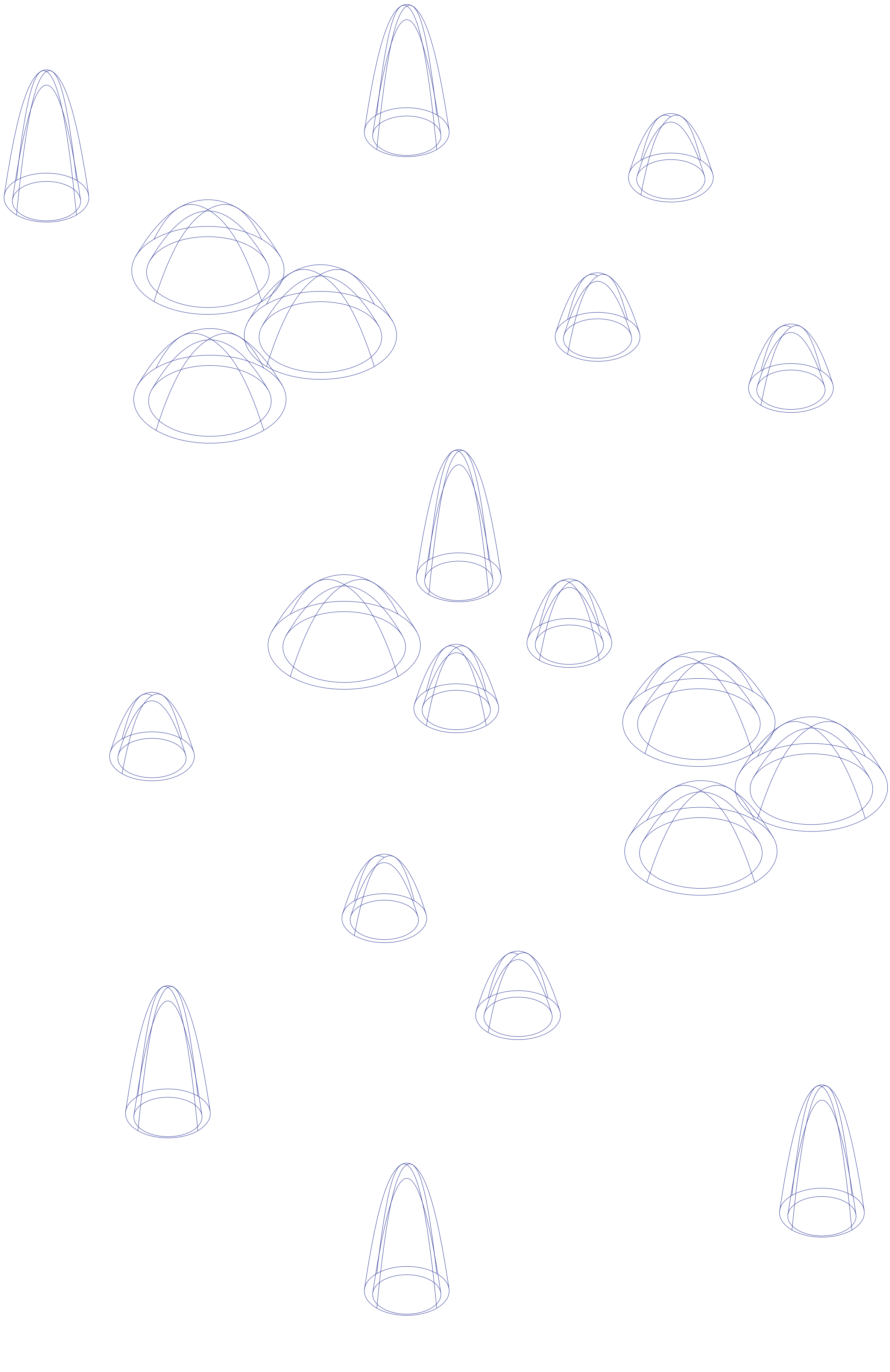
The main part of the strucutre could vary in size and height, (just not exceeding its max. dimensions) depends on the requirements for each module.

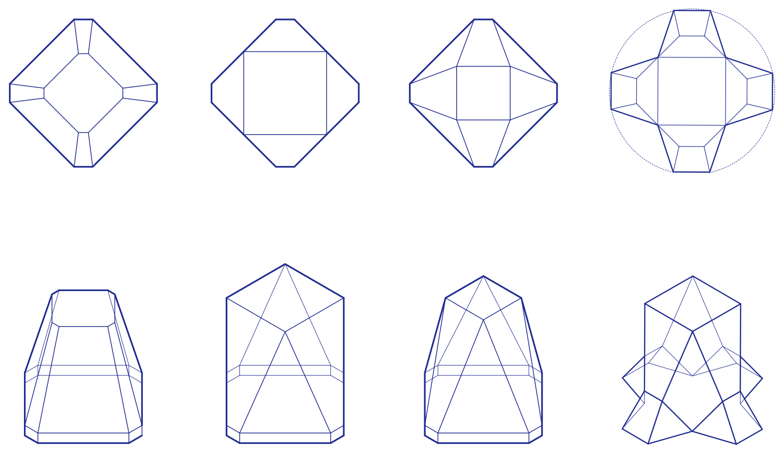
The transition modules alwasy stay the same and the connection change only their lenght.



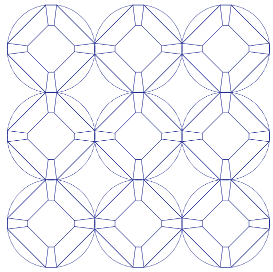
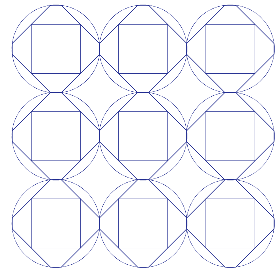


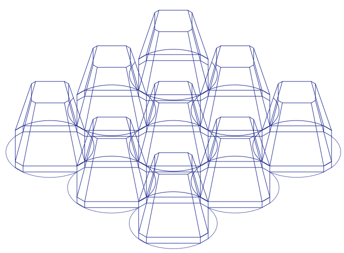
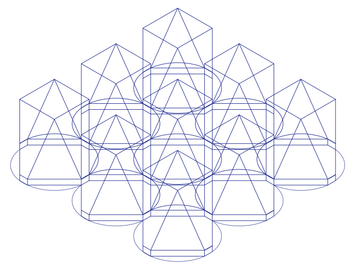
MODULE GEOMETRY

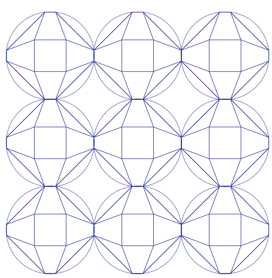
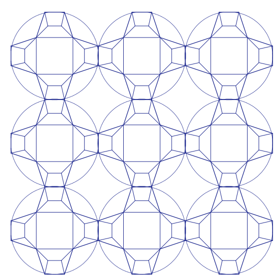


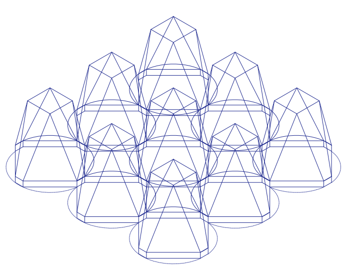
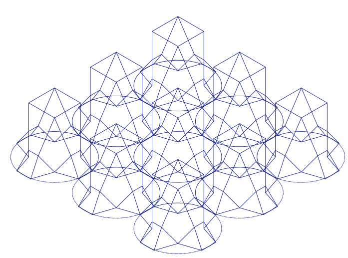


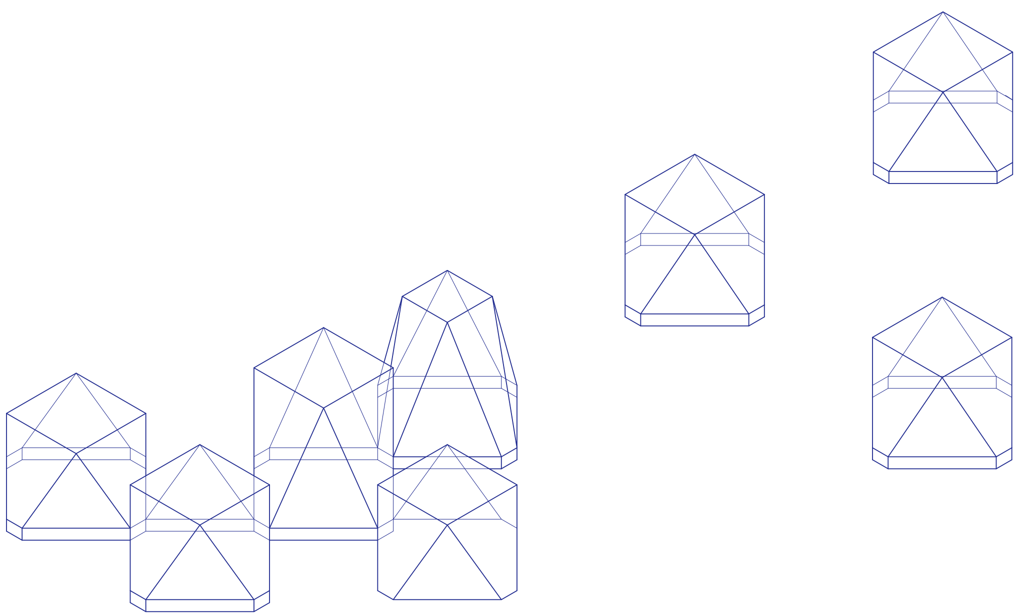
Since the base is arranged on the orthigonal grid and each module requires 4 hatches (connetions) maybe there is no need of having the shapes on circular plan. Due to the production module range it has to fit inside the circular borders, but it can get any shape.

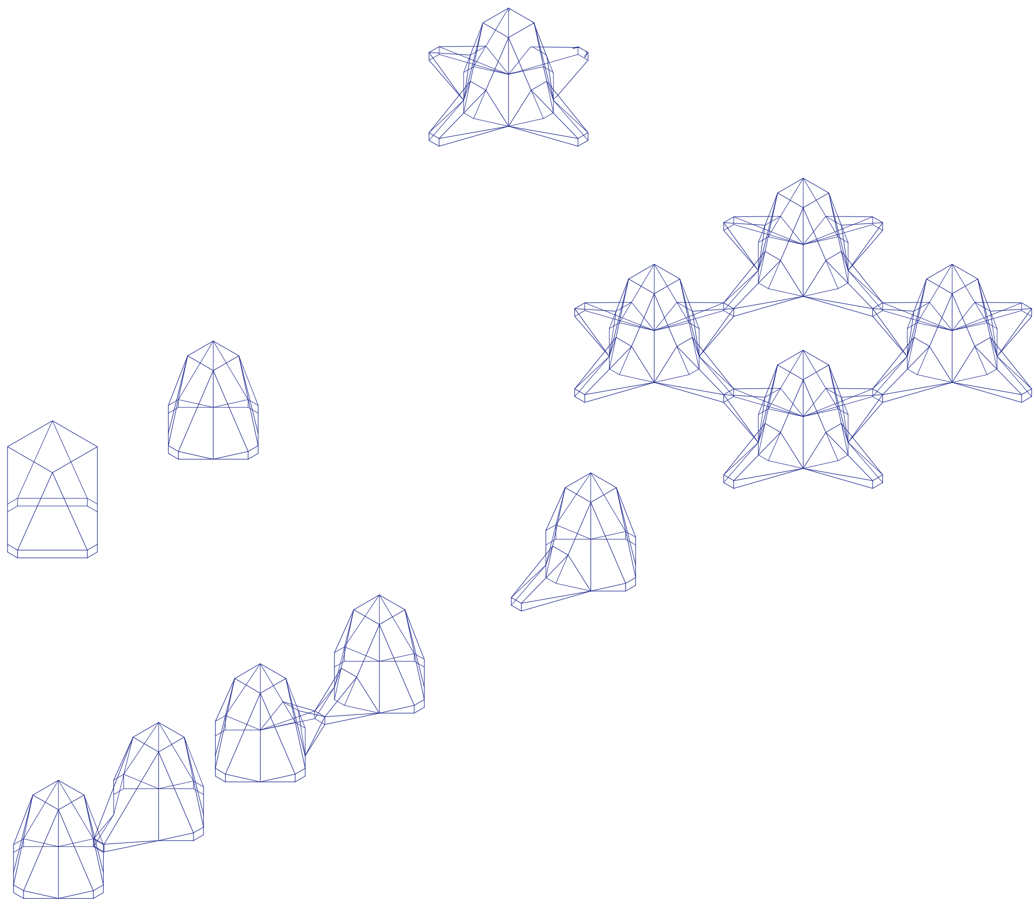



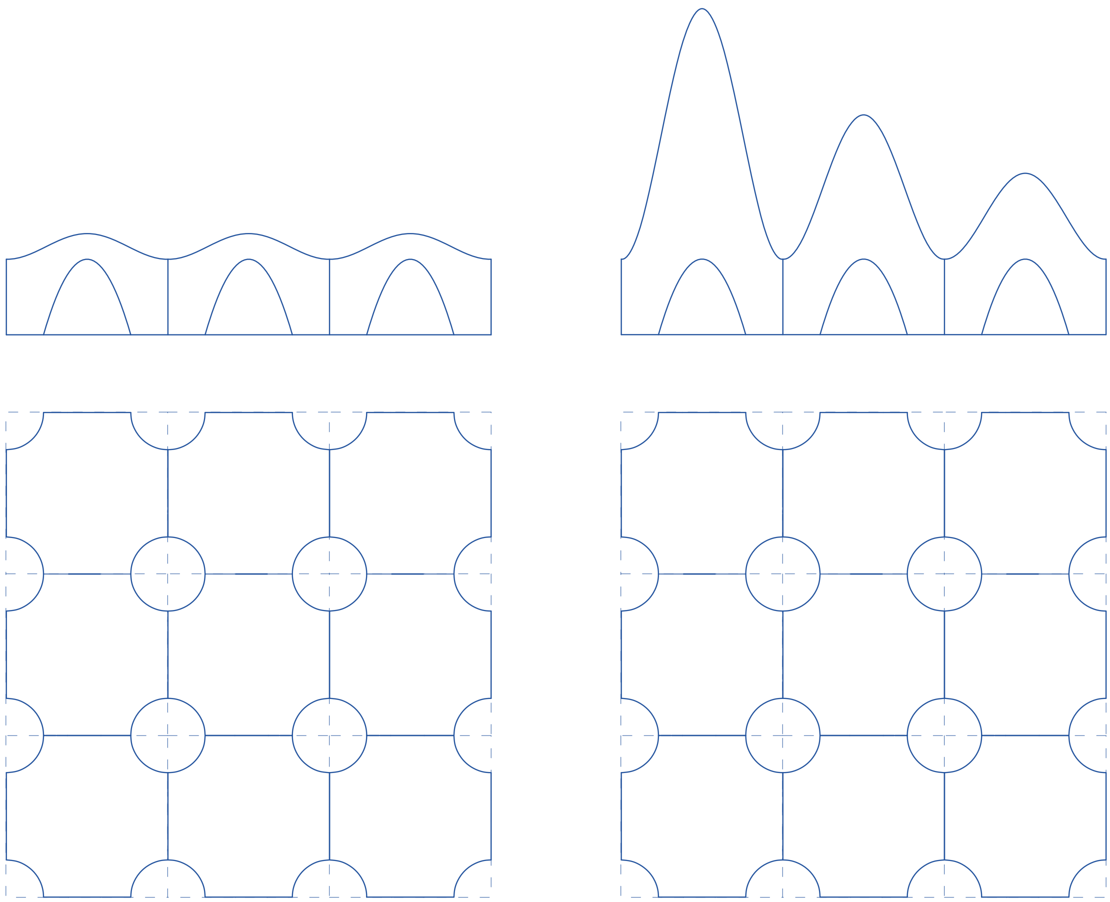



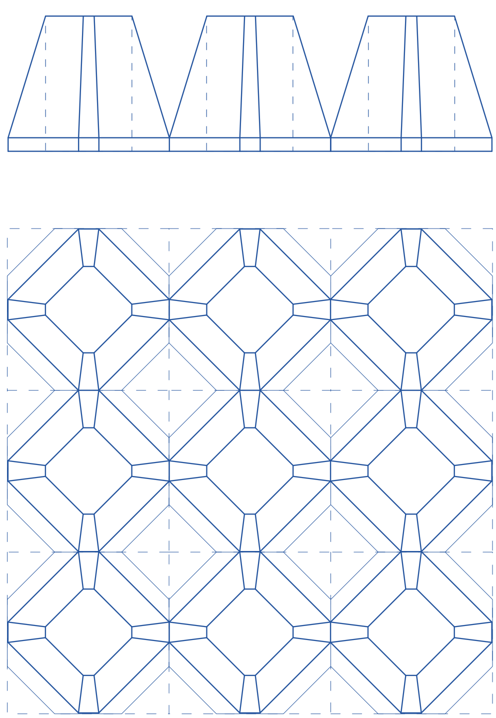



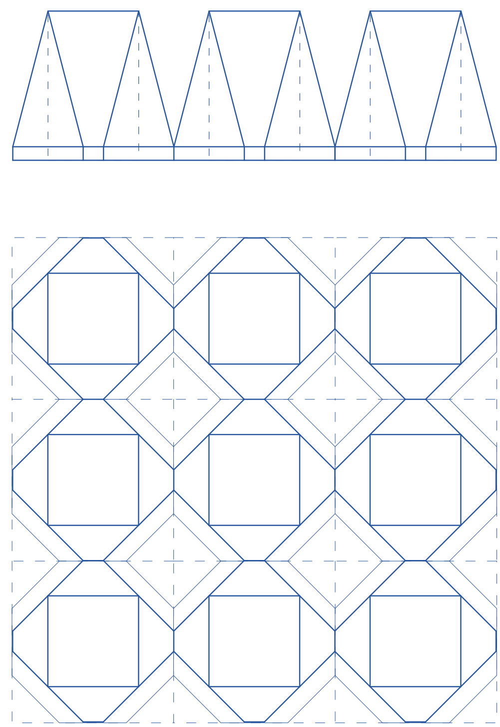



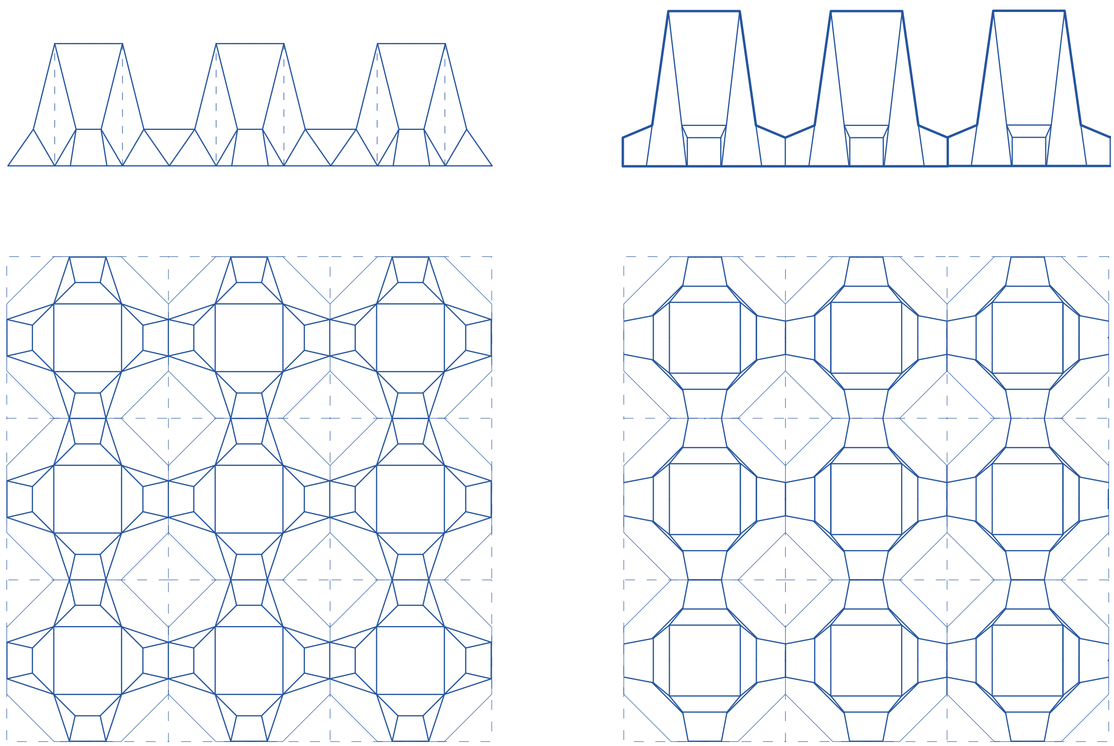


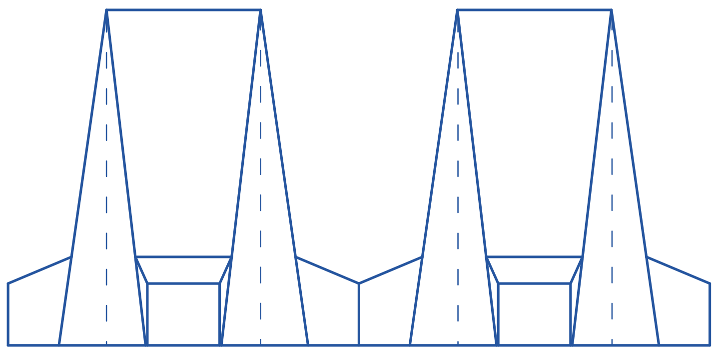


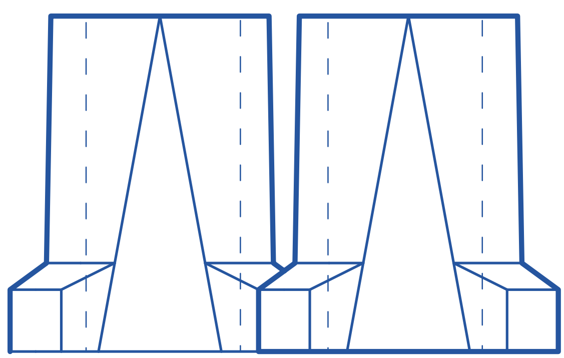






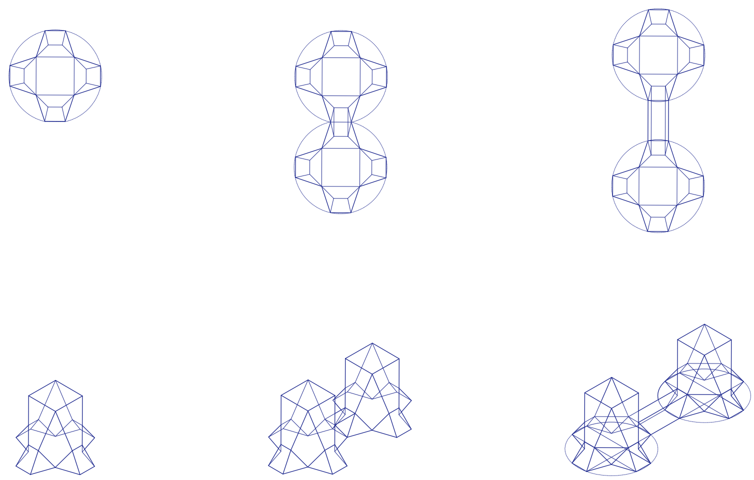


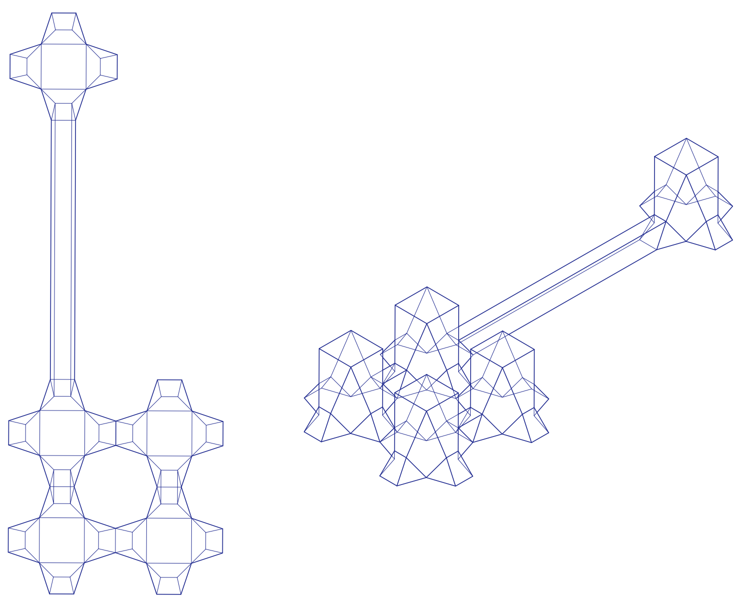




CHOSEN MODULE GEOMETRY

GROWTH / EXPANSION

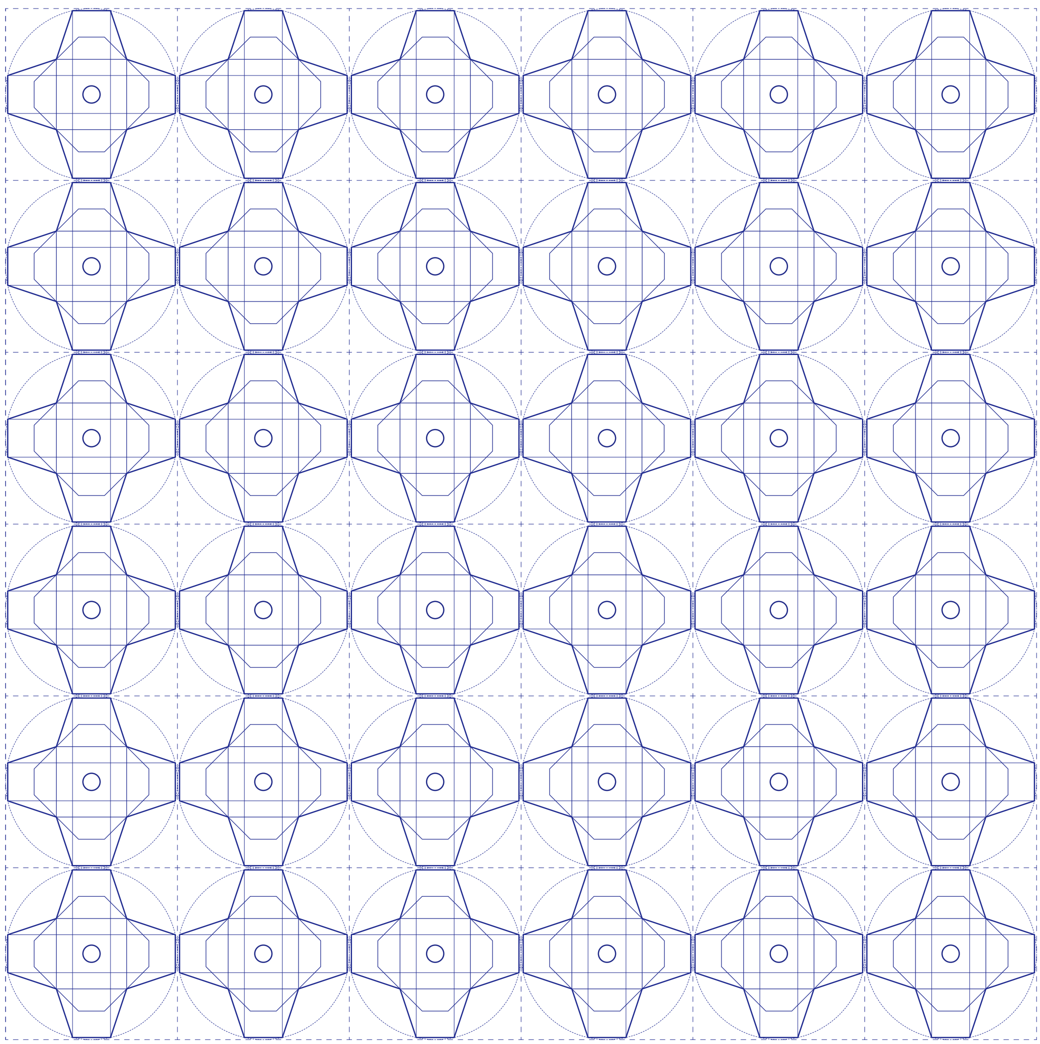




Besides being set on the orthogonal grid, the base can be arranged quite freely. Not every single 'plot' has to be build, they just give the guidlines. It easly adaptable when there is a need of putting some modules further from the others.

POSSIBLE EXPANSION GRID

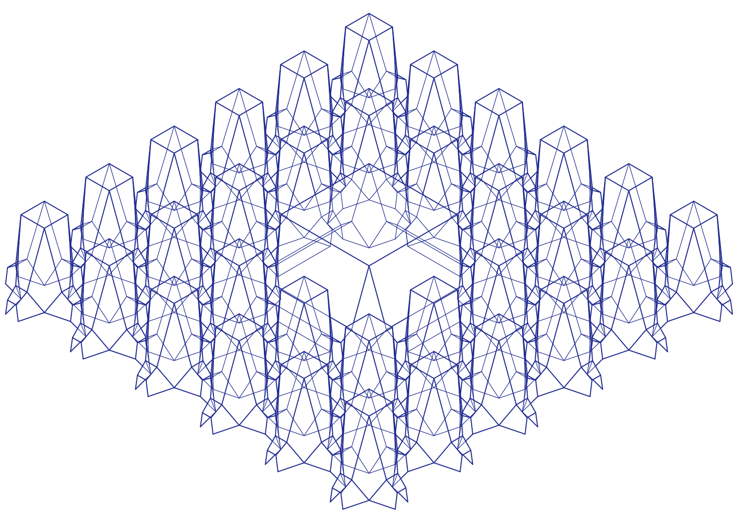
The grid with spots for production modules, guidlines for any further expansions of the base. It may even started with just one module and develop over time. Also it can be developed lineary or circular etc. The grid allows formultiple ways of arranging specific functions and modules withing the overall base settlement.

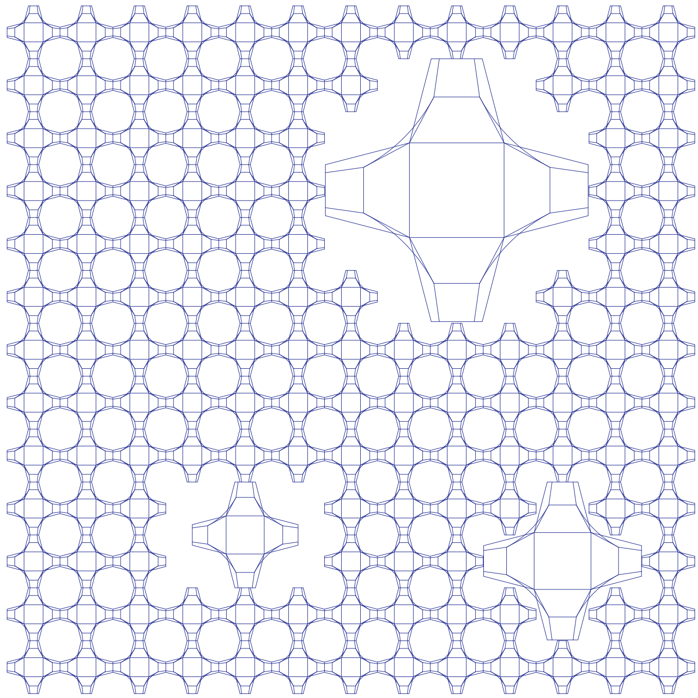


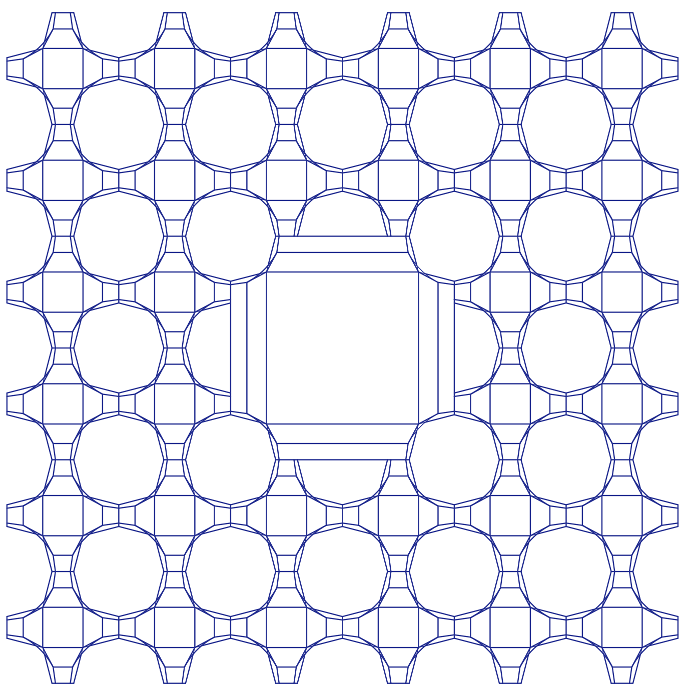
DIFFERENT SIZES OF RIGID SHELLS

With the given system merging multiple shells, following the grid, would be possible. However, due to the payload restrictions, acheived/created spaces would have to be filled with same-size modules as in the single version. Thus, the perception of the space wouldn't change. Strategy of merging shells might play a role in the future / in the cases when there are no payload restrictions for the pressurized modules. when However for the need of the project, the modules are left in the basic form. More important for the project is the vertical differentiation of the shapes than in the xy axes.

Also from the emergency principles, and

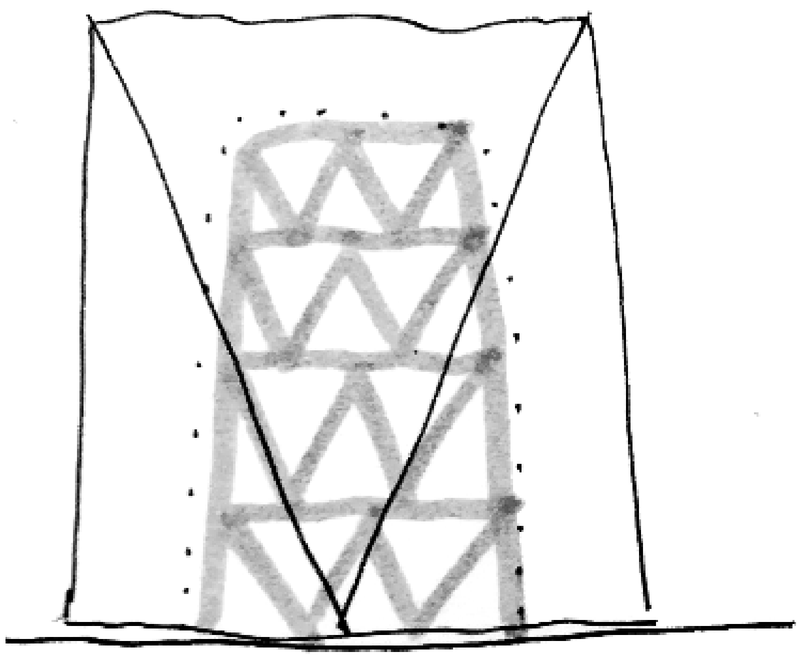


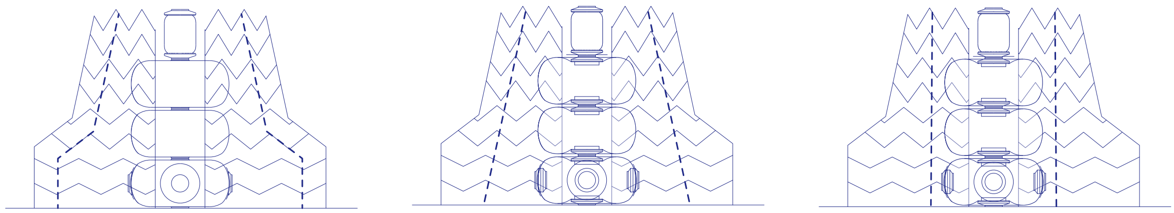




10 | STRUCTURE

RELATIONSHIP BETWEEN RADIATION SHELL AND PRESSURIZED STRUCTURE



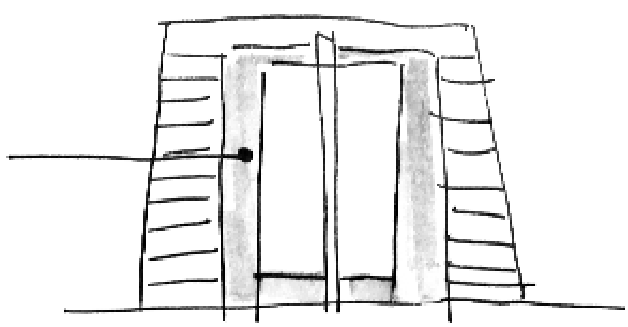


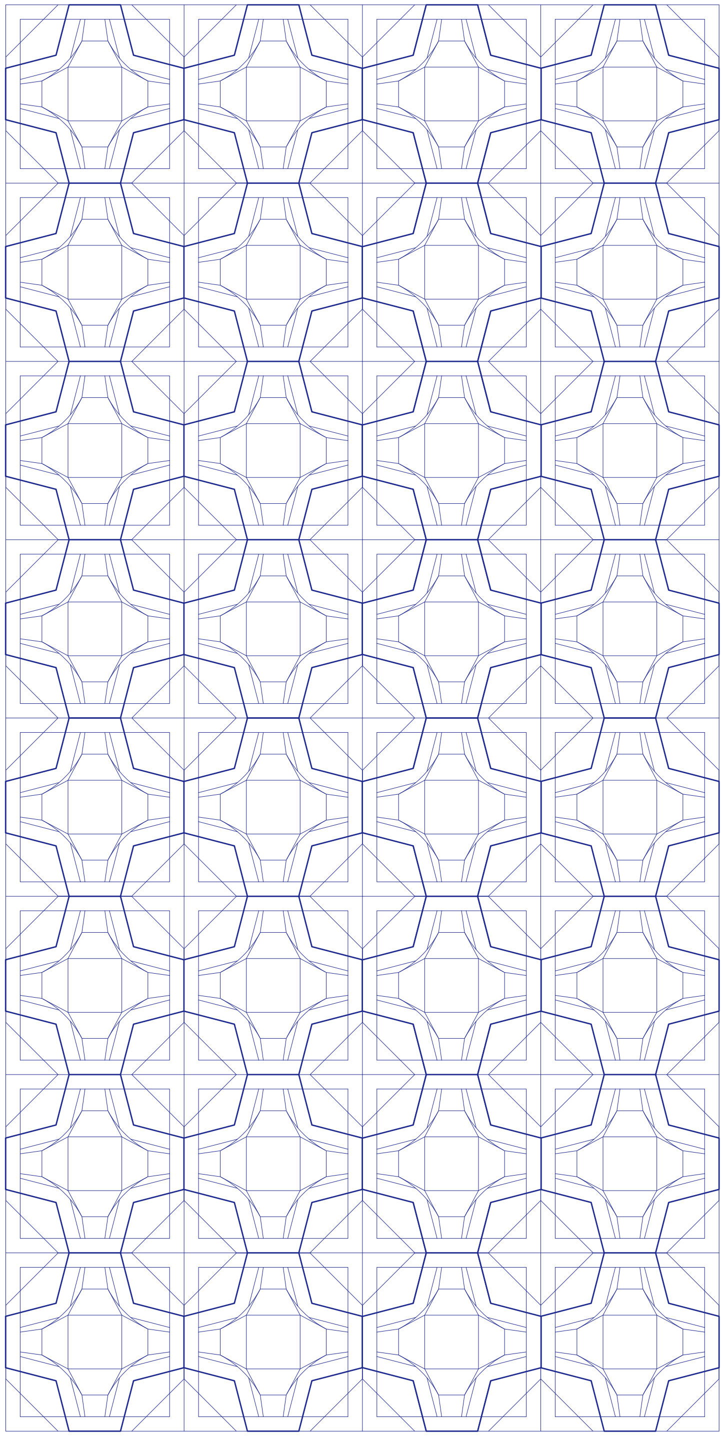
INNER SHAPE DIVERSITY

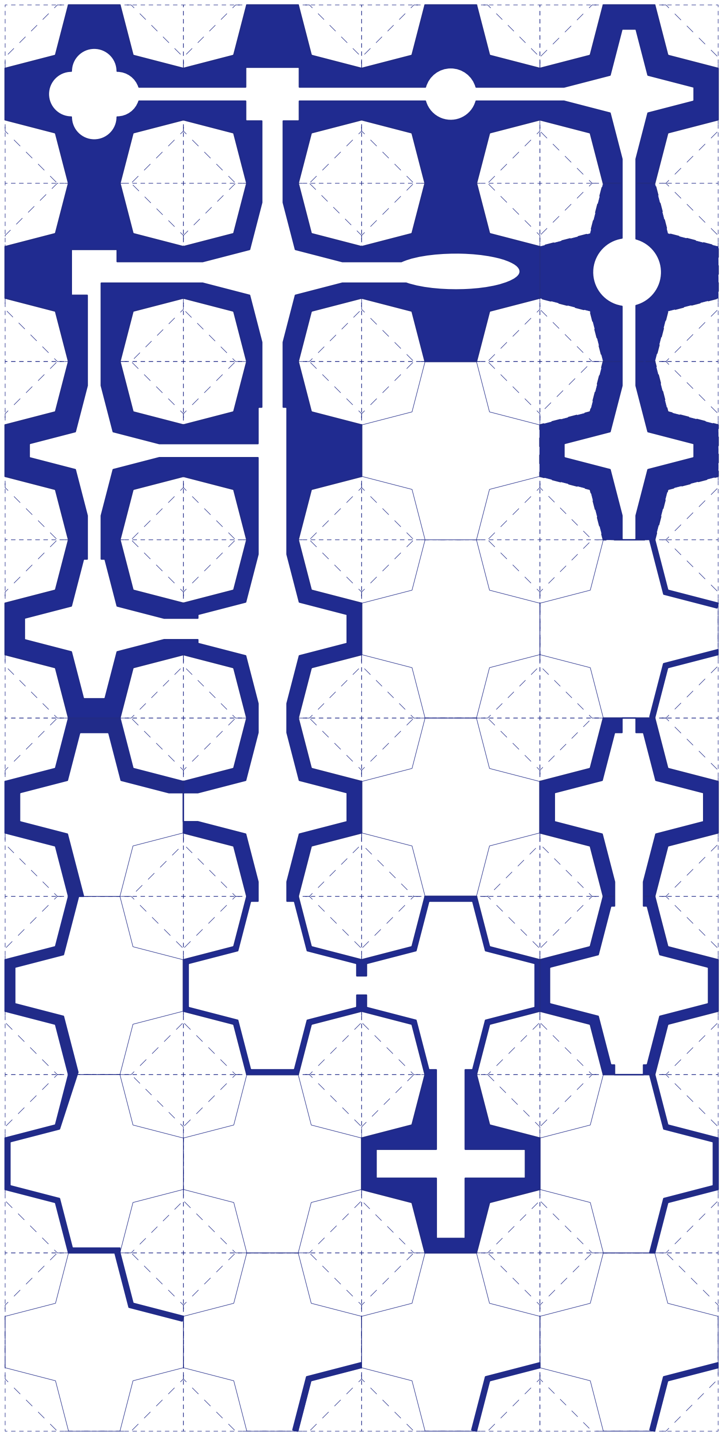
What is the relationship between the pressurized module and the ridig shell structure?

Should one follow the second?

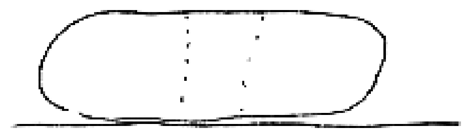
Water and other hydrogenous materials stored behind floors, walls and ceilings in order to contribute to radiation shielding.

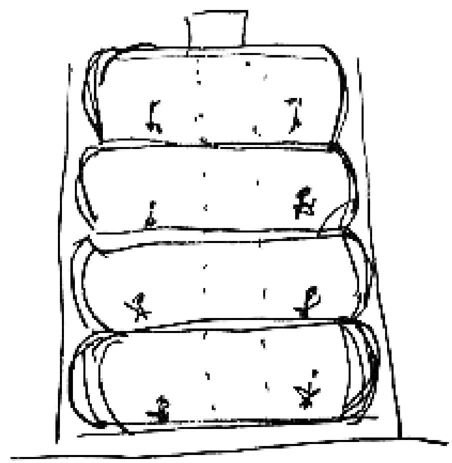






PRESSURIZED MODULE



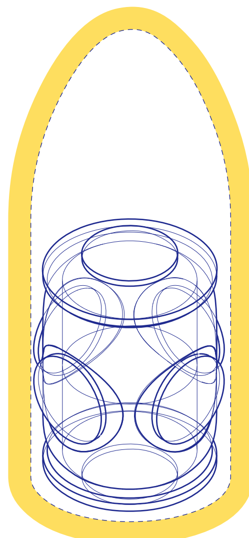


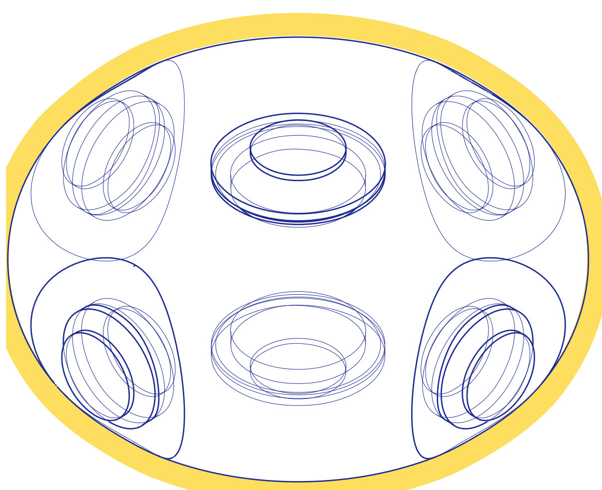
Toroidal shapes of the pressurized module, stacked one on top of another, would be a solution for the floors. Also they might be stacked around one rigid core where they are folded and compressed before the deployment.

Due to the lack of gravity or reduced gravity Carbon Dioxide nitrogen or other gases could accumulate in dangerouse pockets. Tall structure would enhance the air circulation in the habitat and thus help to mix the gases.

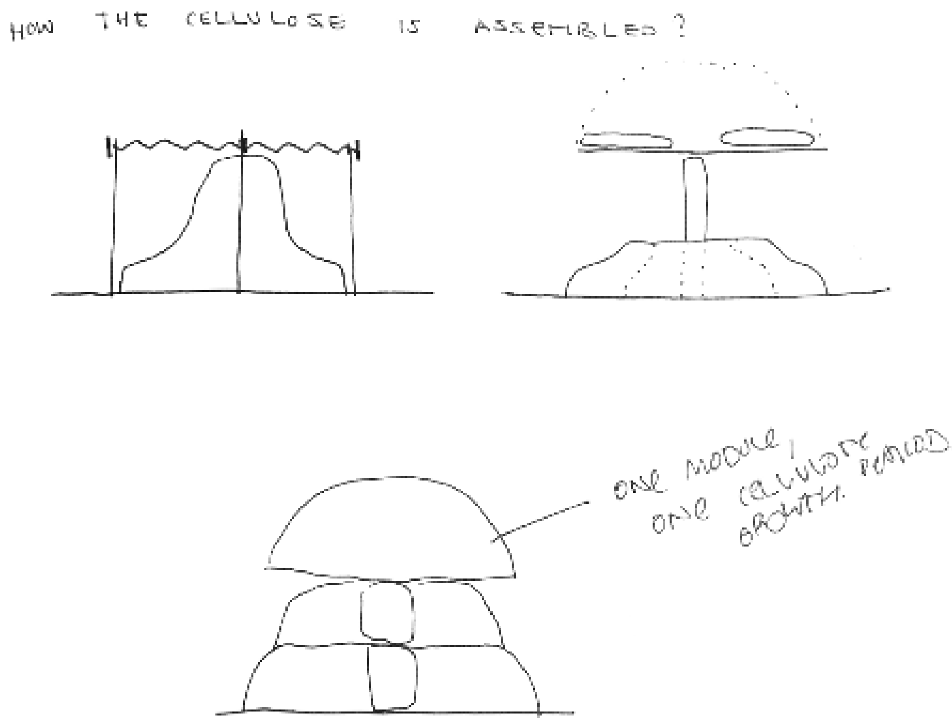
INFLATABLE MODULES

SHAPE OF INFLATABLE MODULE - TORUS

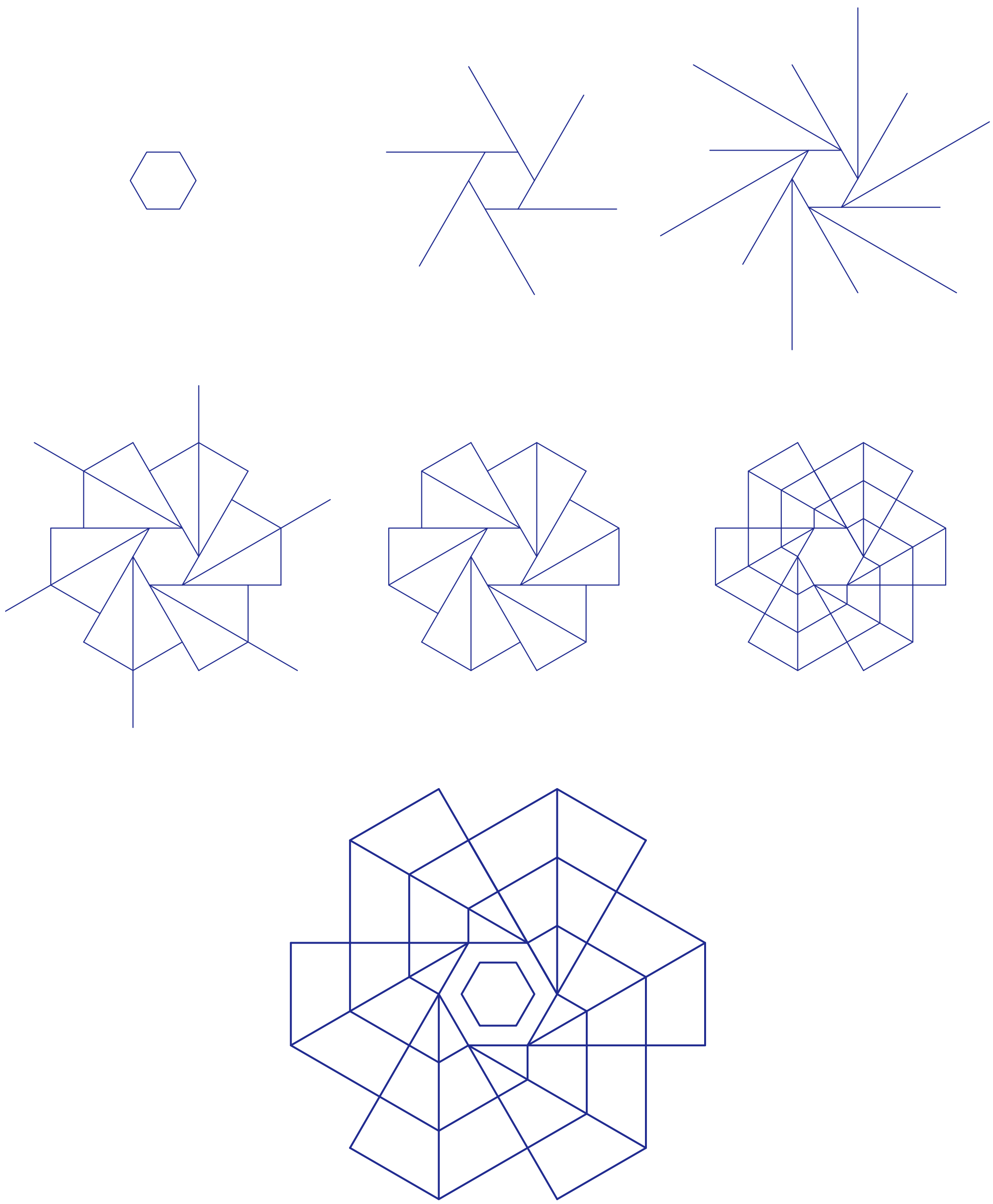


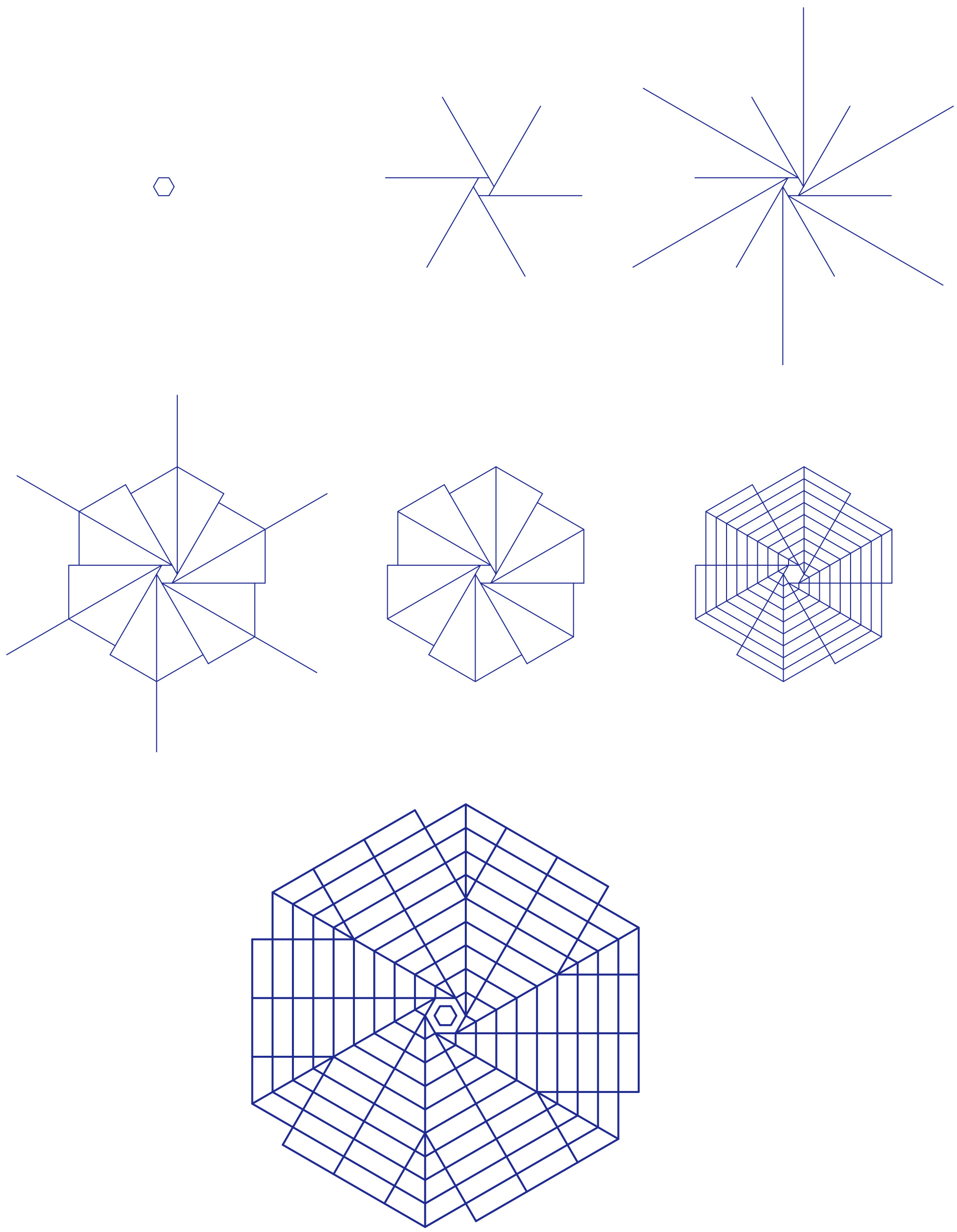


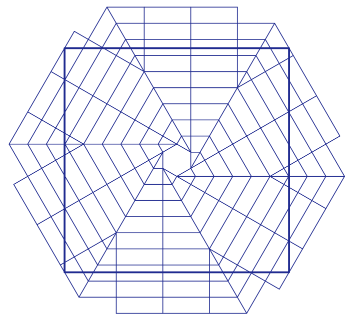
CELLULOSE PRODUCTION MODULE

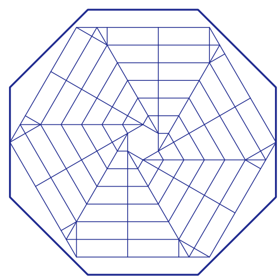

HOW THE CELLULOSE IS ASSEMBLED ?
ONE MODULE /
ONE CELLULOSE PERIOD
GROWTH.

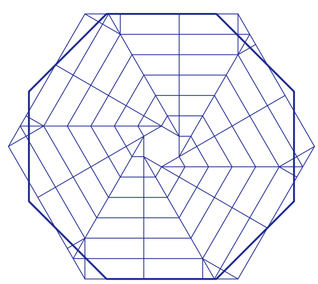
CELLULOSE PRODUCTION PANEL

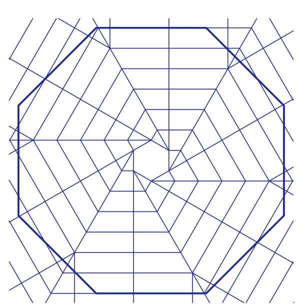




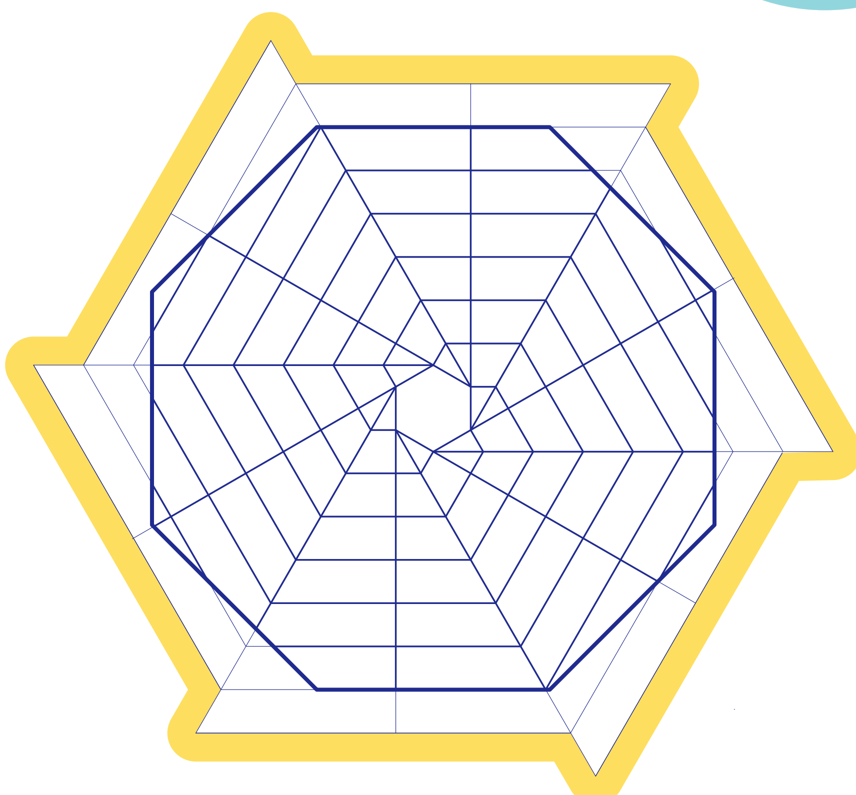


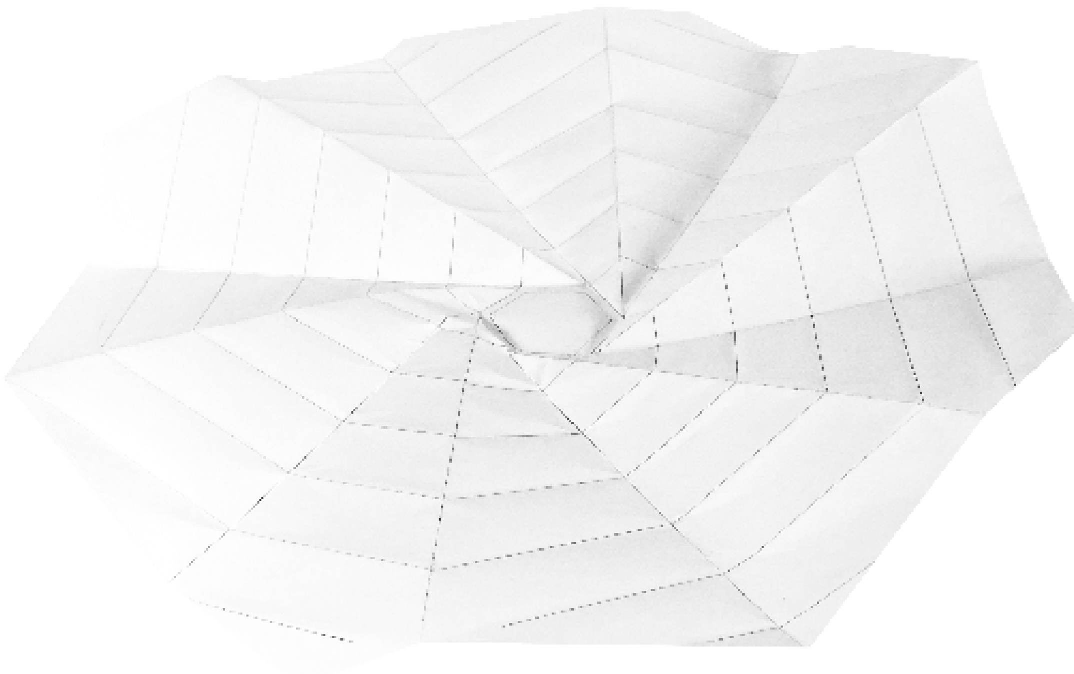






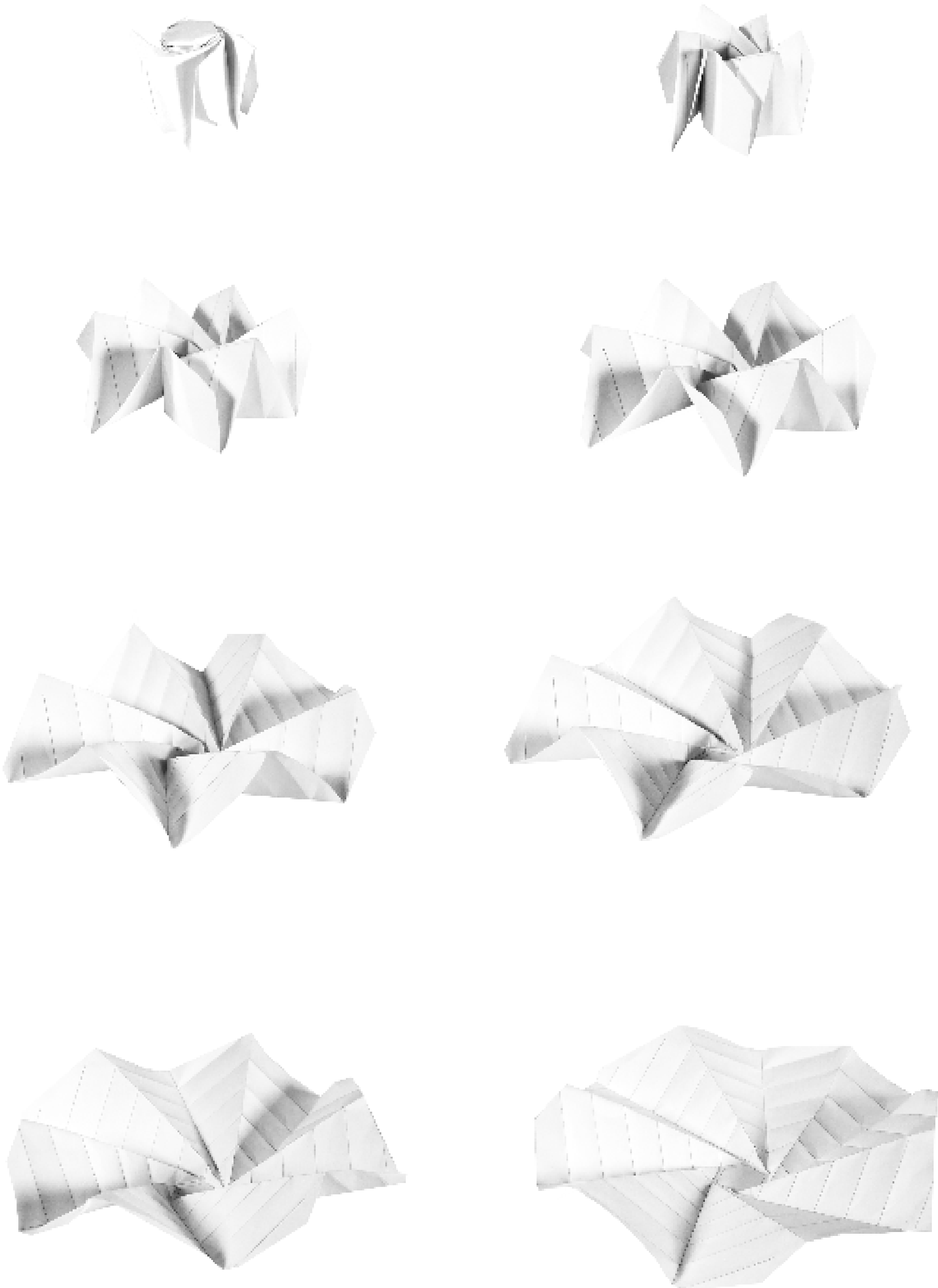
CELLULOSE PRODUCTION PANEL GEOMETRY





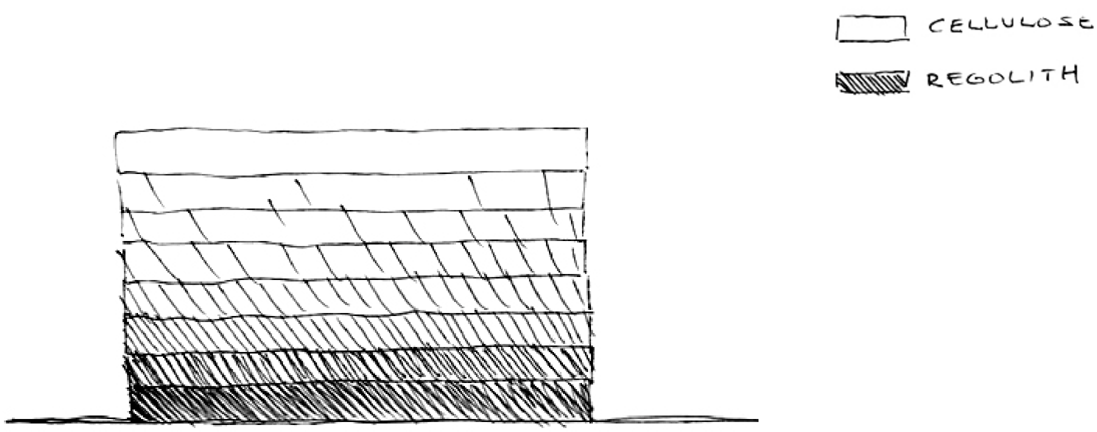
Geometry of the production membrane is based on the Miura Ori fold, similarly to the Origami inspired solar array. Unfolded structure appears to be divided evenly into a checkerboard of parallelograms.

It's great asset is the ease of deployment. There is only one way to open and close it. The mechanical structure of a device that folds this way can be very simple, only one input is required to deploy it.



RADIATION SHELL

GRADIENT



Important aspect of the structure is its gradient character. Due to the construction purposes, parametric optimisation and stress analysis would enable to create forms that distribute material in the most efficient way.

On the bottom there will be more regolith creating the heaviest and the most stable part, while towards the top of the structure the ratio of the regolith and cellulose layers would change. At the top there would be predominance of the cellulose formation. Besides the strength of the shell structure, the main driver of the density optimisation process would be radiation protection itself. There would be areas which have to be protected more then others, thus the shell should be sometimes thicker, more dense or more varied.

CELLULOSE / REGOLITH GRADIENT FROM BOTTOM TO THE TOP

The other argument behind the gradient character of the structure is the light. Nano-cellulose is a translucent material, meaning it lets light go through. When layered together, in a specific amount, it can collect the light and pass it through, to the inside of the shell. Since for now, it is not really possible to have windows in the moon bases (due to the radiation), finding a way to introduce at least some sunlight to the inside would be extremely beneficial. at is way the structure of the shell would be graded to have more 'light-collecting' cellulose layers towards the top, or in the places where the presence of the light would be the most advantageous.

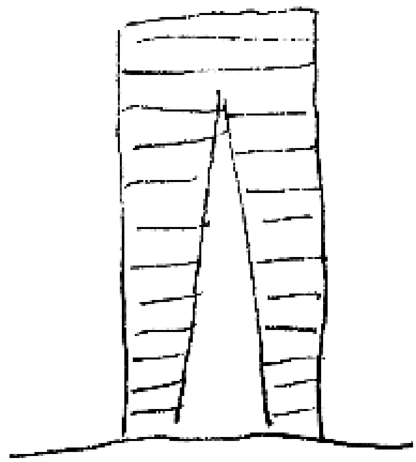
LATERAL STABILIZATION

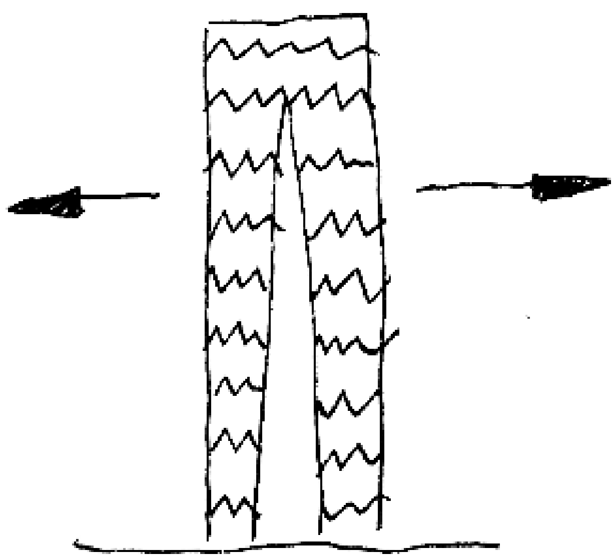
How the Mechanical Stabilization may be assured also in the Z direction?

Should the cellulose layers have any Z-value?

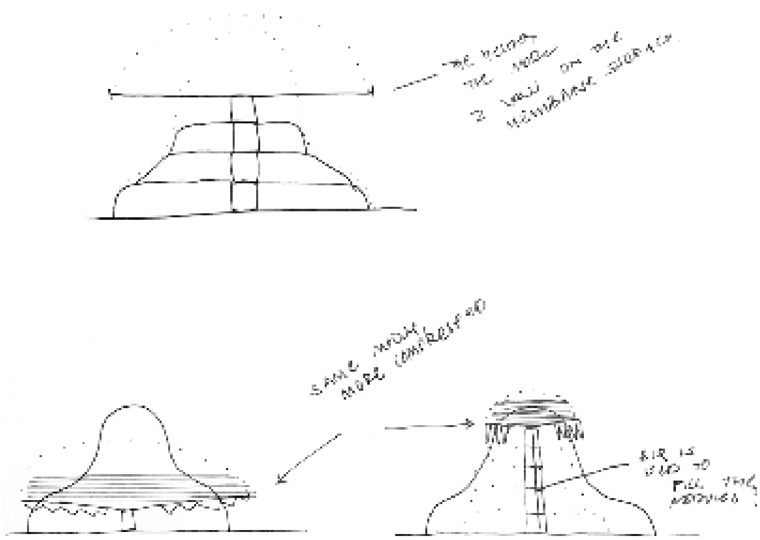
How much that would help?

What is the maximum height of the structure that can be build?

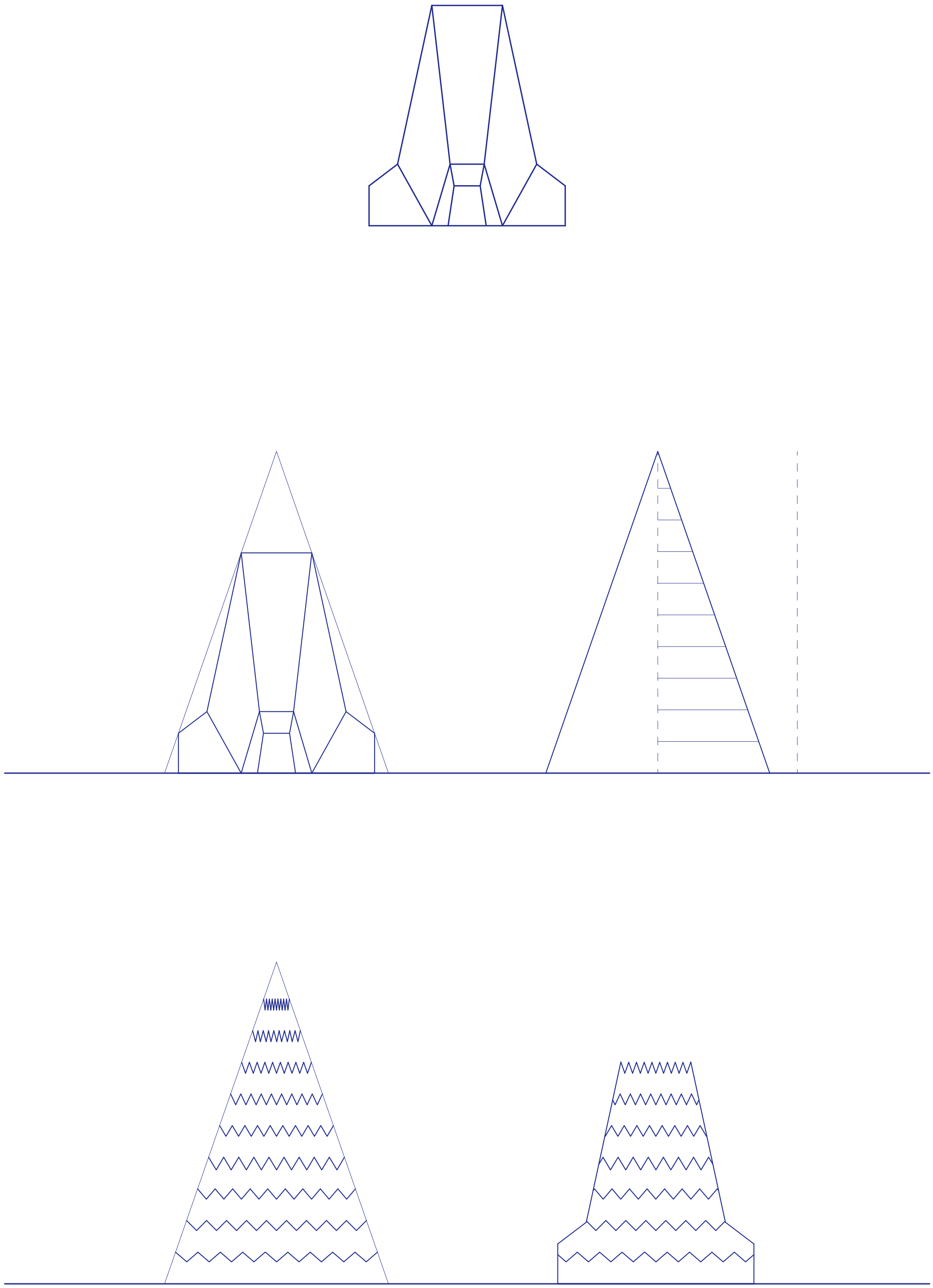




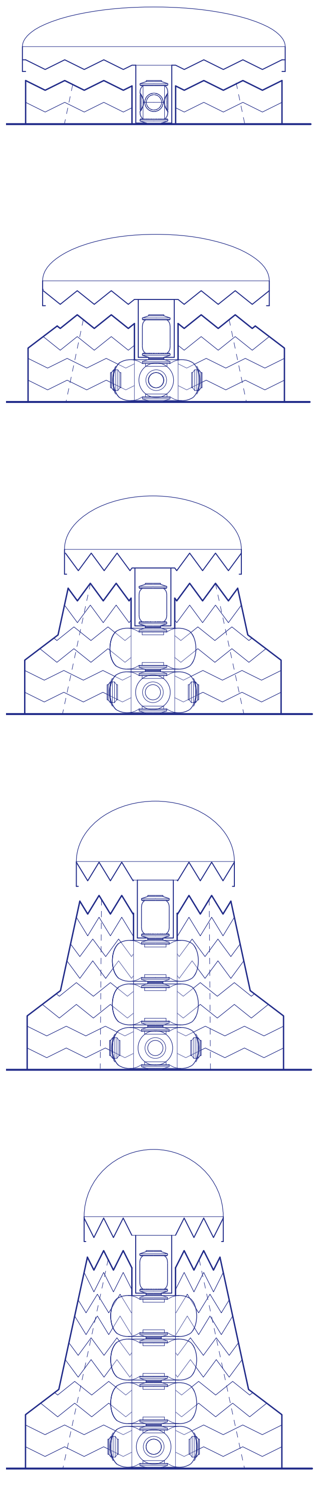
Z VALUE

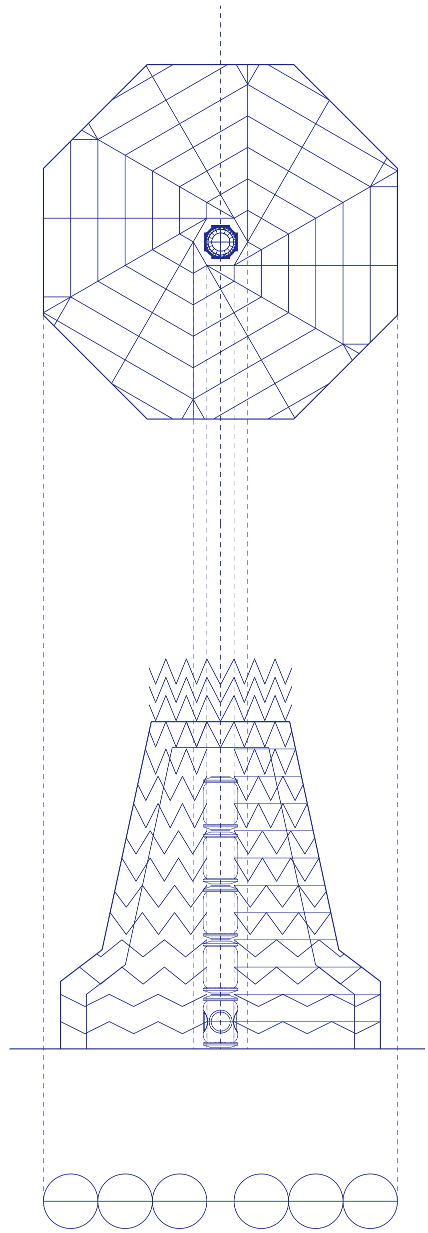


Towards the top of the structure the area which has to be covered by the shell gets smaller. Origami production module / panel folds gradually to cover onluy the needed surface. While the panel is folding it becomes more and more folded (mountains and valleys are getting bigger). Also is becomes more dense. Thus cellulose layers becomed varyfied, on the bottom they are almost flat and not very dense and on the top they have big Z value and are very dense.



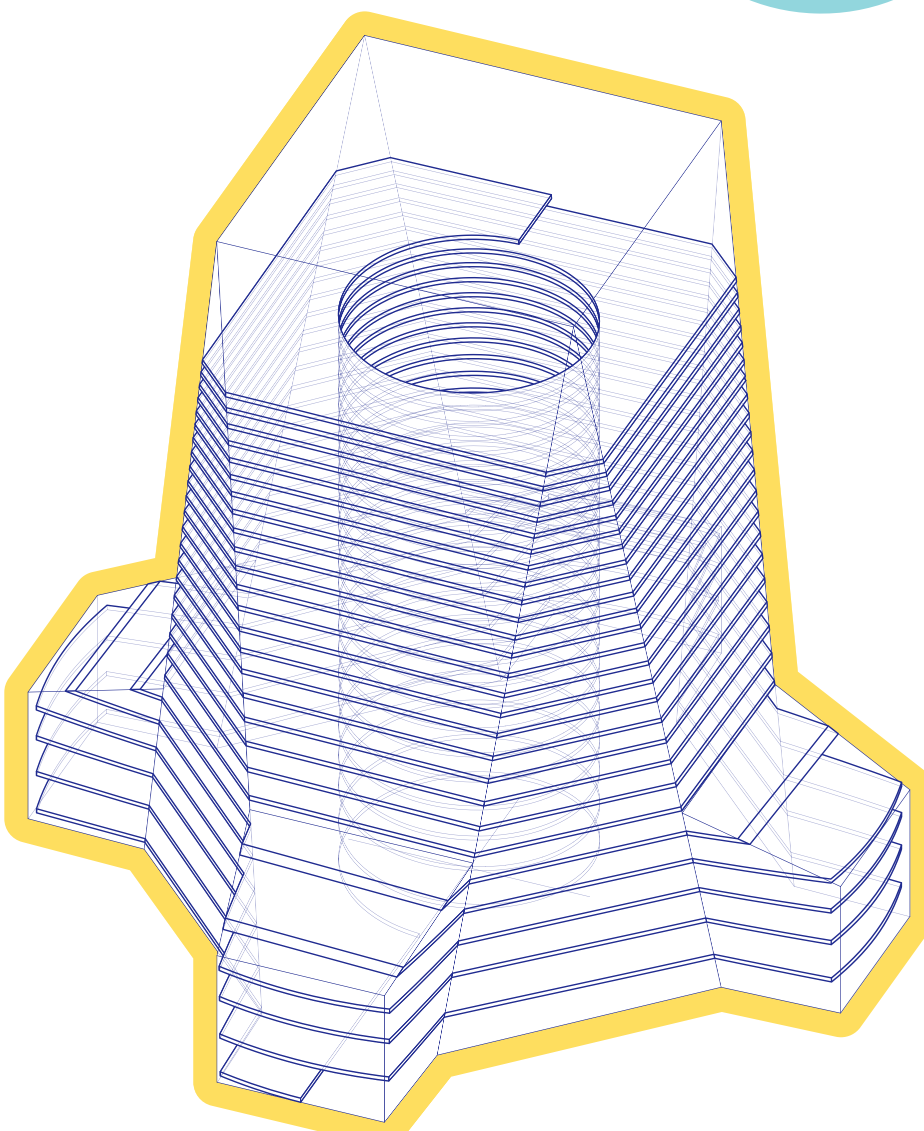
CONSTRUCTION PROCESS

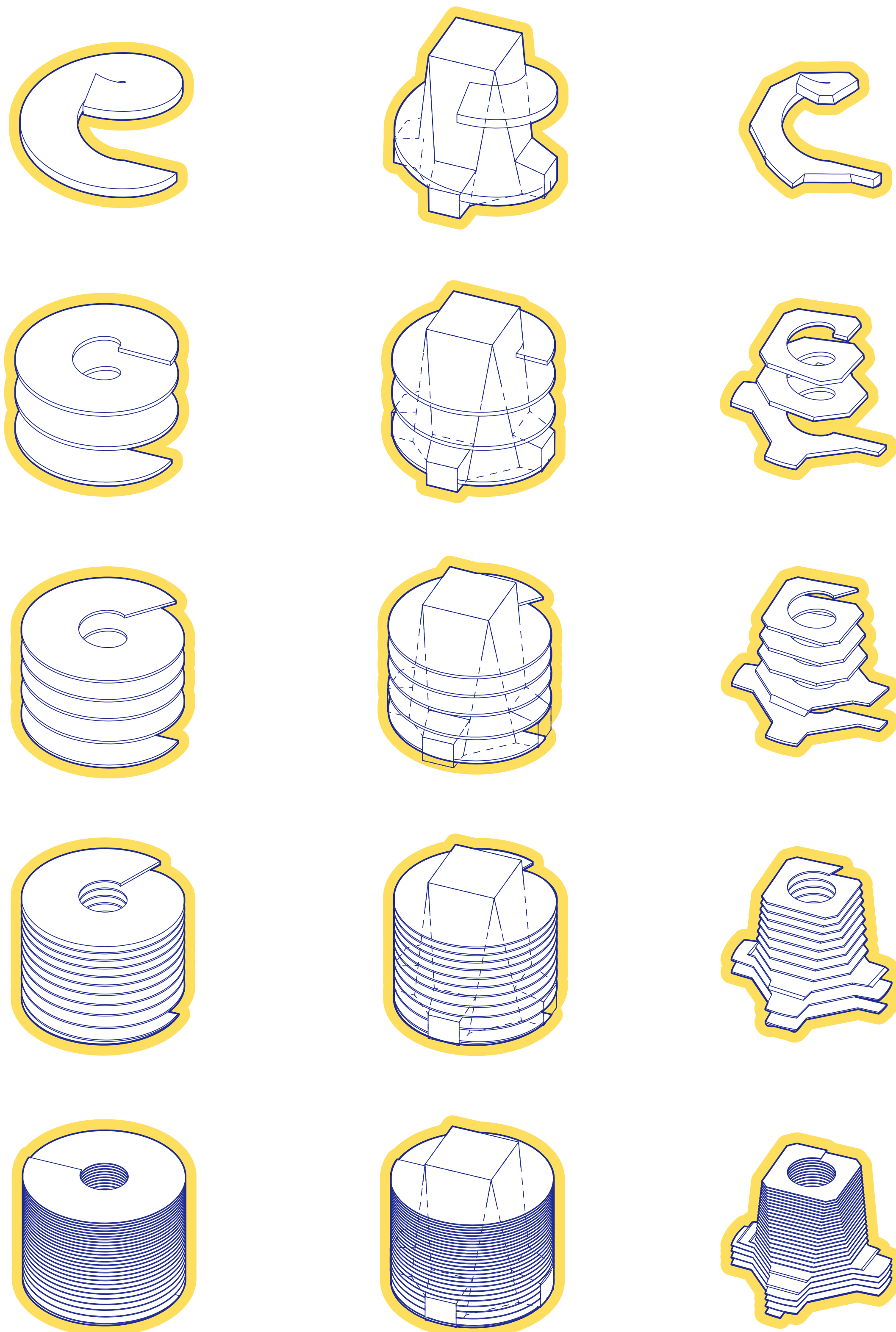




SPIRAL

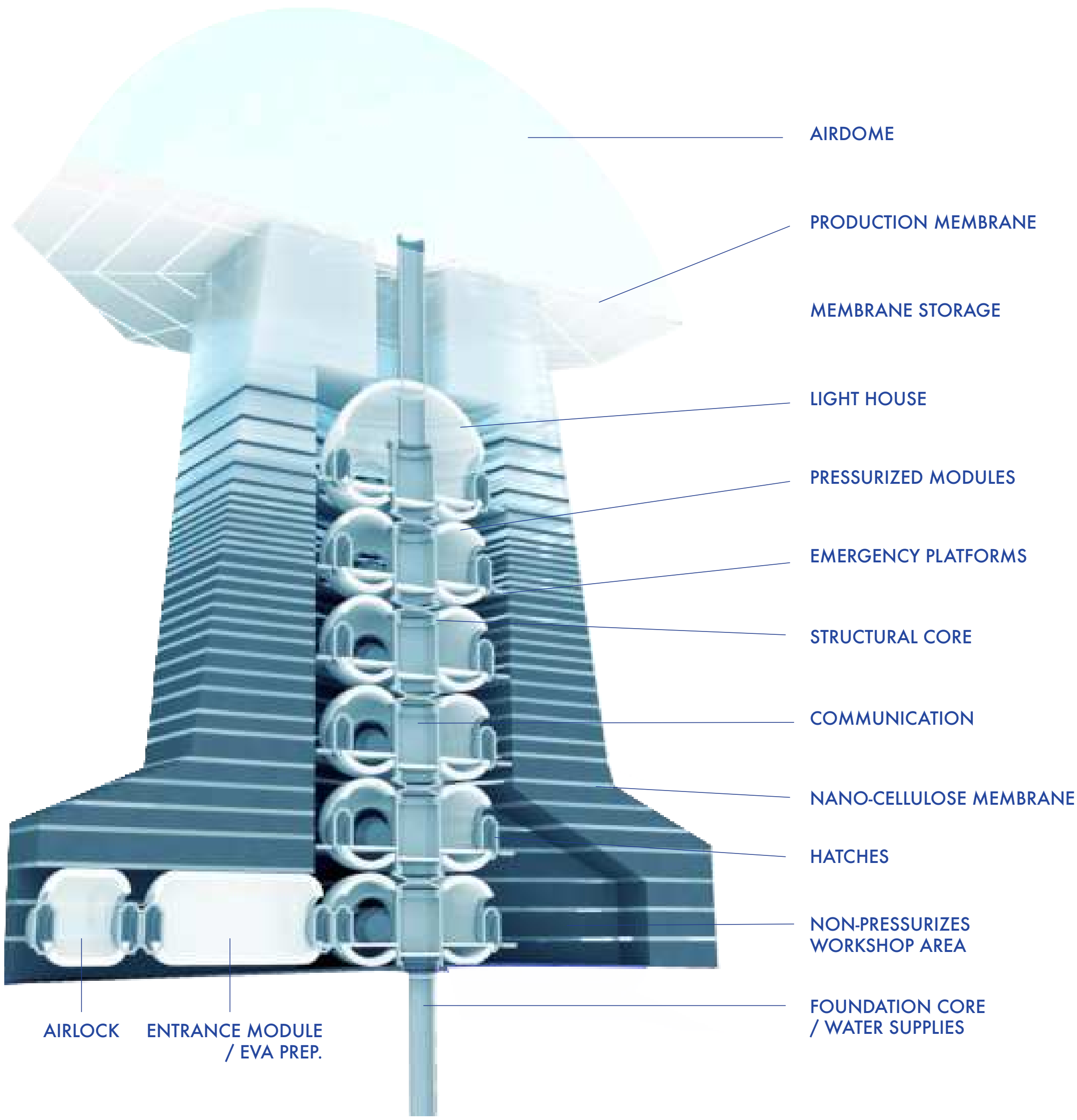
CONTINUOS
SPIRAL ENSURES
LATERAL STABILIZATION





PROJECT

STRUCTURE


AIRDOME
PRODUCTION MEMBRANE
MEMBRANE STORAGE
LIGHT HOUSE
PRESSURIZED MODULES
EMERGENCY PLATFORMS
STRUCTURAL CORE
COMMUNICATION
NANO-CELLULOSE MEMBRANE
HATCHES
NON-PRESSURIZES WORKSHOP AREA
FOUNDATION CORE / WATER SUPPLIES
AIRLOCK
ENTRANCE MODULE / EVA PREP.

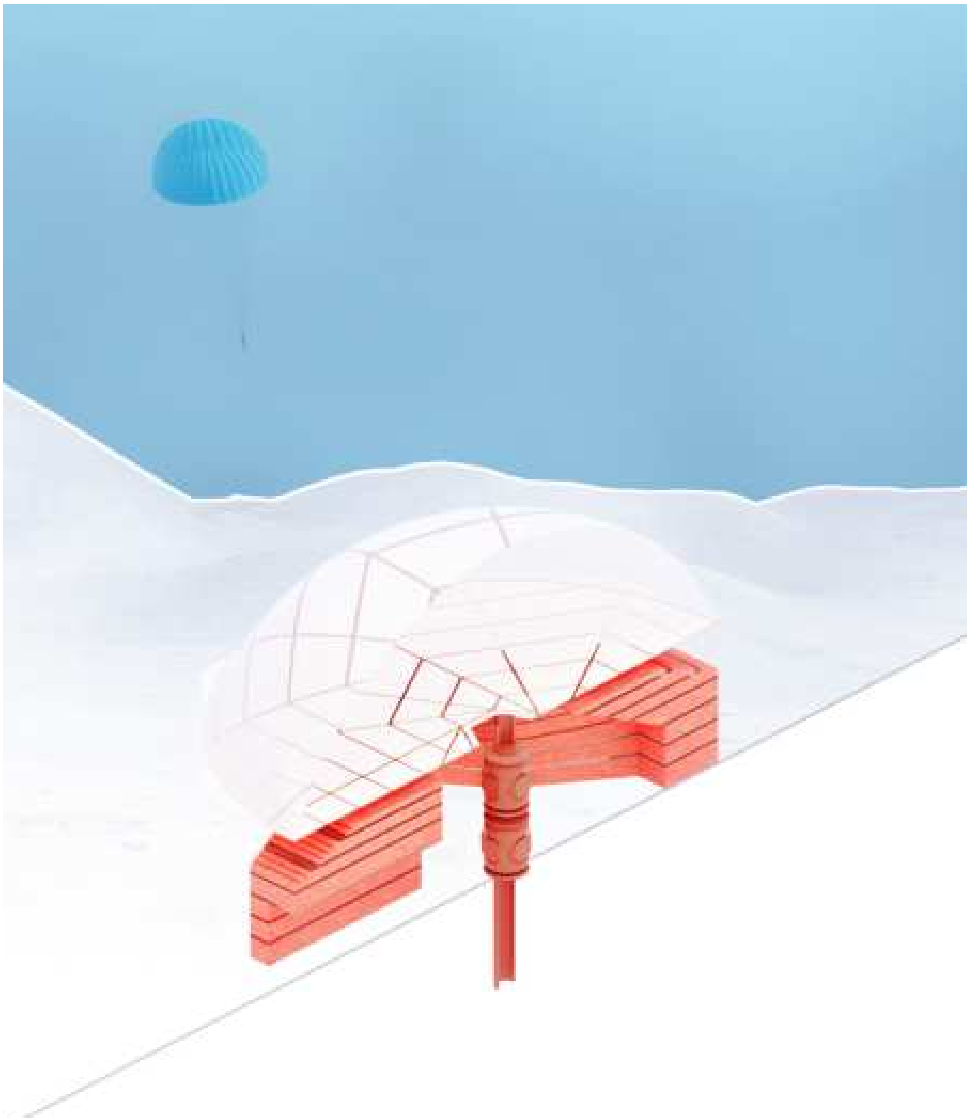
CONSTRUCTION STAGES

LANDING

Foundation and Production Membrane assemble

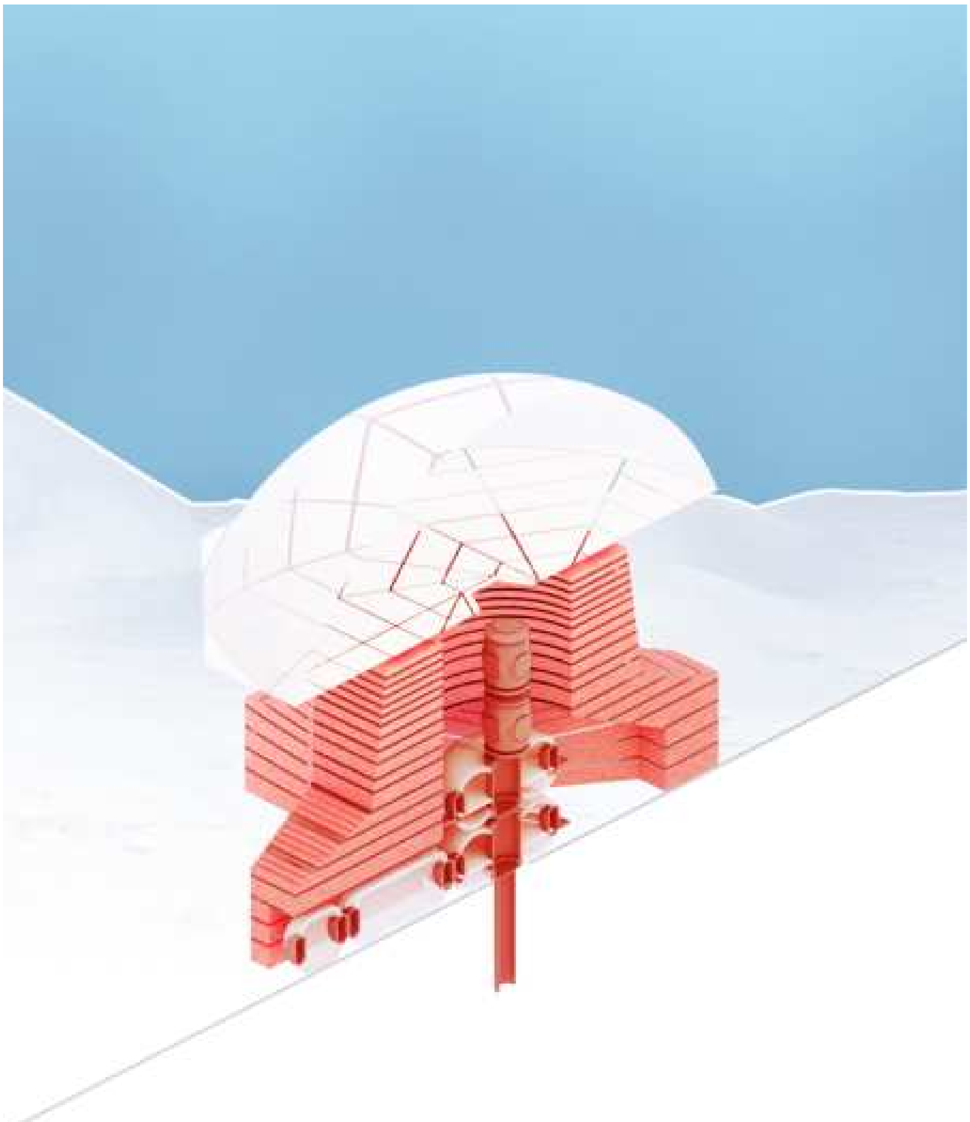
0 MONTHS

Foundation and Production Membrane assemble

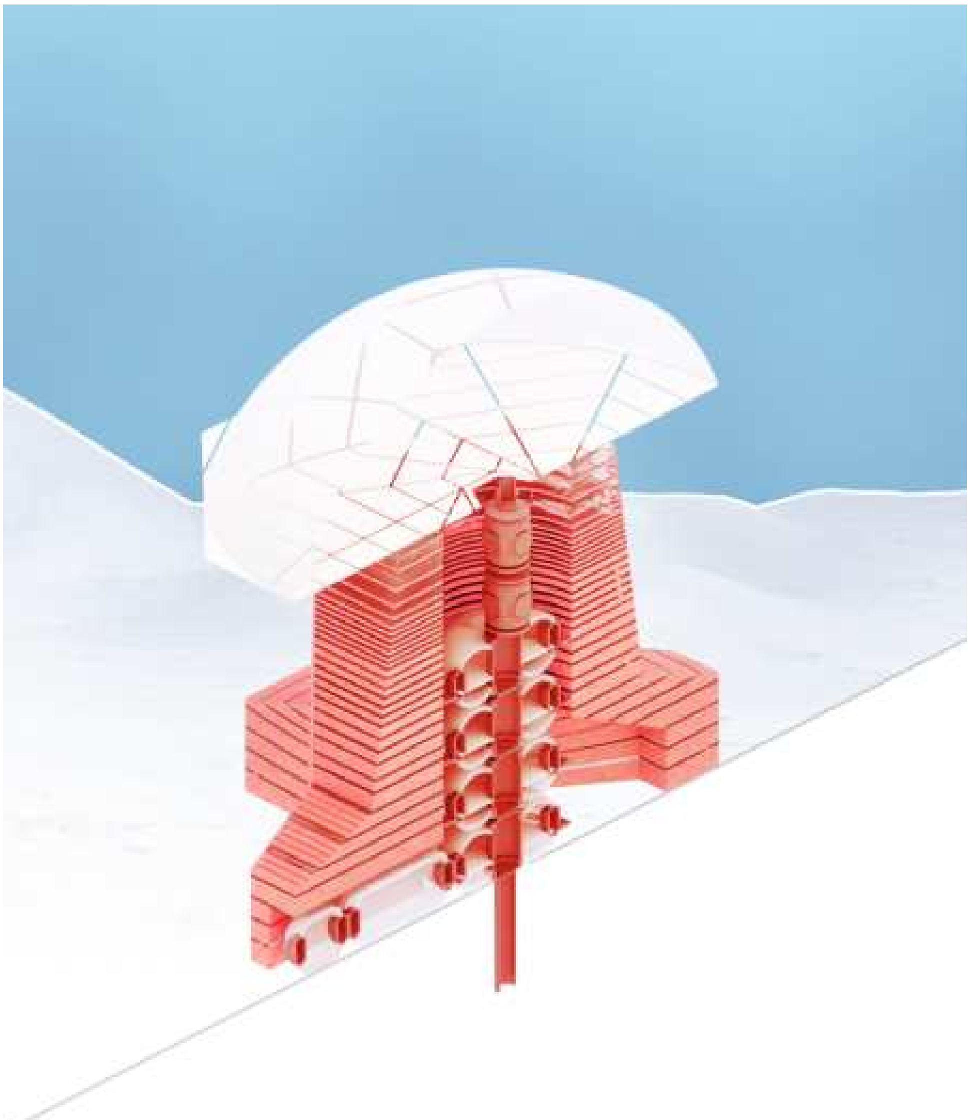


3 MONTHS

Cellulose layers production starts



12 MONTHS
Assembly of the Structure | 2nd Payload



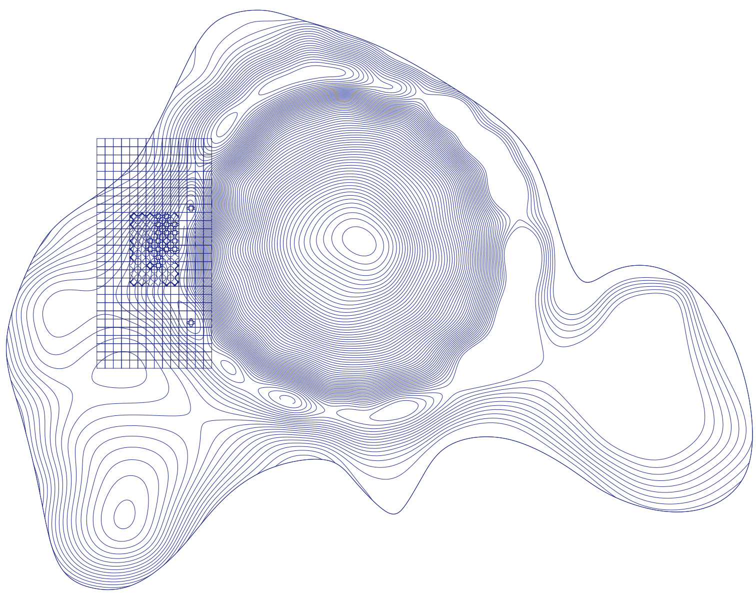
18 MONTHS

Assembly of the Structure | 3rd Payload

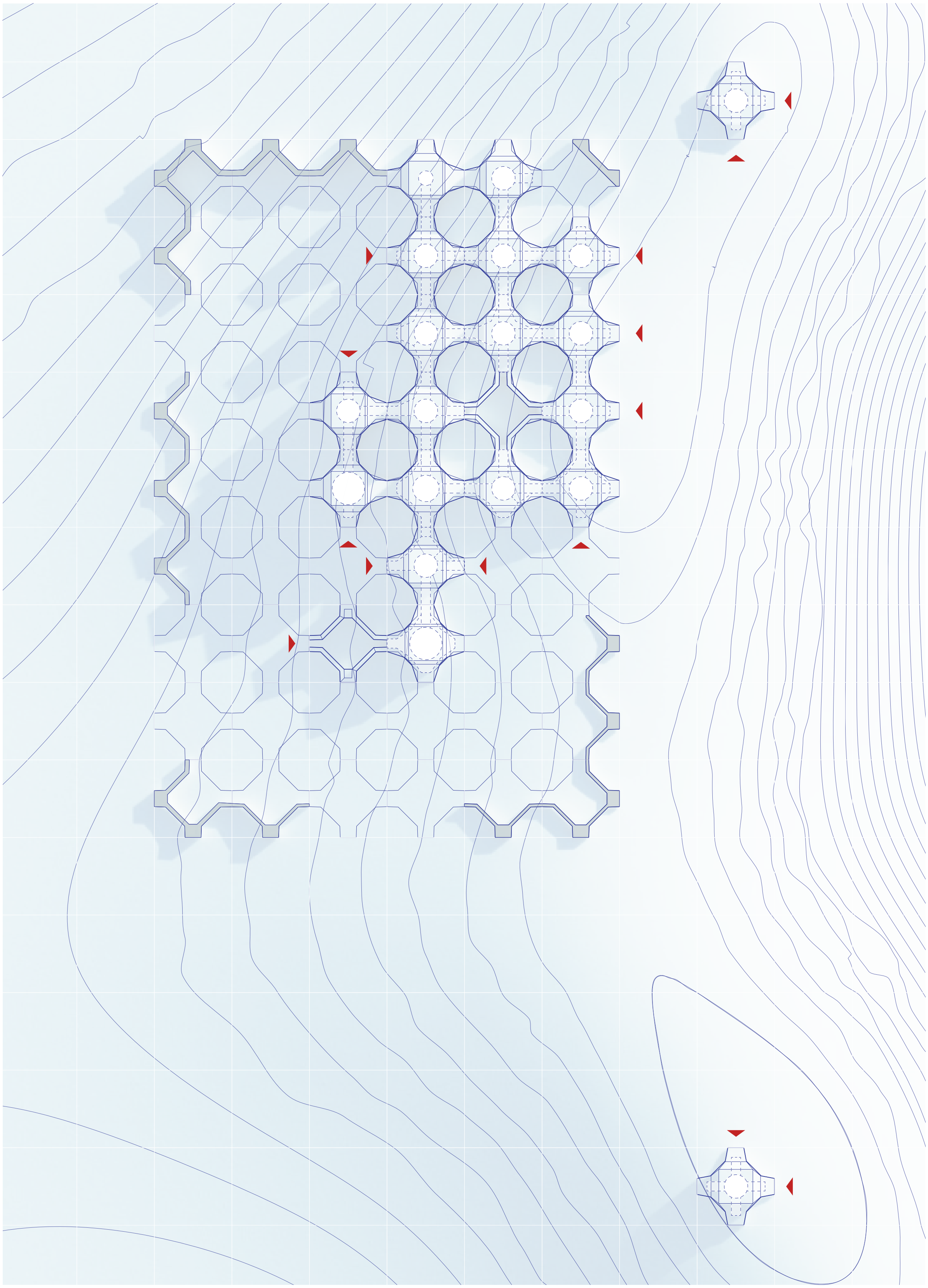
24 MONTHS

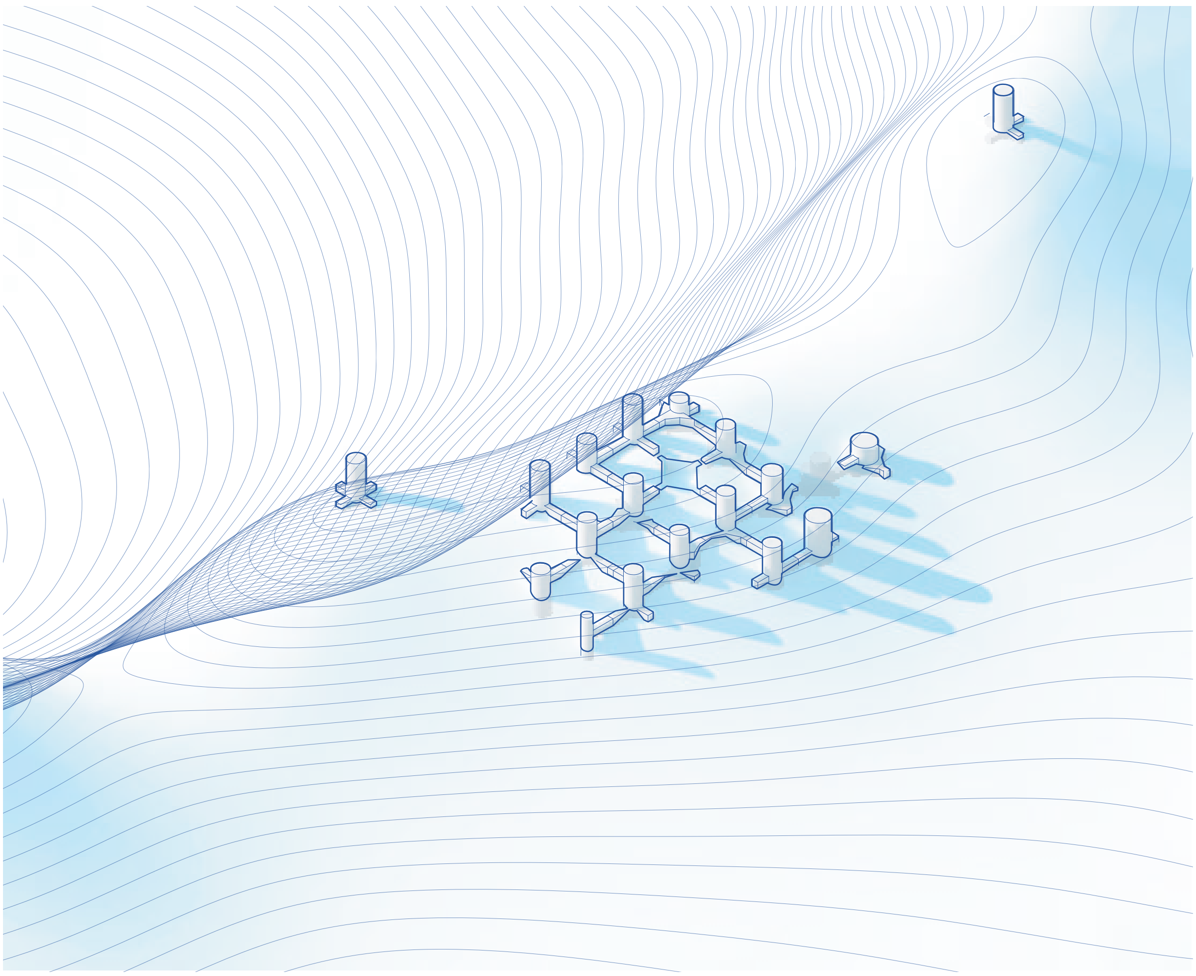
Finished strcutre | Production Membrane folds back

SITEPLAN

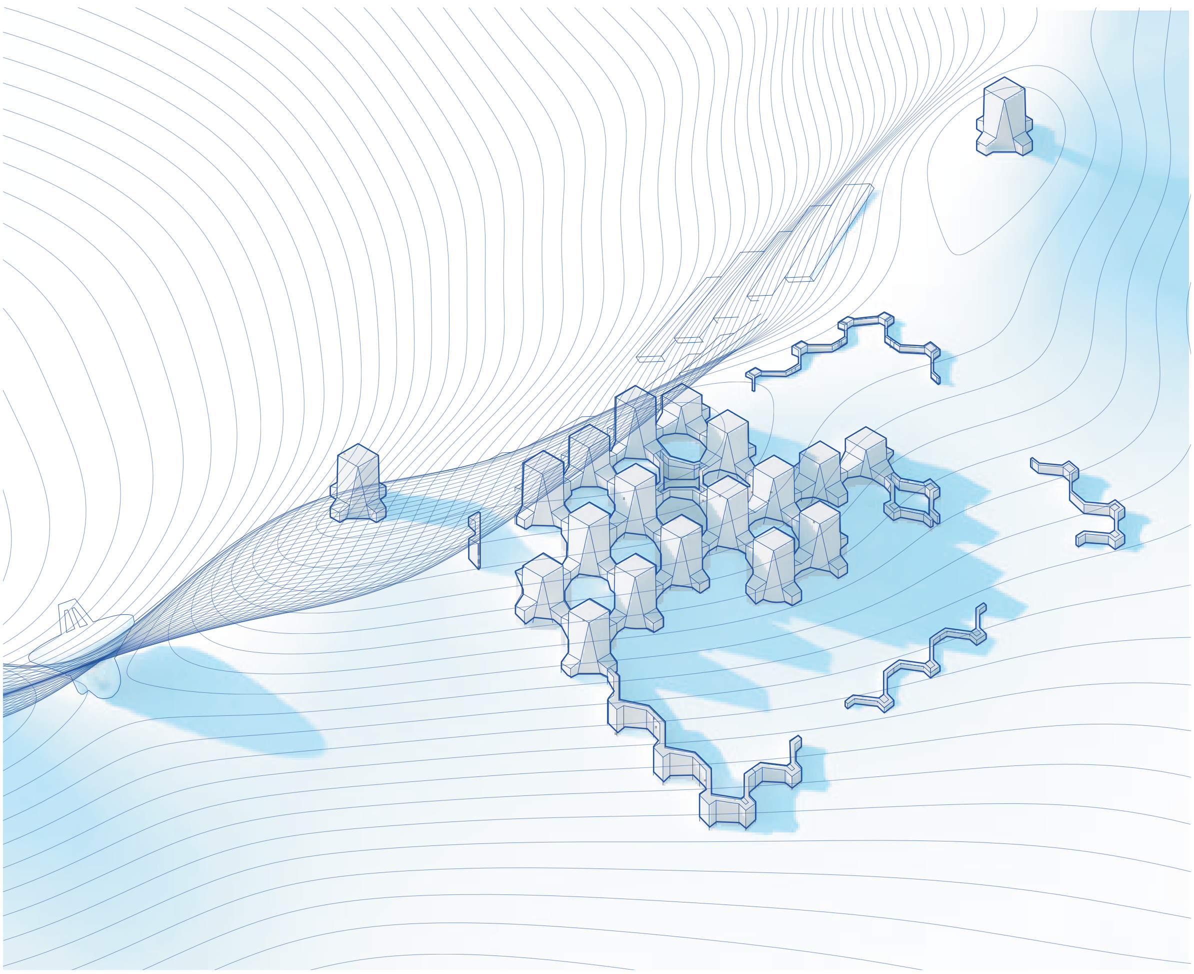


The base is located on the west part of the Shackleton Crater rim, in the Peak of Eternal Light. In the beginning there will be just one 'Light House' together with with all the landing pads, solar panels, radiators, energy storage, hangars for rovers and satellites. However the design allows for further expansion and development over time.





OUTSIDE SHELL



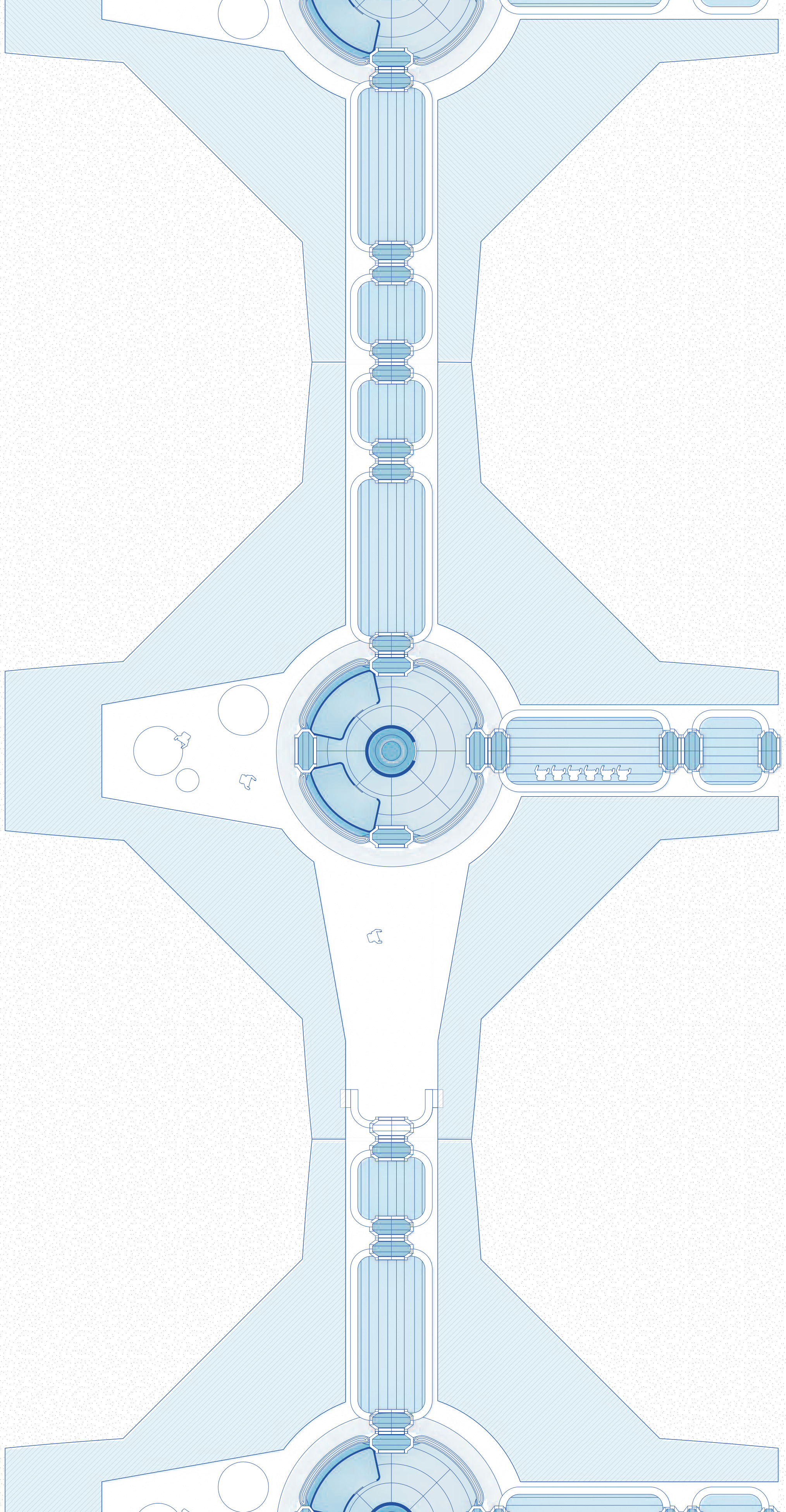
INSIDE SHELL TRUCTURE

HABITAT

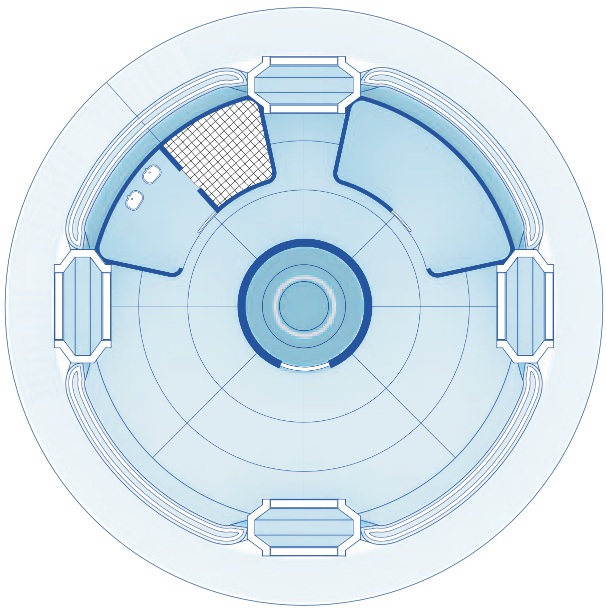
The base consists of two structure systems. To ensure a working life support system, a tight structure able to hold pressure, temperature etc. is needed. Torus shaped inflatable modules brought from Earth are stacked vertically, one on top of another, creating a habitat for the crew with all of the necessary functions, laboratories, greenhouses, workshops etc.

Crew members need to feel comfortable in the habitat. Their comfort is important to ensure a positive outcome of a mission. As a matter of fact NASA made regulations for missions lasting longer than 120 days. Each individual astronaut on such a mission needs to have at least 20m3 of free space to occupy. In spite of those guidelines, it is recommended to increase this volume to that of ISS (120m3 per crew member).

GROUND LEVEL OF THE HABITAT >



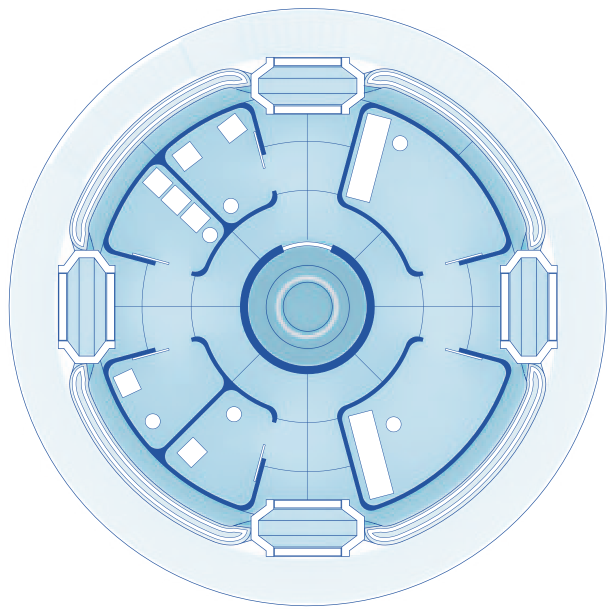
1



WORKSHOP

- Connections with the connection modules and non-pres surized workshop area, aroung the inflatable modules.
- Workshop, fabrication and repair
- EVA (Extra Vechnicular Activity) airlock system, includ ing docking to a pressurized roving vehicle to explore the Lunar surface.
- Sanitary part, where astronauts can get clean after the EVA and other works
- Regenerative ECLSS (Environmental Control and Life Support System) physical/chemical

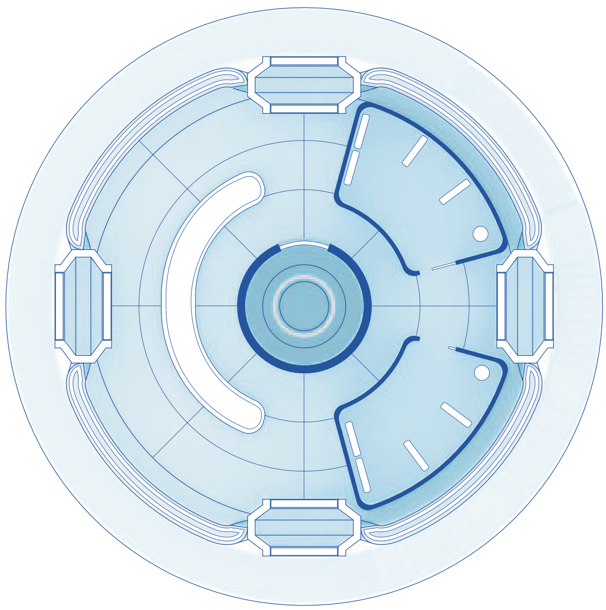
2



LABOLATORIES

- Operation stations to control rovers on the Moon surface in real time, includes a virtual reality display system.
- Astrobiology lab to analyze samples returned from the Moon surface. Includes Bio isolation Level 4 and decontamination capability.
- Medical Facility with outpatient and inpatient accommo dations. Includes telemedicine equipment, including surgical robot.
- Regenerative ECLSS physical/chemical and bioregeneratvie
- 4 Emergency Hatches

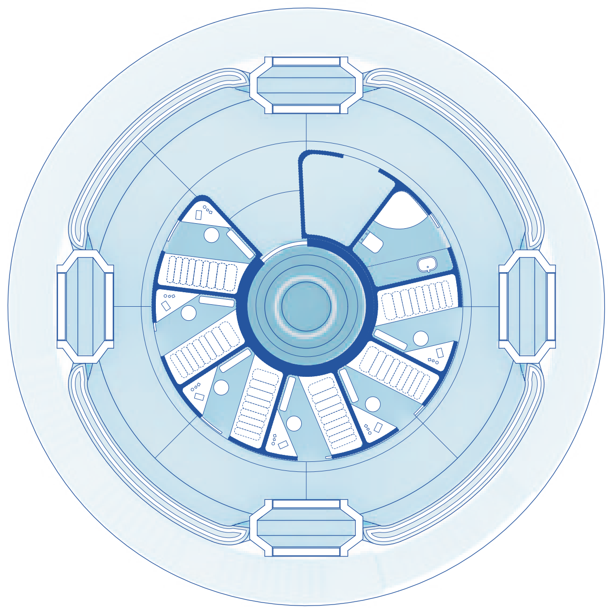
3



GREENHOUSE

- Food production
- Plant labolatories
- Waste management and laundry facility
- Regenerative ECLSS physical/chemical and bioregenerative
- 4 Emergency Hatches

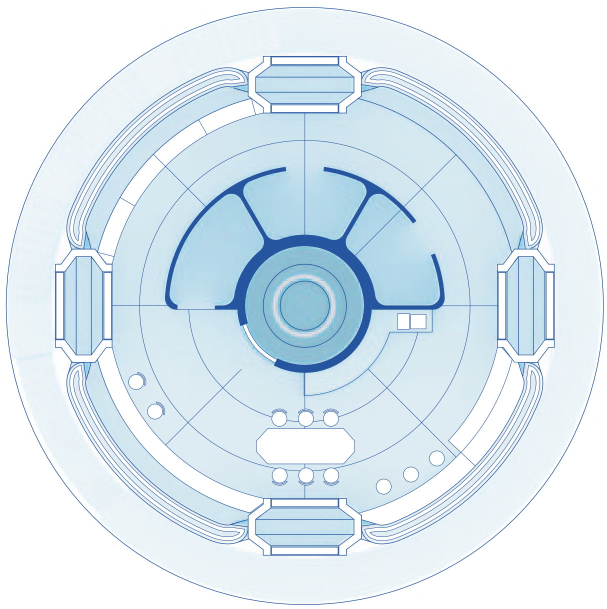
4



PRIVATE QUARTERS

- 6 Private Crew Quarters, Acoustical isolation
- Hygiene, sanitary. Includes showers, toilets, and hand washing.
- Toilets
- Regenerative ECLSS physical/chemical
- 4 Emergency Hatches

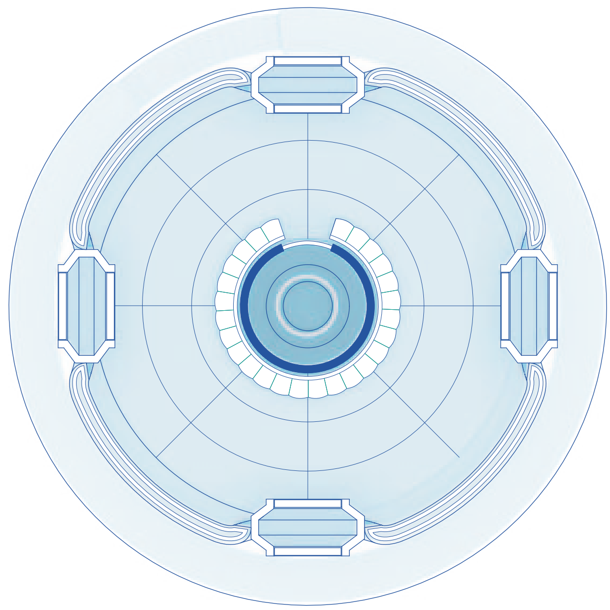
5



COMMON SPACE

- Group Activities Area
- Recreation
- Exercise
- Galley. Food preparation and storage, dish washing
- Wardroom (dining and meeting)
- Regenerative ECLSS physical/chemical
- 4 Emergency Hatches

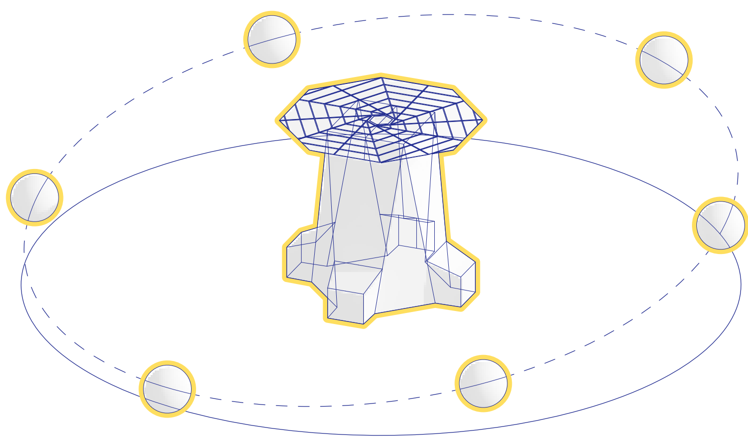
6



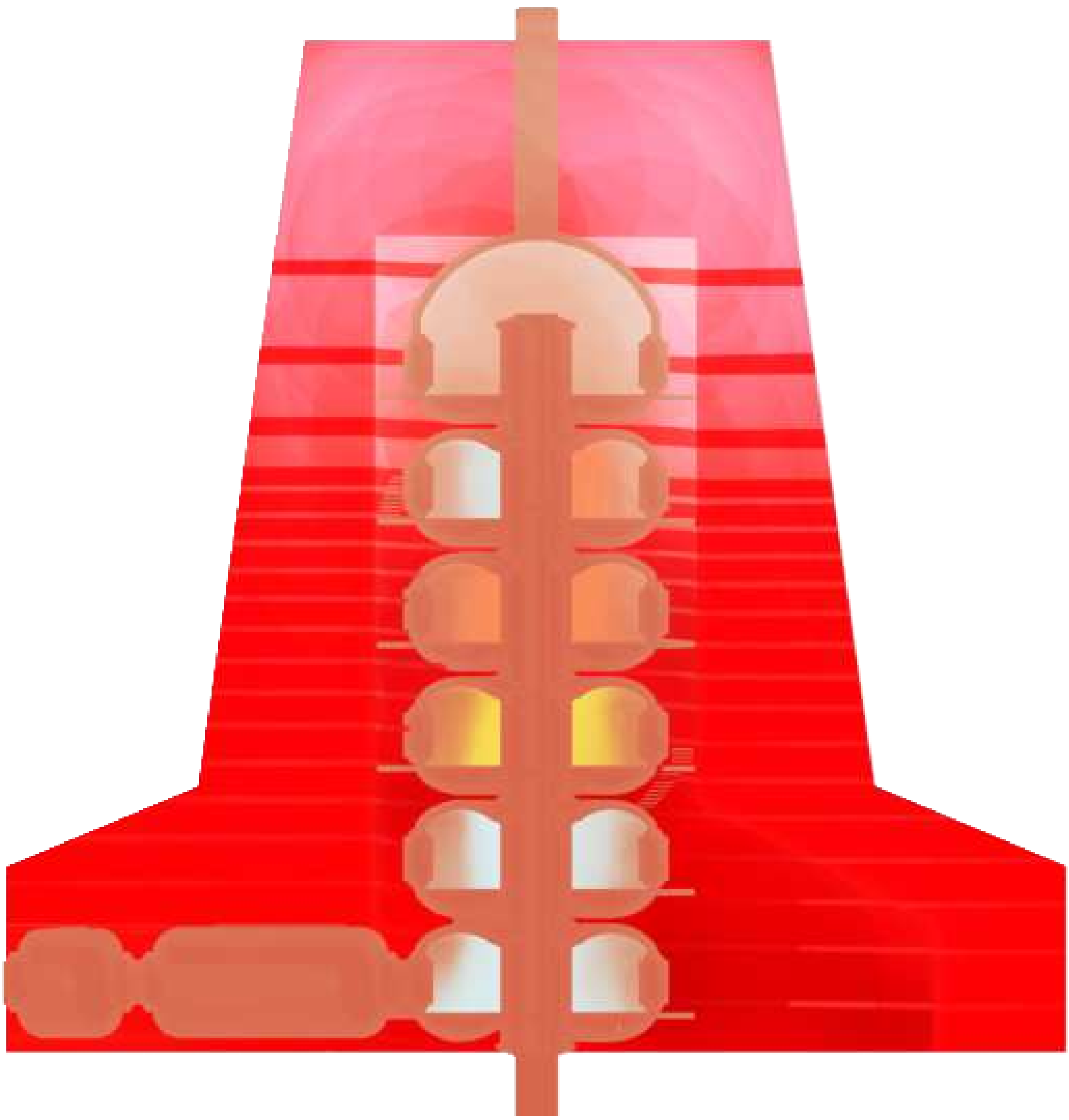
LIGHT HOUSE

- Natural sun-light perception
- Relax zone
- Group Activities Area
- Recreation
- Regenerative ECLSS physical/chemical
- 4 Emergency Hatches

LIGHT



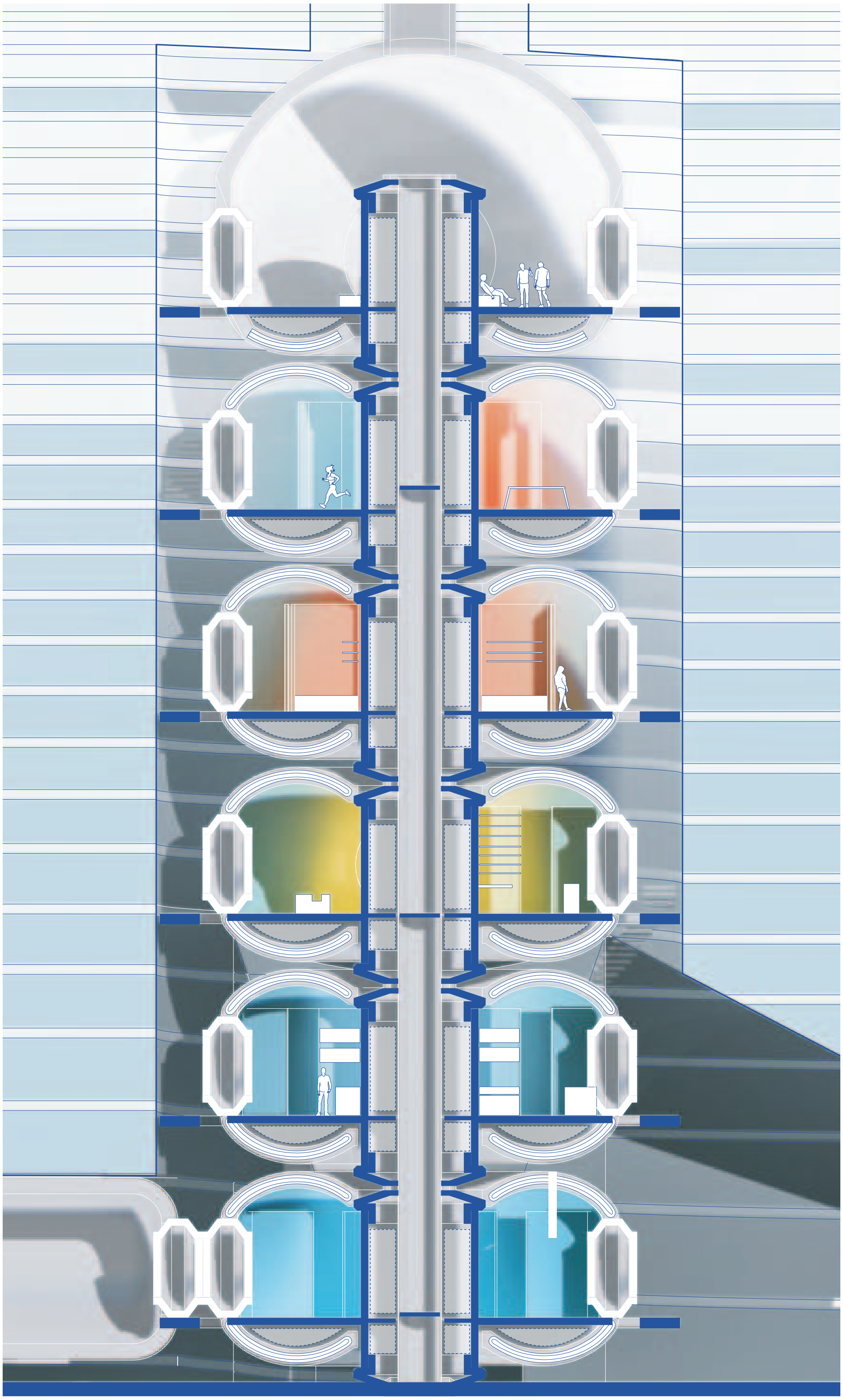
The spiral of nano-cellulose has a differentiated diversity. It's gradient character makes the diffused sun light pass into the structure in a particular manner. On the top level, the sun light provides high luminous intensity. However, towards the bottom less of it reaches the interior. To keep the crew healthy, pressurized modules are equipped with an artifical light system, imitating the day-night cycle on earth. The levels of illumination inside a pressurized module differ. The closer to the center the more intense the artificial lighting needs to be, as less natural light can get there.

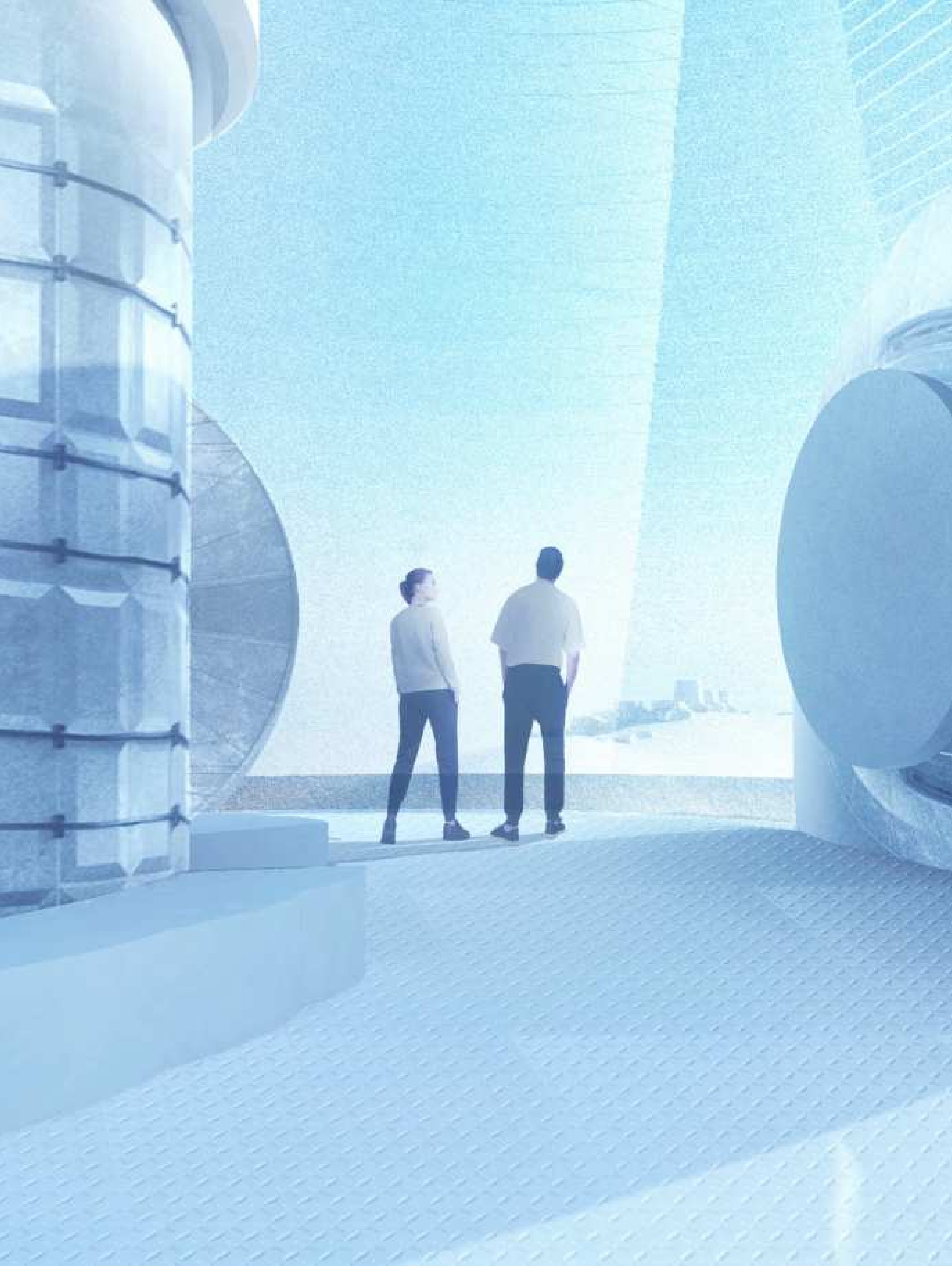


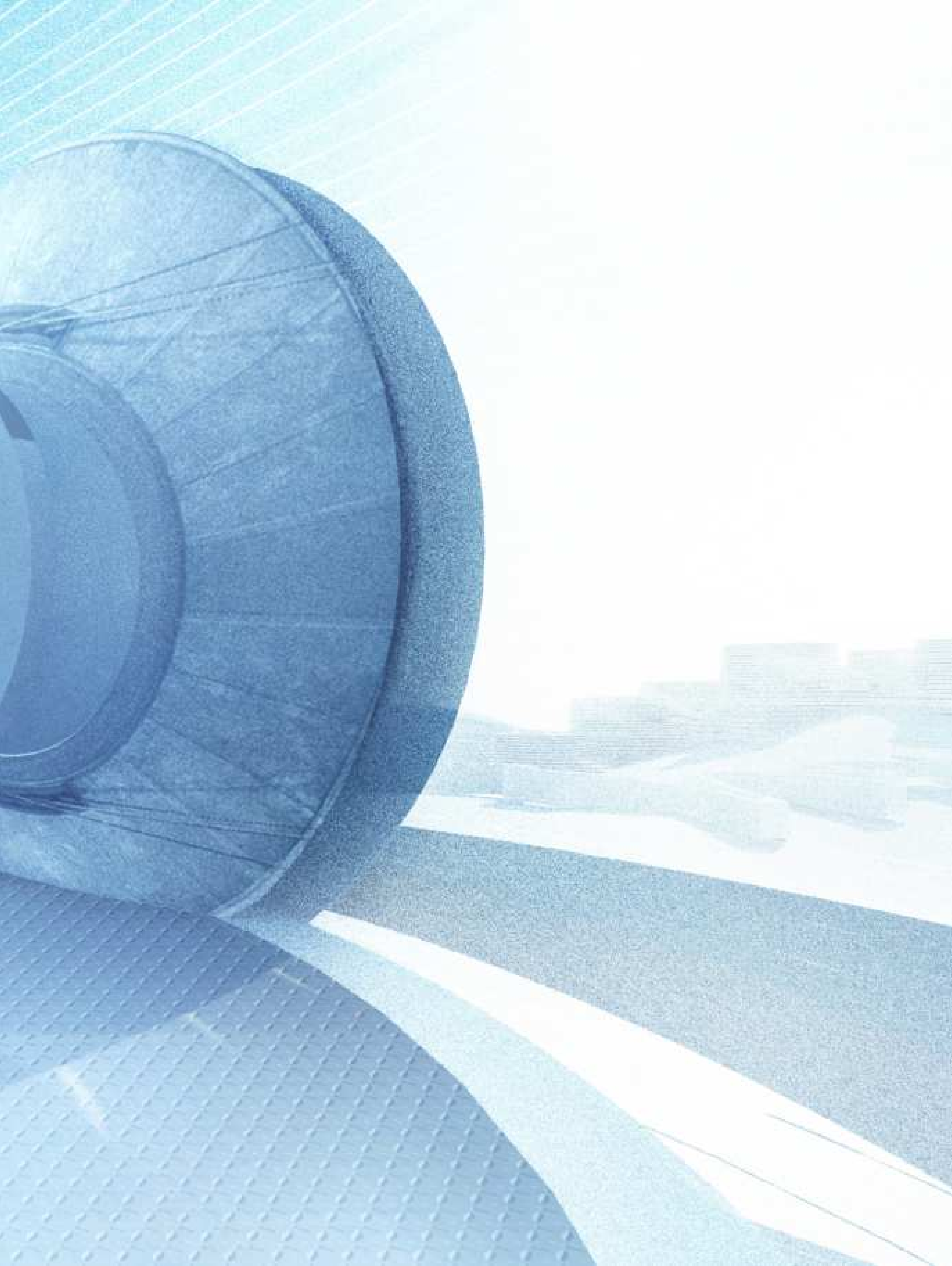
BLUE LIGHT
FOR LABOLATORIS, WORK PLACES
AND EXCERCISE AREA

RED LIGHT
FOR PIVATE QUARTERS
AND COMMON AREA

GREENHOUSE LIGHT
TO ENSURE GOOD, HEALTHY GROWTH
OF THE PLANTS







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Various Sources',
Hanieh Kargarzadeh1, Michael Ioelovich2, Ishak Ahmad1, Sabu Thomas3,4, and Alain Dufresne5,6

‘Bacterial Nanocellulose from Side-Streams of Kombucha Beverages Production: Preparation and Physical-Chemical Properties’
Stefan-Ovidiu Dima 1, Denis-Mihaela Panaitescu 1, Csongor Orban 2 ID , Marius Ghiurea 1, Sanda-Maria Doncea 1, Radu Claudiu Fierascu 1, Cristina Lavinia Nistor 1 ID , Elvira Alexandrescu 1, Cristian-Andi Nicolae 1, Bogdan Trică 1, Angela Moraru 3 and Florin Oancea 1,* ID

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