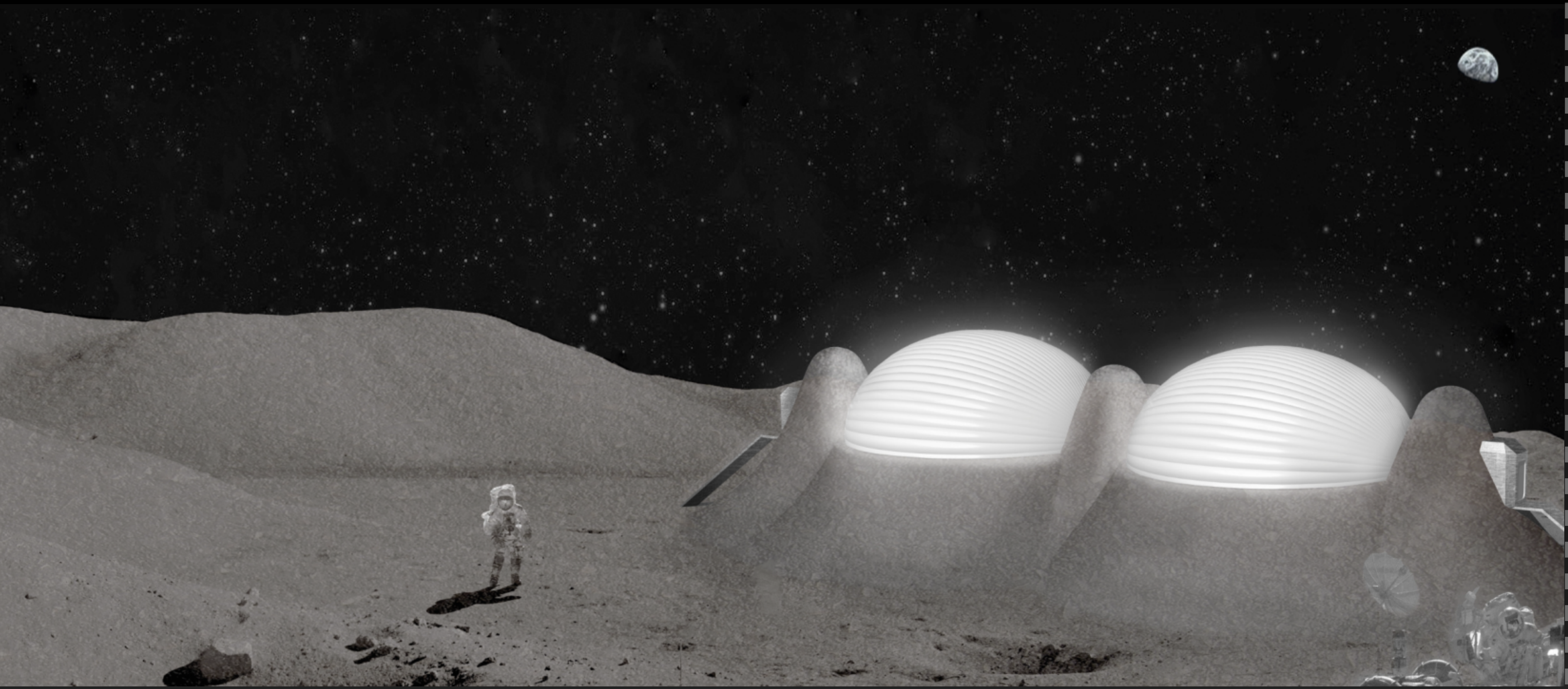
# LUNAR BASE

## - autonomous life on moon -



Prof. José Luis Moro

ESLAB Symposium 2017, ESTEC

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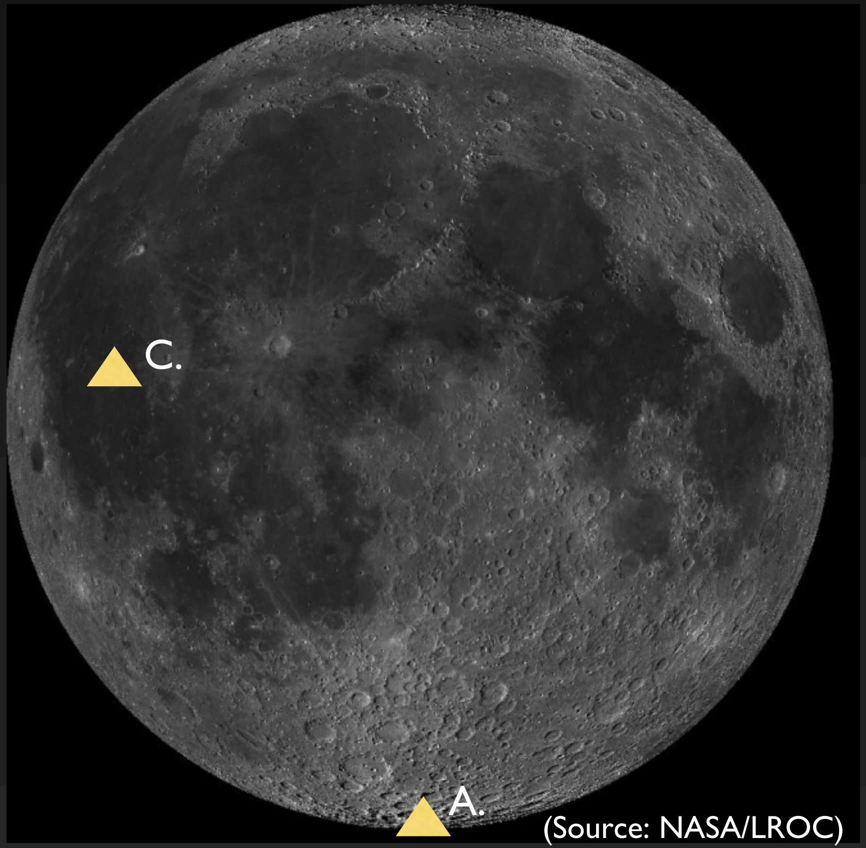
# L U N A R   B A S E   2 0 1 7

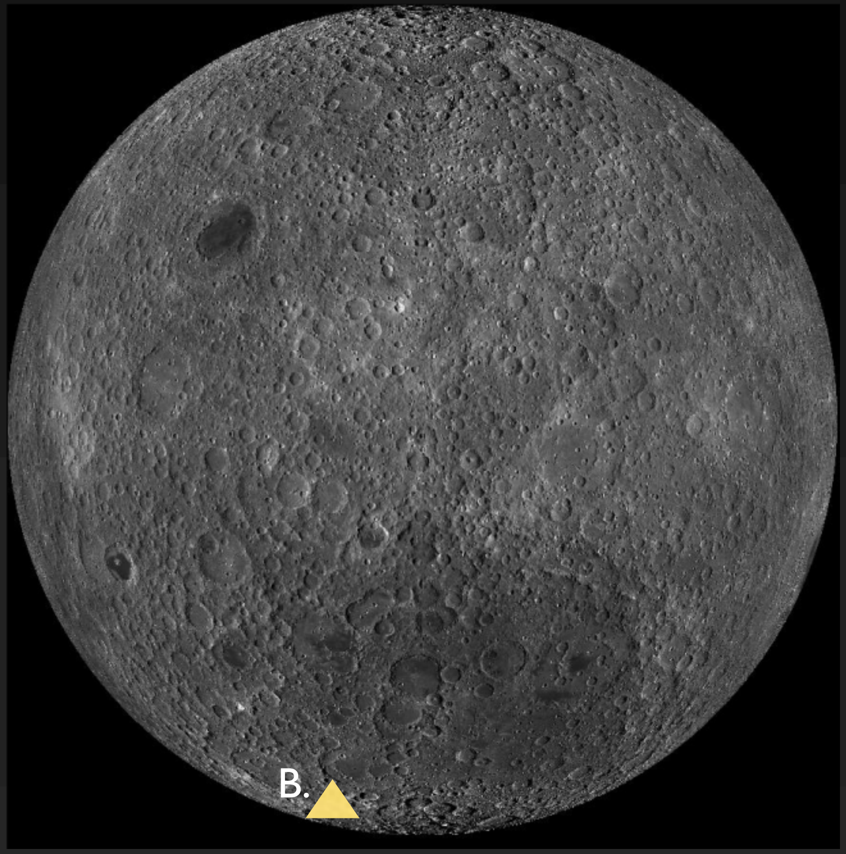
a semester project by architecture and civil engineering students at IEK

supported by the European Space Agency, ILEWG, the Institute for Space Systems IRS and external consultants

Task objectives

1. Design of the core base elements
2. Development of an expansion strategy
3. Maximise usage of in situ resources for construction and sustenance




A. Shackleton Crater

B. Schrodinger Basin

C. Marius Hills (Lava tube)

<u>Project participants:</u>

Students

*IEK:*
Prof. José Luis Moro
Günther Schnell
Tilman Raff
Matthias Rottner

*ESA:*
Hanno Ertel
Hanna Lakk
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Workshop ESTEC

*IRS:*
Marius Schwinning

*International Association for the Advancement of Space Safety:*
Irene Lia Schlacht

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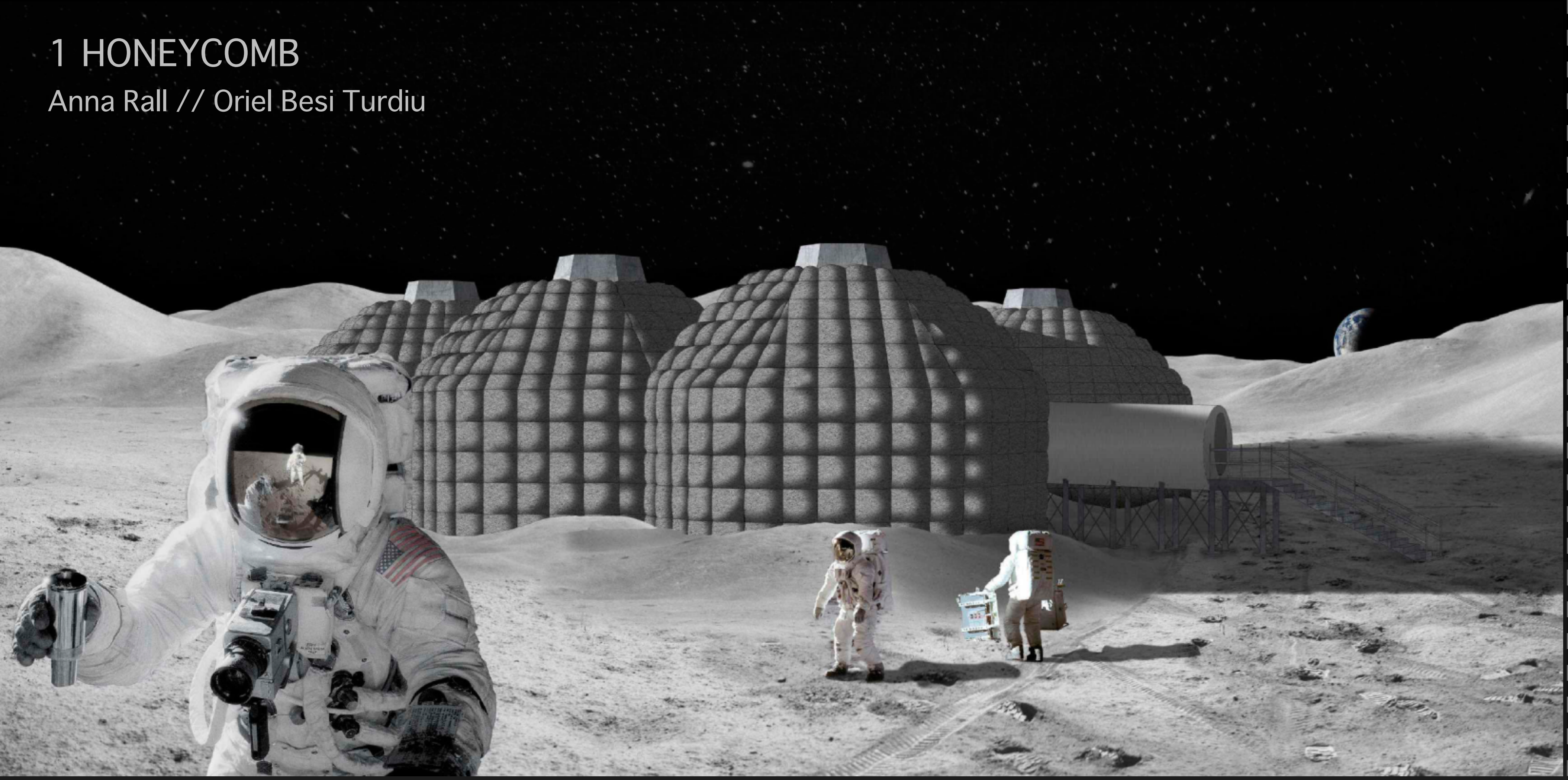
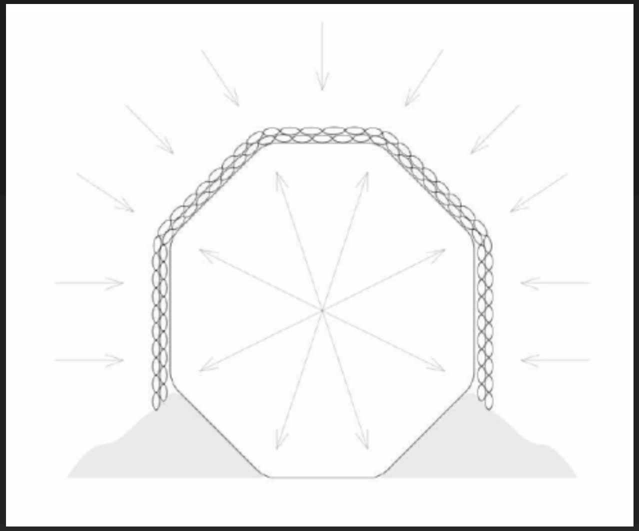
# 1 HONEYCOMB

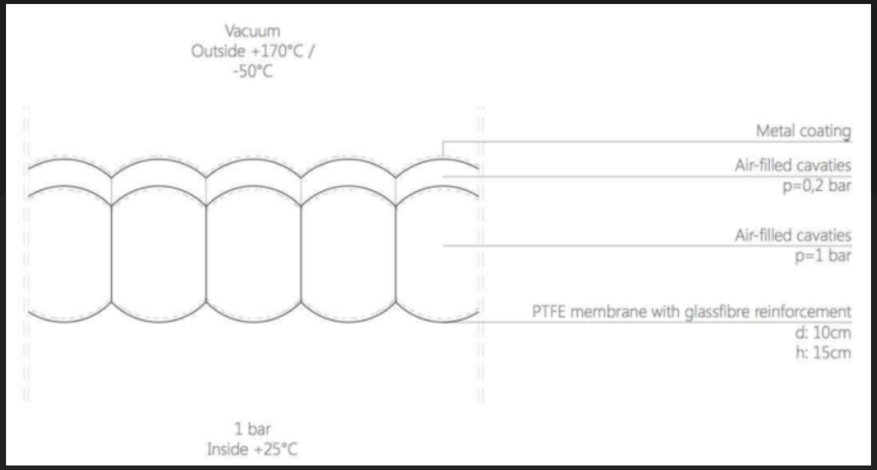
Anna Rall // Oriel Besi Turdiu



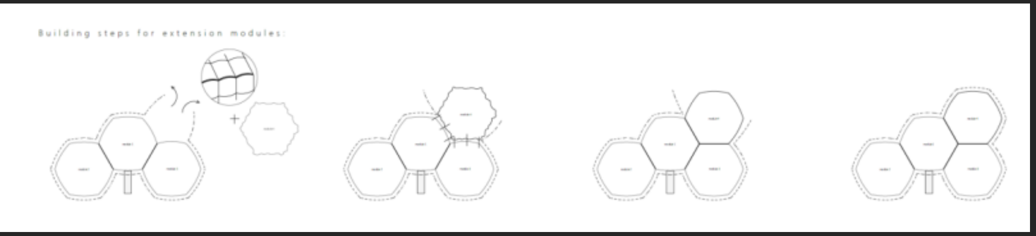

- Main structure: inflated triple layer PTFE membranes with glass fibre reinforcements &
- double layer of pocketed blankets filled with loose regolith
- Dimension: 9.8m internal height
- Module launch mass 10t



Polygonal basic shape




Pressure membrane layering




reconfiguration and biaxial expansion

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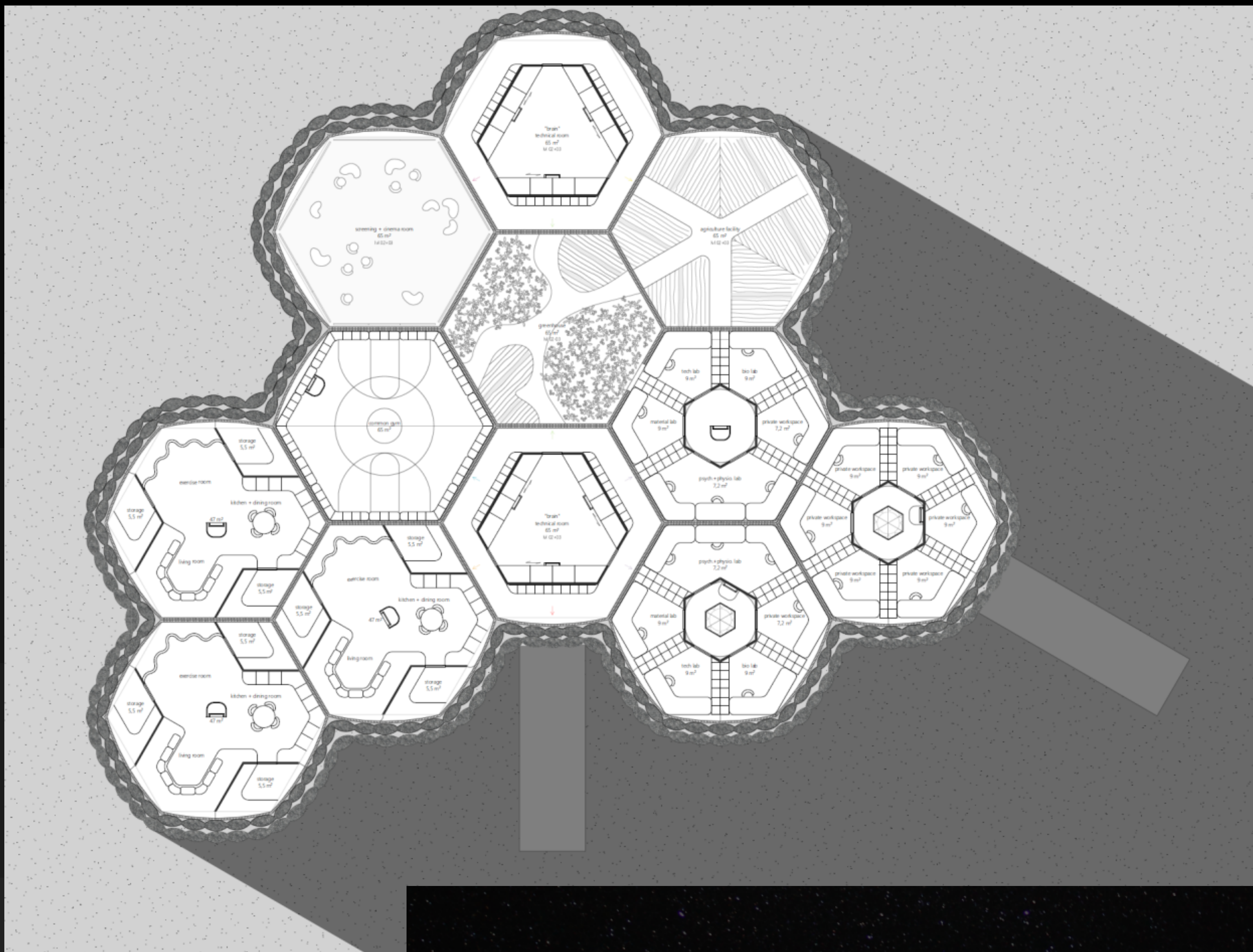

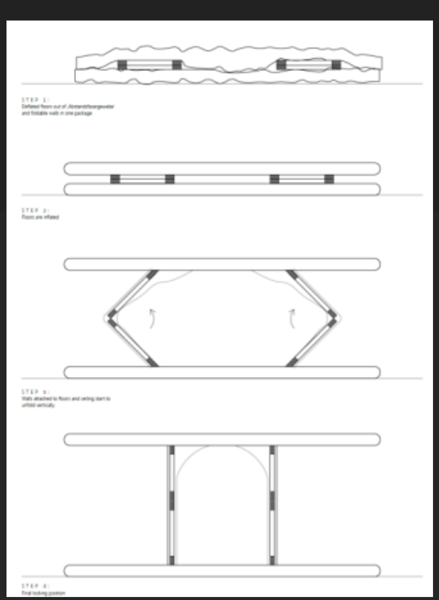

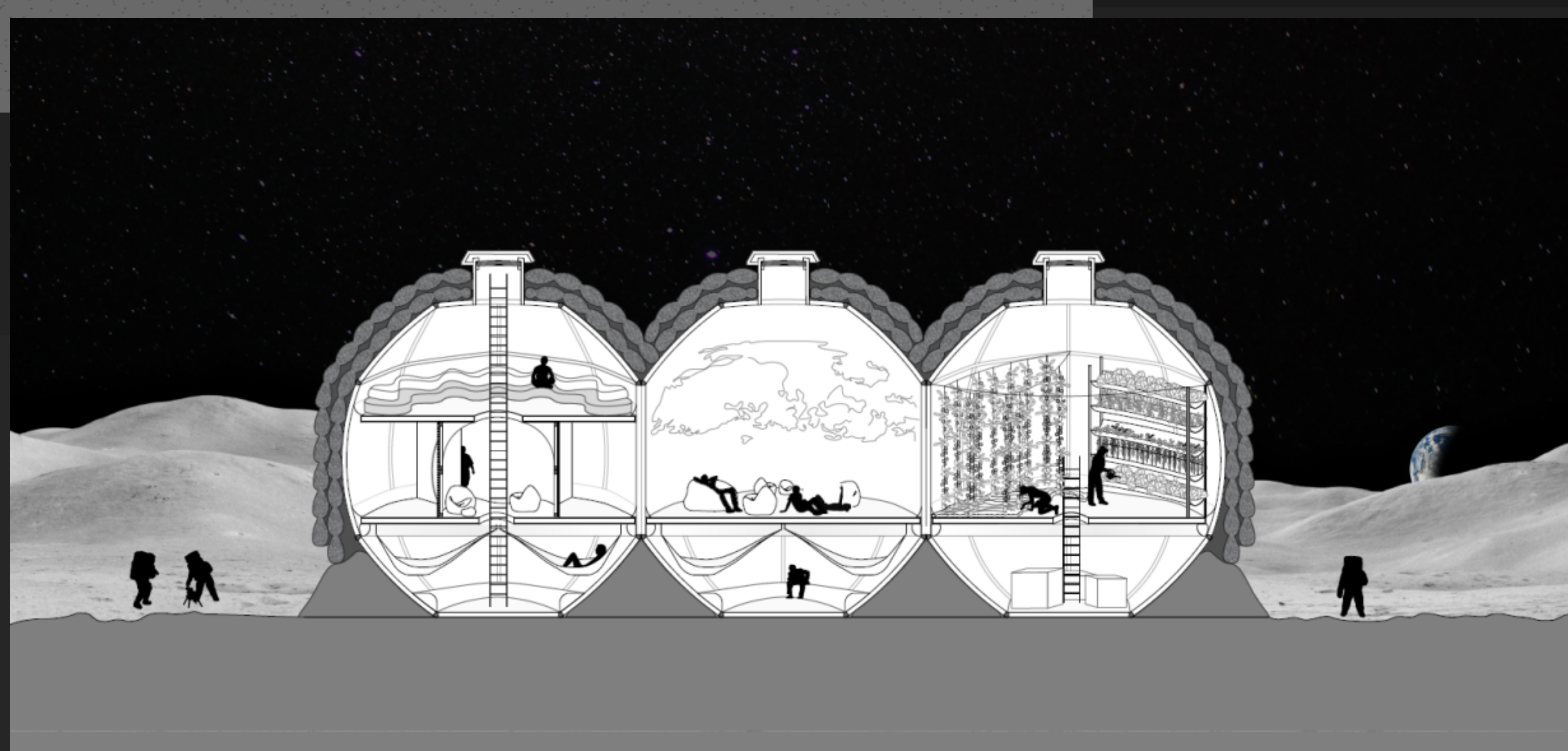

- ECLSS modules, configurable space modules & airlocks
- Dense module configuration
- Partially flat vertical internal surfaces

Internal aspects:

- Varying use of height
- Radiation shelter area at bottom
- Circulation through living areas
- Inflatable internal structure elements and inflatable furniture

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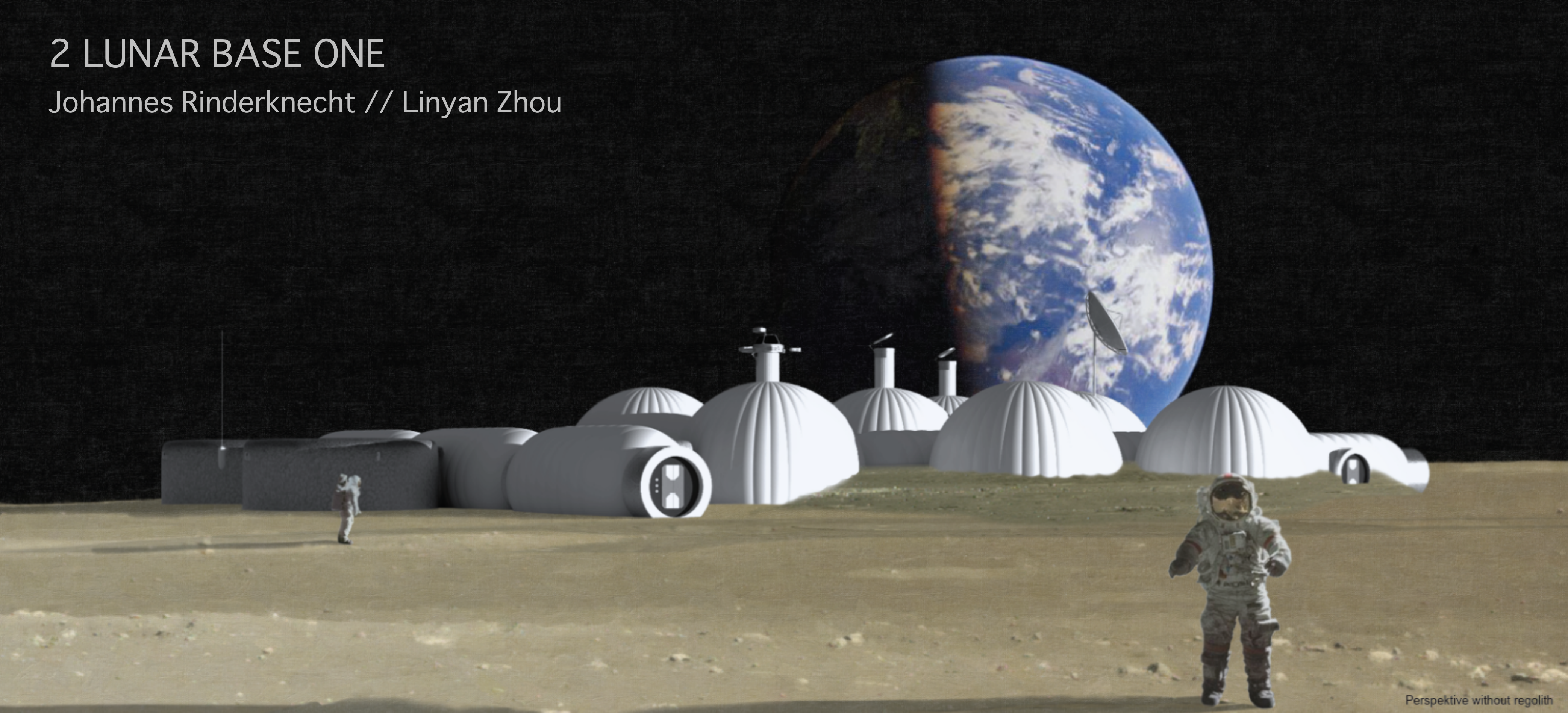
# 2 LUNAR BASE ONE

Johannes Rinderknecht // Linyan Zhou

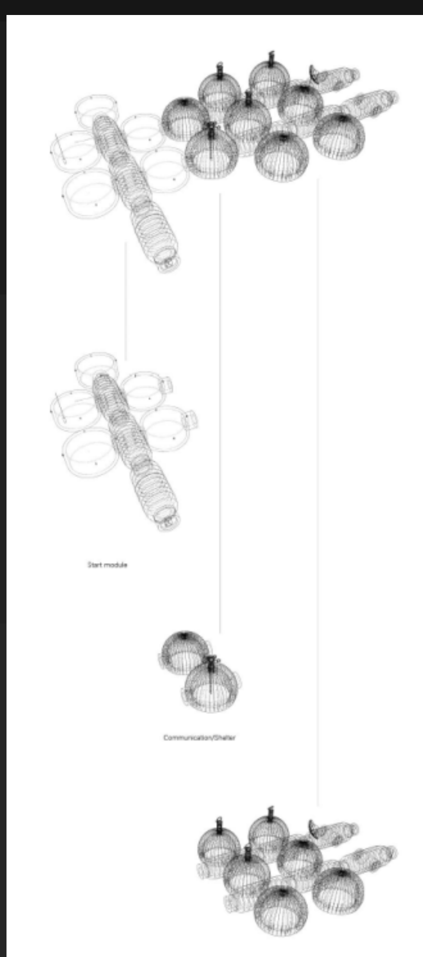



Base stage 2, illustrated w/o regolith cover

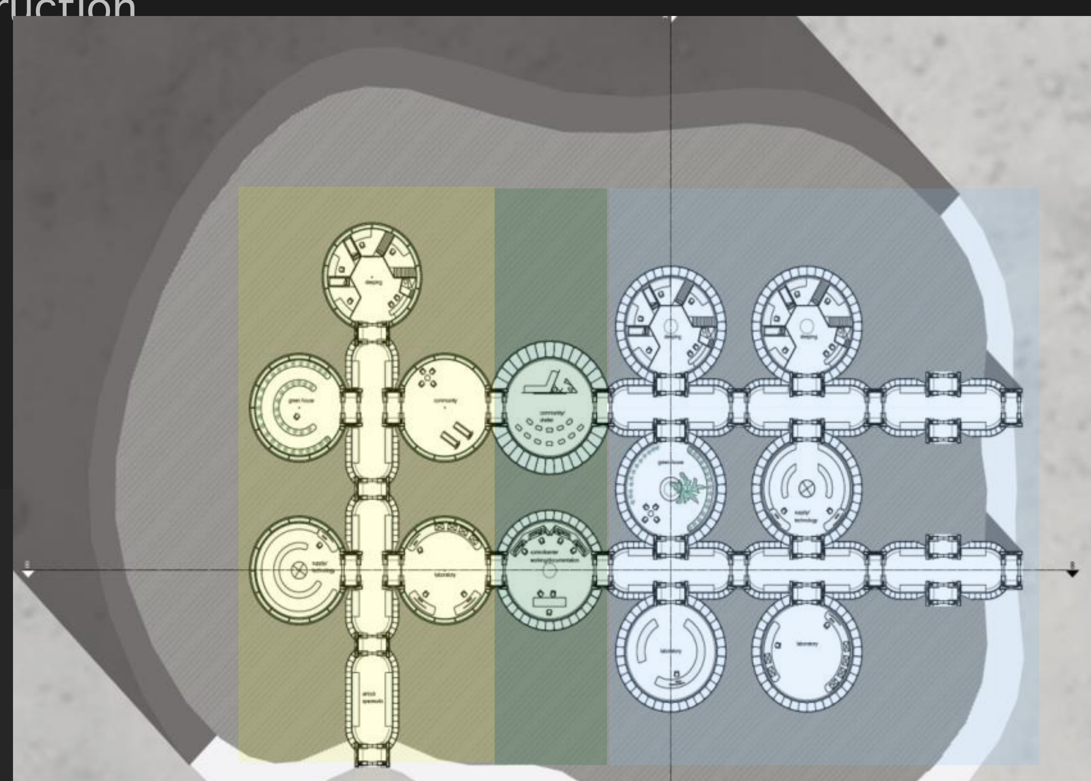

- 5 cylindrical starting modules, inflatable cylindrical corridor modules
- Expansion via spherical Lunar Bubbles
- Expansion bi-spinal

Starting module:

- Launch mass 20t
- Dimension: 8.0m internal diameter
- Polymer based radiation protection, though eventually regolith covered



Phasing approach to base construction



Base stage 2

Stage 0; shelter and comm; expansion

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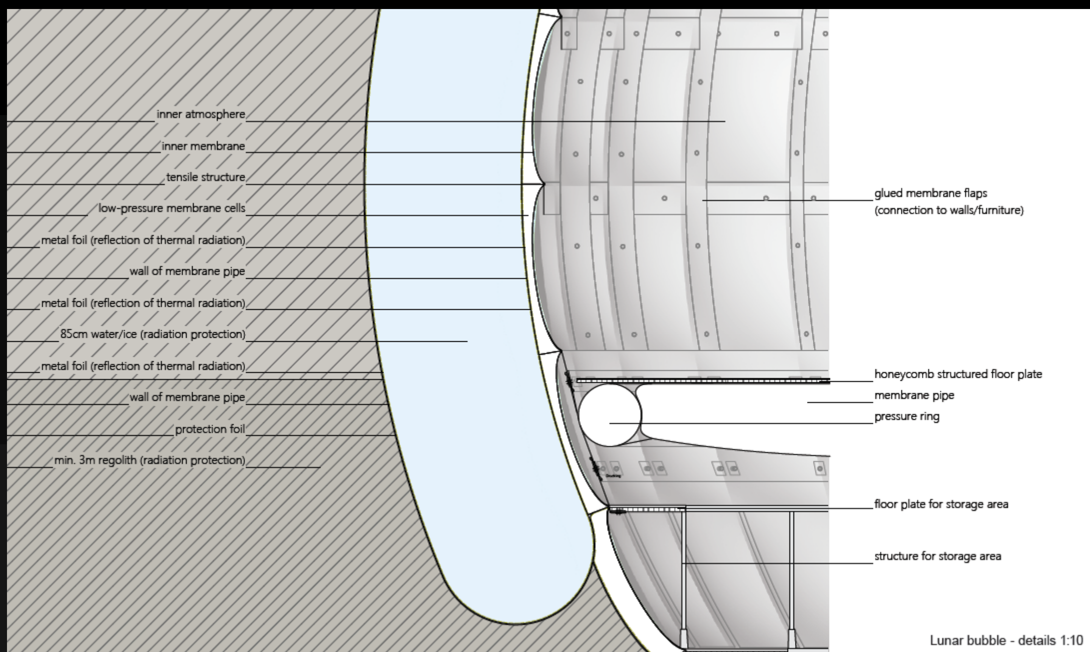
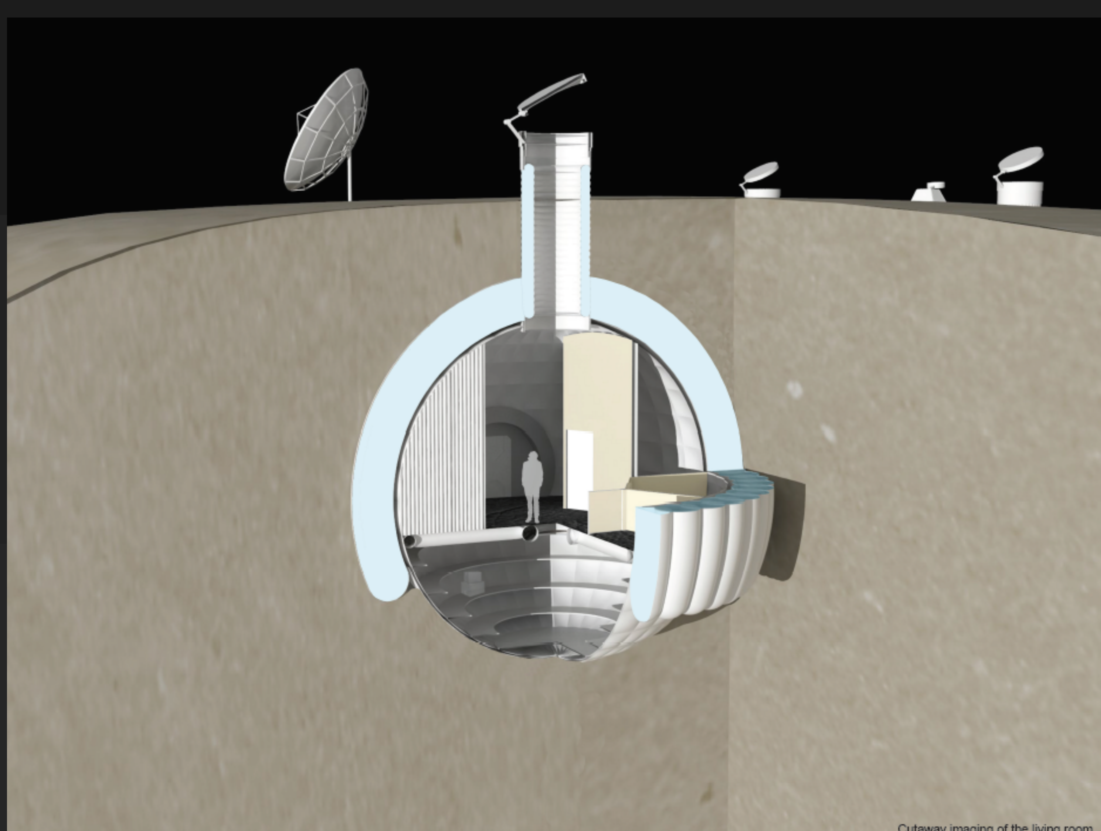
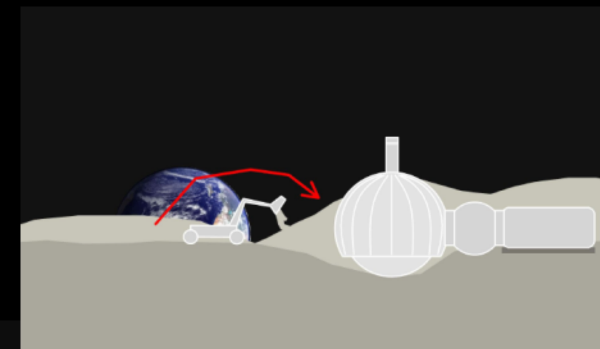
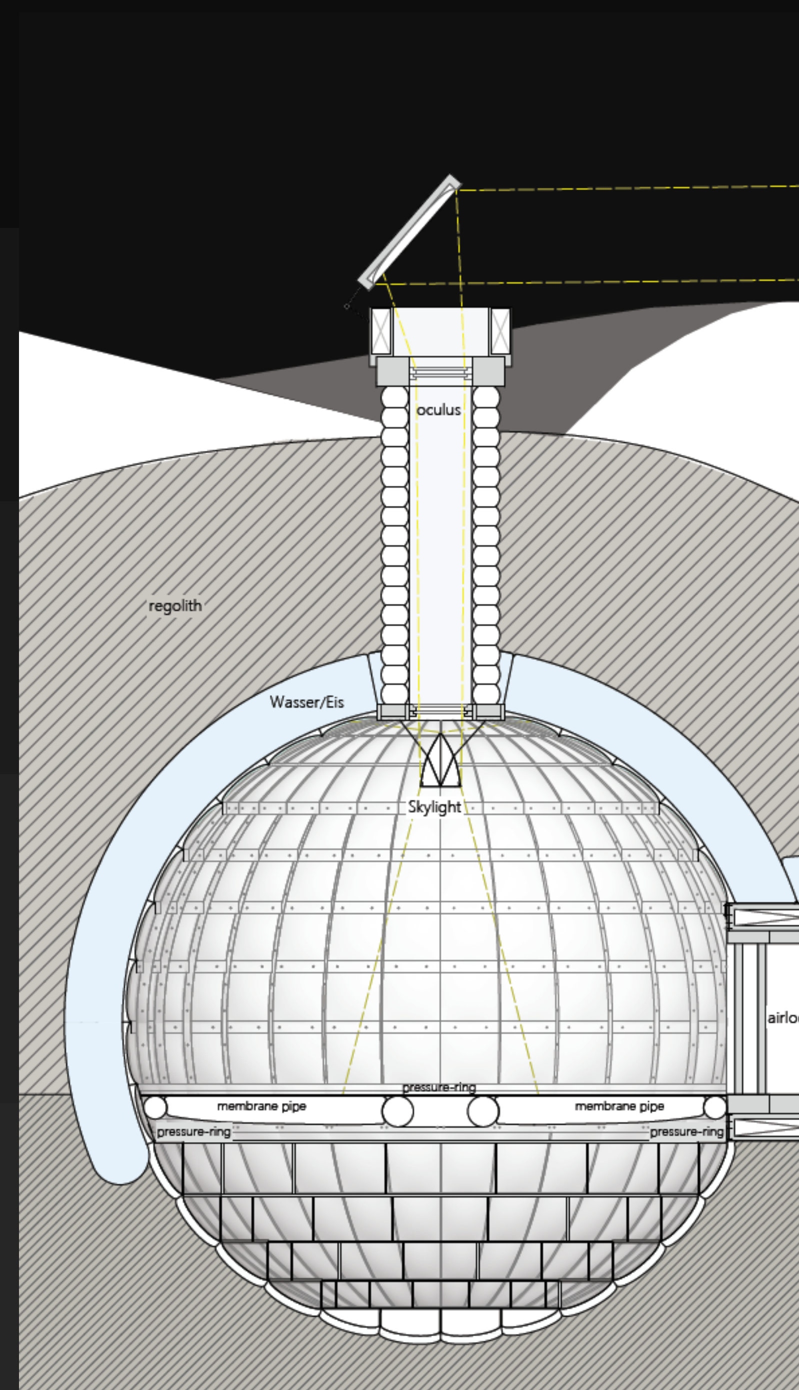



Membrane (triple) layering with ice sleeve






- Radiation and micrometeroid protection by piling loose regolith

Lunar bubble

- Low launch mass for structural mass: 1 t
- Main structure: PTFE membranes with glass fibre reinforcements (pressure), reduced pressure cavity with reflective outer layer (temperature), 85cm water/ice cavities (radiation), >3m regolith heaped
- Dimension: 8.0m internal diameter

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# 2 LUNAR BASE ONE

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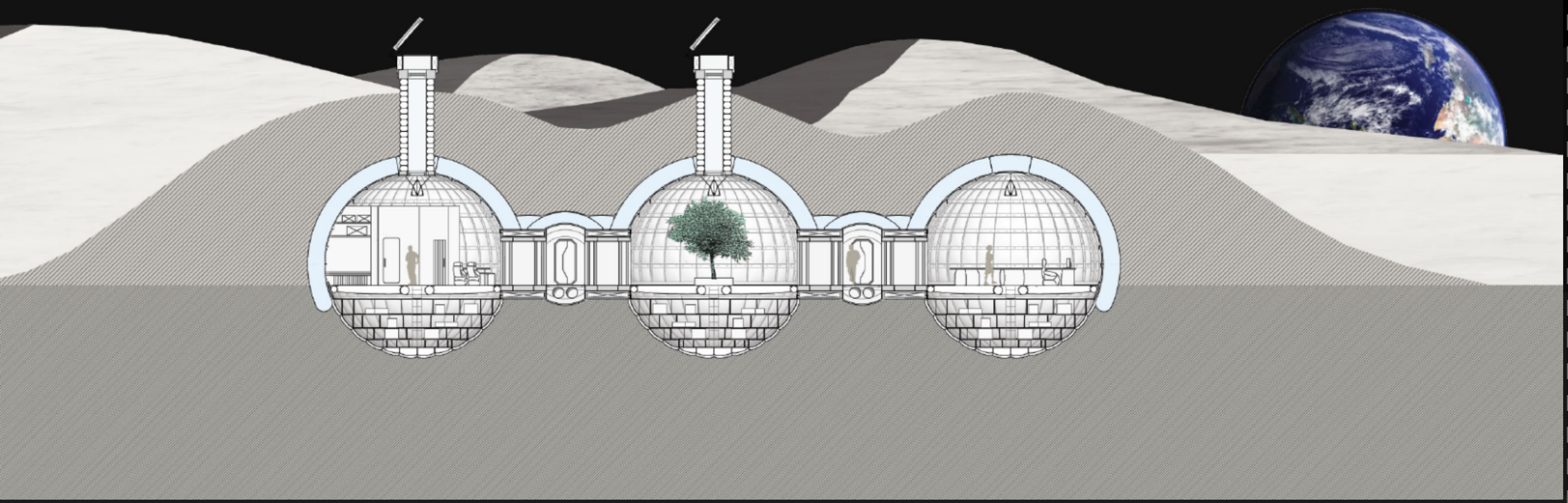
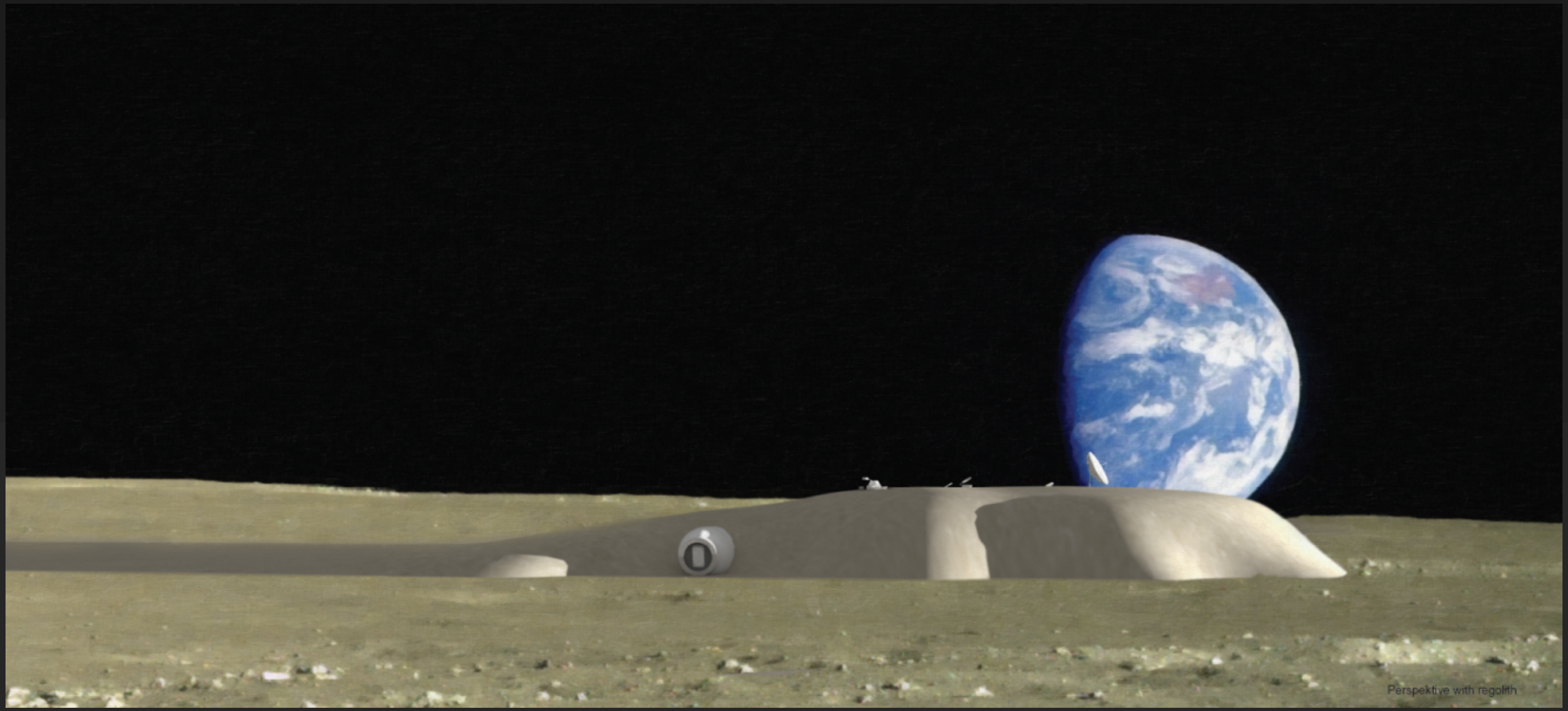


Section cut through lunar bubbles



Base stage 2 covered in regolith

- Radiation and micrometeroid protection by heaping loose regolith

Internal aspects:

- Increased height in lunar bubbles
- Dedicated circulation through corridors
- Daylight only through skylights

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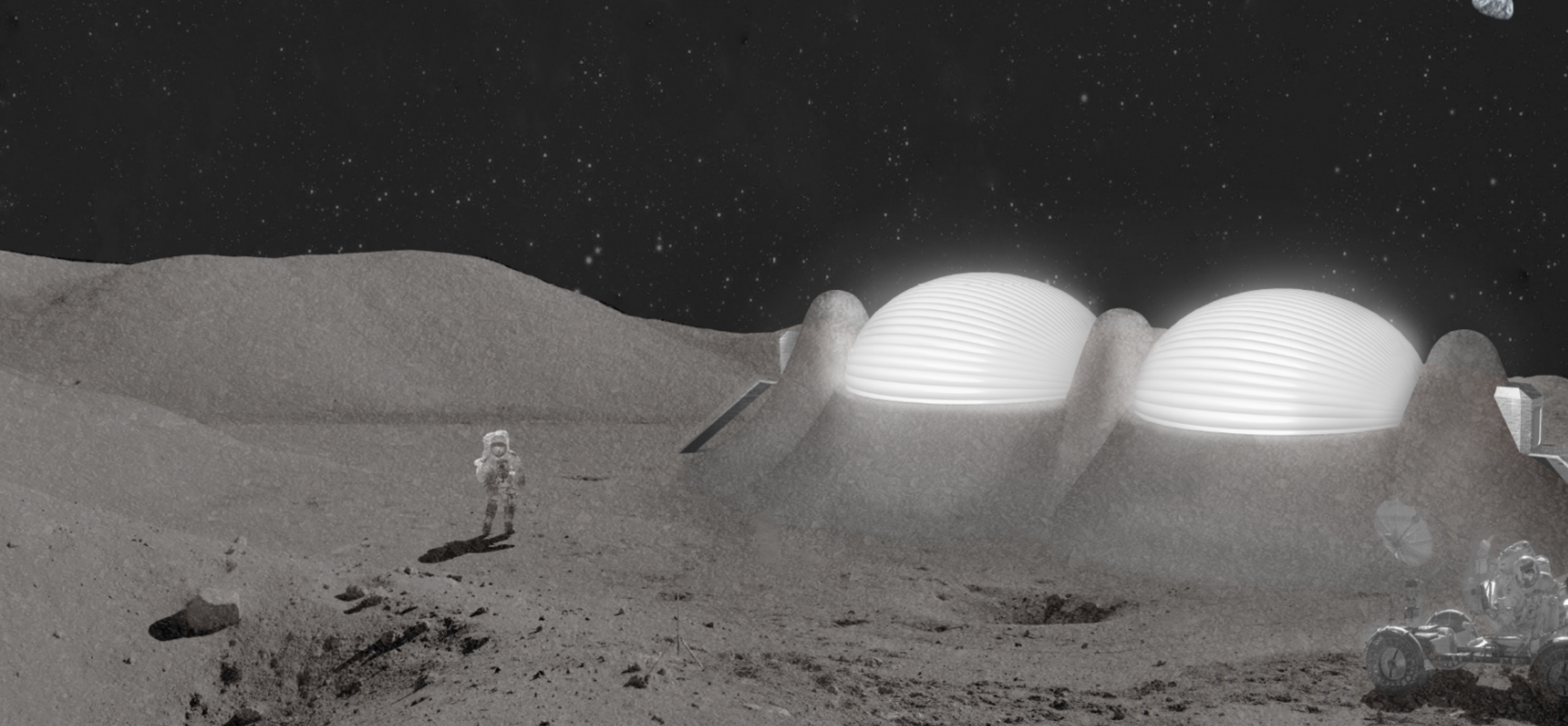
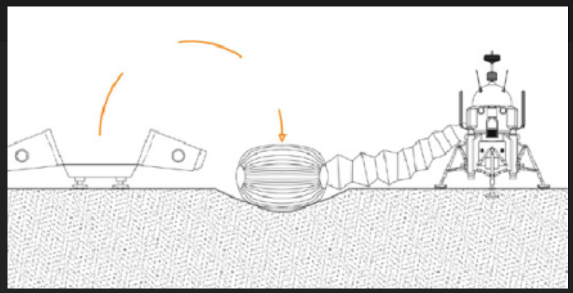
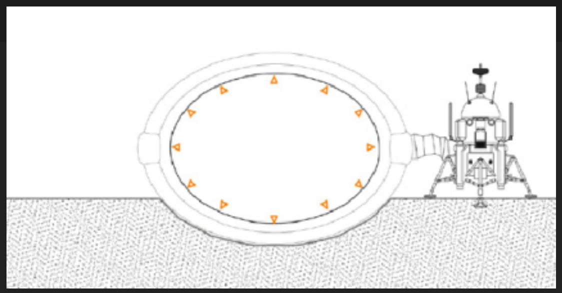
# 3 ICE SHELL

Maximilian John Benn // Julia Cavcic

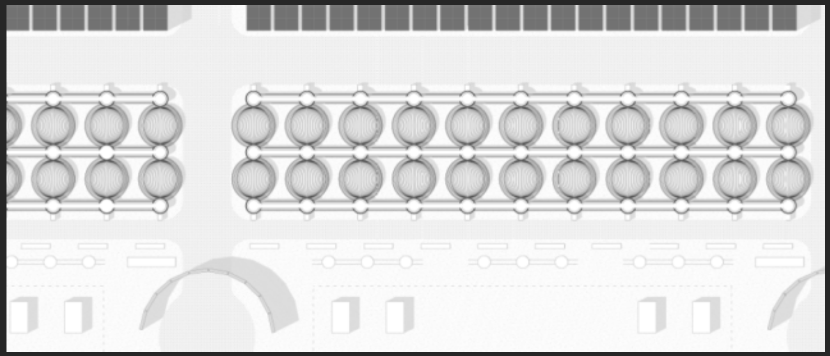



- Core concept: translucent shell
- Ellipsoid (bi-curved) shape
- Triple-spinal expansion, i.e. 2 exits per dwelling module
- Circulation nodes prefabricated, include technical systems
- Dwelling module height 10m





Inflation principle



Expansion concept

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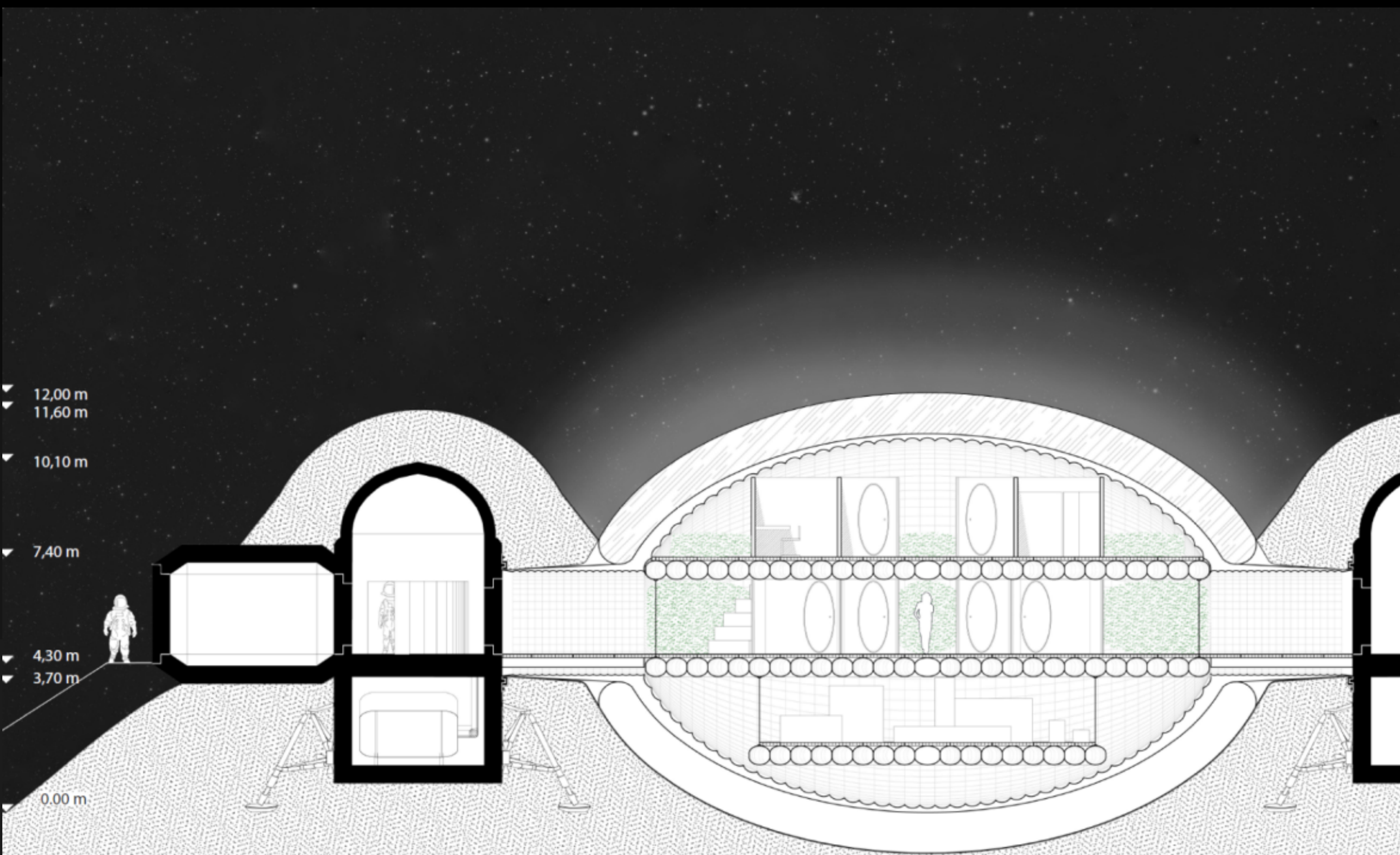
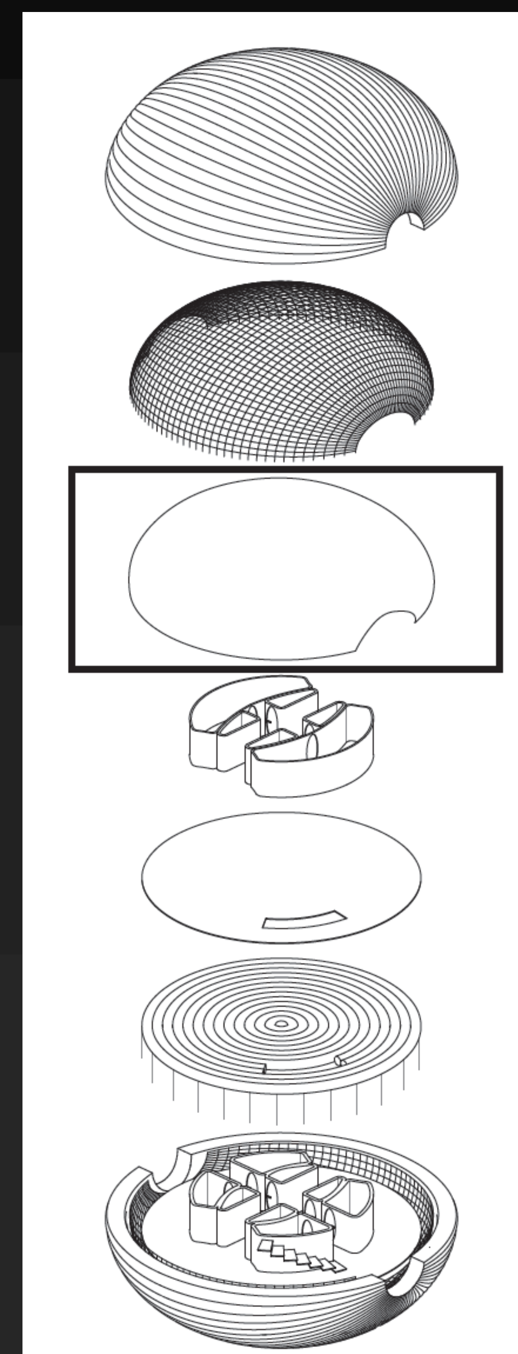
# 3 ICE SHELL

Maximilian John Benn // Julia Cavcic

- Envelope: ice carapace, steel net, PTFE membrane
- pressure steps between layers of 0.5bar
- 1.1m of ice, intermediate level radiation protection
- Lander possible as integrated element in the base
- Furniture and internal floors pneumatic
- Daylighting and plants growing indoors tries to emulate terrestrial conditions

Inflatable furniture (ETFE)

Inflatable furniture (ETFE)

Dwelling module construction

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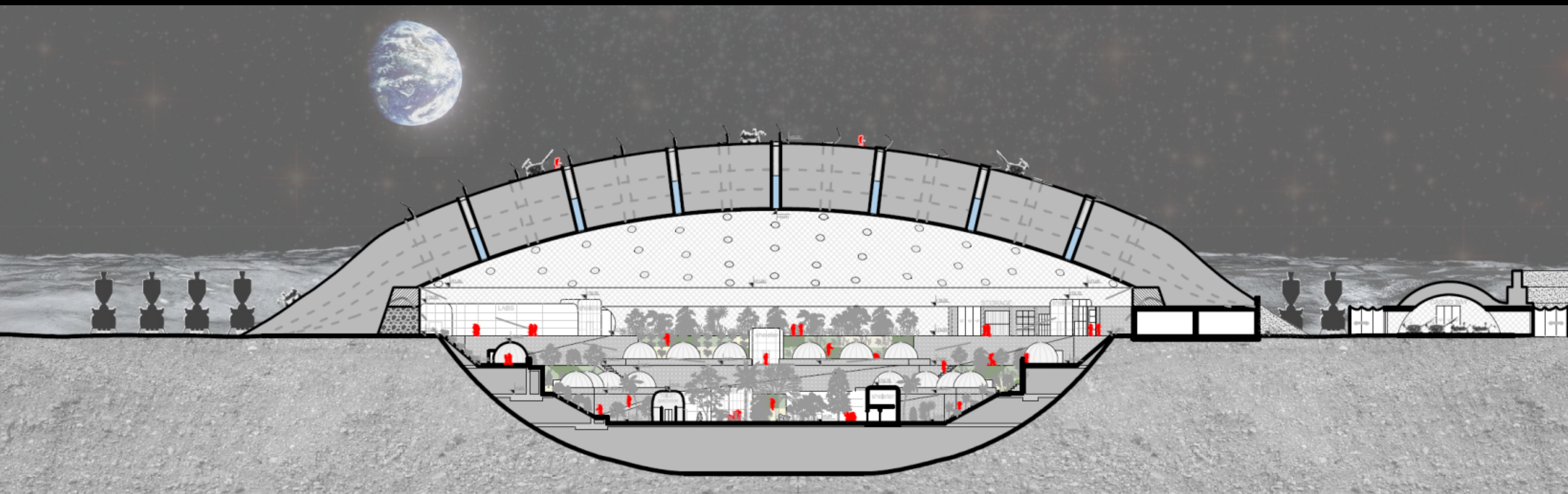
# 4 GREEN BUBBLE BASE

Nikola Mihaljevic // Yanran Song

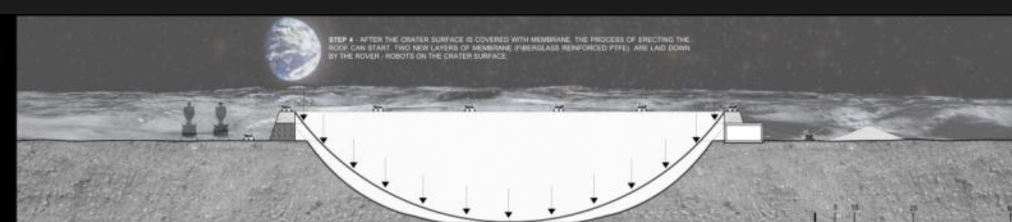



- 120m crater covered by canopy, resulting in vast, open aired space
- Lentil shaped pressure volume
- Transitional habitats required
- Envelope: double layer PTFE membranes with pressure steps of 0.5 bar
- Pliable material that can adapt to different construction phases
- Compression ring from “lunar concrete”
- Construction of fibre glass cables foreseen on the moon

2.

Installation of foundation and compression ring

4.



Lower double PTFE layer

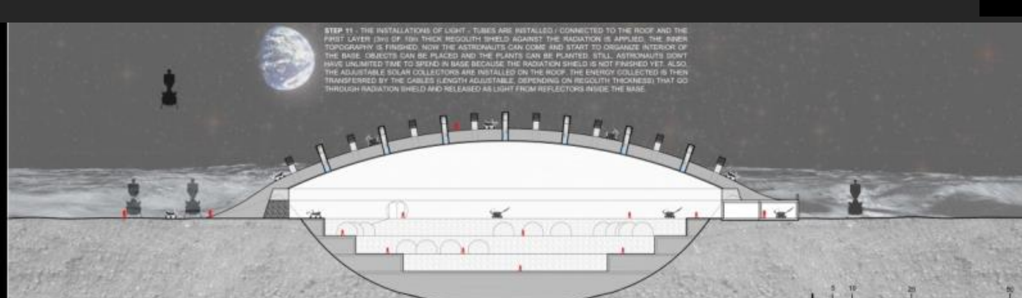
5.

Upper PTFE double layer, covered by fibreglass net and attached to compression ring

6.

Fibres locked in compression ring at minimum height

11.



Installation of skylights and covering with loose regolith (above protective layer)

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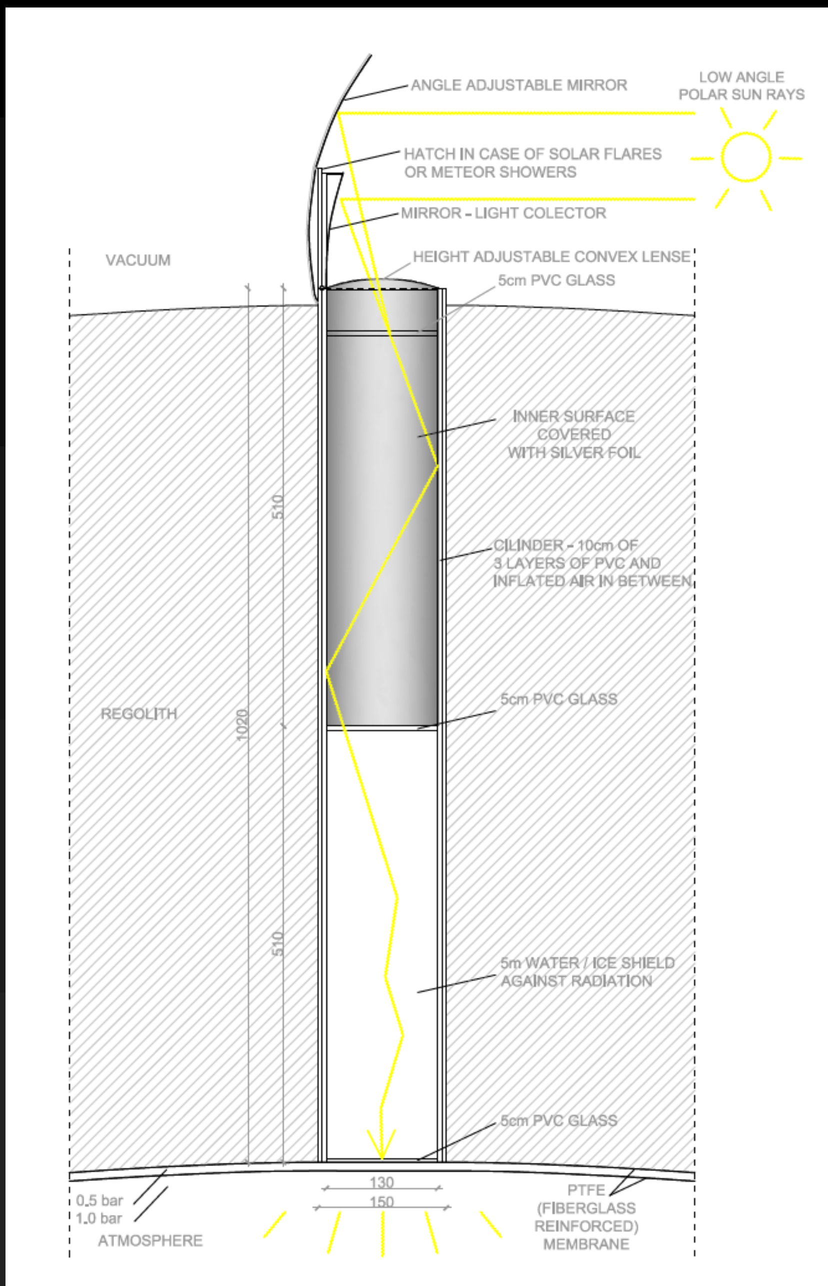
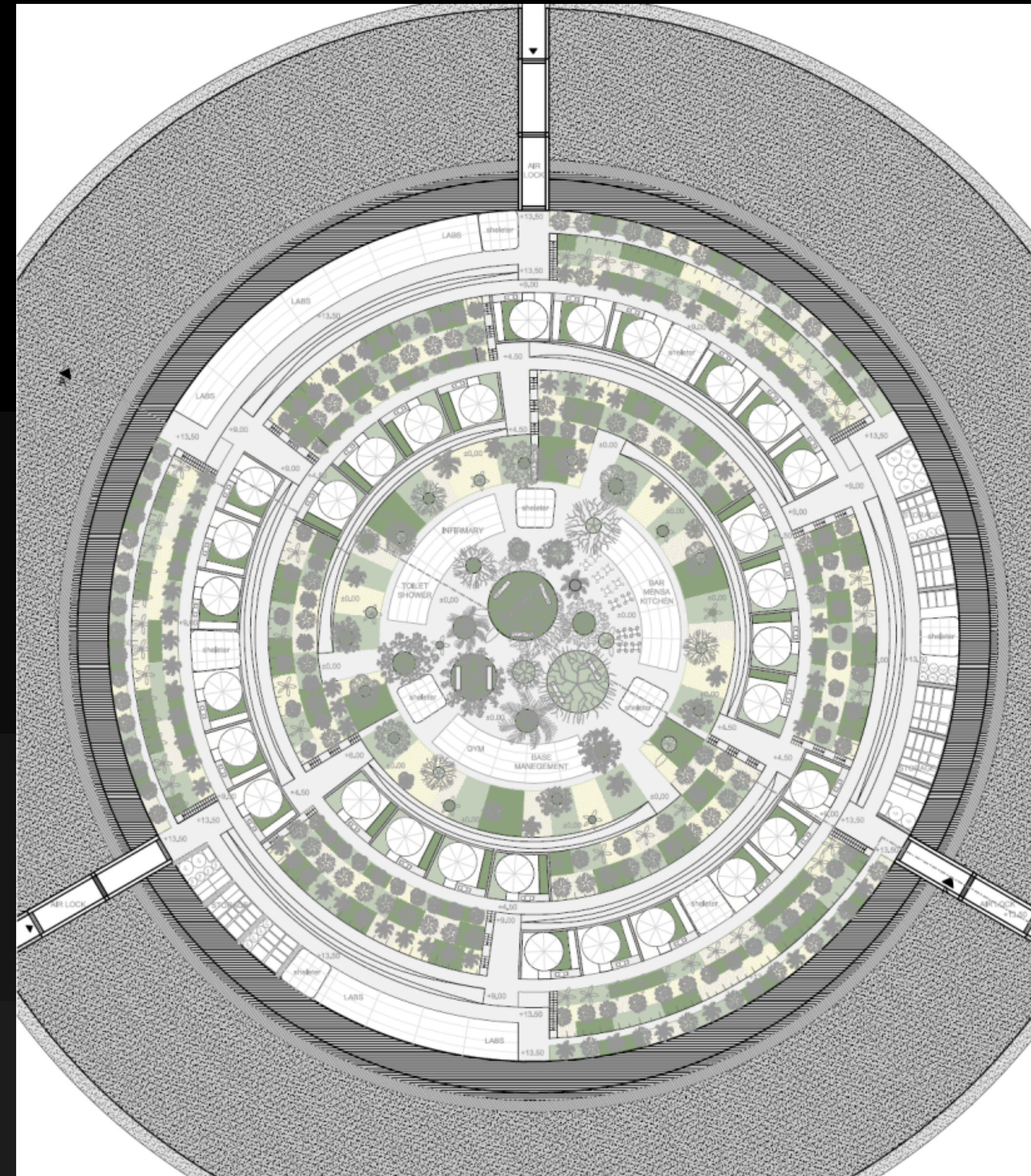
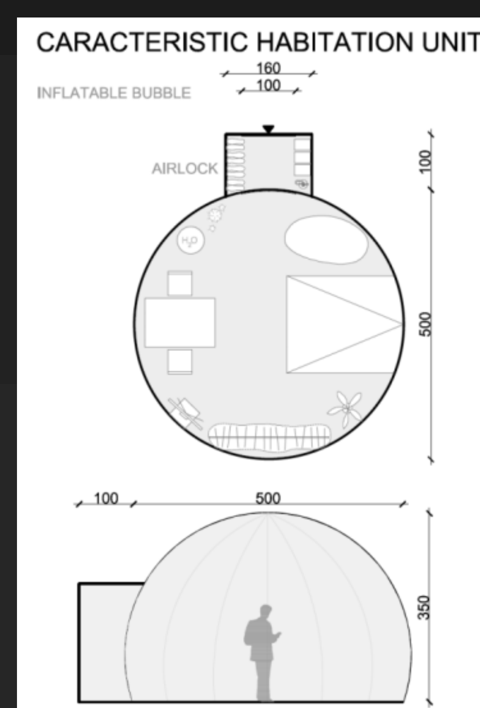
# 4 GREEN BUBBLE BASE

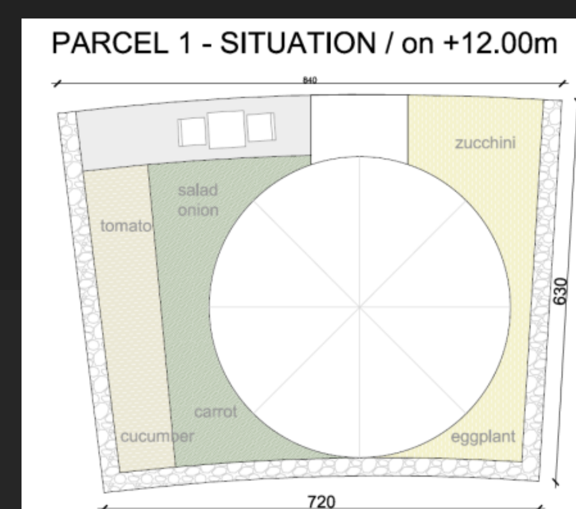
Nikola Mihaljevic // Yanran Song




Skylight construction details






- Geotextile sheet for protection against dust contamination
- Drywalls built inside
- Canopy provides almost all environmental protection. Laboratories, dedicated shelters, communal space, private habitation units can be simple, lightweight constructions
- 10m regolith shield
- Skylights for natural daylight, include radiation protection

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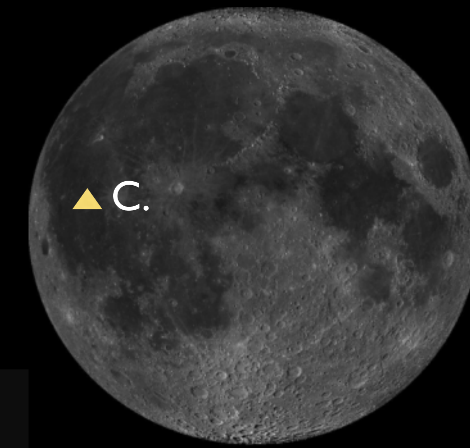
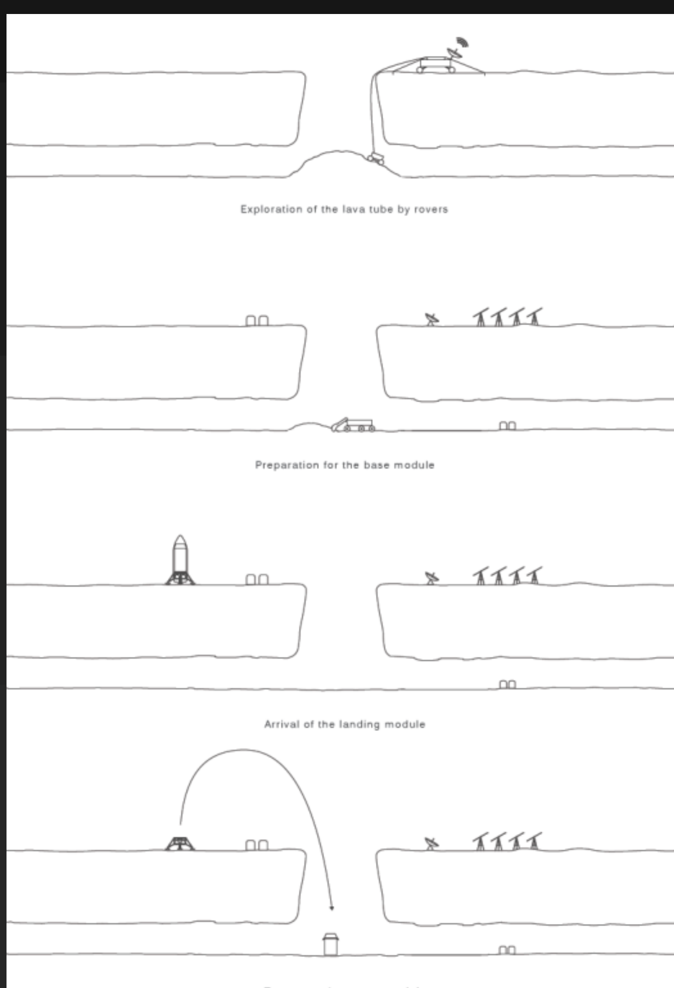
# 5 SELENA

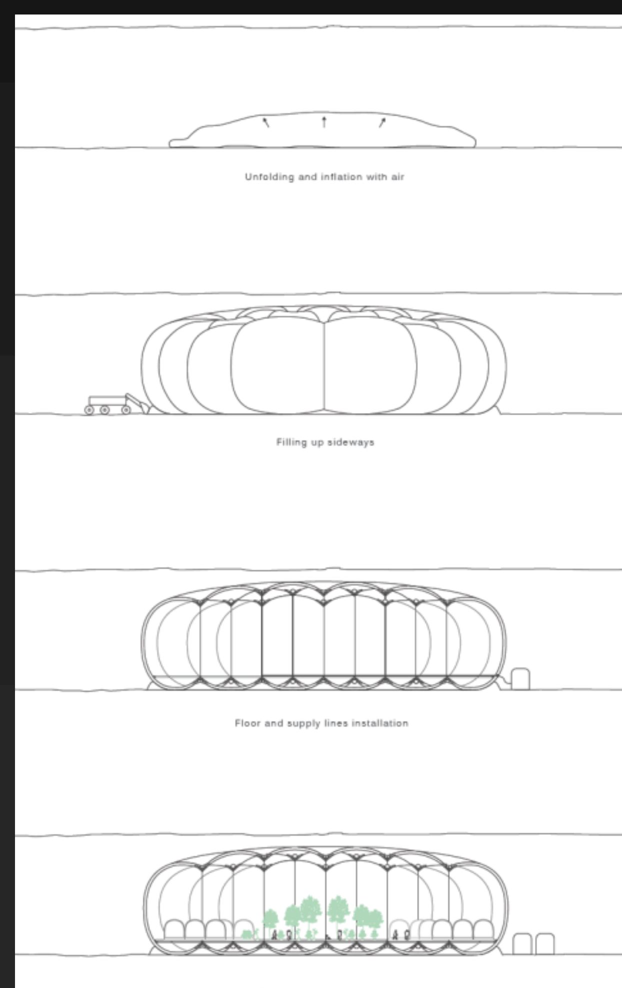
Nigora Djalalova



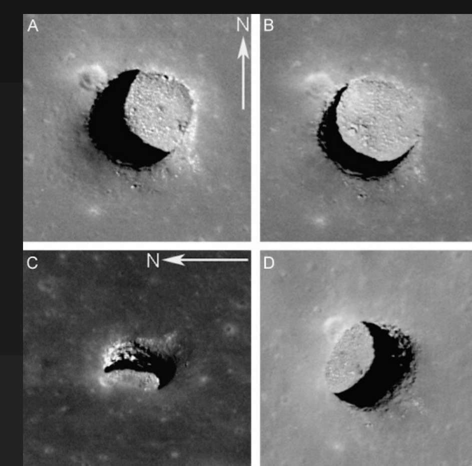

- Inside lava tube
- Lentil shaped pressure volume
- Multiple pneumatic buildings reaching further into the lava tubes, linear expansion on both directions
- Envelope: double layer PTFE membranes with pressure steps of 0.5 bar
- Natural protection against radiation and micrometeroids
- Transitional habitats and lifting mechanism required




Initial phasing and module descent




Inflation and installation




Source: NASA/GSFC/Arizona State Uni

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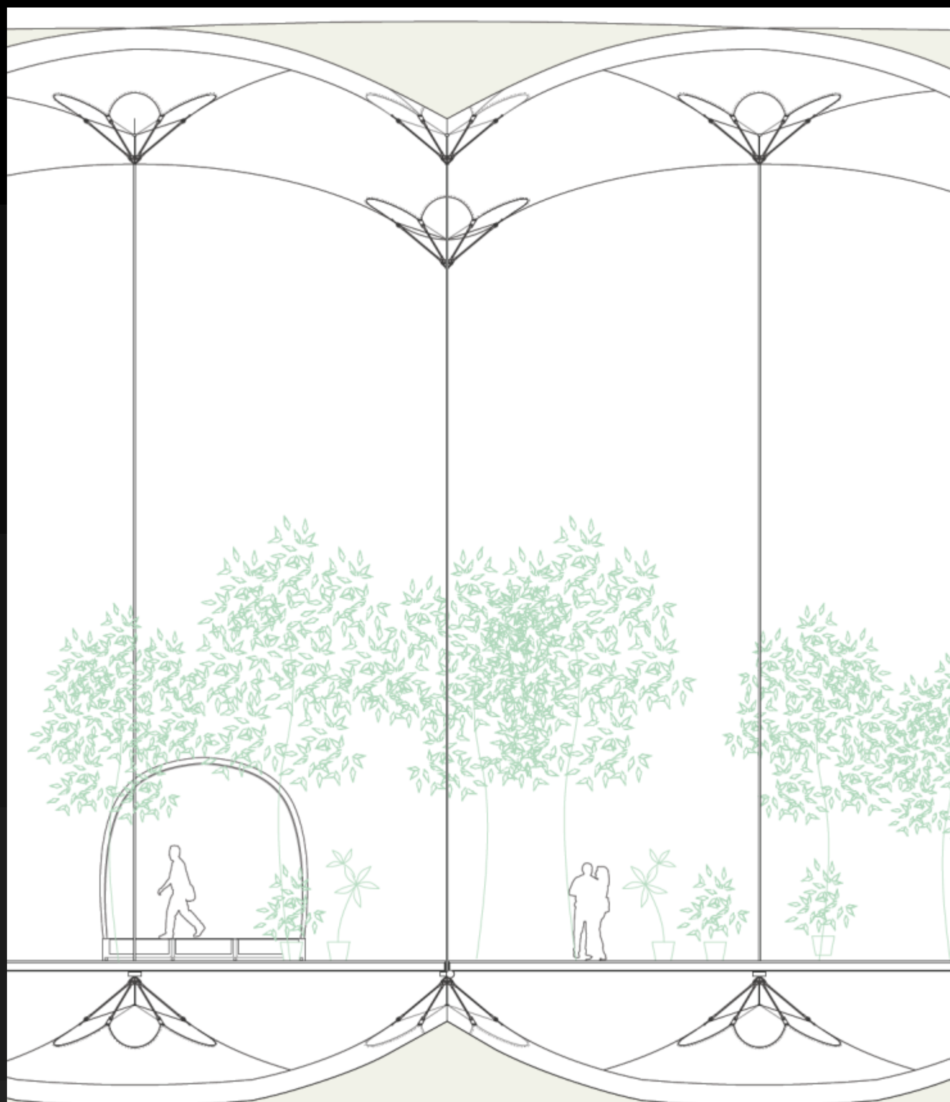
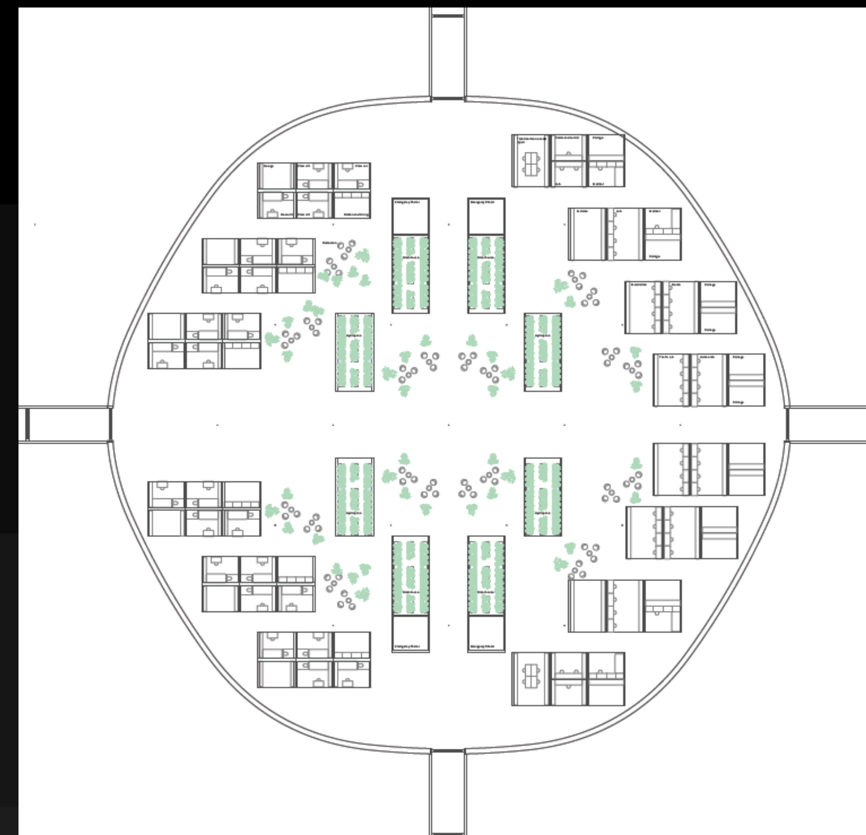
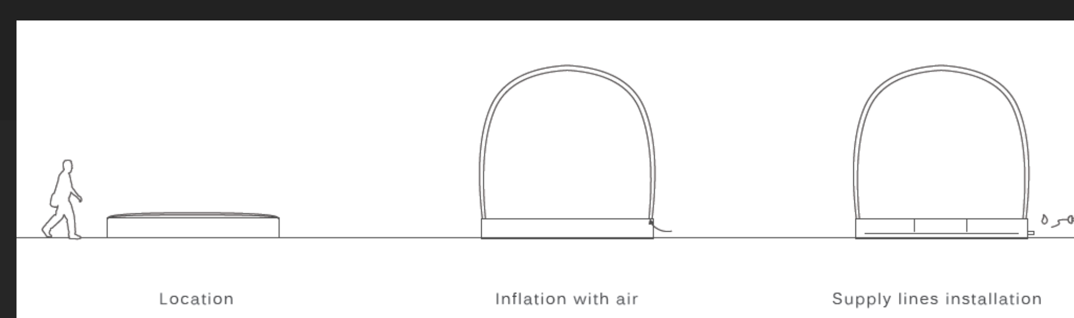


Vertical cables and membrane construction



Internal layout of SELENA




Internal module construction

- Envelope: double layer fibre reinforced PTFE membranes, with cavity pressure of 0.2bar
- Reflective coating on inner membrane for increased thermal insulation (ext. temperature -35° C)
- Bulbous synclastically doubly curved flat shape with vertical cables adapting to lava tube height and reducing tension in membrane
- Canopy provides almost all environmental protection. Laboratories, dedicated shelters, communal space, private habitation units can be simple, lightweight constructions
- Four symmetrically located airlocks create two internal passageways creating a central square-like meeting place

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## Conclusions

- Internal air pressure loads (1bar = 10t/m$^2$): introduction into lunar soil (properties not well known(!)) is not considered feasible. Similar, these loads result in large bending stresses in flat plates and long term air-tightness problems at their joints.
- Short-circuiting and containing pressure induced loads within membranes (spheres, cylinders, ellipsoids) without hazardous joints can solve this issue.
- Double curved surfaces (ellipsoids) permit wider range of design solutions, allowing a better floor-space/volume ratio

- Multi-layered membranes with stepwise reduced pressure levels, combined with radiation reflecting surfaces: could combine structural function (tension decrease per layer) with thermal insulation

- Due to large pressure forced membranes have to be "segmented" with meshes to limit radius (and thereby tension) to an acceptable value

- Inflatable pneumatic structural elements (pressure shell, internal structures (floors/walls), furniture) can significantly decrease structural launch mass.

- A regolith cover does not need to be self-sufficient. Internal pressure in membranes can easily support large regolith layers, it's weight can actually help decrease tensile stresses in the pneumatic structure underneath. This allows for heaping of regolith onto the structure, considerably relaxing construction complexity and energy requirements.

- One module level was preferred: internal floors creating vertical space is more realistic than stacking modules (complexity of construction (machinery))

- Choice of circulation area has an effect on utilisation of space / areas / (vertical) surfaces (e.g. private space)

- Natural lighting, wider spaces, furniture, are ways to help decrease alienation/isolation effect. However, due to time constraints these aspects

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# THANK YOU

## Questions?

A more detailed report is available.

Furthermore:

- Interest in this topic?
- Follow up activity in mind?
- Potential collaboration?
- Exchange of ideas?

Contact points:

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Hanno Ertel: hanno.ertel@esa.int

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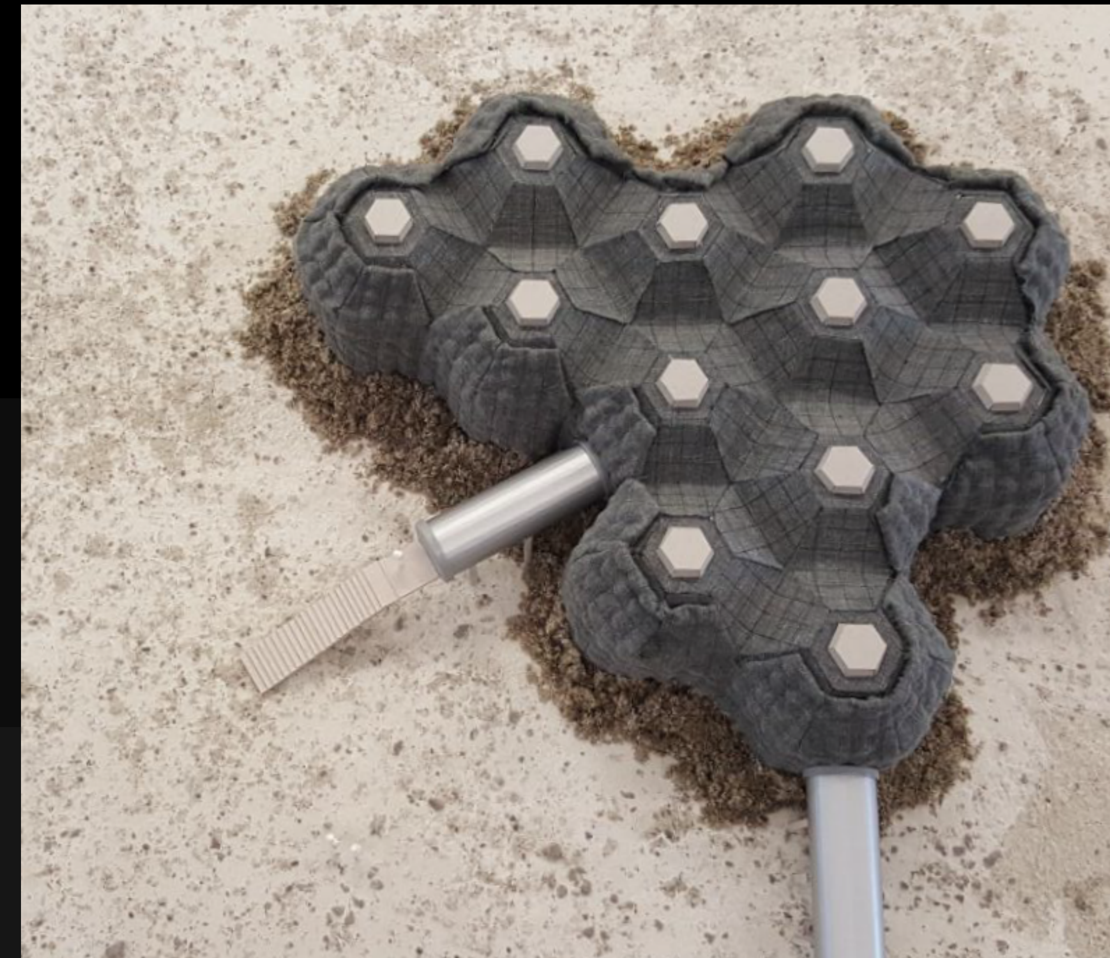
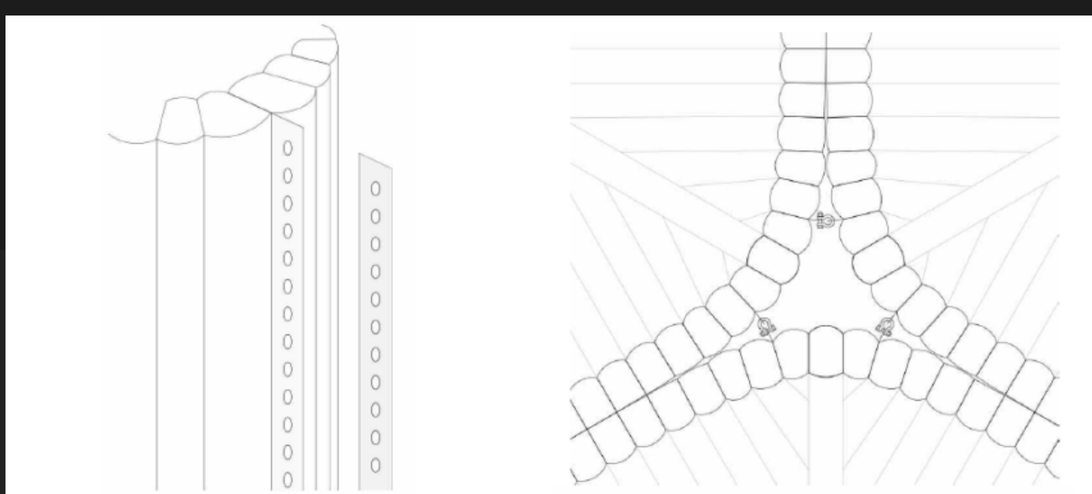
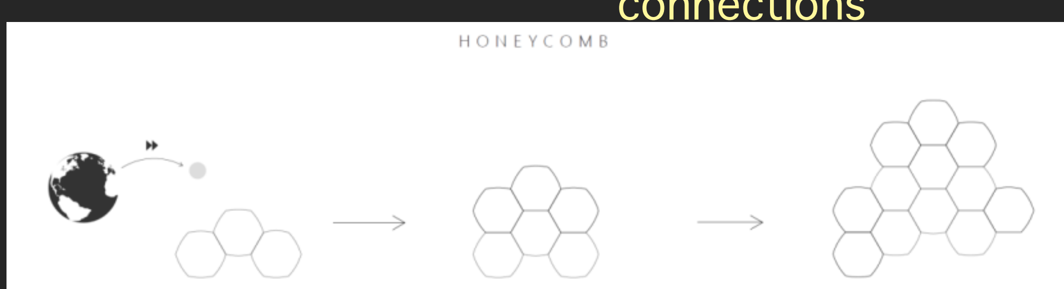


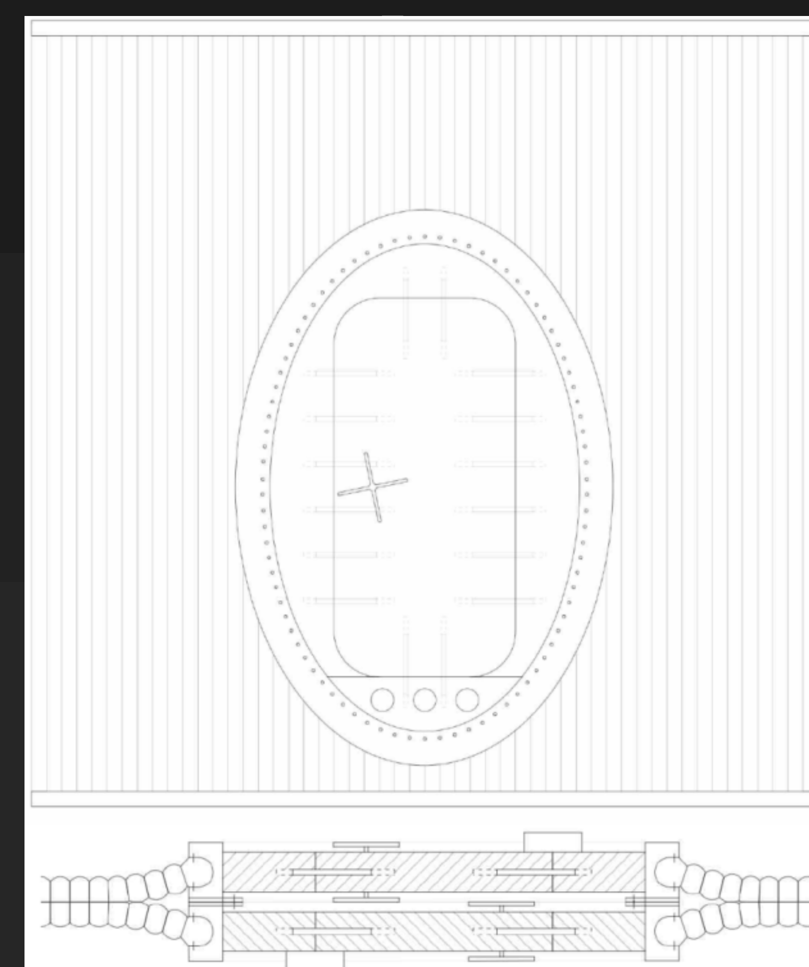


intermodule connections



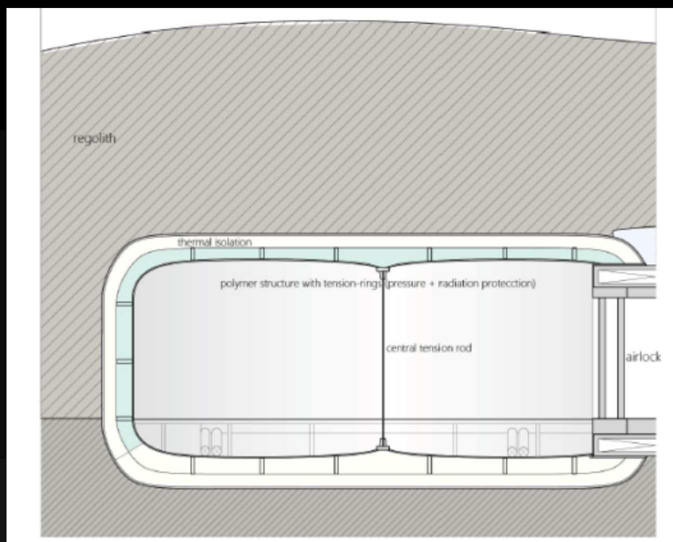

bi-axial expansion

Door segment with details

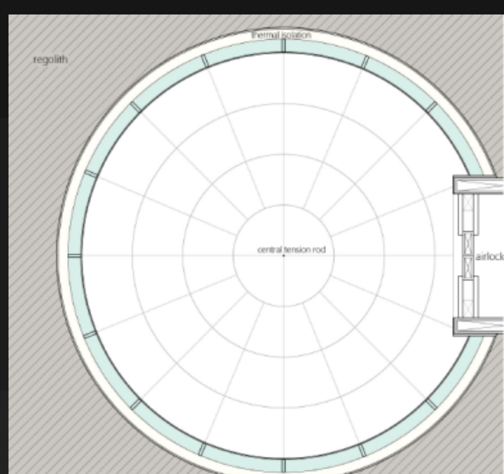


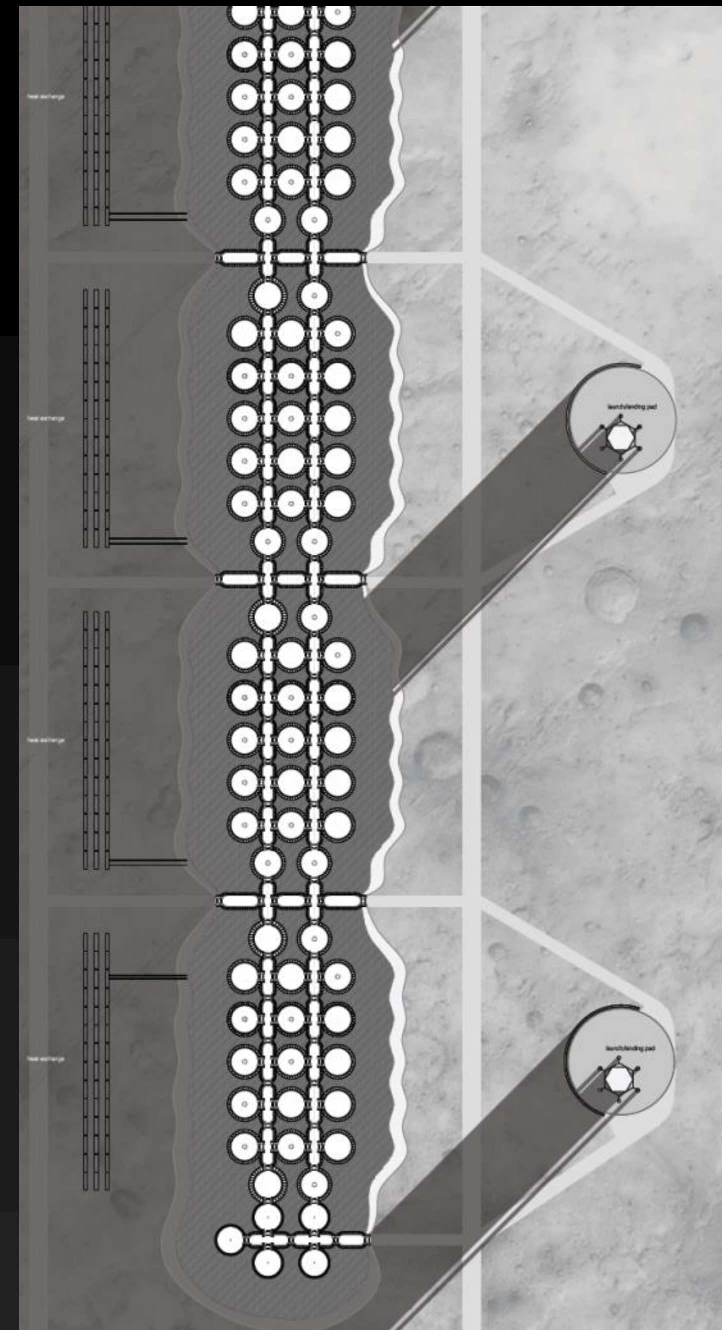
# 2 LUNAR BASE ONE

Johannes Rinderknecht // Linyan Zhou




Starting module



Expansion scheme

| element | geometry | inner diameter (m) | hight (m) | lenght/width (m) | surface floor (m²) | volume of atmosphere (m³) | volume water/ice (m³) | weight water/ice (kg) | lenght tensiles (m) | membrane (m²) | weight membrane (kg) | total weight (kg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| start module | cylinder | 8,0 | 3,5 | 8,5 / 8,5 | 50 | 150 | - | - | - | - | - | 20.000 |
| lunar bubble | sphere | 8,0 | 13,4 | 9,8 / 9,8 | 48 | 270 | 95 | 87.000 | 650 | 780 | 820 | 87.820 |
| connection module | cylinder | 3,5 | 4,2 | 11,9 / 4,6 | 36 | 95 | 38 | 35.000 | 250 | 310 | 325 | 35.325 |
| stage 1 | - | - | 3,5 | 47 / 22 | 350 | 1.020 | 106 | 98.000 | 700 | 870 | 910 | 215.000 |
| stage 2 | - | - | 13,4 | 50 / 38 | 600 | 2.730 | 1.080 | 990.000 | 6.700 | 8.100 | 8.500 | 1.038.000 |
| base (stage 1 + 2) | - | - | 13,4 | 72 / 47 | 950 | 3.750 | 1.186 | 1.088.000 | 7.400 | 8.970 | 9.410 | 1.253.000 |
| regolith coverage | - | - | max. 11 | 80 / 60 | - | 12.000 (volume regolith) | - | - | - | - | - | 18.000.000 |

Construction masses

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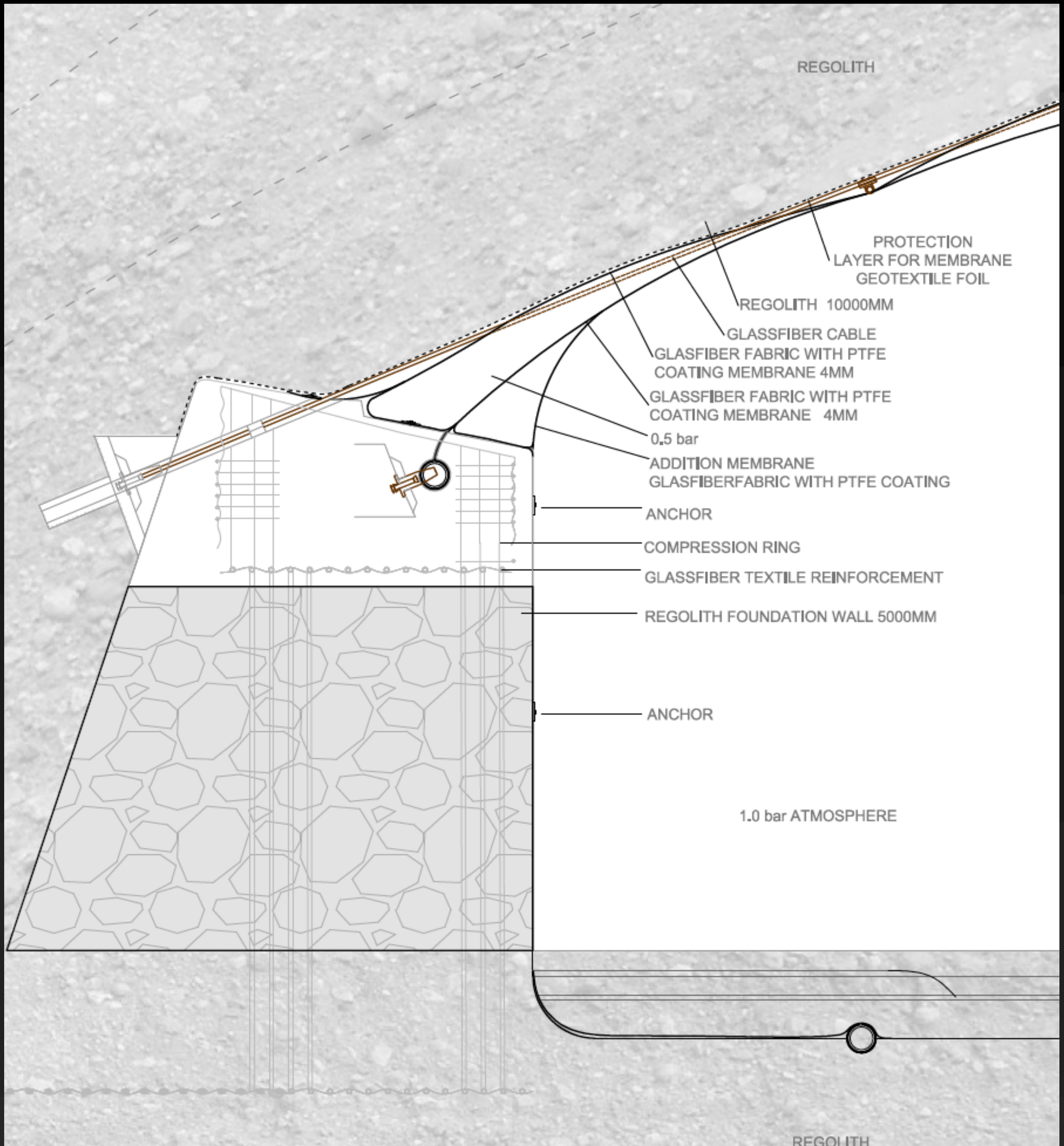
# 4 GREEN BUBBLE BASE

Nikola Mihaljevic // Yanran Song




3D DETAIL - COMPRESSION RING / SCALE 1:25

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5 SELENA

Nigora Djalalova

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