In-Between

Bridging Earth to the Moon with the architectural project

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Bridging Earth to the Moon with the architectural project

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Abstract

“In-Between” investigates the theme of space architecture, with a particular focus on the design process and the creation of a lunar settlement. For several years, numerous studies have supported the idea of humans returning to and potentially permanently residing on the Moon. This has brought about the need to explore the architectural aspect of the endeavor. Within an engineering-focused context, I attempted to shift the perspective from a general and finite view of space projects to an analysis of the lunar settlement as a composition of specific processes culminating in an architectural design.
In this context, the thesis is structured as an investigative journey to establish a connection between the technical and engineering aspects and the socio-cultural dimensions inherent in architectural design.

The thesis aims to explore how human beings, in such a rigid and highly engineered context, can once again become a fundamental factor and not just a tool of science, through the lens of architectural design. To overcome engineering influences, a broader and more strategic vision is proposed, which integrates them, along with a transversal and open approach to different scales.

This work strives to establish a methodological framework to guide upcoming projects within lunar environments.
It introduces an array of innovative tools to comprehend, interpret, and oversee lunar initiatives, encompassing geopolitical, technical, and architectural dimensions. Significantly, the thesis provides guidelines derived from an exhaustive documentary study covering both macro and micro-scale considerations.
This involves a thorough examination of the interaction with concurrently planned projects in the same lunar area, the necessary technical infrastructures, and the topographical features of the lunar terrain.
Architectural analyses are also conducted, presenting technical details such as dimensions for individual environments, while simultaneously delving into reflections on the human factor.
This necessitates a reassessment of concepts that are clear and well-defined on Earth but require reconsideration in the lunar context.
Nevertheless, the investigation remains incomplete, with certain questions left open for potential future discussions.

Mapping has been a vital tool for spatializing the emerging issues, demonstrating how each choice emerged from intrusions and negotiations. This is because the project’s purpose is not to recognize itself in the authorship of the designer but in their ability to continuously engage with the issues inherent to the location.
Space architecture provides the opportunity to critically rethink the design and architectural conventions we unwittingly adopt on Earth. Creating an atlas that narrates not only the final design of a lunar tourist infrastructure, but also all the intermediate steps necessary to arrive at the final proposed project. The thesis is viewed as an infinitely implementable tool that establishes specific points, providing a novel set of instruments that aid in understanding the design.

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Introduction

This thesis deals with the development of a semi-permanent human settlement on the lunar surface, an issue that has been widely discussed in recent years.
Today, more than 50 years after Neil Alden Armstrong walked on the Moon, the goal is to get people there and stay there.
In the last decade, there has been a fundamental shift in the industry, from short-term pioneering expeditions to long-term planning for settlement and new ventures such as space tourism. (Leach 2014)
Many are the reasons for this renewed interest nowadays: the enormous scientific claim that the Moon has generated, the stimulus of new technologies and the exploration of planets even further from Earth, such as Mars. (Neuman 2022)
All of these reasons have also stimulated economic investments, by space agencies and various Nations worldwide, that have a keen interest in the future of the Moon and Space.

My research on space architecture for this thesis commenced in March 2023.
Although I have long been captivated by outer space, the notion of combining it with architecture didn't occur to me until I came across an ongoing research framework initiated at my university in 2021, through the thesis entitled “Processo progettuale e progettazione di un'infrastruttura turistica in ambiente lunare” by Simone Alongi, Massimo Beccia and Marco Ranieri (Alongi et al., 2022).
Space architecture enables us to challenge traditional design principles on Earth and apply them in extreme environments, such as the Moon. Essentially, spatial architecture expands on terrestrial architecture, introducing a range of issues that extend beyond technical concerns and encompass social considerations.
Designing such architecture is a demanding task that necessitates ensuring and enhancing safety, sustainability, livability, dependability, crew effectiveness, efficiency, and comfort amidst exceedingly challenging surroundings.

The hypothesis of this thesis proposes that by studying and creating an architectural project in an extreme environment, it is possible to reassess terrestrial architectural conventions. This reassessment involves re-contextualizing the elements that impact us and presenting them in a wholly new perspective.

In this context, the thesis endeavor is structured as an investigative pursuit seeking to establish a nexus between the inherent technical and engineering facets characterizing a project of this type, and the sociocultural dimensions inherent in architectural project.
Within this paradigm, the selected title for this thesis serves as a symbolic representation of a transitional process, emblematic of perpetual engagement with novel stakeholders, thereby emphasizing the inherent dynamism associated with both the architectural project and the present thesis.
From the outset, the legitimisation of this project was even more necessary than on Earth, essential to prevent it from being assimilated into a pure exercise in style.

The project prefigures a circumstance that is not yet given and therefore needs a solid foundation based on specific argumentative strategies to define agreements on a symbolic, technical and bureaucratic level.
For the restitution of the experience, it was deemed necessary to identify narrative expedients that would make it possible to read the route taken and the observations that arose from it. It was therefore decided to adopt the narrative form of the “logbook” through which all the events and the entire project’s route are narrated diachronically.
The design process involves promises that gradually collide with demands arising from the continuous exchange with the project’s collective.
The scenario, representing a future vision, will be linked to the present through legitimising elements.
In each scenario chapter, the implications of the contract for the future will be explained.
The aim is to explain through the tool of maps the process that will have as its rule $X = Y\ (t1) \Longrightarrow X = [J, K, L \text{ etc.}]$ in M. (Armando and Durbiano 2017, p. 460)

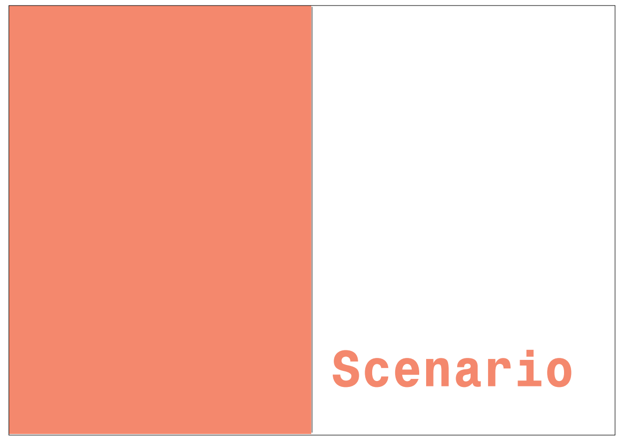
In this way, an unprecedented lunar geography of sources is realised, in which the territory is read both in its present aspect and in its potential future dimensions.
The structure of the work, both in terms of narration and content, is divided into three main categories.

The first part is closely linked to the real plane and involves a concrete and detailed analysis.
The second part, concerning scenarios, shifts to a figurative plane where all design actions come to life.
Finally, the third part seeks to integrate the information gathered from the real and figurative planes, translating issues that need reconceptualization from Earth to the Moon.

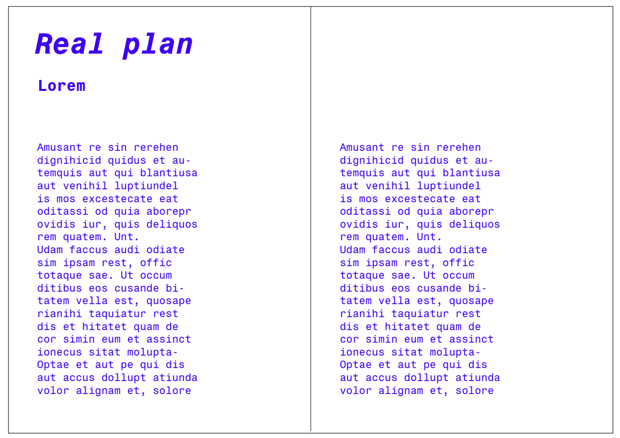
The narrative of the research work sees the intertwining of two above mentioned planes. The real plane represents and describes the current situation on the basis of documents and news reports. The figurative plane, on the other hand, is where all the exchanges between designer - narrator and actors take place.
It is at this stage that various architectural proposals are examined in detail, scenario by scenario.
Scenarios are a subset of the narrative that promotes storytelling and the deconstruction of the design process.
In addition, there are two other layers to the narrative of the thesis: that of the inserts and that of the in-depth.
The “insert” pages contains transcripts of direct or indirect conversations that are important inputs for the acquisition of awareness about specific aspects. While the in-depths are insights that have been developed in each cycle and they are closely linked to elements peculiar to the individual project proposals.

Color code

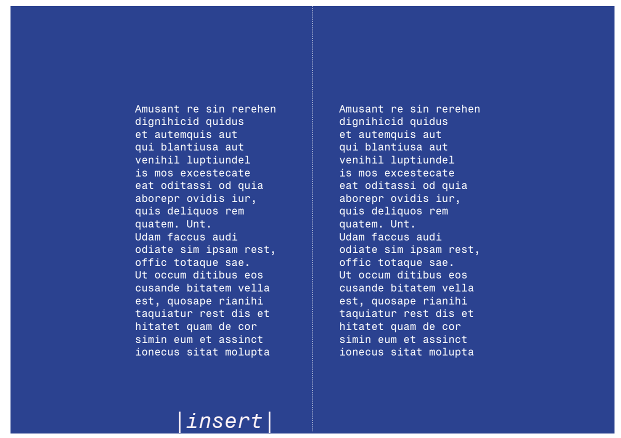
The four layers discussed previously - the real plane, figured plane with its subset of scenarios, insert, and in-depth - are easily identifiable in the thesis due to their distinct graphical representation.



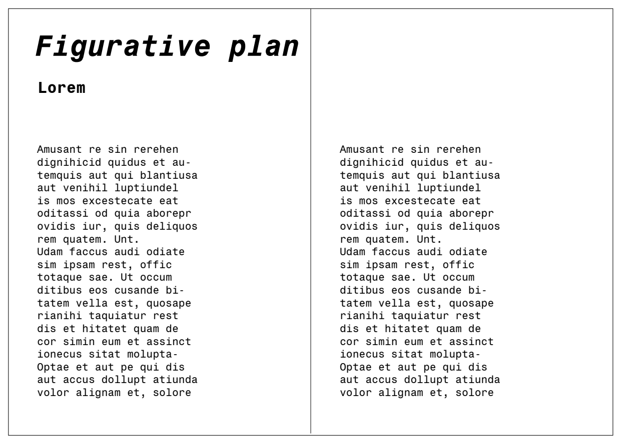
Scenario: where the action takes place



Real plan



Insert: direct or indirect conversations



Figurative plan

In-depht: detailed analysis

1.

The Earth and the Moon

This chapter delves into the intricate connection between Earth and its natural satellite, the Moon. Its primary objective is to delineate this connection by initially drawing a comparative analysis between Earth and the Moon as celestial bodies, thereby establishing their geophysical relationship.

Subsequently, it explores the junctures where terrestrial context meets lunar context, using maps to outline when, where, and how humans have intersected with the lunar surface.

As the narrative progresses, attention turns to current interests that drive lunar exploration.
This involves examining key players in the field, the economic forces that impact lunar missions and the geopolitical climate that defines this era of space exploration.
By conducting this analysis, the chapter aims to uncover the intricacies and drivers behind the renewed curiosity in lunar pursuits.

Towards the end of the chapter, the focus is on space programmes that are dedicated to the construction of lunar settlements.
The following examination takes a forward-looking perspective by carefully analyzing the technological advancements, strategic considerations and collaborative efforts that enable promising projects of this kind. By examining the potential and challenges associated with establishing lunar settlements, this chapter provides insight into the possibilities and implications of a human presence on the Moon for space exploration and our perspective from Earth.

1.1 Lunar Exploration

1.1.1 Background

For more than half a century, space had a strategic meaning linked to specific historical periods. Begun during the Cold War, the first space race extended the ideological and strategic military opposition between the United States and the Soviet Union beyond the Earth's atmosphere.
Sixty years later, the importance of the space industry has increased: Space has proven to be a significant driver of technology and science, with impacts reaching far beyond its immediate domain.
While the United States and Russia have a rich history in lunar exploration, China, a newer player, currently has a greater hold on the cislunar space (Merriam-Webster 2023). This area is significant as its resources, power and scientific discovery are the driving forces behind mission planning for the future establishment of humankind on the Moon.

Is it fair to ask when a significant turning point has occurred in recent years that has brought the idea of man on the Moon back into vogue?
Two **key dates** can be identified: 2015 and 2017.

In **2015**: The concept of an international "*Moon Village*" introduced by the Director General of ESA, Jan Wörner (2015), has been a catalyst for renewed interest in developing a permanent settlement on the Moon.
While in **2017** Chinese activism regarding lunar exploration, prompted President Trump (PBS NewsHour 2017) to initiate a new space programme, Artemis, to bring the US space sector back to the forefront (Pedoja 2023).
Several interests fuel the renewed fascination with the Moon and man's return to it.
Firstly, there is scientific curiosity about the Moon as it remains an enigmatic natural satellite with several unresolved questions.
Moreover, human presence on the Moon could prove advantageous in answering these mysteries. Craig Hardgrove highlights that, unlike robots, humans are able to amass a larger quantity of samples rapidly. (Neuman 2022)
Secondly, the exploration of Mars is also at stake. The red planet is situated approximately 200 times further away from Earth than our Moon. (David and Collom 2018)
Furthermore, opportunities for launches to Mars arise only once every two years, increasing the requirement for astronauts to remain on the planet for extended periods. Therefore, it is crucial to first develop and test a settlement on the Moon as a preliminary step before embarking on a mission to Mars. (Neuman 2022)
In addition, the development of new technologies and their potential benefits to Earth must be taken into account, as the Apollo programme demonstrated. (David and Collom 2018)
If the aforementioned interests point more to technical aspects that stimulate the renewed interest in a human lunar settlement, this thesis will aim from these elements to probe all the social aspects of the design of a lunar settlement.
Projects involving space, perhaps more than others, tend to be technical and engineered given the hostility of the environment; the architect's task is to excavate and find the social dimension of the project, thus restoring the true nature of the architectural project as a socio-technical object.
The conditions affecting our satellite are unique and very different from those on Earth, and it is, therefore, necessary to analyse them in order to be able to identify the socio-technical constraints, actors and actors with which the project will have to interface.

1.1 Lunar Exploration

1.1.2 Enviromental conditions

Thanks to the book ‘The Sky at Night: Book of the Moon - A Guide to Our Closest Neighbour’ (Aderin-Pocock, 2018) by Dr. Maggie Aderin-Pocock, a space scientist and science divulgator who provides an authentic insight into the physical properties of the Moon, it was possible to analyse in-depht the lunar enviromental conditions. The book is replete with legendary narratives and precise depictions of the Moon’s environmental traits and has been an inexhaustible source of information for this sub-chapter of the thesis.

The Moon even if is a celestial body like the Earth, has a very different environment and special physical conditions. However, a detailed comparison can facilitate our understanding of them. To project a settlement on the Moon’s surface is necessary to know some information about it.

The Moon is a nearly spherical rock, gravitationally tied to Earth with an elliptical orbit, situated at an average distance of approximately 385,000 km from Earth. The Moon is a satellite and is significantly smaller than the Earth, having merely 7% of its area. Hence, land-use planning becomes a crucial aspect, because so many entities are interested in settling in this small area.

Moreover, as the Moon is much smaller in volume than the Earth, its volume is only 2% of the latter’s.

As expected, its mass is minor compared to that of the Earth, weighing in at just 1.2% of our planet’s mass. Additionally, its density is relatively low, at 60%.

The lunar surface is comparable to that of Earth, with a maximum elevation of approximately 8 km above the mean surface level and depths reaching 9 km below. This range is similar to that found on Earth but on a smaller celestial body.

Although the morphology of the lunar landscape is similar to that of Earth, the processes that generated it differ greatly. Earth’s surface irregularities are the result of plate tectonics, whereas, on the Moon, differences in elevation are due to billions of years of asteroid and meteor impacts. These craters have remained unchanged since their creation, unlike on Earth where corrosion has altered them, due to the Moon’s thin atmosphere.

The Moon differs from the Earth in various aspects, and its atmosphere stands out as a significant contrast. Contrary to popular belief, the Moon has an atmosphere, albeit a relatively low-value one referred to as the “exosphere” (NASA 2019).

The lunar environment exhibits a wide range of temperatures, varying from a minimum of -247 °C to a maximum of 120 °C. The environment can be divided into two zones: polar and non-polar regions, with both experiencing significant temperature swings.

Non-polar regions exhibit greater susceptibility to this phenomenon, in contrast to reduced temperature fluctuations that occur in polar regions due to the reception of sunlight at grazing angles, without direct exposure. Heat transfer on the moon is exclusively achieved through radiation because of its sparse atmosphere. This has advantages as it permits the potential for living in polar regions.

The aforementioned low mass of the moon results in a considerably weak gravitational field. Due to the Moon’s lack of atmosphere, air resistance is absent, the gravitational force exerted on the Moon’s surface is just under 17% [1.6 m/s^2] of that on Earth. Furthermore, it has been interestingly discovered that the Moon’s gravitational field is uneven.

The unevenness of the lunar surface is attributed to pockets of mass that exist below the Moon’s crust, resulting in significant positive gravitational anomalies. This knowledge was crucial during the Moon landing mission, as alterations in the gravitational field could lead to lunar probes veering off course or crashing onto the lunar surface. To better understand these gravitational hazards for future lunar missions, further research is undoubtedly needed.

The Moon’s surface has had a turbulent history, enduring countless collisions with asteroids and meteors throughout its lifetime. These impacts have relentlessly eroded the topmost layers of its crust, resulting in a powdery lunar veneer known as regolith.

Regolith, which also occurs in the Earth’s crust, is the loose layer of material that rests on the bedrock of a planet or celestial body. It consists mainly of soil, rock fragments, sand, volcanic ash, and glacial deposits. The composition of the Moon’s regolith is distinctly different due to the fragmentation of the lunar crust by asteroids and meteors. The regolith consists primarily of oxygen, with trace amounts of silicon, iron, calcium, aluminium, and magnesium, along with rarer elements such as titanium, thorium, and manganese. The lunar atmosphere is thought to comprise helium, argon, sodium, and potassium, but none of these elements are conducive to sustaining oxygen-dependent life. However, oxygen is not absent on the Moon; instead, it is present both within the PSRs and within the regolith, as previously noted.

Water on the Moon was previously believed to be primarily contained within the PSRs.

However, a recent study from the Chinese Academy of Sciences (He et al 2023), discovered a considerable amount of water in previously unexplored natural glass grains formed by the impact of meteorites and micrometeorites on the Moon’s rock surface. This finding is noteworthy as it enables consideration of potential settlements beyond the immediate vicinity of the PSRs. Currently, numerous studies are being carried out to explore the potential utilization of lunar elements. This is due to the objective of utilizing the intrinsic resources of the lunar environment for future settlements and research purposes.

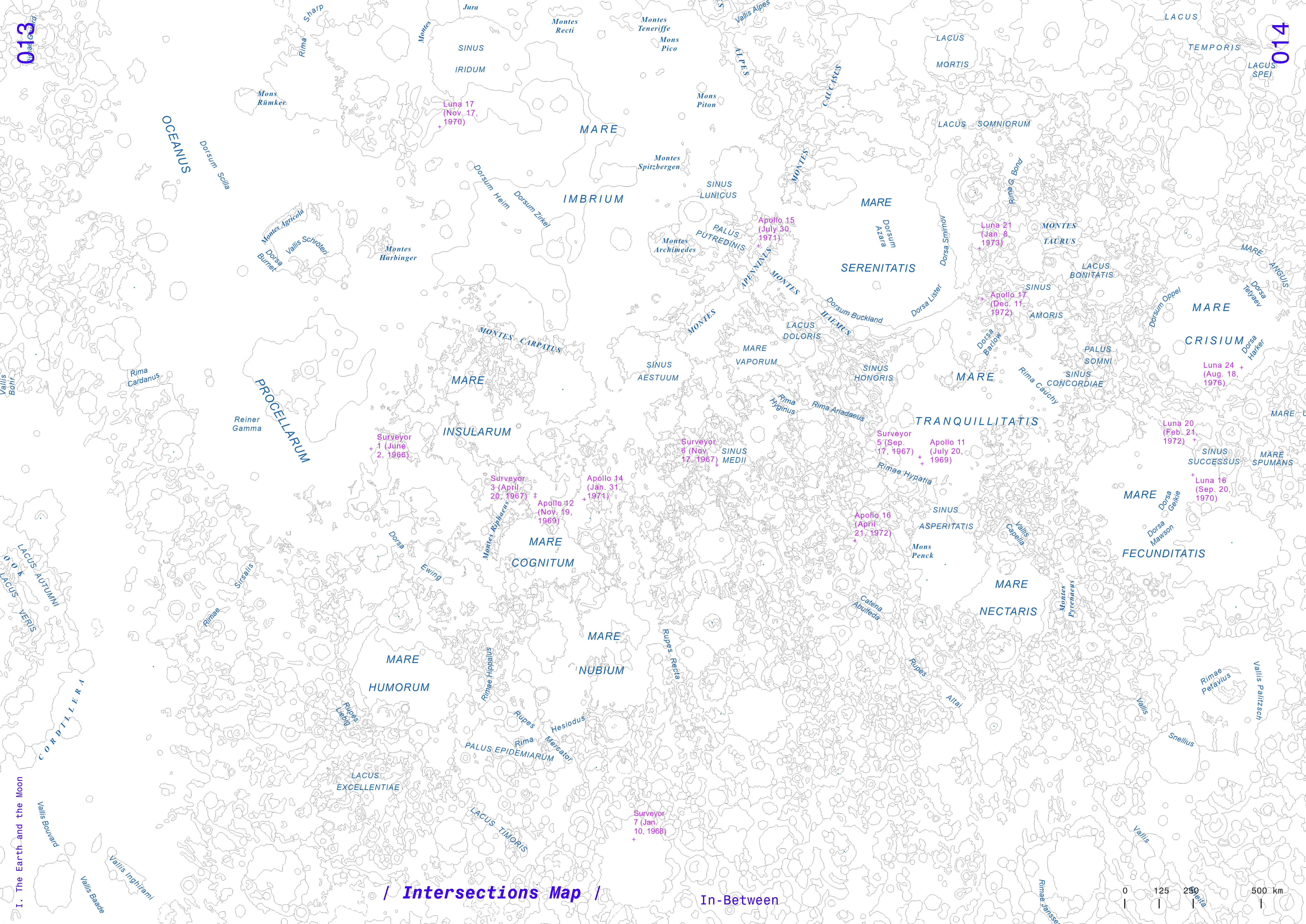
1.1 Lunar Exploration

1.1.3 Intersections

Although, as mentioned earlier, non-polar areas are not particularly suitable from a thermal point of view and for the availability of resources, they are nevertheless the ones most familiar to humans.
The map on the following pages displays the location of every human/robotic encounter with the Moon's surface, using the Mercator representation to allow for the mapping of the whole Moon.
The map was produced by overlaying data from various missions using the USGS geological map as a reference.
The results suggest that the Apollo, Surveyor (USA), and LUNA (USSR) missions were mainly focused on exploring the lunar equatorial belt.
In the early stages of Moon exploration and research, only the equatorial region was considered worth investigating.
As a result of these missions, we have gathered extensive data on this area. (Barnett 2019)
All available evidence suggests that due to unfavourable environmental conditions and scarcity of resources on site, there has been a shift of interest towards more suitable areas for scientific research and human settlement, specifically the lunar poles.
Until now, human interactions with the Moon have been limited to visits, either in person or by robot.

Today, however, a paradigm shift has occurred, as the Moon is no longer just a destination to visit, but a place that offers opportunities for settlement.
This raises the question: Have people established habitation in any locations beyond Earth? Two sites meet this criterion: the International Space Station (Bleacher 2023) and the Tiangong Space Station (Jones and Dobrijevic 2023). Designed primarily for scientific research, these facilities are located in low Earth orbit. Currently, these two space stations are the only human habitats in Space. In particulary the ISS functions as a collaborative initiative between five space agencies: NASA of the US, RKA of Russia, ESA of Europe (including its partner space agencies), JAXA of Japan and CSA-ASC of Canada.
Since 1998, the ISS has been orbiting the Earth in free fall, at an altitude of 400 km and a speed of 28,000 km/h. It has been continuously occupied by a crew of between 2 and 7 astronauts since November 2nd, 2000. (Howell 2023)
Over the years, the team has undergone a multitude of replacements with some astronauts having made multiple returns to the ISS.
The space station can be seen as an example both for the habitat that has been created but also for the principle on which it is based, i.e. cooperation between different space agencies.
In fact, based on the positive experience of international collaboration that facilitated the construction of this station, the Director General of ESA has proposed an ambitious project to construct a lunar surface settlement, with a particular focus on international cooperation. (Petrov 2019)
This concept is in contrast to the adversarial competition paradigm, where space programmes develop capabilities independently and for their exclusive purposes. The Moon Village aims to establish a shared infrastructure on the Moon through a development model that pools resources from multiple stakeholders. This infrastructure will facilitate a variety of activities and missions.

"The south pole is far from the Apollo landing sites clustered around the equator, so it will offer us a new challange and new environment to explore as we build our capabilities to travel farther into space." (Barnett 2019)


Jura
Sharp
Rima
Montes
SINUS
IRIDUM
Montes
Recti
Montes
Teneriffe
Mons
Pico
Vallis Alpes
ALPES
CAUCASUS
Mons
Piton
LACUS
MORTIS
LACUS
TEMPORIS
LACUS
SPEI
LACUS SOMNIORUM
Mons
Rümker
Luna 17
(Nov. 17,
1970)
OCEANUS
Dorsum Scilla
MARE
IMBRIUM
Montes
Spitzbergen
Dorsum Heim
Dorsum Zirkel
SINUS
LUNICUS
MONTES
MARE
SERENITATIS
Dorsum
Azara
Dorsa Smirnov
Rima G. Bond
Luna 21
(Jan. 8,
1973)
MONTES
TAURUS
LACUS
BONITATIS
MARE
ANGUIS
Montes Agricola
Vallis Schröteri
Dorsa
Burnet
Montes
Harbinger
Montes
Archimedes
PALUS
PUTREDINIS
Apollo 15
(July 30,
1971)
APENNINUS
MONTES
Dorsum Buckland
Dorsa Lister
SINUS
Apollo 17
(Dec. 11,
1972)
AMORIS
Dorsum Oppel
Dorsa
Tetyaev
MARE
CRISIUM
Dorsa
Harker
MONTES CARPATUS
MONTES
HAEMUS
LACUS
DOLORIS
MARE
VAPORUM
SINUS
AESTUUM
MARE
INSULARUM
Rima
Cardanus
Vallis
Bohr
PROCELLARUM
Reiner
Gamma
SINUS
HONORIS
Dorsa
Barlow
MARE
TRANQUILLITATIS
Rima Cauchy
PALUS
SOMNI
SINUS
CONCORDIAE
Luna 24
(Aug. 18,
1976)
Rima
Hyginus
Rima Ariadaeus
Surveyor
1 (June
2, 1966)
Surveyor
6 (Nov.
17, 1967)
SINUS
MEDII
Surveyor
5 (Sep.
17, 1967)
Apollo 11
(July 20,
1969)
Luna 20
(Feb. 21,
1972)
MARE
SINUS
SUCCESSUS
MARE
SPUMANS
Surveyor
3 (April
20, 1967)
Apollo 12
(Nov. 19,
1969)
Apollo 14
(Jan. 31,
1971)
Rimae Hypatia
Luna 16
(Sep. 20,
1970)
MARE
Dorsa
Geikie
Dorsa
Mawson
MARE
FECUNDITATIS
Montes Riphaeus
MARE
COGNITUM
Dorsa
Ewing
Apollo 16
(April
21, 1972)
SINUS
ASPERITATIS
Mons
Penck
Vallis
Capella
LACUS AUTUMNI
LACUS VERIS
Sirsalis
Rimae
Catena
Abulfeda
MARE
NECTARIS
Montes
Pyrenaeus
MARE
HUMORUM
Rimae Hippalus
MARE
NUBIUM
Rupes Recta
Rupes
Altai
Rimae
Petavius
Vallis Palitzsch
CORDILLERA
Rupes
Liebig
Rupes
Hesiodus
Rima
Mercator
PALUS EPIDEMIARUM
Vallis
Snellius
LACUS
EXCELLENTIAE
Vallis Bouvard
LACUS TIMORIS
Surveyor
7 (Jan.
10, 1968)
Vallis
Vallis Inghirami
Vallis Baade
Rimae Janssen
0
125
250
500 km

1.1 Lunar Exploration

1.1.4 South Pole

As mentioned earlier, the Moon's polar regions are distinctive areas known for their favorable environmental conditions, particularly concerning temperature and the presence of Permanently Shadowed Regions (PSRs). These PSRs, found near both the north and south poles of the Moon, function as frigid traps due to their complete absence of direct sunlight, resulting in extremely low temperatures ranging from -248°C to -203°C. (Aderin-Pocock 2018)

This unique condition arises from the Moon's minimal axial tilt of just 1.5 degrees relative to the ecliptic plane, which encompasses both Earth and the Moon's orbit around the Sun.

Consequently, the interiors of several craters in the vicinity of the Moon's poles remain perpetually in darkness, never touched by direct sunlight. (GSFC 2013)

As a result of this exclusive geometry, any water that happens to find its way into these permanently shadowed regions can remain there for long periods. Although cold traps are exposed to the vacuum of space so that water ice and other volatile materials like ammonia and methane can accumulate in them, they are still cold and dark.

If substantial volatile deposits are indeed verified in these areas, they could potentially offer valuable resources for future human missions. Therefore, it is crucial to gain a thorough comprehension of the interiors of these cold traps. (Henriksen 2018) Additionally, due to the Moon's slight 1.5-degree axial tilt and its orbit around the Earth, rather than the Sun, there is an absence of seasonal variation.

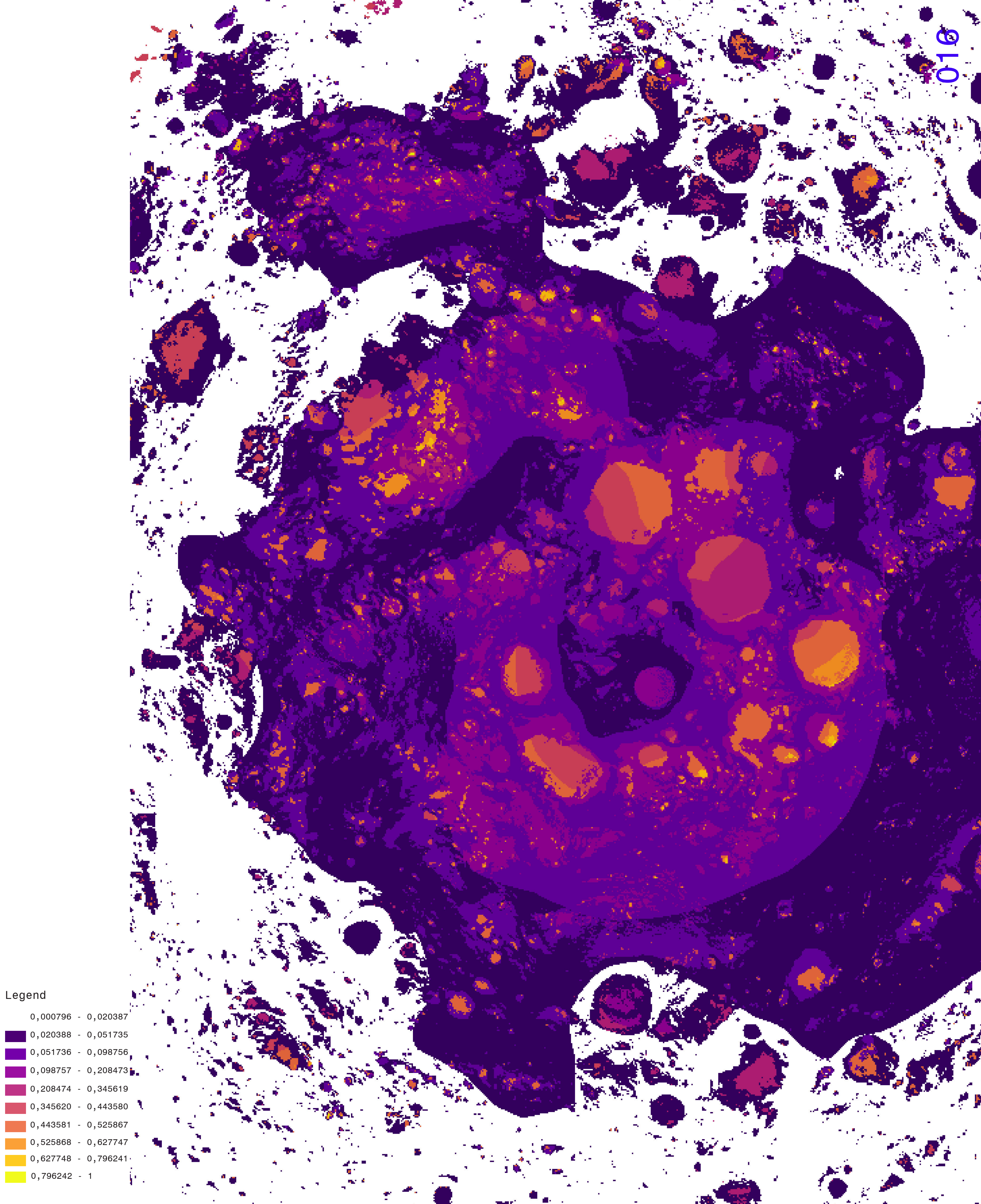
Due to many analyses and studies, today the attention is focused on the Moon's South Pole. The elliptical and polar orbit of NASA's Lunar Reconnaissance Orbiter, LRO, is the closest to the Moon during its passage over the South Pole region. Through its thousands of orbits over the past decade, LRO has gathered more accurate information about the South Pole region than any other, giving scientists precise details about its topography, temperature, and location of probable ice water.

A study conducted by Cannon and Britt (2020) reports a system model for understanding these ice water deposits. Moreover, researchers claim that even "the best ice deposits for extracting likely exist 10s of cm deep or more, even in locations where ice is currently stable at the very surface". (Cannon & Britt 2020)

The image alongside is a reinterpretation of data from the study conducted by Cannon and Britt, indicating the percentage of ice present at the South Pole. The areas where ice is nearly absent are depicted in white, while those with substantial amounts are shown in orange.

From a design perspective, this translates into a strategic evaluation of project organization. Indeed, the availability of resources holds paramount significance when considering the design of human settlements.

More specifically, being in proximity to sources of water, even in the form of ice, could facilitate the extraction of vital oxygen for human life and hydrogen that could serve as rocket and spacecraft fuel. Consequently, this would lead to a reduced need for shipments from the Moon to Earth, resulting in substantial cost savings. To put it into perspective, transporting just 1 L of water from Earth to the Moon currently costs around one million dollars. (Pedoja 2023)



// Conversation with

Marco Ranieri

*Marco Ranieri is an architect who completed his studies at the Turin Polytechnic in 2022.
Thanks to the thesis he co-authored with Simone Alongi and Massimo Beccia entitled ‘Processo progettuale e progettazione di un’infrastruttura turistica in ambiente lunare’, he began a strand of studies on spatial architecture at the Turin Polytechnic’s architecture department.*

1. What inspired your choice to undertake a project on the lunar surface?

M.R: *The inspiration to focus my thesis project on the lunar surface stemmed from an article I came across in a magazine.
This article featured an interview with Valentina Sumini, our co-rapporteur, discussing the Moon Village project. Reading about it and viewing the accompanying images instantly ignited the idea of creating something akin to it for my thesis. The primary motivation behind this decision was my eagerness to embrace a fresh and invigorating challenge, diverging from conventional atelier projects. I perceived this opportunity not only as a challenge in the realm of new architecture but also as an experience that could enhance my design skills here on Earth.*

2. How did you approach the matter of the land subdivision?

M.R.:*The approach started with an in-depth analysis of the specific conditions of the lunar surface, including parameters such as temperature, soil composition and illumination.
Subsequently, we moved towards a geopolitical analysis, considering the allotment of a surface that, although not currently occupiable, is collectively owned. This change of perspective was fundamental in order to comprehensively address the issue of allotment, as it prompted us to consider not only the technical and physical aspects, but also the social, political and ethical implications of subdividing and managing a territory shared by all.*

3. Why did you decide not to consider the Moon Village project as a pre-existence in your project?

M.R: *Initially, during the preliminary phase of our analysis, we considered the Moon Village project.
However, during the subsequent development, having chosen a different site for our proposal, we decided not to consider Moon Village as a direct pre-existence in our project.
This was mainly due to the complexity that would arise in attempting to establish a direct connection with the Moon Village, considering the significant distance between the two sites. The geographical distance between the two locations would have posed logistical and communication challenges that would have compromised the overall efficiency of the project. Consequently, we preferred to focus on an independent solution that could more directly and optimally address the specific needs of our selected site, ensuring a more cohesive and functional project.*

4. Methodologically, what were the main difficulties?

M.R.: *Initially, we were faced with a seemingly insurmountable challenge, as the conditions of the lunar surface differ substantially from what we are used to in the terrestrial architectural context.
This disparity led to the need to question and overcome the dogmas and rules of architecture that we usually take for granted.
The main challenge was therefore to govern the project in a completely foreign environment, trying to find a methodological approach that could effectively adapt to the unique conditions of the lunar surface.*

5. What were the results of your research on an architectural and theoretical level?

M.R: The most significant results of our research, architecturally and theoretically, were the conception and realisation of a master plan for the lunar surface, an unprecedented innovation in this field. The creation of a structure followed this effort, but the real challenge was to establish rules for the expansion and occupation of the lunar surface. This achievement represents a milestone, as it made it possible to develop a master plan that, although it may seem trivial, respects all the particularities of the lunar surface and the surrounding geopolitical conditions.

6. Do you think that lunar design can become a tool for terrestrial design? And if so, how and why?

*We believe that designing in extreme and radically different conditions from those on Earth is crucial to understanding the importance of governing every aspect of a project optimally, with a focus on sustainability. The experience of designing on the Moon results in valuable lessons that can be directly applied to improve design on Earth, promoting the creation of sustainable, environmentally friendly structures focused on individual well-being.
In this context, it is imperative to design facilities that operate in a 100% complete recycling cycle, as there is no possibility of wasting resources. This perspective, which requires careful and sustainable management of every resource, should be a transferable lesson on Earth. Design on the Moon has taught us to think more comprehensively and holistically, pointing the way to creating architectural environments that respect our planet and its resources in a more conscious way.*

1.2 Mapping the interest

1.2.1 Geopolitical conditions

The Moon is starting to be the mirror that reflects human concerns on Earth, and it is important to overlook the significance of terrestrial ambitions in determining the course of the space industry.
The Moon presents several prospects that might pique the attention of different trailblazers: scientific, governmental and commercial.
Being only a three-day journey away, (Wibisono 2018) it is the nearest aspiration for several of the cosmic organizations that will discuss below.

In recent times, Space has acquired undisputed strategic significance in numerous aspects.
Nevertheless, the parties involved have decidedly shifted from the historical phases of the first Space Race.
Currently, private actors are actively participating in space activities, and it is set to progress swiftly, along with the rapid evolution of space activities.
Significant research has also been undertaken into harnessing energy from Space, and the space tourism industry is gearing itself up to send the first space tourists into Low Earth Orbit. In fact, over the last decade, there has been a fundamental shift in the space industry from short-term pioneering expeditions to long-term planning for human settling and new ventures such as space tourism.

While scientific lunar exploration is the conventional rationale put forth by nations to go to the Moon, a new wave of concepts for lunar activity is being shaped around commerce.
An examination of the stakeholders, the associated geopolitical and economic factors, is essential to a complete vision of a future space settlement. Gaining an understanding of the connections between the stakeholders and their objectives, offers valuable insight into the potential designs for the settlement on the Moon.
In fact, to establish a presence in cislunar space, it is necessary to identify suitable sites for infrastructure. These may include the lunar surface, lunar orbits, Lagrange points and lunar transit orbits .
Consequently, a plethora of planned activities has arisen for both lunar and cislunar missions.

The new race to the Moon necessitates updated regulations, as the current ones date back to 1967 and are encompassed in the "Treaty on Outer Space."
Initially signed by the United States, the United Kingdom and the Soviet Union, the treaty, which now includes 110 nations, outlines the peaceful exploration of outer space by its signatories and the commitment not to claim rights over celestial bodies.
The treaty laid the foundation for all activities beyond Earth, establishing prohibitions on the appropriation of outer space, control over artificial objects in orbit, and responsibility for the actions of such objects. While the treaty forms the basis of outer space diplomacy, it has not been updated to reflect the current state of cosmic exploration.
"There is no law that details the use of space resources, but a significant number of public and private entities aim to reach the Moon within five years. This will create fertile ground for conflicts," remarks Martin Elvis, a researcher at the Harvard-Smithsonian Center for Astrophysics and the author of the study (Fabriani 2020)

The main problem arises from certain clauses in the treaty that govern the relationships between signatories.
Each Nation commits not to harm the probes and outposts of others, meaning a Nation cannot land probes near those of another nation.
This effectively makes a site exclusive to the nation that arrives there first, creating a scenario of "first come, first served." However, the scientifically and economically valuable areas on the Moon are insufficient to satisfy the interests of all nations.
International tensions and the rapid depletion of resources could jeopardize the future of lunar exploration.
A competition governed by shared rules, however, could prevent its militarization and promote scientific development. (Fabriani 2020)
The Outer Space Treaty (OST) is widely recognised as the cornerstone of international space law.
The doctoral researcher Antonino Salmeri, in his paper titled "Developing and Managing Moon and Mars Settlements in Accordance with International Space Law" (Salmeri 2020) offers an overview and interpretation of space law. He focuses on addressing the question of how to develop and manage such settlements while adhering to international space law.
To accomplish this goal, Salmeri conducts a systematic analysis of the Outer Space Treaty with the objective of assessing the extent of freedom in using celestial bodies while abiding by the constraints of international space law.
The establishment of a settlement on a celestial body presents a unique challenge, as the Outer Space Treaty (OST) lacks specific criteria for distinguishing legitimate utilization from unauthorized appropriation of celestial bodies.
Therefore, the crucial question that emerges is how to interpret the information within the sole legislative instrument currently in effect.
Antonino Salmeri, in his paper, undertakes the task of interpreting the key provisions of the OST to comprehend their implications concerning the freedom to exploit celestial bodies for the construction of settlements on their surfaces. The analysis begins with Article I of the Outer Space Treaty (OST), which is foundational in international space law.

It emphasizes the global importance of outer space and declares the freedom to explore and utilize it with an emphasis on international cooperation. This article has significant legal implications for establishing permanent human settlements on celestial bodies.
Article I of the OST is the legal basis for the freedom to explore and use outer space, including celestial bodies. “Use” is broadly defined and encompasses various activities. It implies the right to exclusively possess and use celestial bodies for lawful purposes, potentially including the establishment of permanent settlements.
However, this interpretation of “use” is subject to limitations and conditions, both within and outside Article I of the OST. To distinguish between legitimate uses and unlawful actions, one must identify and interpret the limits and conditions that affect the freedom of use. Article I of the OST already specifies five conditions for the valid exercise of this freedom, and other relevant limitations in Articles II, III, IV, and IX of the OST must also be considered.
Article I of the Outer Space Treaty (OST) outlines crucial “inherent conditions” for activities in outer space and on celestial bodies, and they are considered significant due to their placement in the same article.
Benefit and Interest of All Countries: Article I (1) OST emphasizes that space activities should be carried out for the benefit and in the interests of all countries, regardless of their level of economic or scientific development. It further declares that outer space is the province of all humankind. The interpretation of this provision can be challenging due to its broad and ambiguous wording. State practice shows that there is no general duty to share the benefits of space activities. Instead, states are encouraged to share benefits through cooperation, mutual assistance, and inclusiveness. The global trend favors sharing benefits.
Province of All Mankind: The literal interpretation of “province of all mankind” establishes outer space and celestial bodies as res communes omnium, i.e., resources belonging to everyone. This interpretation is strengthened by the prohibition of national appropriation under Article II of the OST and the principle of due regard under Article IX, solidifying the concept of outer space as a global common. From this, two provisional conclusions can be drawn: States are not obliged to immediately distribute benefits from extraterrestrial settlements, and such settlements should prevent monopolistic behavior in using celestial bodies.

Non-Discrimination: The second inherent condition is the principle of non-discrimination, reinforcing the idea of space as a shared environment. This should be read alongside the third condition in Article I, which complements non-discrimination with the principle of equality. Substantive equality, which promotes a “level-playing field” for all states to conduct space activities, has been favored in practice. Consequently, developing an extraterrestrial settlement should not involve granting unilateral privileges for a limited group of countries, and it should be an inclusive process open to contributions from international partners.
In Accordance with International Law: Article I (1) OST specifies that celestial bodies should be used “in accordance with international law.” This clause affirms that outer space is subject to public international law, meaning that celestial bodies should not be used in ways that are inconsistent with international law.

Free Access: Article I (2) OST states that there shall be “free access to all areas of celestial bodies,” ensuring unrestricted access to celestial bodies.

These conditions form a critical part of the legal framework for activities in outer space and on celestial bodies, promoting the idea of shared resources and cooperation among nations.
At first glance, Article I (2) of the Outer Space Treaty (OST) may appear to unequivocally prohibit any form of exclusive territorial control over celestial bodies. However, a strict literal interpretation of this provision could lead to impractical and unreasonable outcomes, effectively prohibiting any stable activities on celestial body surfaces.
To address this issue, a systematic reading of the OST suggests that the principle of “free access to all areas of celestial bodies” should be carefully balanced against the right to use celestial bodies as outlined in other articles of the treaty. Article XII of the OST, for instance, states that all stations constructed on another celestial body should be open to representatives of other OST Parties “on a basis of reciprocity.” This implies the implicit recognition of the right to establish such stations in the first place. A strict literal interpretation of Article I (2) could undermine the legal significance of Article XII, which implies that the principle of free access is primarily applicable to natural areas of celestial bodies, excluding human-made stations.
This interpretation is further corroborated by Article VIII of the OST, which stipulates that states maintain jurisdiction and control over their registered space objects, including those constructed on the surface of another celestial body.
In conclusion, based on this analysis, it can be asserted that states have a legitimate right to utilize the territory of celestial bodies for constructing artificial installations to establish settlements. However, they cannot restrict access to the natural territory surrounding these installations.

// *Conversation with*

Antonino Salmeri

Antonino Salmeri is an Italian space lawyer specializing in the regulation of space resource and lunar activities.
Currently serving as a policy analyst at the Open Lunar Foundation, he holds four advanced degrees in law. These include a Ph.D. in Space Law from the University of Luxembourg, an Advanced LL.M. in Air & Space Law from the University of Leiden, a 2nd level LL.M. in EU Law & Policy from LUISS University of Rome, and a Master's Degree in Law from the University of Catania.
Antonino Salmeri's expertise lies in developing adaptive governance mechanisms and innovative policy solutions to ensure the peaceful, cooperative, safe, and sustainable conduct of lunar and space resource activities.

1. Currently, most space projects are publicly led by space agencies, with private partners providing support. Nevertheless, I am curious about the entry of private individuals into this scenario and how the construction of their projects, such as my own, would be regulated in this context.

A. S.: *The answer is actually very simple, because there is an article in the Outer Space Treaty (OST), specifically Article 6, which provides for the possibility of private parties conducting space activities of a non-governmental nature. These activities take place under the supervision, authorisation and international responsibility of a State Party to the Treaty. It is therefore necessary for there to be a State that authorises and takes responsibility for a private party to carry out this type of activity. This is a standard procedure, as it is for all other space activities. At the moment there is no other procedure. It is possible that there will be special channels in the future, but there are no plans at the moment. So it is feasible, clearly within the principles of the treaty, but you still need the oversight of a state.*

2. Would it be feasible to establish a territorial zoning plan for the Moon, outlining various lots for specific purposes?

A.S.: *That's a very good question, there is nothing of that kind at the moment, in the sense that the Moon has not been divided into functional areas to be dedicated to certain types of activities. So at the moment everyone goes where they need to go to carry out their planned activities, nevertheless there are processes that are starting to create a kind of idea of where certain elements are best placed.*
The organisation of which I am director is involved in promoting precisely this kind of thinking, in particular a decalogue of policies has been made and one deliverable we are proposing is precisely an infrastructure plan. So the idea is to be able to come up with this kind of deliverable. There was also another colleague Ethan Hudgins who proposed an interesting paper just on lunar zoning.

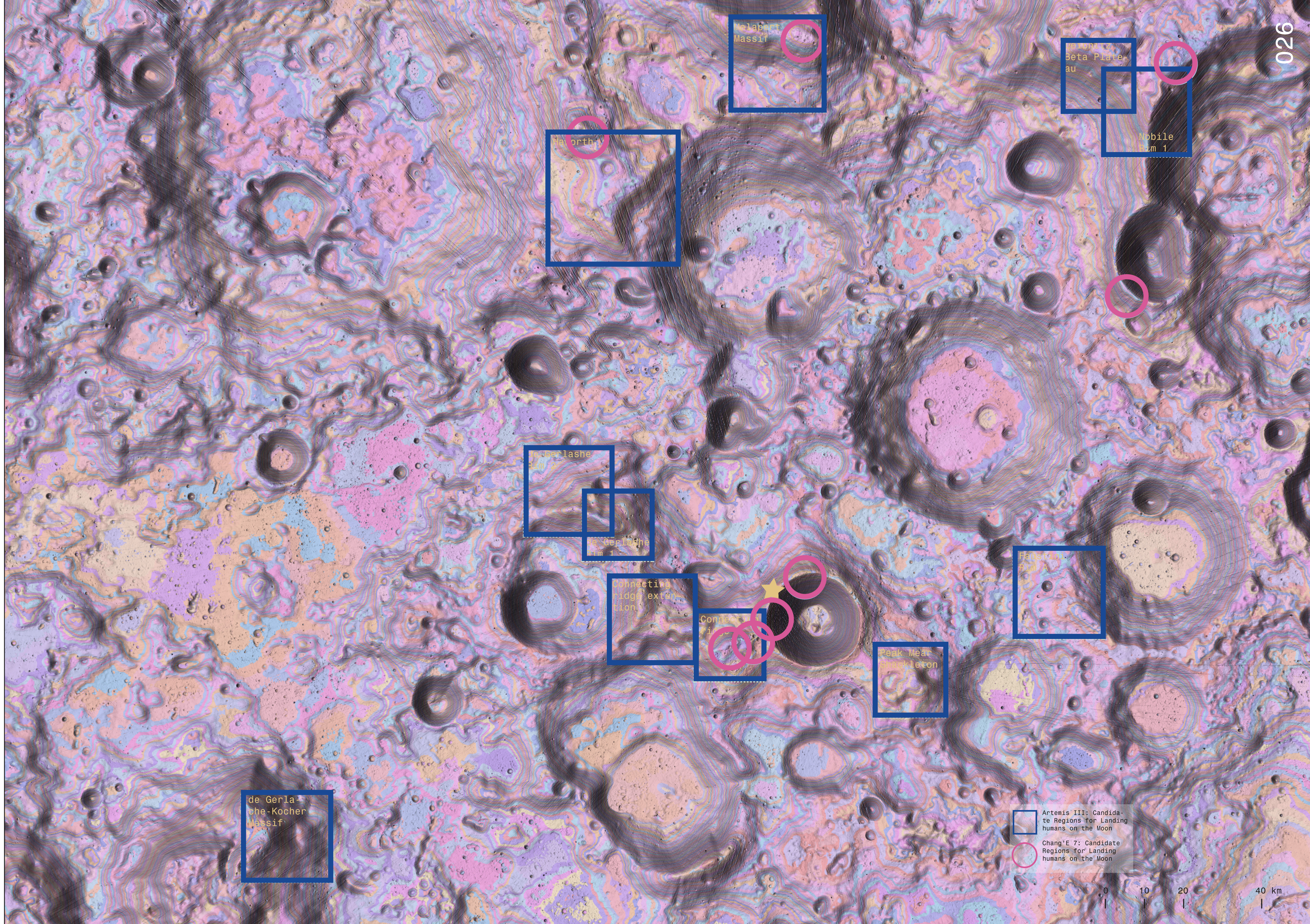
3. How could the possibility of cooperation between different entities take place and how could it be regulated?

Certainly the idea of cooperation is to be pursued, but bilateral agreements would be necessary, as in the case of the international space station. Then there are broader issues concerning the right of access by all, because according to international space law it is mandatory to allow free access to all natural areas of the Moon. Which begs the question: when we build artificial settlements, are we violating this principle? The answer is not so simple, probably the answer is no, but at the same time we have to understand how far this activity of cementing the Moon goes. Because if we go so far as to fill the entire lunar surface with artificial structures, we are circumventing the will of the treaty.
There is another article within the Outer Space Treaty, the Article 12, which prescribes the possibility of regulating visits to lunar stations and infrastructures. And this article provides for this right on the basis of reciprocity. Which, however, can be interpreted in two ways: on the one hand that you let in everyone who lets you in, the other version could be more limited in that it gives you the possibility to refuse access but you will be refused access by others.
It is a question of interpretation that has not yet been resolved and that inevitably brings with it
It is a question of interpretation that has not yet been resolved and that inevitably brings with it geopolitical issues.

1.2 Mapping the interest

1.2.2 Economical conditions

According to the “Budget of the United States Government, Fiscal Year 2024” the US has allocated an annual budget of $27.2 billion for the space sector, of which $8.1 billion will support the Artemis programme. (OFFICE OF MANAGEMENT AND BUDGET 2023)
A new generation of NASA rockets will transport humans to the Moon, and China is also preparing a similar venture on a similar timescale. Extensive preparations are currently underway on both sides of the Pacific Ocean. (Silk 2022)
Additionally, China in collaboration with Russia, both space-faring nations themselves, have their own lunar aspirations. In particular the chinese space agency (CNSA) with its programme Chang’E is ready to challenge the Western front, and according to a study conducted by Euroconsult for this programme China spent roughly $12 billion in 2022. (Vanleynseele 2022) The main purpose of the Chang’E mission, like that of the Artemis programme, is scientific research. The mission aims to establish an outpost, the International Lunar Research Station. (Wall 2021)
It will carry out various research activities, lunar observations and scientific experiments. Again, international cooperation is one of the basic principles. Indeed, China is willing to work with partners such as Russia, Saudi Arabia, the United Arab Emirates, Bahrain, Kuwait, Oman and Qatar.
Artemis 3 and Chang’e-7 both identify sites near Shackleton, Haworth and Nobile craters as potential landing zones. (Jones 2022)
On the following page, there is a revised map depicting the overlap between the possible landing locations designated by NASA and CNSA. (Jones 2023b) Notably, there is a significant intersection located near Shackleton crater, with multiple landing sites pinpointed by both CNSA and NASA. As a result, exploring this location with my thesis project holds considerable interest due to the potential gains at stake.



1.2 Mapping the interest

1.2.3 Current Moon programmes

Currently, there are multiple space programs in progress, but two of them encompass an extensive series of meticulously planned activities, which will be analyzed below, ultimately aiming to establish a human settlement on the Moon.
NASA leads the **Artemis** programme, which has garnered a range of international collaborators such as the space agencies of Japan, Canada and Europe. Indeed, a fundamental principle of the Artemis programme is to work strategically, collaborating with both international partners and private industry. (NASA 2020)

- Artemis II, set for November 24th, exact date pending confirmation, will be the first crewed test flight of the Space Launch System and the Orion spacecraft on a lunar trajectory. During this roughly 10-day mission, a crew of four astronauts will launch from NASA's Kennedy Space Center in Florida atop NASA's Moon rocket. Over about two days, they will assess Orion's systems and perform a targeting demonstration test close to Earth before heading to the Moon. (Zisk 2023)

- In 2025, Artemis III will be the first crewed Moon landing since 1972. NASA will send astronauts to explore the lunar South Pole, conducting scientific studies during their week-long mission before returning to Earth. (Mohon 2023)

- Artemis IV, scheduled for 2028 will deliver the International Habitation (I-Hab) module to Gateway, which will be followed by another crewed lunar landing with two astronauts. (*Artemis Programme: What You Need to Know About NASA's Moon Missions*, n.d.)

- In 2029, during the Artemis V mission, another module of the Gateway, known as ESPRIT
(European Space Agency's contribution to the Artemis program), will be delivered. Following this module delivery, a subsequent lunar landing will occur, involving two more astronauts who will conduct additional surface science activities and collect more lunar samples for return to Earth. (*Artemis Programme: What You Need to Know About NASA's Moon Missions*, n.d.)

- Artemis VI, planned for the late 2020s, will likely explore sites visited by prior robotic missions. It will consist of three main modules: the Surface Habitat (SH), the Lunar Terrain Vehicle (LTV), and the Pressurized Rover (PR). These modules will support missions lasting up to two months and aid in testing technologies for future Mars exploration. (Schwaller 2022)

Chang'E Storytime:

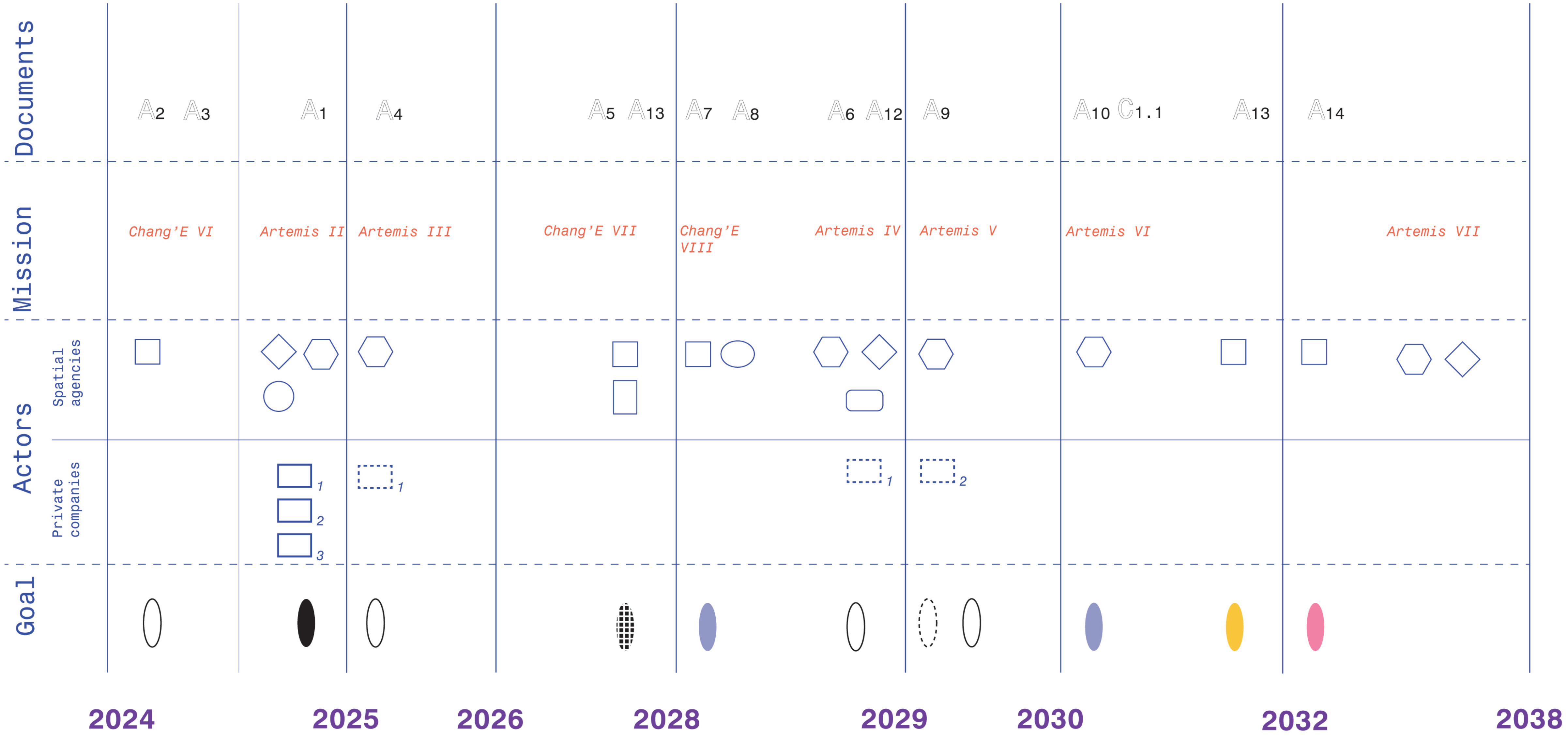
Unlike Artemis, the Chinese programme began in 2007 with **Chang'E** 1 and aims to continue into the future. The timeline below covers missions from 2024.

- Chang'E 6, scheduled for May 2024, has the mission objective of collecting samples during its 53-day journey. Similar to Chang'e-5, the goal is to secure approximately 2,000 grams (about 4.4 pounds) of material. (Society 2023)

- In 2026, Chang'E 7 is set to land a robotic rover on the Moon's south pole, with the mission's primary goal being the search for water and other lunar south pole resources. (Singer & Corbett 2023)

- Chang'E 8, scheduled for 2028, was initially intended to follow up on Chang'E-7's exploration and determine the optimal location for the International Lunar Research Station at the Moon's south pole. However, it seems that the timeline was accelerated in the past year, and Chang'E-8 is now tasked with commencing the initial construction of the facility and demonstrating its feasibility. (Singer & Corbett 2023)

The visual representation below seeks to delineate all the stakeholders engaged in the present state of the documents, as well as their existing connections and mission objectives. Its intent is to provide an unbiased mapping of the collected information, devoid of any subjective assessments. The structure of the representation follows a logical sequence, establishing vital cause-and-effect relationships between statements.



Legend

Goal

Systems check

Sample collection/exploration of the lunar surface

Robotic hunt for hunt for water and other resources

Assembly of the Lunar Gataway

Build a basic model of a lunar research station

Researchers insediation

Extention

Actors

space agencies

CSNA

NASA

ESA

Roscosmos

CSA

JAXA

ISRO

KARI

UAE

private companies

Oldspace companies

1. *Lockheedmartin*
2. *Aerojet Rocketdyne*
3. *Boeing*

Newspace companies

1. *Space X*
2. *Blue Origin*
3. *Icon*

Documents

An [article]

Cn [conference]

An [article]

1. (Artemis II - NASA. n.d.).

2. Society, P. 2023

3. (Zeng et al. 2023)

4. (Mohon 2023)

5. (Singer & Corbett 2023)

6. (Human landing Systems - NASA. n.d.).

7. (Maglione 2023)

8. (Berger 2021)

9. (NASA selects Blue Origin as second Artemis Lunar Lander provider - NASA. n.d.)

10. (Albright 2023)

11. (Cgtn. 2023)

12. (Artemis IV. n.d.)

13. (Piccin 2022).

14. (Caixin Global 2022).

Cn [conference]

1.1 (Petrov et al 2019).

2.

Scenarios

The foundation of this work's theory is rooted in the idea that buildings are not stationary and lifeless structures but rather dynamic entities. Their dynamism arises from the deconstruction of the processes that contributed to their design, construction, and utilization. This transformation shifts the stagnant perception of a building into a series of numerous sequential moments that collectively represent the uninterrupted flow of the building process. (Latour & Yaneva 2008)
The lunar facility project demonstrates how design in a non-terrestrial context is also closely linked to a controversial passage of data, which increasingly becomes more intricate.
From the idea of being able to transform a static view of the project-building into a dynamic navigation through the process, comes the division of the thesis into scenarios. Scenarios serve as a figurative stage, much like a theater, where the project is tested step by step, instance by instance. The narrative of the design process is crafted with the intention of establishing critical milestones for future progress, ensuring that the process remains open and adaptable, ready for continuous transformation. Each scenario's creation was grounded in a thorough document analysis, which facilitated the identification of the project collective's specific instances and requirements.

Scenario's fixed elements:
· Project Collective Map
· Istances overview
· Map describing the project action

This scenario structure applies starting with scenario 1, as scenario 0 is intended to be a solid, concrete basis that communicates the main assumptions on which the project is based.

This first scenario served to create a solid base, on which to layer all the design hypotheses proposed in subsequent scenarios. Its function is to describe the context within which the spatial settlement project proposed by this thesis is to be placed.
Scenario 0 acts as a connection between the description of current conditions set out in the previous chapters and the desired future conditions. It attempts to analyse what happens in this time span between the present and 2041, the date proposed as the start of work on the project.
The analysis moves between the real and the figurative plan, trying to define players, documents, actions and project repercussions.
An attempt has been made to outline a future scenario by identifying the actors who will be involved from now until then, how it will interact with the present, and what kind of spatialisation it will require.
Design is understood as a succession of production and exchange phases.

Scenario 0

Context

2.1 Scenario 0 - *context*

2.1.1 Players

Many skilled parties have turned their attention to the Moon. Unlike the early space race, space exploration is no longer solely limited to Nations with their respective space agencies; private players have also entered the game.
Brent Sherwood (2016) put forward a compelling conjecture of a forthcoming scenario during the Sixty-Seventh International Astronautical Congress. This concept provides categorization of different stakeholders, facilitating the envisioning of future assets.

The first group is composed of four main "nations": USA, China, Europe and Russia.
Each of these nations has substantial spaceflight firms which are able to build, launch and sustain habitable lunar spaceflight systems. These abilities render them well-suited to serving as pioneers in the pursuit of lunar settlement, either on their own or in partnership with others. Their economic, technical, and political potential designates them as significant participants in the formation of spatial settlements. Consequently, each of these four nations could compete, collaborate, or surpass each other's projects if motivated.

Then there is the second group called "supporters". This group includes all states with space programmes, such as Japan, Canada, India, Korea, Brazil, and the United Arab Emirates.
They showcase a combination of experience in interplanetary or lunar orbital missions, partnerships with the ISS, experience in launching missions, lunar mission ambitions and plans, and related interplanetary mission capabilities. None of them have the capacity to inspire or establish a settlement. However, utilising space travel as a driving force for technological advancement, public motivation, and showcasing of skills, they would probably engage in multinational lunar endeavours initiated or guided by external parties, leveraging their distinct skill sets.

Finally, there is the third group known as "industrials".
This group is composed of private companies.
Currently, the private sector is at the forefront of pursuing financial gain and contributing to the "new space economy". (Piloto 2023)
Indeed, an important factor of the space economy is that it involves not only large aerospace companies such as Lockheed Martin, Northrop Grunman, Arianespace, Boeing or Airbus, but also many new companies such as those of Elon Musk, Jeff Bezos or Richard Branson, people who have made fortunes in other sectors but who have recognised the potential of the space economy.
Oldspace companies tend to have established relationships with traditional government customers, and established supply-chain networks. Responsibility to shareholders and business inertia constrain them to follow their customers' money and interests, including lunar activities that may be pursued by Groups I or II.
Instead, new space companies are typically motivated by a combination of charismatic vision, commitment to disruptive principles, and the potential for breakthrough profits from new customers and new markets.

Undoubtedly today, space tourism is a burgeoning industry valued at $1 billion, representing just a small fraction of the overall space economy, which is worth almost $ 400 billion. The satellite industry accounts for three-quarters of this value and will continue to expand with the planned launch of 15,000 new satellites in the next decade, making it an increasingly coveted market. Moreover, space travellers are keen to establish themselves in this economy, which is projected to be worth £1.1 trillion by 2040. (ISPI 2021)

For lunar settlement, the key feature of industrial space companies is that they will increasingly be able to reach the Moon on their own, outside the scope of government projects.
All three groups of players are most likely to participate in a lunar village, and the precedent of mixed-use commercial areas (Sherwood 2017) on Earth implies that all three would probably be indispensable.
Scherwood (2016) makes an interesting prediction:
Group I could make primary investments to eliminate major technical risks, and build shared infrastructure and anchor service markets; Group II could provide technical specialities and functional redundancies and promote multinational cooperation and standards of conduct; and Group III could provide services, early profit thinking and disruptive innovation.
However, to enable Moon's settlements long-term growth, only the III group could attract or leverage private capital beyond government-sponsored budgets. If all three groups of actors are indeed essential for the sustainable growth of the settlement, then their respective requirements and expectations are also essential: concepts, plans, operating environments and standards must take this diversity into account in order to create a viable, sustainable lunar settlement.

2.1 Scenario 0 - *context*

2.1.2 Road to 2041

As can be seen above, plans for the realisation of a settlement on the lunar surface will begin in the late 2020s.
The project of this thesis involving a tourist infrastructure, could fit into this context from 2040 onwards.
Considering that it would probably take a few years before the main infrastructure is built and the economic conditions are in place for space tourism trips to be financed and sponsored by private actors.
As a hypothesis, based on the available information, and mainly from Sherwood's paper (2016), it is possible to assume that:

Phase I [exploration]

In the period **2024-2028**, the main space agencies in Groups 1 and 2 will coordinate a series of major activities mainly related to lunar exploration.
Private actors have already joined these initial stages as they can offer essential resources such as transportation means and pressurised rovers.
Between **2028 and 2030**, actors such as ESA, the USA and China plan missions that will result in the construction of the first lunar outpost. This will be a class I module, i.e. fully fabricated, integrated and ready for use when delivered into space.
At this stage, a possible critical issue could arise due to the known rivalry between the USA and China as both plan to build the lunar settlement.
In this context, the **ESA** could be the needle of the scales and impose itself to stimulate a climate of **international collaboration.**

Phase II

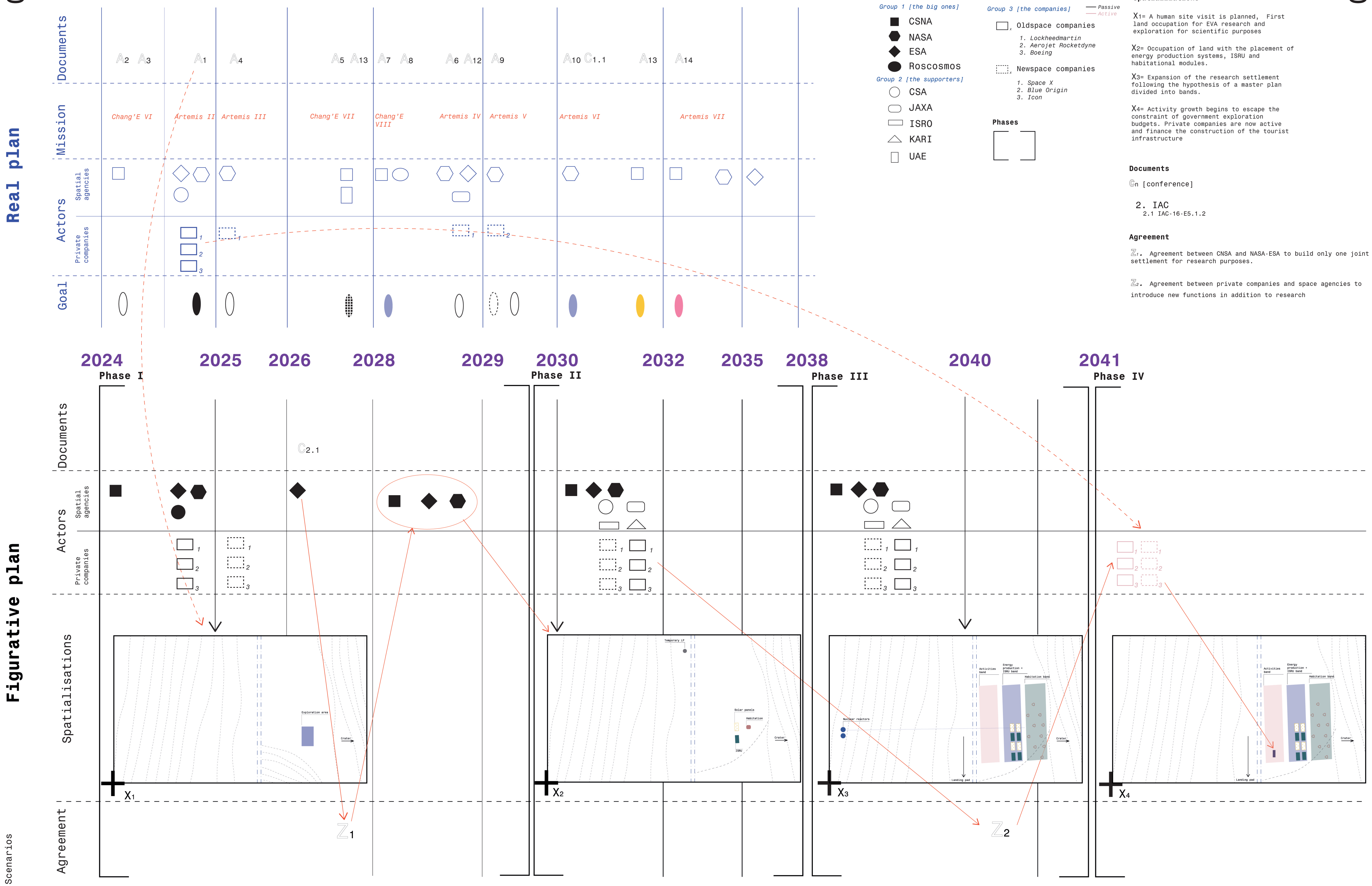
In this scenario, it is hypothesised that China is actively involved in the implementation of the 'Moon Village' project proposed by ESA in collaboration with NASA. The objective of the project is to construct a research base with living quarters for astronauts, as well as laboratories.
From **2030 to 2035** these years are aimed at the infrastructure of the lunar territory, first the transport of pressurised rovers from Earth, and 3D printing machines. In any case, research activities will continue within the outpost. By the end of these years, energy and water infrastructure, roads and landing pads will have been built.
From **2035 to 2038** The main infrastructure is in place and the class II modules are being transported in situ. The last phase will involve the realisation of the regolith shielding by means of 3D printing of the modules. The ISRU areas are being equipped.
In the early stages, activities are closely linked to the budgets provided by space agencies for exploration.
Architecturally speaking, transporting prefabricated modules from Earth poses a size limitation, thus requiring adaptation to the capacity of transport means such as Orion, Dragon, and CST-100.

From a geopolitical and economic standpoint, the most powerful nations negotiate with emerging governments in Group II. Simultaneously, they allocate necessary services as competitive opportunities for various companies in Group III, including Oldspace and Newspace.

Phase III
From **2038 to 2040**, although activities remain tied to the available budgets of Group I and II governments, the space architecture expands involving in-depth master plans and first settlement expansions.

Phase IV
From **2040 onwards**, given the success of research activities as well as resource extraction on the Moon, private actors are motivated and begin to finance projects involving the tertiary sector such as lunar tourism.
The settlement, which began as a place exclusively for scientific research activities, expands and begins to embrace a broader range of functions.

"In the beginning, people will only go to the Moon for a week, but future Artemis missions will establish people there for a month or two. Eventually, permanent settlements will be made" (Schwaller 2022)



Group 1 [the big ones]

- CSNA
- NASA
- ESA
- Roscosmos

Group 2 [the supporters]

- CSA
- JAXA
- ISRO
- KARI
- UAE

Group 3 [the companies]

Passive
Active

Oldspace companies

1. Lockheedmartin
2. Aerojet Rocketdyne
3. Boeing

Newspace companies

1. Space X
2. Blue Origin
3. Icon

Phases

Spatializations

X_1= A human site visit is planned, First land occupation for EVA research and exploration for scientific purposes

X_2= Occupation of land with the placement of energy production systems, ISRU and habitational modules.

X_3= Expansion of the research settlement following the hypothesis of a master plan divided into bands.

X_4= Activity growth begins to escape the constraint of government exploration budgets. Private companies are now active and finance the construction of the tourist infrastructure

Documents

C_n [conference]

2. IAC
   2.1 IAC-16-E5.1.2

Agreement

Z_1. Agreement between CNSA and NASA-ESA to build only one joint settlement for research purposes.

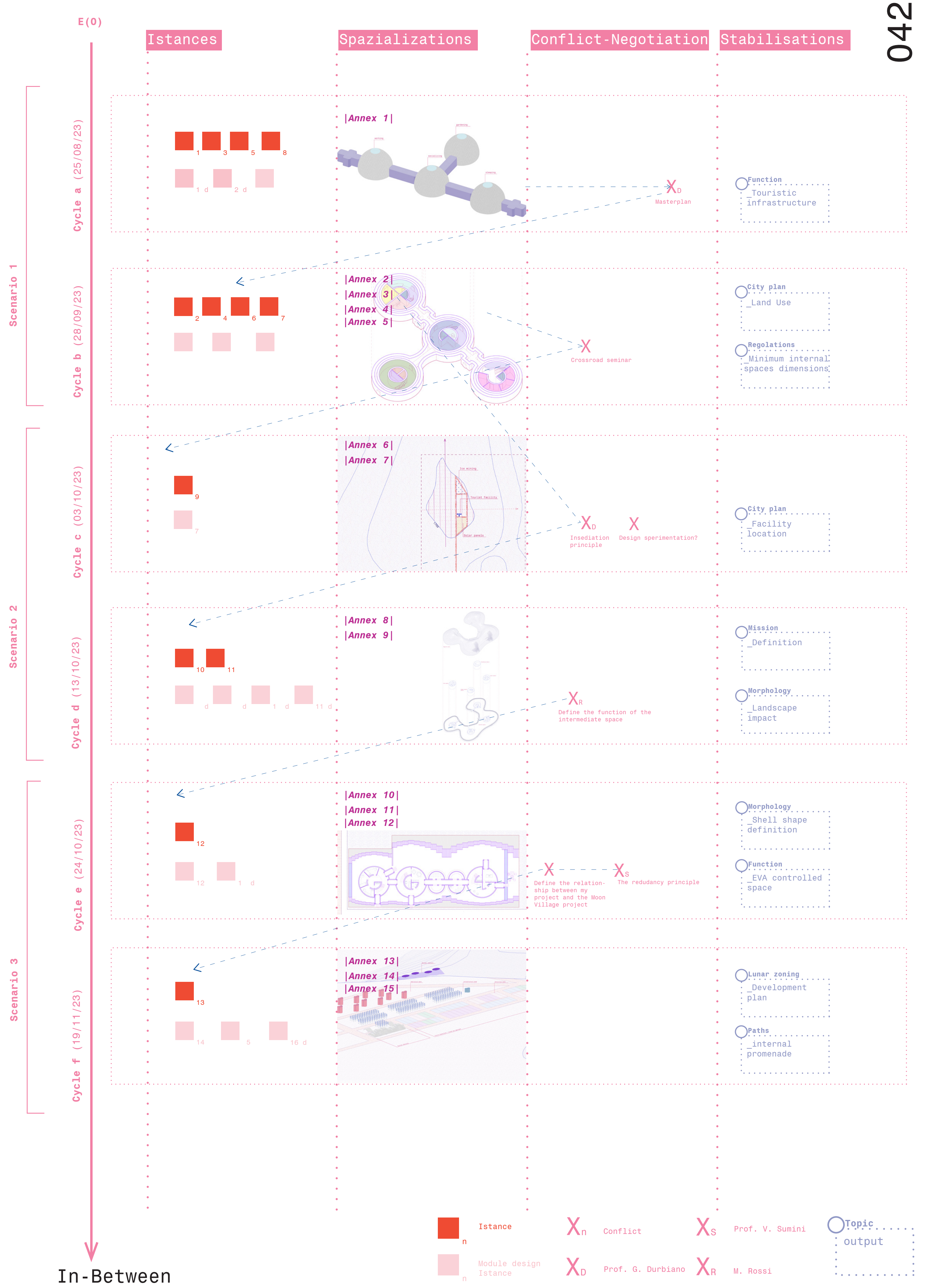
Z_2. Agreement between private companies and space agencies to introduce new functions in addition to research

In-Between

2.1 Scenario 0 - *context*

2.1.3 Trace

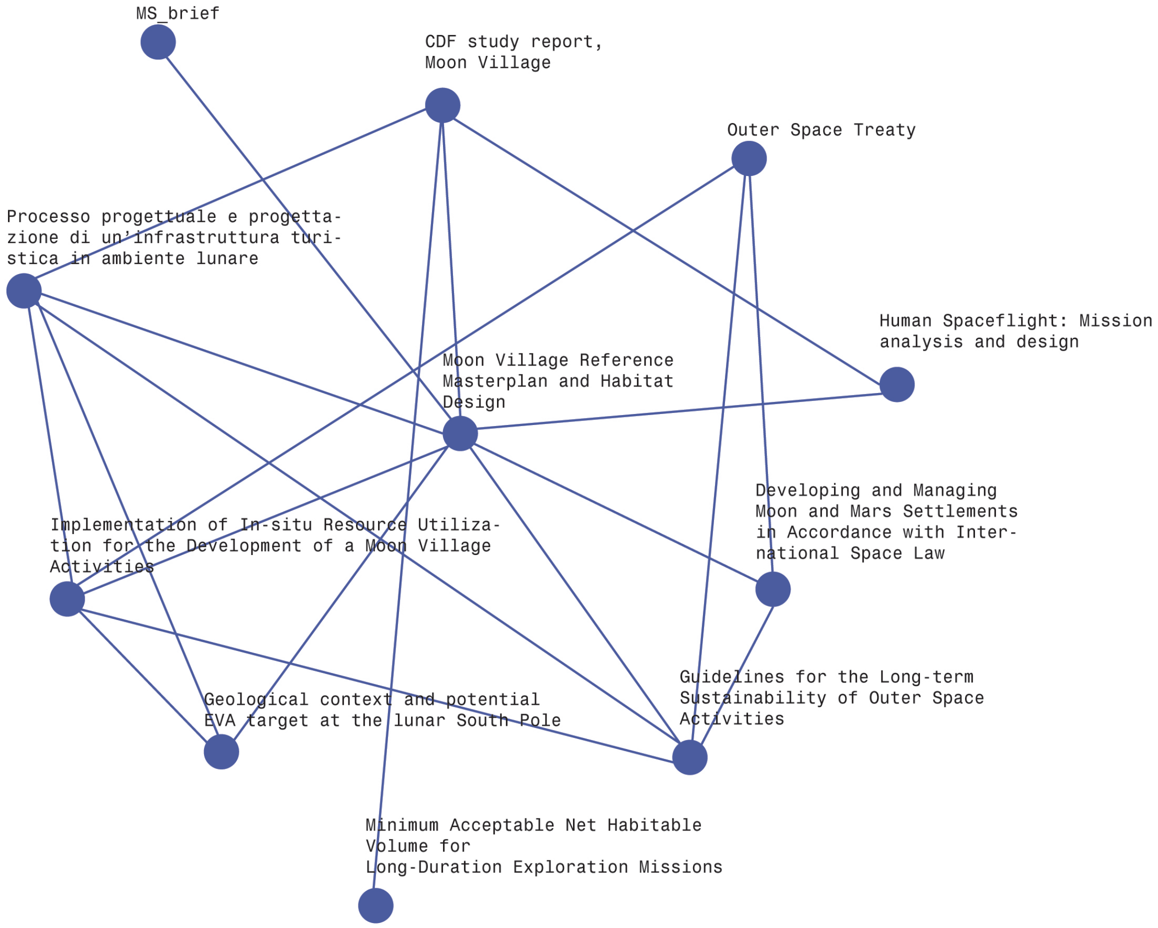
Architectural project springs from a process and its traceability is fundamental. The graph presented here is a reinterpreted version of the Shenzen's diagram (Armando et al 2015). Its purpose is to narrate and describe the currents lying under a static design drawing, highlighting the controversies leading to its evolution in time and space. Mapping such controversies enables us to comprehend the dynamics guiding a project while following the actor network theory approach (Yaneva & Heaphy 2012). This theory enables us to discover, understand, analyse and finally map the variety of elements that make up a building, as well as the variety of elements that interfere with the design. The purpose of these maps is to demonstrate the approach that leads to the final project development. The development narrative is shaped by ongoing project reassessment, an iterative process that is subject to a range of factors and is motivated by the growing project collective. Differences in direction arose due to interruptions from educators, co-trainers and the fortuitous discovery of new source materials. The formulation of each project hypothesis sparked a chain reaction, leading to the identification and acquisition of crucial project components that are able to stabilize within the process and in most cases overcome cycles of discussion. It is advisable to study this chart in conjunction with the instance overview, as each square denotes a unique moment. The instances are divided into two primary categories: general instances and module design instances. This method enables an evaluation of a space's potential in relation to a particular moment and circumstances, facilitating the determination of the viability of the suggested strategy.



Scenario 1

From instances to spatializations

2.2 Scenario 1 - *from istances to spatializations*



The initial project scenario was formulated from July to September 2023, after conducting several document searches in the preceding months.
This scenario was developed after a series of dialogues with the thesis group, who expressed the need to identify particular instances within the earlier located documents.
The instances that were found inside the documents served to point out some fundamental elements that in this first draft were crucial.
The scenario has emerged from two cycles of discussion within the thesis collective and has yielded a set of multi-scaled documents. These documents effectively represent design decisions that pertain to both design and urban planning instruments, some of which have not yet been officially established on the Moon.

Instances overview

1) Unnecessary duplications of functions and efforts *[C.3.3, Guidelines for the Long Term Sustainability of Outer Space Activities]*

2) Positioning of possible EVA points of interest *[Geological context and potential EVA targets at the lunar south pole]*

3) Safety: it requires that there should be a number of interconnected and individually pressurised elements. (two egress for each element in case of emergency) *[Moon Village Reference Masterplan and Habitat Design]*

4) Efficiency: since the settlement is far away from the Earth is necessary to optimise the lengths and number of connections of all infrastructure elements, such as pipe, cables, and ducts. *[Moon Village Reference Masterplan and Habitat Design]*

5) Expandability: requires that the pattern of development be easily repeatable and expandable without compromising the qualities of the structures that have already been completed. *[Moon Village Reference Masterplan and Habitat Design]*

6) Landing pad 1.5 km from the habitat to prevent debris during landing and take-off from hitting the settlement. *[Implementation of In-situ Resource Utilization for the Development of a Moon Village]*

7) The issue of cost-effectiveness: the possibility of having the settlement in close proximity to facilities that extract ice and transform it into water and oxygen would limit costs and lead to infrastructure collaboration. *[Developing and Managing Moon and Mars Settlements in Accordance with International Space Law]*

8) Prohibition of the permanent appropriation of a part of the lunar territory considered a good of mankind and therefore not appropriated *[OST]*

1 d) Ladders take up less space than stairways, but they might pose problems with safe translation between levels when injured or carrying items. In case a ladder is used for vertical translation of the crew, options to move items without them being carried (such as a small elevator) should be provided. The stairs should have an inclination, ideally between 67°and 78°. *[CDF, Study Report Moon Village]*

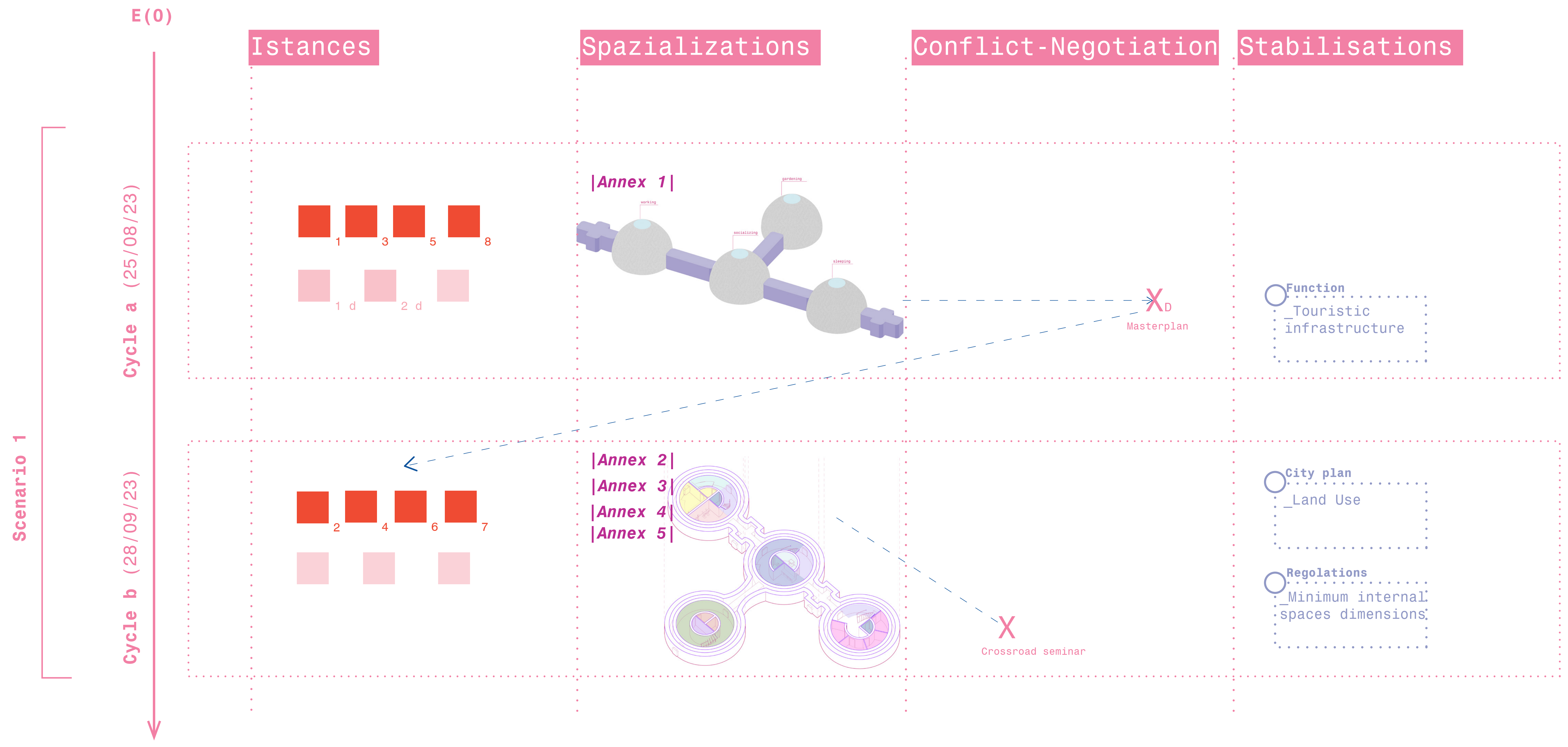
2 d) Inflatable structures are found to be insufficient for radiation protection. Protection against solar particle events will need to come from additional layers of e.g. water or regolith, as well as optimization of internal equipment placing (e.g. move beds to lower floor), or moving the ground floor below the lunar surface. *[CDF, Study Report Moon Village]*

3 d) An investigation is proposed to study 2-floor modules of maximum 28.6T Mass (possibly tobe integrated on lunar surface) *[CDF, Study Report Moon Village]*

4 d) Given the varied functions necessary in the habitat, the crew size and the long duration of the surface mission (500 days) a minimum net habitable volume of about 80 m^3 per person is recommended.*[CDF, Study Report Moon Village]*

5 d) Individual private quarters are to be provided for each crewmember (5.4 m3) *[Minimum Acceptable Net Habitable Volume for Long-Duration Exploration Missions]*

6 d) Dining: Minimal volume assumes sufficiently large space to simultaneously fit all members, so that all can dine together, as well as sit together to view video or participate in a team event *[Minimum Acceptable Net Habitable Volume for Long-Duration Exploration Missions]*


E(0)
Istances
Spazializations
Conflict-Negotiation
Stabilisations
Scenario 1
Cycle a (25/08/23)
1
3
5
8
1 d
2 d
|Annex 1|
X_D
Masterplan
Function
_Touristic infrastructure
Cycle b (28/09/23)
2
4
6
7
|Annex 2|
|Annex 3|
|Annex 4|
|Annex 5|
X
Crossroad seminar
City plan
_Land Use
Regolations
_Minimum internal spaces dimensions


Istance
Module design Istance
X_n Conflict
X_D Prof. G. Durbiano
X_S Prof. V. Sumini
X_R M. Rossi
Topic
output

2.2.1 cycle a

Framing

The initial spatialisation proposal for cycle a, was developed between June and July 2023 after extensive prior research.
The objective of the designed settlement, which will serve as a tourist destination, is to provide accommodation for a total of ten individuals, including three staff and seven visitors. The decision to attribute this function to the settlement was not accidental, but stems both from a previous master's thesis on the design of a tourist infrastructure in a lunar environment (Alongi et al. 2022) and from the analysis of a series of supporting documents.
Notably, during the investigation of functions explored by other projects within the same field, such as the Moon Village project (ESA 2020) and Project Olympus: The Lunar Lantern (ICON and SEArch+ 2020), it became evident that these projects primarily focused on research, particularly in their initial stages. To avoid redundancy of functions, which aligns with one of the key recommendations outlined in the conference room paper on guidelines for the long-term sustainability of space activities (UNOOSA 2018), and to leverage the increasing interest from private entities in the space economy (Aresu & Mauro 2022), the choice of the tourism function was considered the most appropriate (Leach 2014).

These reflections prompted a reconsideration of the timeline. It is indeed more appropriate to introduce, this type of tertiary function not in the early stages of lunar settlement, but during a later phase.
The initial hypothesis suggests a potential start date for the tourist facility's construction around 2040 and, notably, envisions that some of the visitors, especially the crew, may stay for an extended duration, approximately 300 days.
It was determined that a Class II module, which is a module constructed on Earth and assembled on the Moon, would be employed. An example of such a module would be inflatable structures, as exemplified by Yashar et al. (2021).
The CDF document by ESA (2020) highlights that the inflatable layer which forms the module is inadequate in shielding it from radiation for extended periods, with a maximum lifespan of three months. As a result, an additional protective outer layer is necessary.
This is especially important in a challenging lunar environment characterized by ultra-high vacuum, cosmic radiation, extreme temperature fluctuations, and frequent meteoroid impacts, where the construction of reliable shelters is essential, as emphasized by Cai (2019).

The CDF study report, published by the ESA in 2020, proposes two approaches to address the problem.
Firstly, the use of various materials for outer layers and secondly, the possibility of underground solutions. However, the second option could lead to legal complications, even if it is technically effective. According to the Outer Space Treaty (UNOOSA 1966), particularly Article II, this is declared. " Outer space, including the moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means." Therefore, it can be surmised that an invasive excavation approach, as previously described, may pose issues regarding the secure acquisition of lunar land.

This is why, at the design stage, the preference was to remain above ground and choose less intrusive solutions. So it was preferred to adopt the first proposal solution and adding an other layer such as regolith or water.
Nevertheless, the use of water is not considered appropriate as it would be illogical to use it on site, considering its essential role in sustaining the inhabitants. The transport of water from Earth would involve additional journeys, resulting in increased cost and time.
Regolith, on the other hand, is a material that is available in abundance at the site and allows for significant savings in terms of time and cost. It can be used either in pockets within the module's inflatable fabric or sintered (Han 2022) to form protective outer walls.

The concepts mentioned above introduce a fundamental idea that will carry significant weight throughout the thesis: In-Situ Resource Utilization (ISRU). ISRU involves the utilization of local natural resources at mission destinations, rather than relying solely on supplies from Earth, with the aim of enhancing human exploration capabilities. This entails demonstrating technologies for utilizing the Moon's resources to produce water, fuel, and other essential provisions, while also developing the capacity to excavate and construct structures on the lunar surface. (Dunbar 2023)

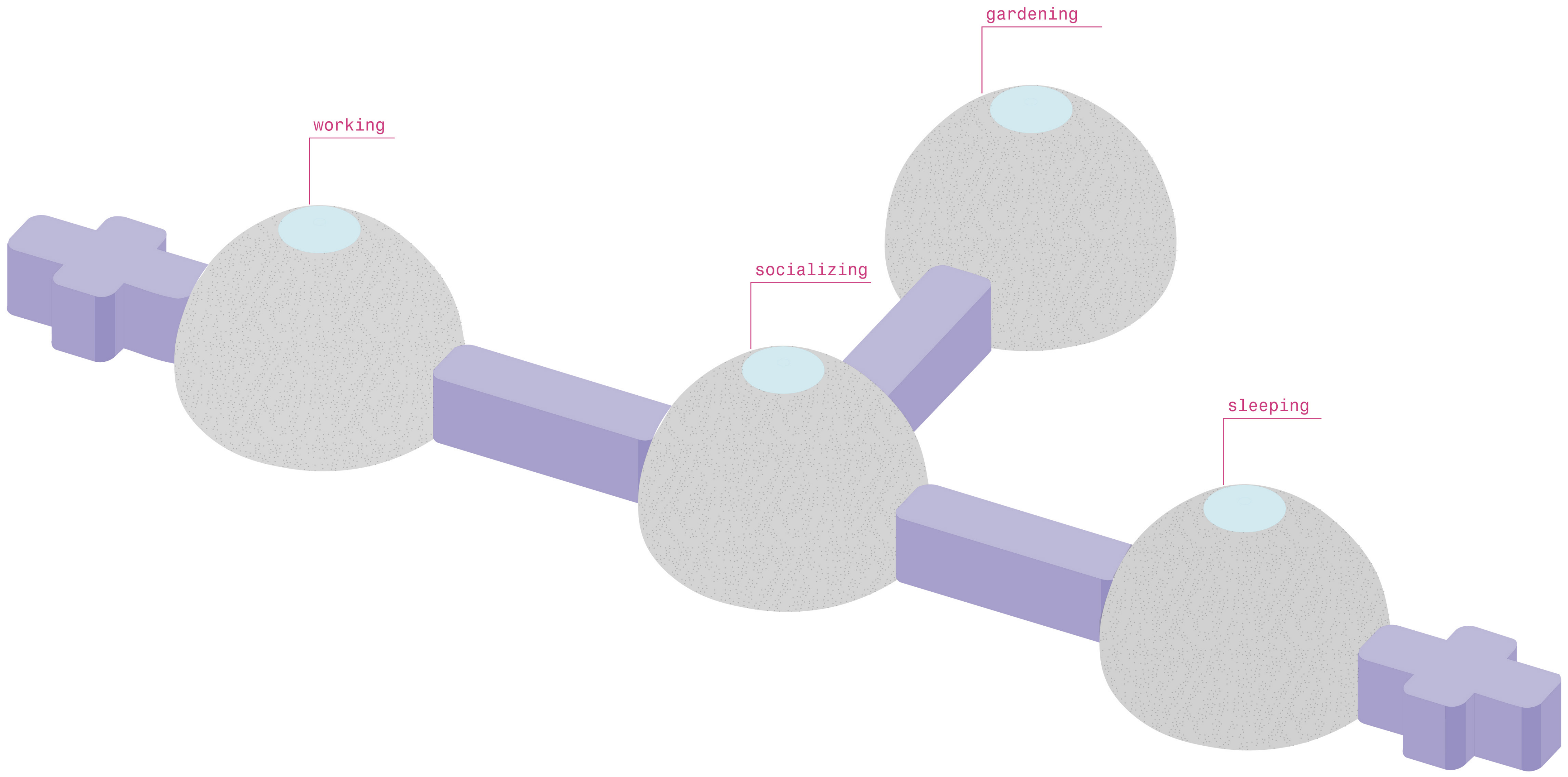
2.2.1 cycle a

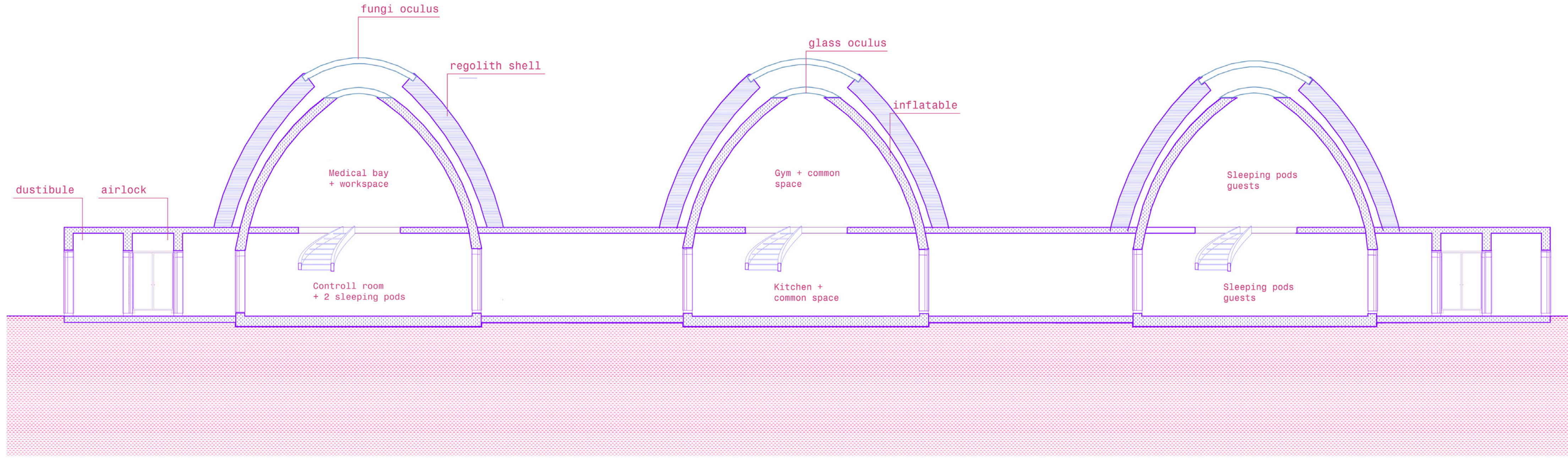
Framing

The functions proposed in this design hypothesis were distributed among four modules to create a comfortable, spacious, and secure environment for both the crew and guests. This approach was necessitated by the limitations of available means of transportation, which cannot accommodate modules large enough to encompass all the required functions. This observation aligns with a point previously noted by Bodkin et al. (2006) in their paper, 'A Solution for the Lunar Surface Base and Infrastructure.'
Each module, comprising two above-ground floors, was designated for a specific purpose: work, socializing, sleeping, and cultivation.
From the outset, one of the primary goals of this thesis was to ensure adequate living space, promoting both shared communal areas and appropriately sized private spaces.
An effort was made to provide more space and make comparisons between the minimum room and space dimensions on Earth and those previously adopted in long-term lunar settlement projects such as the International Space Station, the Lunar Lantern and the Moon Village.

The module layout placed the communal space, intended for all settlement inhabitants, at the center, with direct connections to the other three modules.
To ensure safety, each module needed to get pressurised and isolated.
The connection process was carried out using two types of airlocks: one for internal-to-external movement, where "external" denotes the lunar surface, and the other for internal-to-internal transit, essentially forming a hallway that lets occupants move freely without the requirement for spacesuits.
A filtration zone is required between the interior and exterior of lunar habitats to protect both human occupants and equipment from lunar dust, which has been found to be harmful. According to the European Space Agency , during the Apollo 17 mission, (ESA 2018) contact with lunar dust caused sore throats and watery eyes among astronauts.

The design of the habitats also incorporates natural light sources to ensure comfortable living conditions. An oculus was installed at the top of each module.
The oculus in the inflatable inner shell was made of glass, while the one in the outer shell was constructed of a material called "Fungal mycelium."
As mentioned earlier, safeguarding against radiation is of utmost importance because openings in the protective layer can elevate vulnerability to radiation.
Although various materials can be used to shield against radiation, some substances, such as the fungal mycelium, have the dual capability of offering protection and allowing natural light to pass through.
However, the initial concept had limitations as it didn't allow for external visibility, given that the fungi only facilitated the transmission of light.





IN - DEPHT

Fungal Mycelium

As seen in the design drawings, one of the materials used is fungal mycelium.
The concept of “mico-architecture” (Rothschild et. al 2018) is an evolving phenomenon, thanks to the studies conducted by Lynn Rothschild.
To create a structure using mycelium, a mold of the desired shape is designed. The mold is then filled with a growing medium for the mycelium to feed on, and nutrients are added. The mycelium naturally binds to the medium within the mold and fills out the structure as it grows. If the final product is baked after the growth period, it becomes a hardened material suitable for making housing, tables, and chairs.

On Earth, a flexible plastic shell produced to the final habitat dimensions would be seeded with mycelia and dried feedstock, and the exterior would be sterilized. Upon arrival at the destination, the shell could be configured to its final interior dimensions using struts. The mycelial and feedstock material would be moistened with Martian or terrestrial water, depending on mass trade-offs, and heated to initiate fungal (and living feedstock) growth. Mycelial growth would stop when the feedstock is consumed, heat is withdrawn, or the mycelia are heat-killed. If additions or repairs to the structures are necessary, water, heat, and feedstock can be added to reactivate the growth of the dormant fungi.
This material is also advantageous due to its cost-effectiveness and ease of use.

One example of the use of this material, albeit in an integrated manner, is by Redhousestudio in the Mars Habitat project. (Scarano 2022)
Another example is from Mino Architettura (De Angeli 2020), where an habitat is created with three layers composed of ice, organisms, and mycelium. The organisms would receive filtered light from the first layer of ice and transform it into carbon dioxide and oxygen. The mycelium, on the other hand, would ensure structural integrity and regulate internal humidity.

Image credits: RedHouse Studio (Mars Habitat – Redhouse, n.d.)

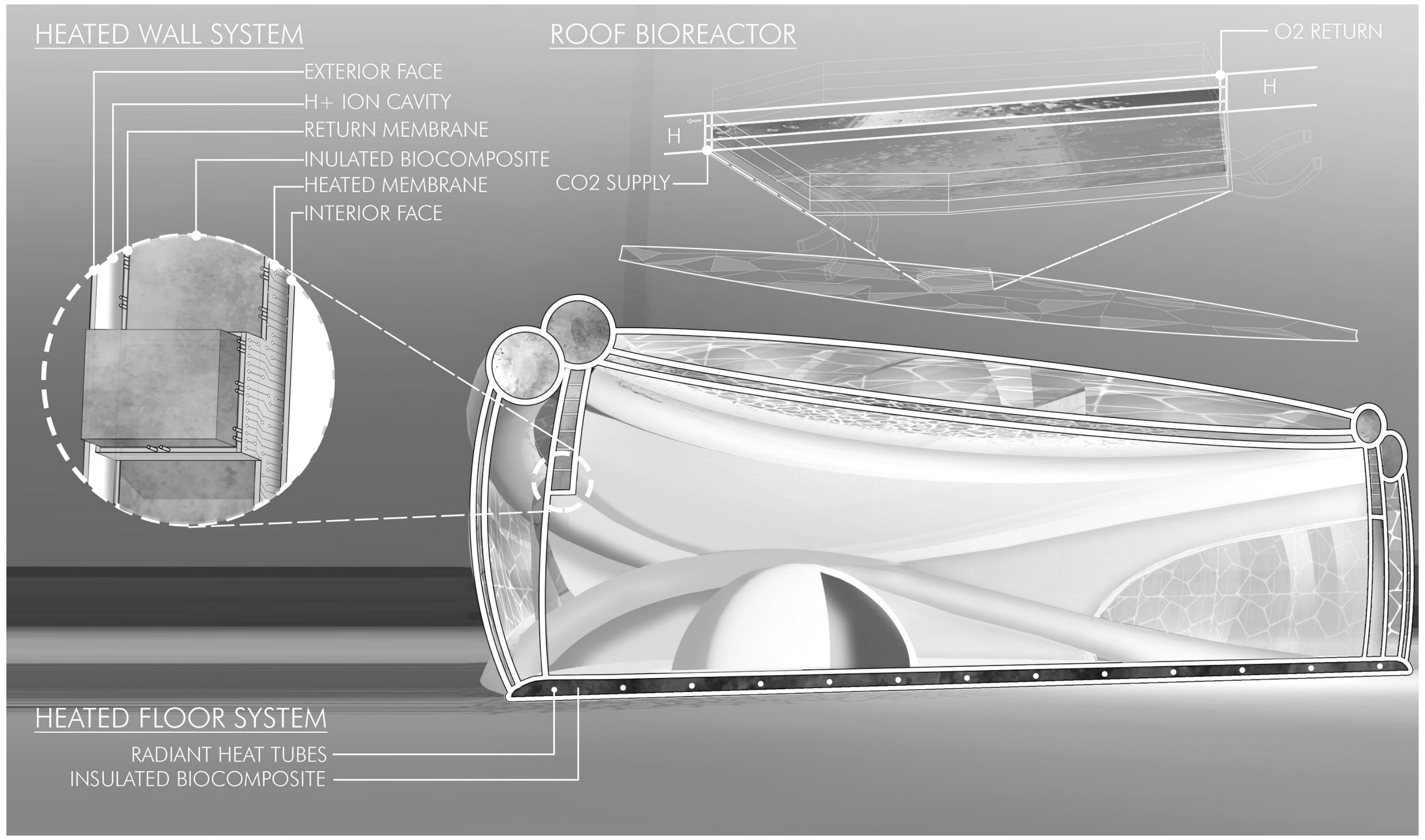
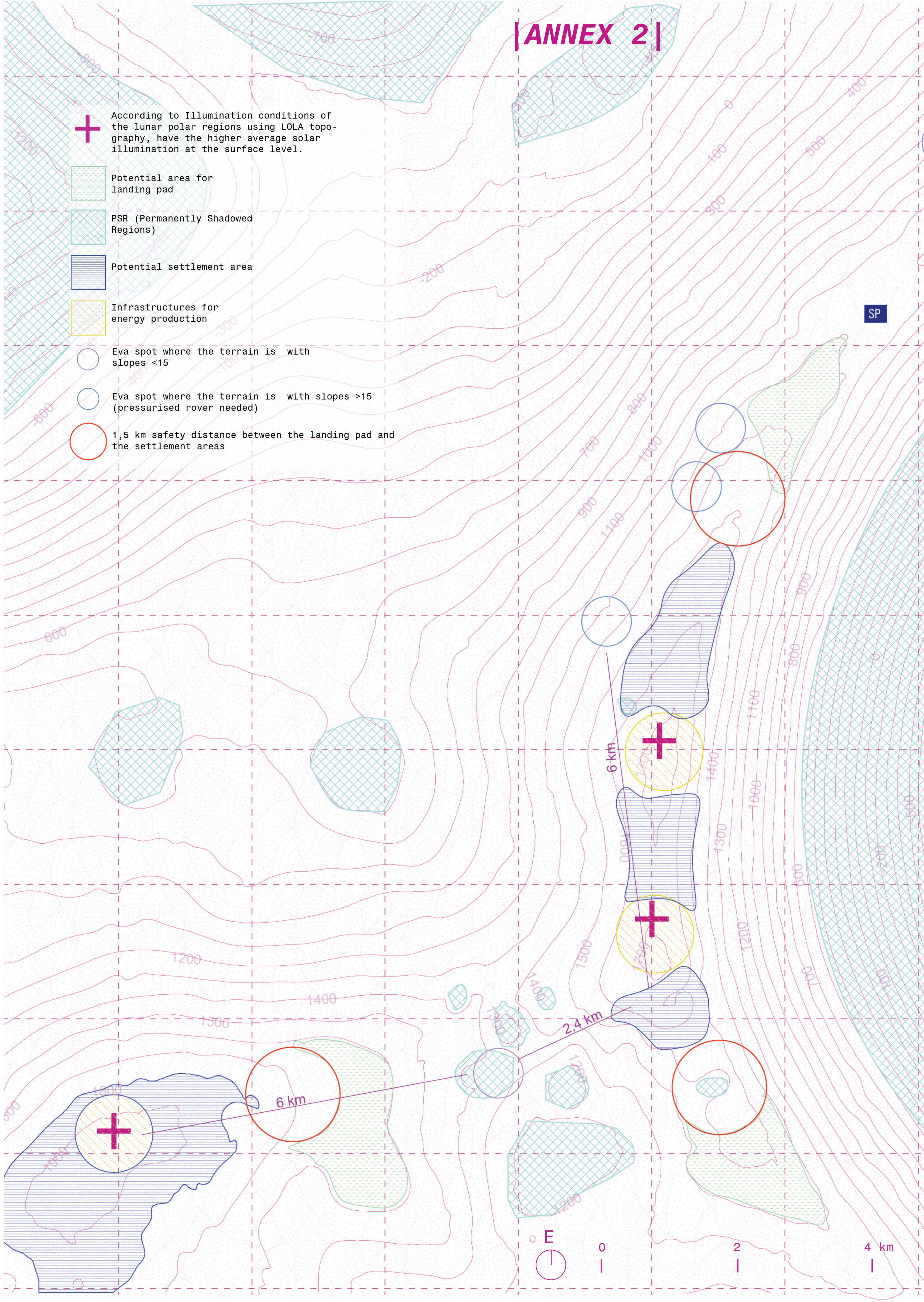


Image credits: RedHouse Studio (Mars Habitat – Redhouse, n.d.)

2.2.2 cycle b

Land Use

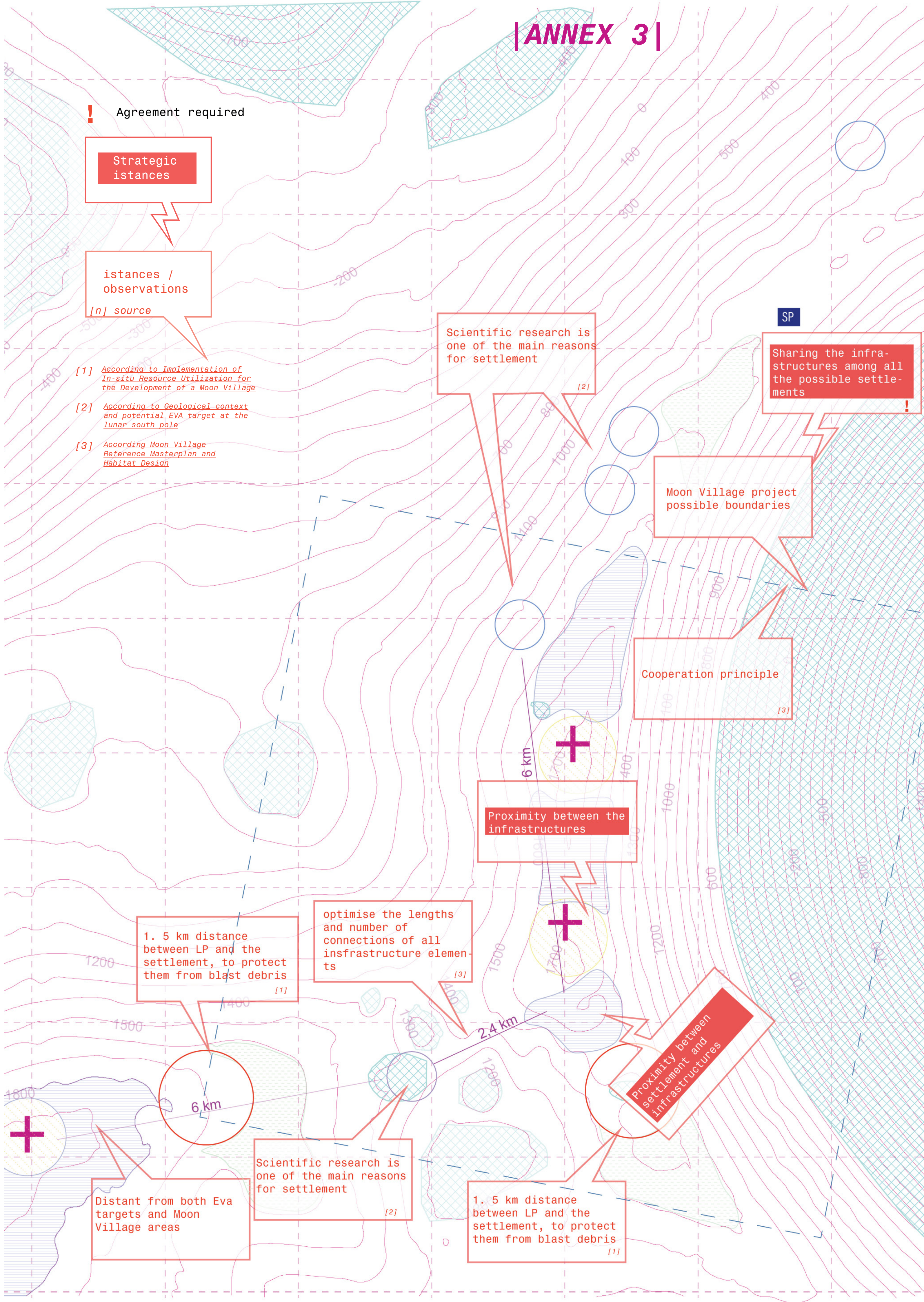
Following the initial meeting with the thesis collective, it was observed that the first project hypothesis lacked a clearly defined location and a masterplan capable of accommodating various components. Therefore, as an initial step, it was deemed essential to generate a map **[Annex 1]** that would classify areas on a territorial scale.
Even in these early stages, there was a need to employ tools related to terrestrial planning and modify them by altering the assumptions that underpin them.
The goal was to explore how tools for terrestrial spatial governance could be adapted for this context. Given the area's significant appeal, largely due to its physical characteristics (D'Ottavio 2021), this map aimed to outline areas suitable for specific functions based on their physical and morphological attributes.
The categorization resulted from the analysis of various compiled documents. Notably, Mazarico's study (2011) and Glaser's study (2014) played a crucial role in pinpointing areas with optimal lighting conditions.
Simultaneously, Gawronska's research (2020) assisted in assessing the geological conditions of the areas and identifying those suitable for extravehicular activities, EVA (Mars 2023).
The analysis covered a substantial portion of the Shackleton crater rim, extending to include several adjacent areas deemed fitting for diverse functions such as settlement, energy production, and research.
This comprehensive examination aimed not only to identify prime locations within the Shackleton crater but also neighboring areas that could contribute to the overall objectives of the project.



2.2.1 cycle b

Geolocalised instances

The analysis of instances concerning mainly physical and geopolitical aspects was then transformed into spatialisation.
The map opposite brings together the information gathered during the construction phase of the land-use plan with the instances that are spatialised.
After a process of geo-location of the instances, a specific location for the tourism facility was identified.
Alongside physical and morphological conditions, other aspects concerning geopolitical and strategic dimensions were also taken into account.
One particular aspect significantly influenced the precise location choice for the infrastructure: cooperation.
The Moon Village project, proposed by the Director General of the ESA in 2015 (Wörner 2015), prioritises international cooperation. To align with this project, the tourism infrastructure was positioned near the designated area for its realisation. The goal was to bring together a planned project with this thesis project.
This collaboration would not only authenticate and legitimate the thesis project but also foster an atmosphere of cooperation and collaboration, potentially leading to the sharing of vital infrastructures. This method would help to circumvent needless duplication of efforts and tasks.
Nonetheless, aligning with a project that is already in progress can be challenging due to the lack of precise information regarding the positioning of the Moon Village, beyond its potential boundaries **[see to Annex 2]**.

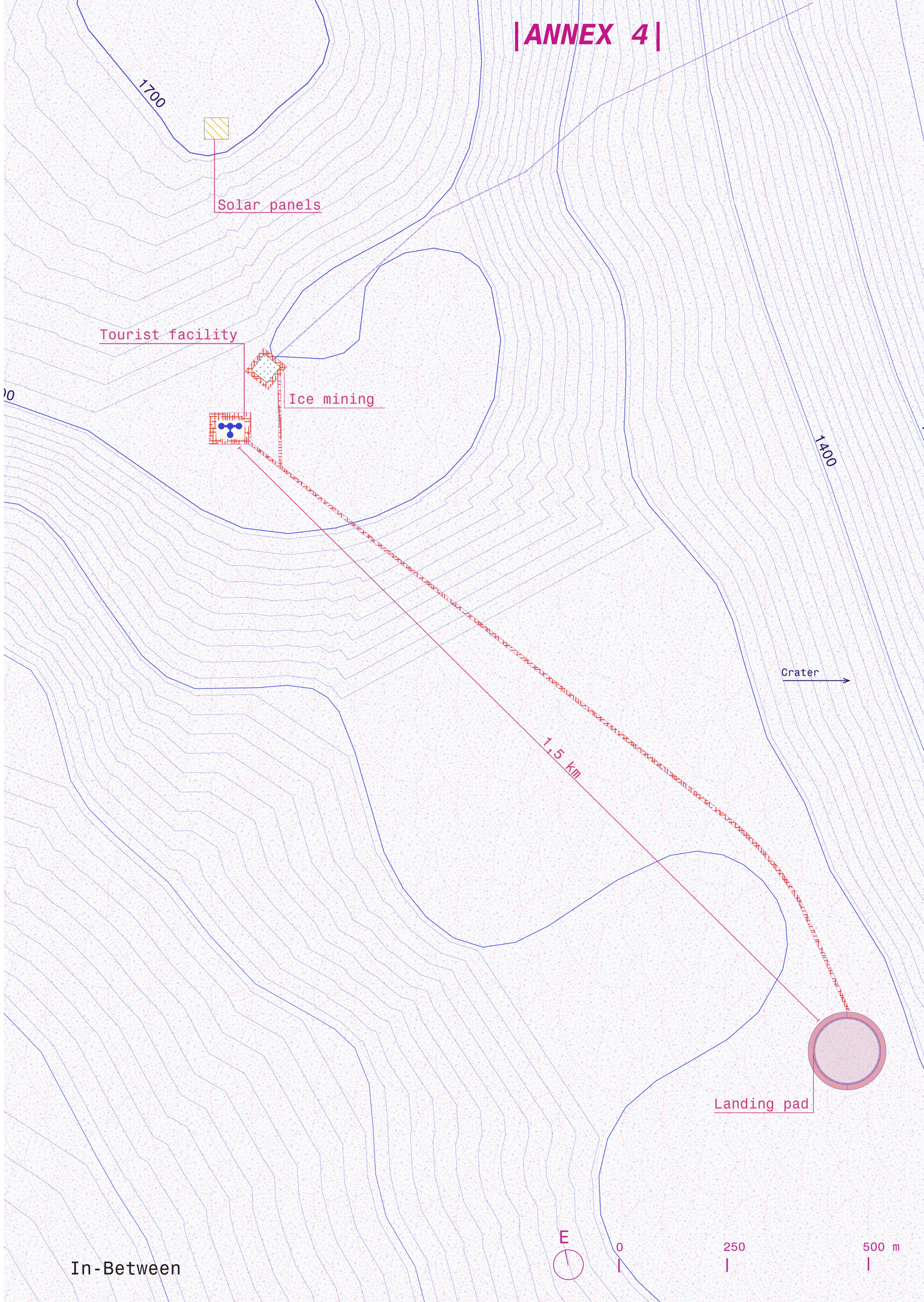


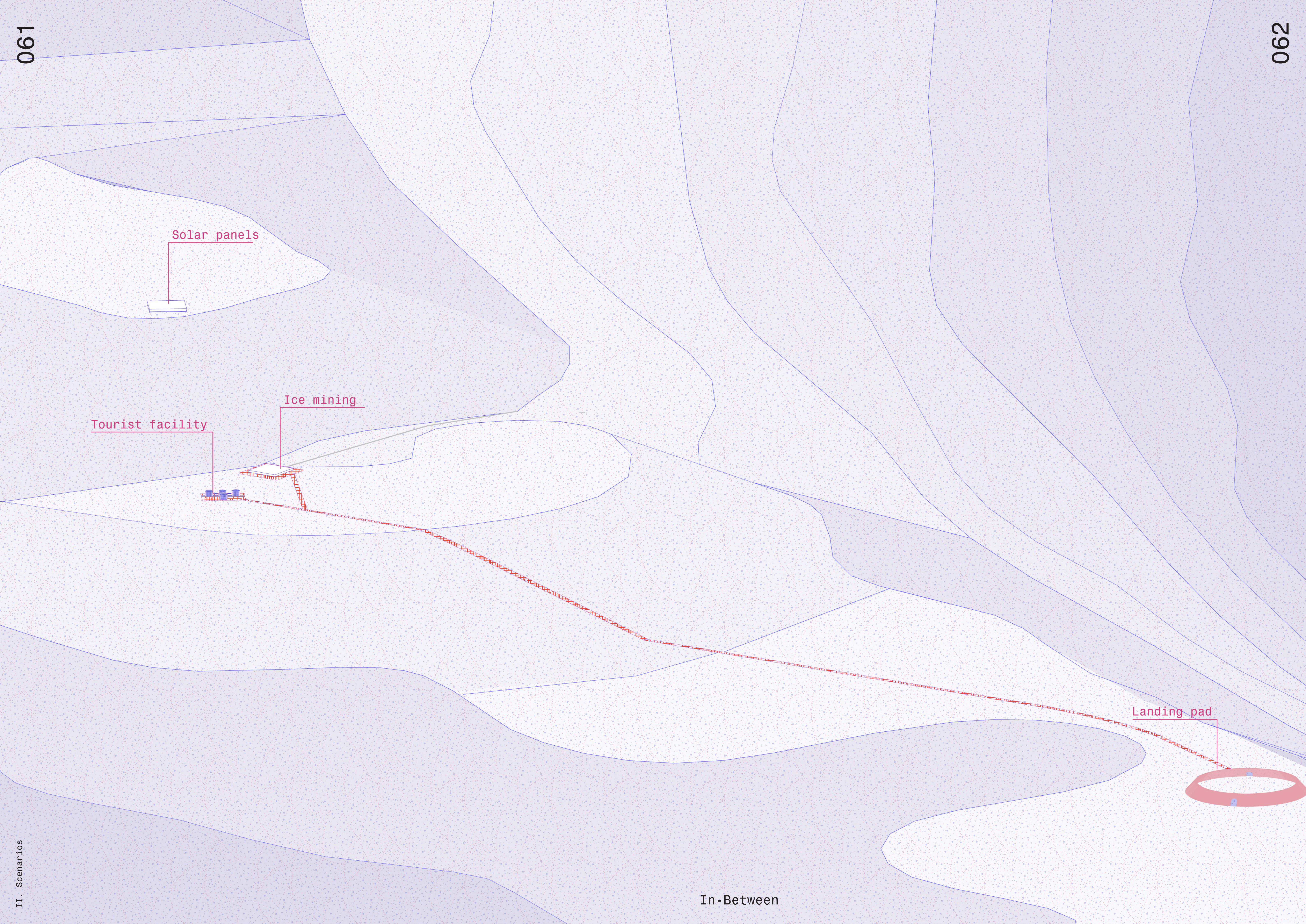
2.2.1 cycle b

Masterplan

Therefore, at this stage, not being aware of the specific location of the main infrastructures such as the landing pad, the solar power plant and the ice extraction plant, it was decided to proceed with their design and positioning.
In particular, following as basic principles for the landing pad the information found in the document Project Olympus: Off-World Additive Construction for Lunar Surface Infrastructure (Yashar et al. 2021).
From the aforementioned document, it can be deduced that lunar landing pads would benefit from being close to infrastructure elements because this would allow for the safe and efficient unloading of goods, people and resources. While proximity between infrastructures would increase operational efficiency, standoff distances would ensure the safety of habitable and occupiable structures. Not only must the standoff distances be large enough to protect the outpost facilities from damage caused by rocket plumes, but also from the acceleration of dust particles during landing and launch.

Due to the potentially severe damage to hardware caused by high-speed dust impacts, exclusion zones are of extreme importance. Larger landers may require greater exclusion distances, and sensitive equipment may require additional prohibition specifications.
These distances remain a critical constraint in site planning. Current research is still unable to define safe landing distances, although NASA guidelines define an arbitrary exclusion zone of 1.5-2 km.



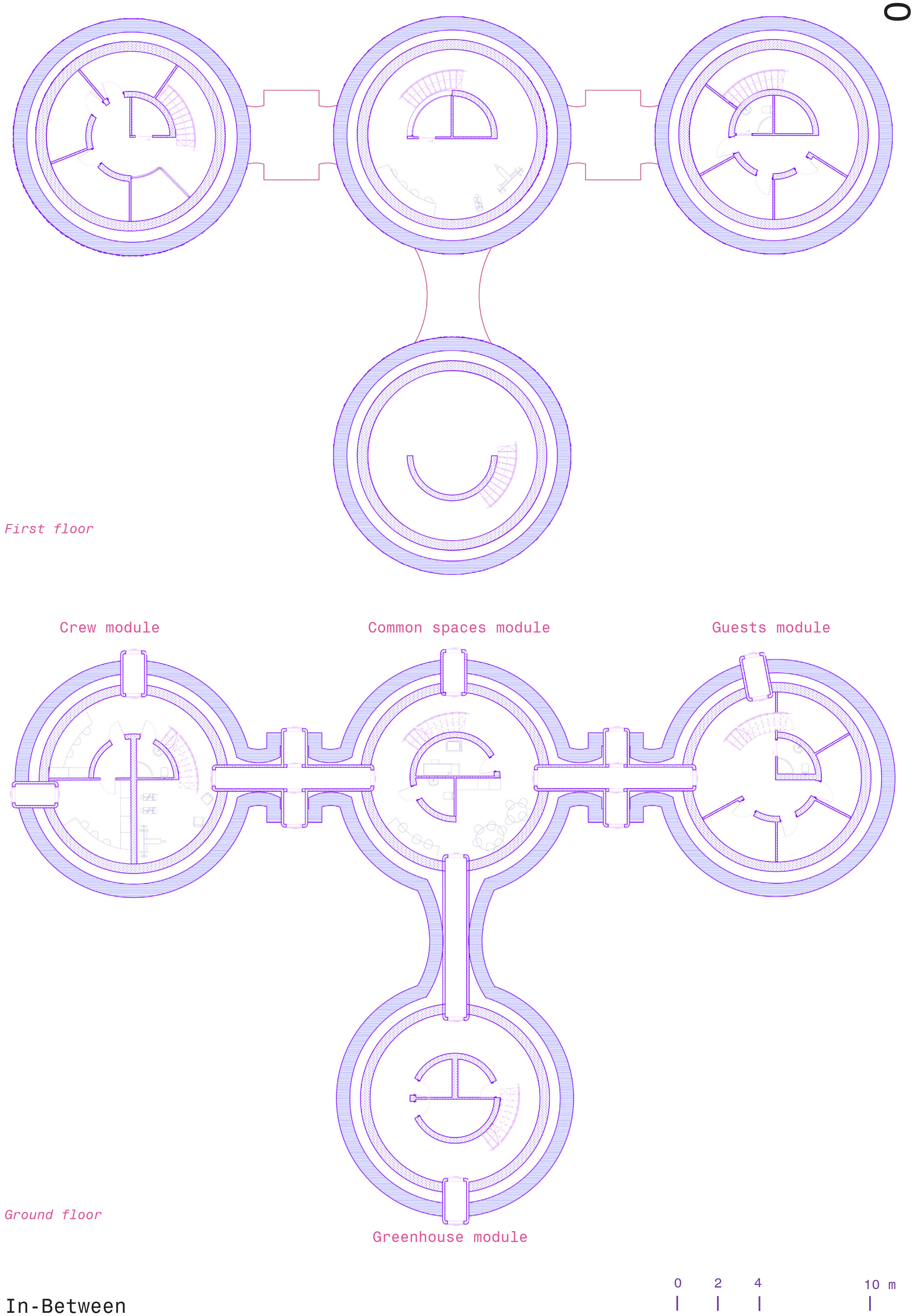

Solar panels
Ice mining
Tourist facility
Landing pad

2.2.1 cycle b

Facility definition

In addition to addressing urban considerations, the delineation of precise functions and their respective spatial allocations within each module constituted a critical aspect of this inquiry.

Drawing upon existing documentation, a comparative analysis was conducted to assess their alignment with the minimum standards stipulated by Italian regulations.
The challenge at hand was to reconcile the imperative for maximal functionalization of spaces with the recreational (tourist) function inherent in the context of such an extreme environment.
A pivotal facet of this phase involved the conceptualization of a module characterized by its capacity to accommodate disparate functions while retaining a replicable and systematic geometry.
The envisioned approach centered on maintaining the functional core at the module's center, housing mechanical systems, bathrooms, and stairs. Subsequent internal layout adjustments were conceived to be adaptable, allowing for modifications contingent upon the specific functions to be accommodated.
This strategic framework ensures both adaptability and efficiency, addressing the nuanced and multifaceted requirements of the spatial configuration.



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Studies related to individual volume requirements

Through an analysis of the document 'Minimum Acceptable Net Habitable Volume for Long-Duration Exploration Missions' by Whitmire (2015), it became possible to make considerations about identifying the essential functions, their relationships, and the required internal volumes.
Drawing from the insights provided in Whitmire's document (2015) and the minimum acceptable net habitable volume identified by them and the one defined by ESA (2020), the differences between the two were examined.

The initial text proposes a minimum of 25 m³ per person, whereas the second document defines it as "the absolute minimum for deep space activities." In fact, according to the ESA CDF (2020), the minimum net habitable volume is around 80 m³ per person. The justification is the diverse functionalities needed within the habitat and the extended duration of the surface mission, lasting for 500 days.
The ESA CDF (2020) compares the volume per person in other space projects, including the ISS (85.17 m³) and Skylab (120.33 m³), highlighting that 25 m³ is relatively small. This may pose a challenge when designing a tourism infrastructure.

Although small volumes may be physically feasible and optimizing space is a key element in this harsh environment, it is important to acknowledge that smaller volumes could be unacceptable from a human factors and behavioral health perspective. This could have negative consequences for the psychosocial well-being and performance of the crew, thus potentially impacting the tourist experience and mission success.

In this context, consideration was given to how these values could be related to Earth's square footage. Initially, a comparison was made between the specific sizes of the individual project functions in the two documents. The following numbers are values per person.

Minimum Acceptable Net Habitable Volume for Long-Duration Exploration Missions (Whitmire 2015)

\ Berthing, or sleeping space private, crew quarters = 5.4 m³

\ Recreating/ dining = 8,3 m³

\ Workspace = 3,6 m³

\ Exercise = 2,9 m³

\ Hygiene = 2,9 m³

Moon Village project measures

\ Berthing, or sleeping space private, crew quarters = 14,8 m³

\ Recreating/ dining = 15,5 m³

\ Workspace = 43,05 m³

\ Exercise = 10 m³

\ Hygiene = 7,6 m³

After this, a third element was introduced, specifically taking into account the per-person values on Earth, with a particular focus on Italy.

\ Private sleeping space or berthing, crew quarters = 18 m³

\ Recreational/dining = 45 m³

\ Workspace/Laboratory = 30 m³

\ Exercise = 30 m³

\ Hygiene = 10.5 m³

Following this initial analysis, efforts were made to systematize all the values and identify appropriate dimensions for each designated function in the tourist facility proposed by this thesis. The subsequent pages leverage this comparison through the proposed design.

2.2.2 cycle b

Functions

In the previous cycle, a fundamental consideration was based on the segregation of macro-functions, attempting to cluster similar functions and objectives within the same module. At this stage it was assumed that the facility would be able to accommodate a total of 10 people, including 3 crew members and 7 tourists.
In this hypothesis, these functions are further explored, dimensioned, and the connections between them are carefully analyzed.
[in-depth : Studies related to individual volume requirements]
Several previous papers had examined the coexistence of various functions in the same space (Whitmire et al. 2015, p. 3). However, in this particular case, the methodology employed was to amalgamate these functions into coherent units.
Several key assumptions guided the design process:

\ Rational layout of areas to allow for the separation of quiet and loud activities.
\ Separation of private and communal spaces.
\ Separation of crew and tourists quarters to avoid interference between these groups.

The functions identified through Whitmire et al. (2015) and CDF (ESA 2020) included:

1) Private sleeping quarters for the crew
Individual bedrooms for the crew.

2) Private sleeping quarters for the guests
Individual bedrooms for the guests.

3) Dining and communal activities
A space designed for the preparation and consumption of food serves a purpose beyond basic sustenance; it can be viewed as a venue for socialization. Consequently, this environment should be accessible to both staff and guests, encouraging interaction and recreation alongside its fundamental function.

4) Laboratories
Even though it is a tourist facility, it was still deemed necessary to have a crew laboratory in which experiments could be conducted.

5) Communication center/Control room
An area designated to house the complex control instrumentation for life support in the tourist infrastructure.

6) ECLSS (Environmental control and life support system)
One is required in each module

7) Exercise areas
The effects of gravity can cause physical discomfort for the human body. Therefore, it is essential to consider a space that promotes healthy exercise to combat these inconveniences.

8) Hygiene facilities

9) Medical bay
Dedicated room for medical care, equipped for all eventualities and emergencies.

10) Greenhouse
The most feasible solution to guarantee a consistent food supply at a low cost is to produce resources on-site. Therefore, hydroponic and aeroponic crops will serve as functional components of life.

11) Translation portals and pass-throughs
Transitional spaces are necessary to safeguard the inhabitants, as the transition between the pressurized interiors and the non-pressurized lunar environment can lead to critical pressure losses.

CREW MODULE
Ground Floor

Laboratory: 15,2 sqm
Laboratory Airlock: 3,2 sqm

Gym + common space: 15,6 sqm

Entrance + suits storage: 11,6 sqm

Communication + storage: 11,6 sqm

Bathroom: 3,2 sqm

First Floor

Crew bedroom: 7,2 sqm (3x)

Herbal green house: 3,2 sqm

ECLSS: 3,2 sqm

COMMON SPACES MODULE
Ground Floor

Medical Bay: 6,7 sqm

Entrace + suit storage: 11,6 sqm

Kitchen + common space: 26, 2 sqm

Bathroom: 3,2 sqm

First Floor

Gym + common space: 14,6 sqm

Herbal green house: 3,2 sqm

ECLSS: 3,2 sqm

GUESTS MODULE
Ground Floor

Guest bedroom: 7,2 sqm (4x)

Entrance + suit storage: 11,6 sqm

Bathroom: 3,2 sqm

First Floor

Guest bedroom: 7,2 sqm (3x)

Herbal green house: 3,2 sqm

Bathroom: 3,2 sqm

ECLSS: 3,2 sqm

GREENHOUSE MODULE
Ground Floor

Greenhouse: 34,1 sqm

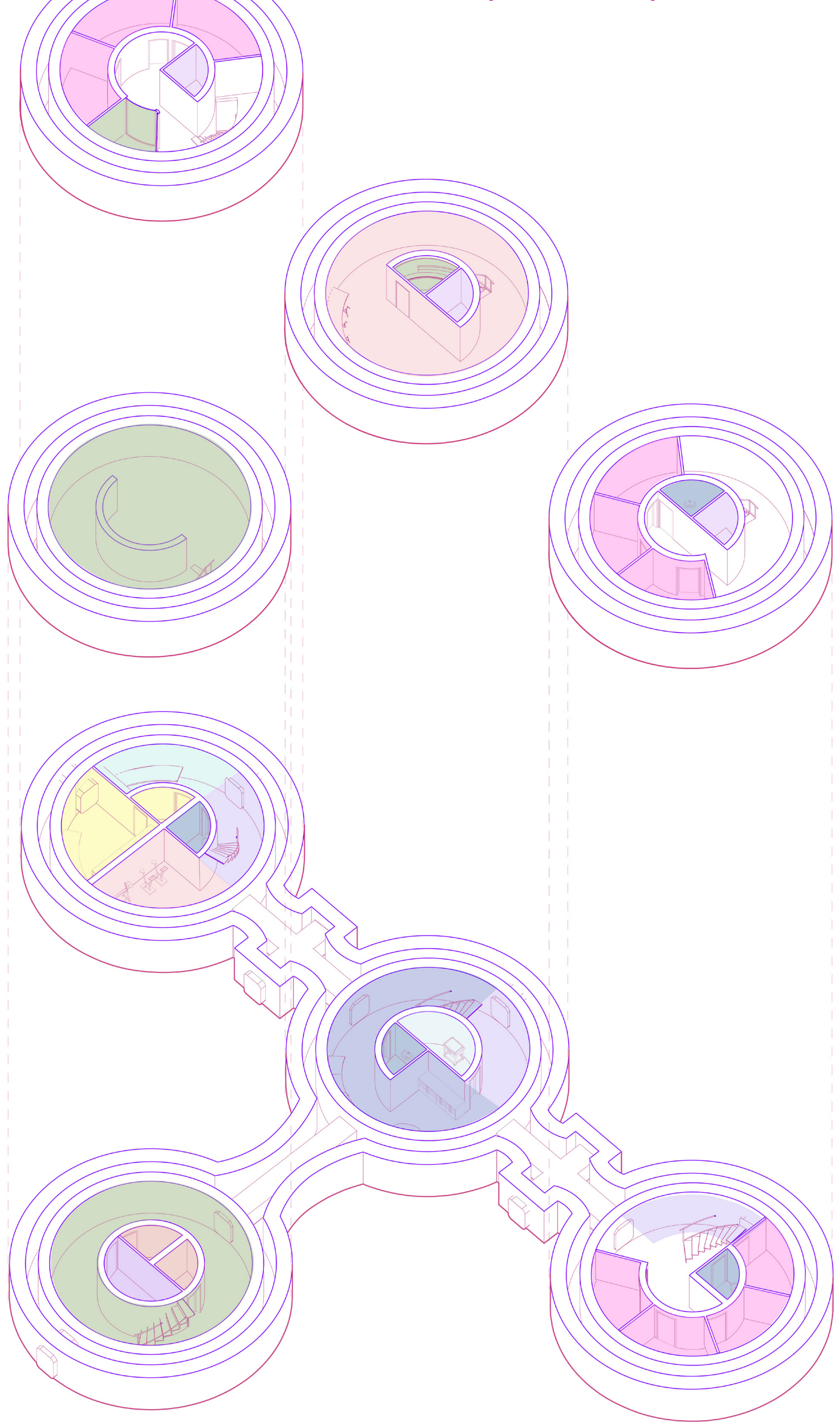
Storage: 3,2 sqm (2x)

ECLSS : 3,2 sqm

First Floor

Greenhouse: 59 sqm

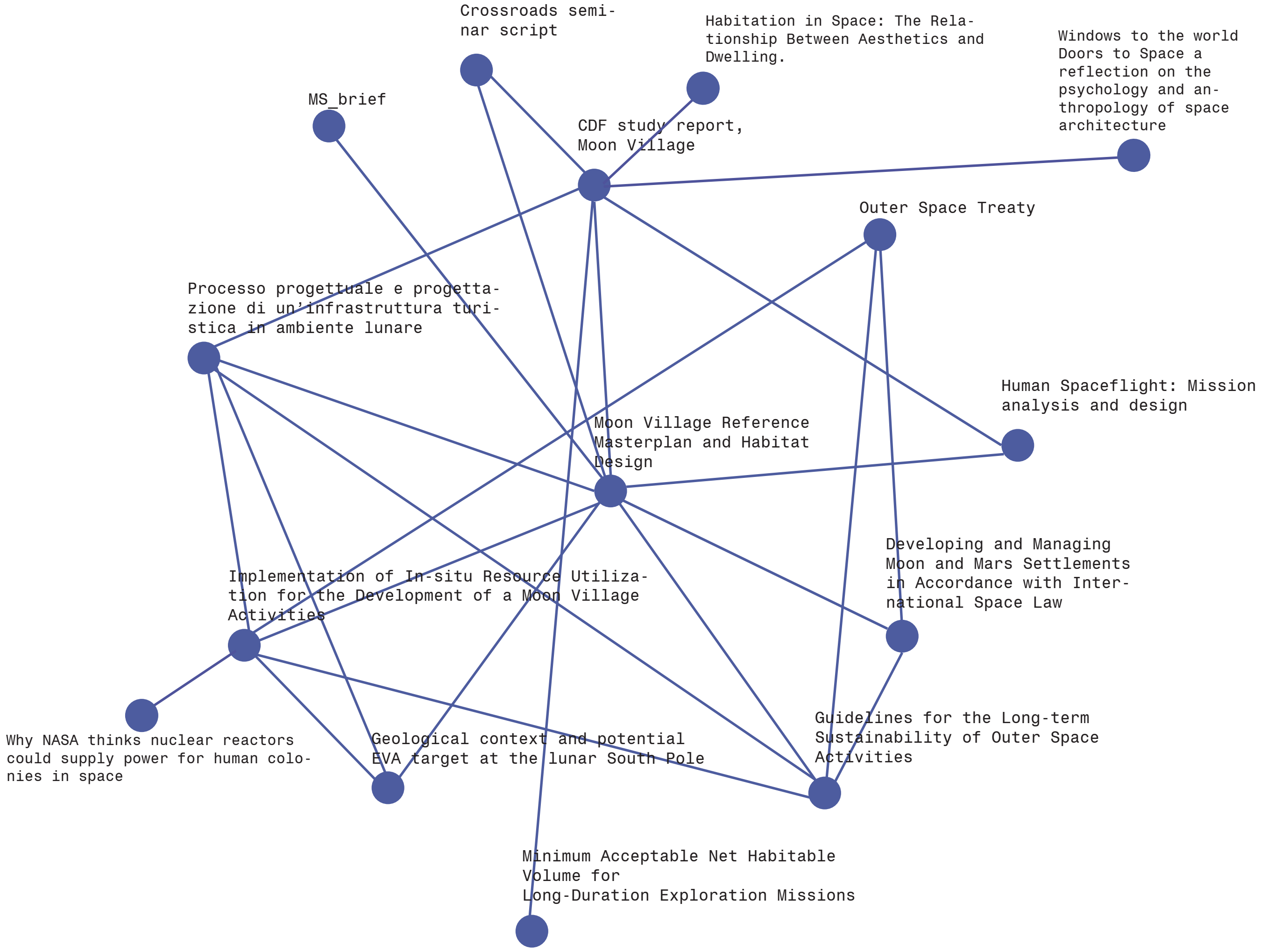
|ANNEX 5|



Scenario 2

Institution of a new framework

2.3 Scenario 2 - *institution of a new framework*



Scenario 2 was formulated between late September and mid-October. A series of meetings with the thesis group and external contributors, accompanied by further documentary research, led to more in-depth reflections. During the initial phase, it was considered vital to conduct a critical review of the link between projects already planned for the particular region. The objective was to comprehend the possible spatial discourse between these projects and the proposed tourism infrastructure. Subsequently, a coordinated effort was made to explore the complex relationship between the new settlement and the surrounding landscape, as well as the connection between the interior and exterior spaces in such an extreme context.This involved a concentrated investigation, aiming to analyze the issue and define the diverse levels of architectural permeability. Furthermore, there was an investigation into the potential psychological effects that an extreme environment could have on inhabitants.

Instances overview

9) Moon Village precise location *[Colin Koop, 2023, "title intervention" presented at the crossroads seminar. Turin, 28.10.23]*

Another key element in being able to develop the integration with the Moon Village was being able to understand where exactly it was located on the crater rim.
Thanks to my participation in the cross roads seminar, I had access to an additional map, which, subject to those found from other sources, allowed me to draw all the elements more precisely and to the point.

10) "Orange are zones that can be used by the various stakeholders for their specific activities" *[ICES, 2019-280]*

Crucial to the development of this scenario was the exploration of how to establish a meaningful connection with the Moon Village.
The objective was to integrate the project outlined in this thesis within the designated bands of the Moon Village master plan. Specifically, the focus was on the band allocated for various activities, as highlighted in the above excerpt, where there are no specific constraints regarding function or actors involved.
Given that the financing for the thesis-proposed project would come from private actors, and considering that its function is non-redundant with the Moon Village project, it appeared fitting to proceed in this manner.
The approach aimed to align the proposed project strategically within the parameters of the Moon Village master plan, optimizing compatibility and resource utilization.

11) NASA thinks nuclear reactors could supply power for human colonies in space. *[Nguyen T., "Why NASA thinks nuclear reactors could supply power for human colonies in space"]*

Until the introduction of this instance, it was considered essential to use only one type of infrastructure for energy production, namely solar panels.

7 d) Includes a window with a portal (~ 0.5 m3[1.7 ft3]) as a way to visually extend the social space and provide an important countermeasure for psychological health. *[Minimum Acceptable Net Habitable Volume for Long-Duration Exploration Missions]*

8 d) "Astronauts on the ISS enjoygoing to the "cupola" and practicing "Earth gazing" during theirfree time." *[White, W. F. (2021). The overview effect and creative performance in extreme human environments. Frontiers in Psychology, 12]*

This instance was essential in the initial consideration of the development, its orientation and the main axes to be considered. It was of paramount importance to comprehend the essential axes that inherently connect the project to its location. The challenge is to ensure that the result is not solely an architectural module but a design that is distinctly linked to its specific environment, avoiding the risk of creating a generic structure that can be applied indiscriminately to different sites.

9 d) "New human factors criteria need to be developed to adress a different set of physical and psycologial requirements" *[Lockard, E. S. (2006). Habitation in Space: The Relationship Between Aesthetics and Dwelling.]*

The discovery and reading of the document, an excerpt of which is quoted above, was fundamental to the development of the subsequent design hypotheses, as it allowed for a deeper investigation of aspects that had hitherto only been timidly addressed.

10 d) Relationship between the interior and the exterior environment. *[Lockard, E. S. (2006). Habitation in Space: The Relationship Between Aesthetics and Dwelling.]*

The opportunity to investigate the relationship between the interior and exterior, afforded by this document, has led to a reflection on the intermediate spaces of the settlement.

11 d) Environmental impact

One of the issues that had emerged during the interview with Marco Ranieri first and the discussions with Marta Rossi later was the environmental impact of the project. In particular, referring not only to economic-environmental issues but also visual ones. Since the structure will be located in one place, numerous reflections arose regarding this issue.

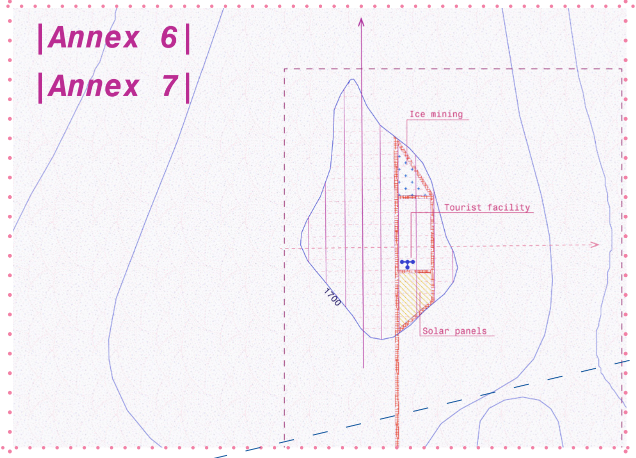
Istances	Spazializations	Conflict-Negotiation	Stabilisations
		X Crossroad seminar	

Scenario 2

Cycle c (03/10/23)

Istances: 9, 7

|Annex 6|
|Annex 7|



X_D Insediation principle

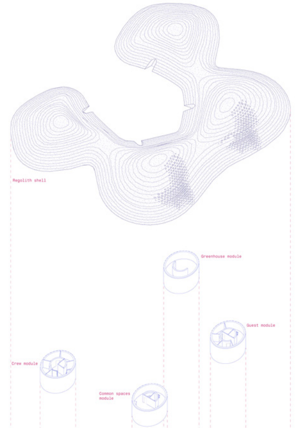
X Design sperimentation?

City plan
_Facility location

Cycle d (13/10/23)

Istances: 10, 11, 8 d, 9 d, 1, 11

|Annex 8|
|Annex 9|



X_R Define the function of the intermediate space

Mission
_Definition

Morphology
_Landscape impact

Istance n

Module design Istance n

X_n Conflict

X_D Prof. G. Durbiano

X_S Prof. V. Sumini

X_R M. Rossi

Topic output

// Indirect **Conversation with** Coolin Koop

During the 4th International Conference on Interiors and Exhibit Design held at the Politecnico di Torino, I had the privilege of attending a captivating presentation by Coolin Koop.
Koop, an architect at SOM, the studio collaborating with MIT and ESA in designing the Moon Village, delved into intriguing aspects.
His talk shed light on the architect's role in space design and addressed challenges inherent in projects set in complex and extreme environments.

The role of the architect in outer space

C.K: *I explore space architectures as an extension of my experience as a terrestrial architect, approaching the subject without deep expertise but with a commitment to prioritizing human-centric interests in architectural design principles. The integration of artistic thinking with scientific and engineering knowledge is identified as the next frontier in space architecture design, facilitated by our interdisciplinary team comprising engineers, architects, and industrial designers who have collectively contributed to diverse space projects.*

Our participation in the 23rd triennial exhibit aimed to convey the inherent challenges in space design to a broad audience. This effort resulted in the creation of the "Dachalog for Space Architecture," delineating ten fundamental principles encompassing gravity, confinement, environmental shifts, species symbiosis, cycles, material cycles, resilience, safety, cosmic rays, daylight, color, and mass.

Addressing gravity, human adaptation to one gravity becomes a critical consideration. In zero-G or low-G spaces, the body undergoes perilous changes, such as blood clotting and bone density loss, presenting significant design challenges. Resilience in a space environment necessitates distinct considerations, given the impracticality of evacuation. Our goal is to underscore the reality faced by designers in grappling with these challenges.

Principles seemingly taken for granted on Earth, such as cosmic rays, gravity, and daylight, demand deliberate attention in space design. This underscores the imperative to safeguard our planet, as it inherently provides for many of these aspects.

The moon village, design challenges

C.K.: *Collaboration between SOM, ESA, and some researchers at MIT formed the basis of our project. The challenge posed by ESA was to think in immediate terms about establishing a stay away from an optimistic adoption of unproven technologies. The goal was to showcase what could be done right now with sufficient ambition. Treating it like any other design project, we considered factors such as site selection, organization, growth over time, and more.*

Key challenges included the distance to the moon, the forces on construction materials during Earth departure, and the logistics of safely transporting, landing, moving, erecting, and maintaining structures on the moon. Designing for needs like air, water, energy, and food, as well as the materials themselves, posed unique challenges. The poetic aspects of design, considering form, expression over time, materials, and usage, were also vital.

Site selection on the moon involved recognizing its unique day-to-night cycle, with two weeks of daylight and two weeks of night. Seeking a location with maximum access to daylight led to considering the poles, particularly the South Pole with its continuous access to daylight. The Shackleton Crater nearby presented intriguing possibilities for settlement due to its raised rim offering prolonged daylight and access to ancient ice.

Safety, resilience, efficiency, and expandability over time were key criteria for design. The concept of a linear city, expanding around the rim over time, emerged. This pattern included habitation bands, infrastructure bands, and activities bands organized along a clear settlement pattern. The design was influenced by the need for clarity and avoidance of logistical challenges, unlike McWerdo in the Antarctic.

Considering viable and tried-and-true technologies, the design started with the idea of placing materials within rocket fairings. Two types of capsules were explored: rigid, cylindrical capsules similar to those at the International Space Station and inflatable capsules with a central structure.

In summary, the design approach focused on immediate, viable solutions, considering both the practical challenges and the potential for creating a sustainable and resilient lunar settlement.

2.3.1 cycle c

Geolocalised instances

Attendance at the Crossroads seminar in late September was a pivotal moment in the project's relocation.
The seminar yielded a significant breakthrough when an image of the designated site for the Moon Village was unveiled (displayed below).

This discovery helped progress the development of the masterplan substantially.
It was determined that relocation of the designated site for constructing tourism infrastructure a few kilometres away from its former location would be beneficial.
This change aims to optimise several processes and to review and strengthen the project.
Closer proximity to the Moon Village resulted in infrastructure advantages.
In particular, it was decided to locate within the first construction area of the project, as shown in the image below, the area defined as "phase 1".

Although locating near the Moon Village did not solve the urban placement dilemma of the project under investigation.
An effective settlement principle upon which to base future urban developments had not yet been established.

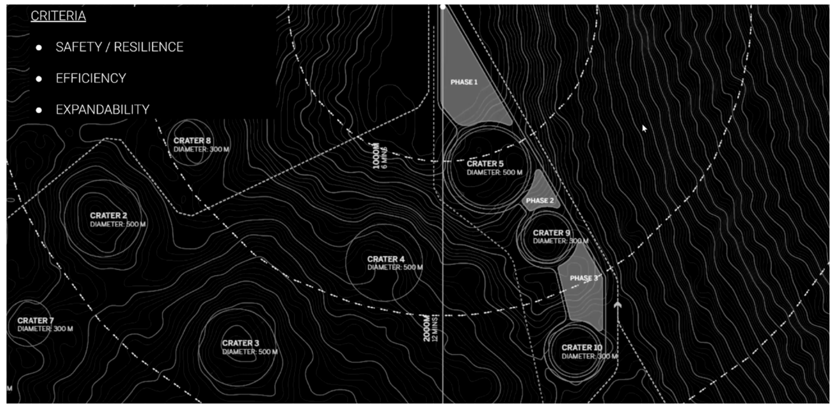
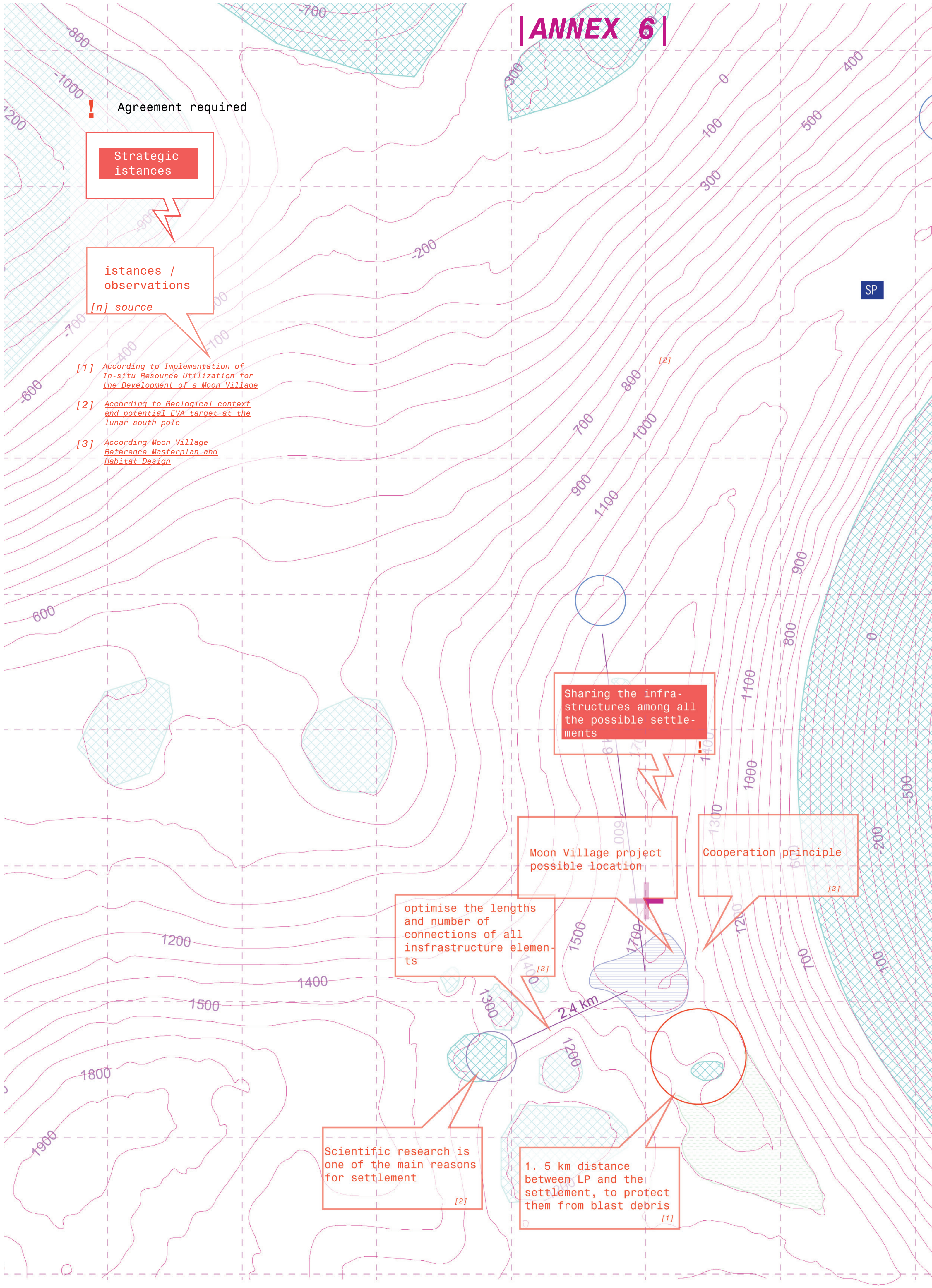


Image credits: SOM (Koop 2023)



2.3.1 cycle c

Grids

Upon analysis of the context, it was observed that the Earth and Shackleton Crater were the two dominant features in the landscape. Accordingly, the research on potential urban development concentrated around these two perspectives.

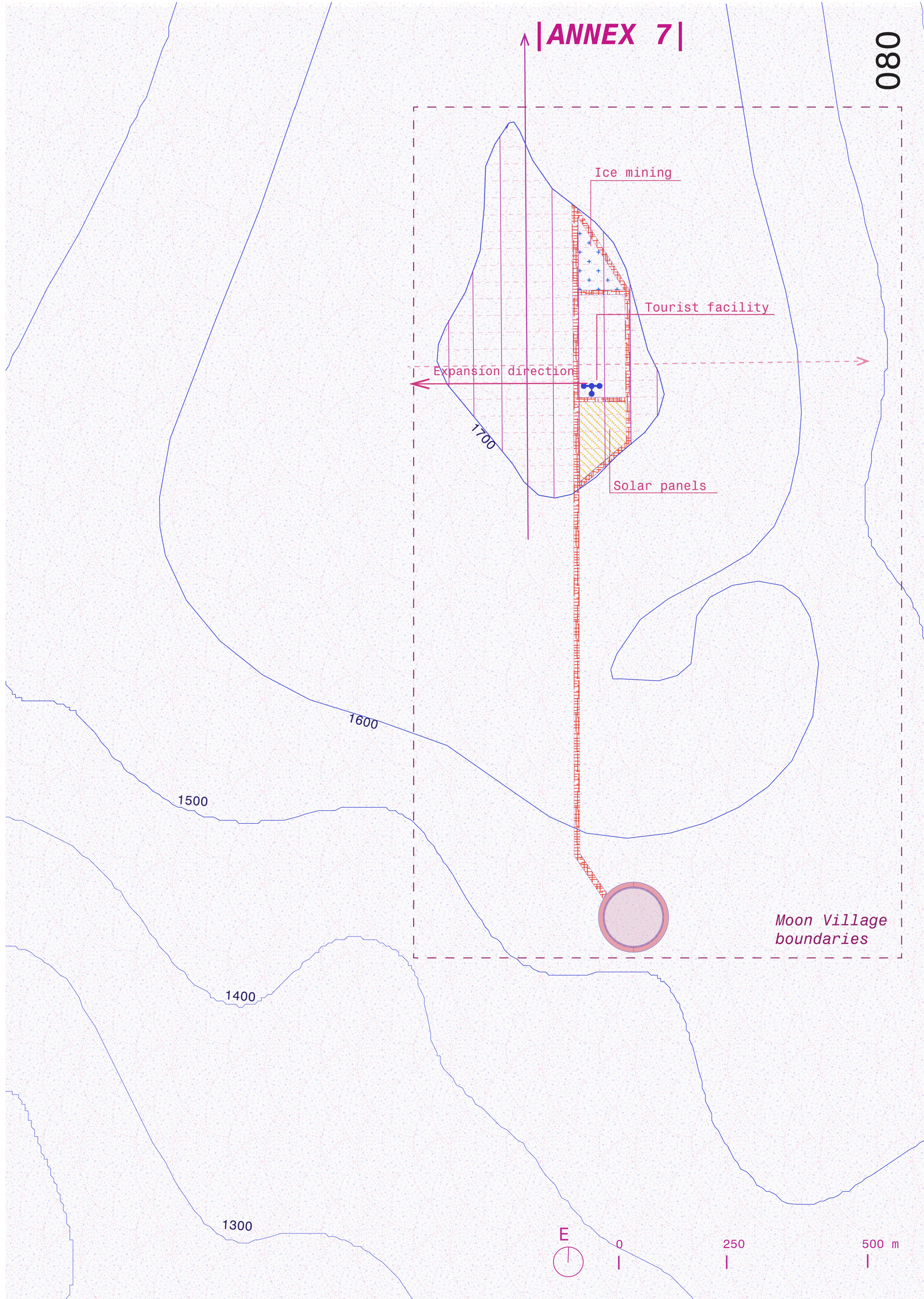
In particular, extensive research and interviews with astronauts, including the findings of Frank White, underline the importance of the first perspective.
White's research has shown that astronauts frequently experience intense emotional reactions and develop a deep connection to humanity and the planet as a whole (White, 1998). This sensation, which White has named the 'overview effect,' describes the positive psychological response astronauts feel upon observing the Earth (White, 2021).

Living in Space presents an exceptional challenge due to the immense distances that surpass human comprehension.
The view of Earth from Space is not only aesthetically captivating but also induces a profound psychological effect by restoring a sensory connection to a familiar place. This connection expands beyond mere recognition and instills a profound awareness of our position within the cosmos.
The principle of settlement places great emphasis on an Earth-focused perspective, acknowledging its significance in nurturing a sense of belonging, identity, and overall happiness for space dwellers.
The second axis is crucial in the exploration of the Moon, and its importance spans functional and morphological dimensions.
The crater, identified by its permanent shaded area, is vital in facilitating human habitation on the Moon.
This axis has special significance as it represents the future for the new lunar generation and embodies the transformative hopes and dreams of lunar exploration.
Morphologically, the lunar crater acts as a physical barrier and a theoretical center, indicating the limits of the Moon's boundaries and representing its capacity for supporting human life.
More fundamentally, the second axis embodies the collaborative link between the Moon's functionality and its symbolic significance. It represents the delicate balance between physical limits and the possibility of human settlement beyond Earth.

The area's plan was meticulously crafted, utilizing a functional distribution strategy and distinct functional bands to delineate zones for settlement, energy generation, and ice extraction. This strategic framework aimed to offer flexibility and adaptability, catering to the evolving needs of the region and facilitating the construction of new residential units and essential infrastructure.

In addition to the division of bands in the land, another layer was incorporated: a grid. Reflecting the dimensions of the project lots at 35m by 55m, this grid played a crucial role in establishing initial plot divisions. It's noteworthy that, at this stage, there was no explicit intention to create a subdivision plan; instead, the grid served as a flexible foundation, allowing for future adjustments and developments in response to changing requirements and opportunities in the region.

Subsequent discussions with the thesis collective revealed two significant deviations from the initial plan.
Firstly, there was an evident lack of substantive design interaction with the Moon Village project, signalling a misalignment with the overarching aims and objectives of this lunar initiative.
Recognising the importance of synchronisation, collaboration, and synergy with the broader Moon Village scheme emerged as a crucial consideration for refining the Spatial Plan.
This understanding emphasised the significance of integrating the principles and objectives of the Moon Village initiative into the settlement strategy, guaranteeing a smooth amalgamation that supports the main aims of lunar exploration and habitat development.
Consequently, the revised strategy prioritises the adoption of cooperative design principles aligned with the Moon Village project, cultivating a uniform approach to lunar settlement planning.



2.3.1 cycle d

Masterplan

The preceding proposal raised concerns by leaving critical questions regarding the masterplan unanswered, particularly in establishing a connection between the identified initial settlement principle and the functions of pre-designed projects, such as the Moon Village.

To address this gap, insights were drawn from the Moon Village Reference Masterplan and Habitat Design document (Petrov 2019).
This analysis led to the proposition of situating tourist infrastructure within a dedicated band, specifically allocated for special activities funded by partners.
The Moon Village project's masterplan, as outlined in the document, introduces the concept of bands designed for distinct purposes, including a band for habitat focused on research, another for supporting infrastructure, and a third for various functions taking up the linear city (Curtis 1987) approach.
This strategic alignment not only enriches the proposed masterplan but also draws inspiration from established frameworks, fostering a more cohesive and comprehensive approach to lunar settlement development.

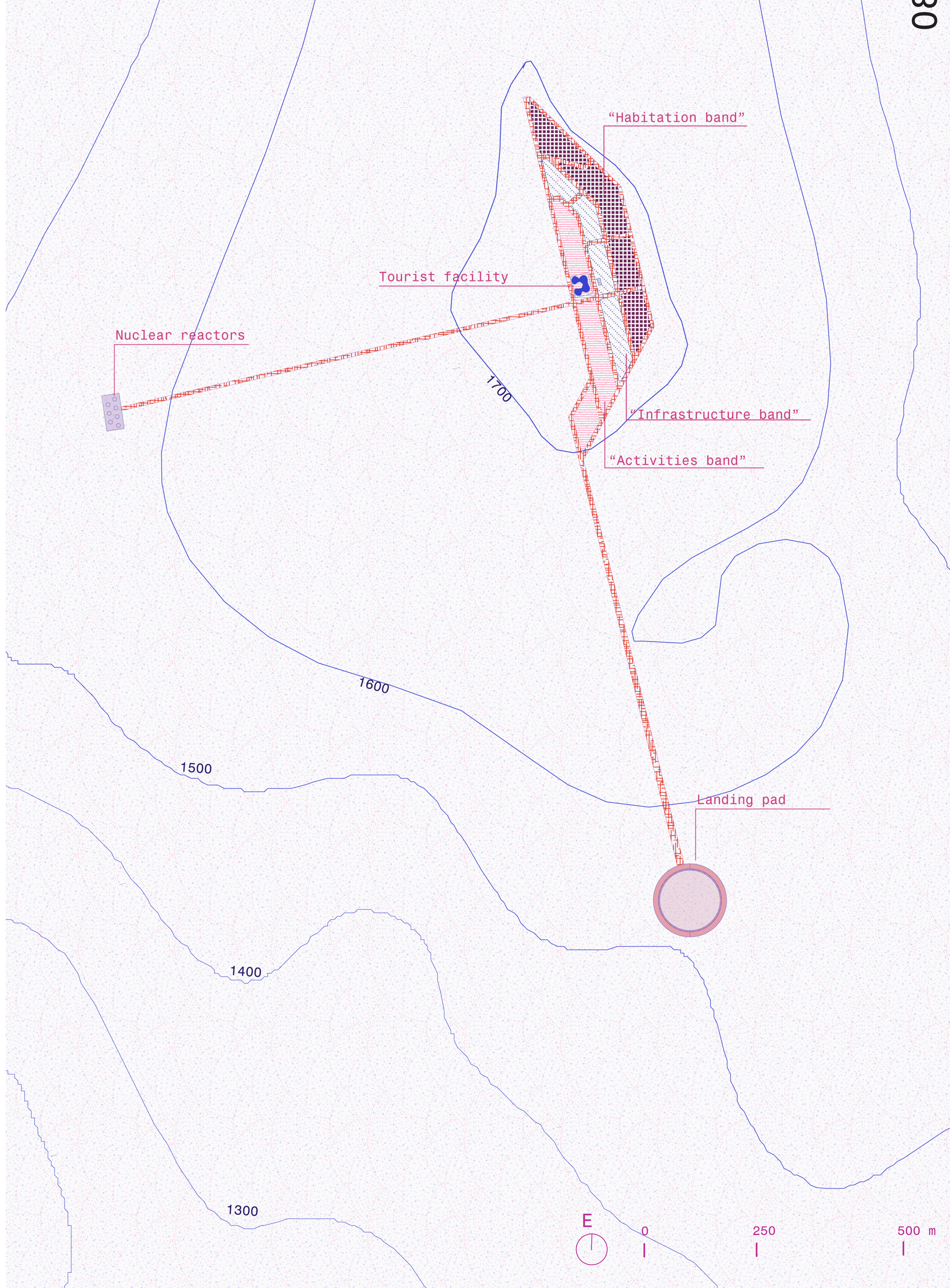
This approach is essential when introducing a non-primary function, as it facilitates the integration with projects that are likely to be developed before our proposed one.
The unique physical conditions of the Moon and the limited availability of areas able to sustain human life, (Gawronska et al. 2020) make collaboration and cooperation essential elements for achieving a successful architectural project.
This entails creating a cohesive fabric rather than a series of disparate, unconnected pieces, which can reconcile functional and architectural differences.
As previously mentioned, the settlement's tertiary function is planned for a future time horizon.
At this point, it was decided to view the Moon Village as a potential existing framework for the proposed settlement to be connected to.

Alongside identifying the location for the tourist habitat, the incorporation of vital supporting infrastructure was also pursued.
While collaboration and shared infrastructure are fundamental principles, specific infrastructure for energy and oxygen production needed to be constructed.
Although the Moon Village project already has infrastructure for energy production and ice extraction, these are only designed to serve the habitat modules.
Assuming that the same infrastructure could support additional habitats would be impractical.
A viable solution would involve the shared use of main viaducts, landing pads, and roads.
In this proposed inclusion of the project within the functional division for the proposed Moon Village project bands, changes were made with regard to the positioning of the landind pad, since for safety reasons it must be at least 1.5 km away from the habitat, and the landing pads in the project did not meet this requirement, so it was decided to build a new, more spacious and distant single landing pad.

As a result, infrastructure has been put in place close to the settlement.
The incorporation of an ice extraction facility and nuclear reactors for energy generation is consistent with the investigation of physical characteristics (Jones 2019) expounded in Chapter 1.1.2.
A specific issue brought up in this study relates to light cycles, necessitating meticulous design for eco-friendly inclusion of crucial amenities.
The lunar day-night cycle is characterised by two weeks of light followed by two weeks of darkness (Aderin-Pocock, 2018).
Consequently, a sole reliance on solar power plants as a primary energy source is not feasible. To overcome this challenge, nuclear reactors have been introduced as an alternative energy source.

The sustainability of nuclear reactors is derived from the utilisation of Helium-3, a rare isotope present in the lunar regolith. Kulcinski et al. (1988) identified Helium-3 as a deposit produced by the solar wind.
The Moon continually encounters the solar wind, and an indiscernible electric current passes through the illuminated lunar surface.
This current reduces occasionally for a few days every month, influenced by Earth's magnetosphere providing partial shielding (Solar Wind | Sun & Moonlight - The Moon: NASA Science, n.d.). Therefore, sustaining nuclear reactors may not present resource-related challenges due to the steady presence of Helium-3 in the lunar regolith.

|ANNEX 8|



2.3.1 cycle d

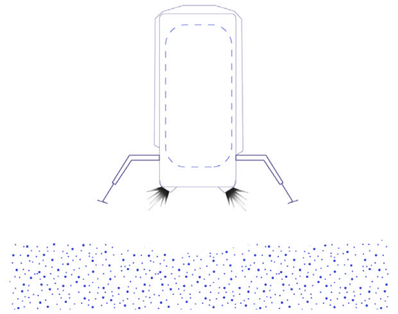
Inside out

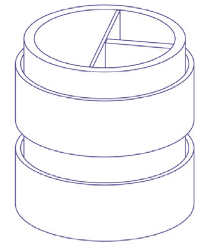
While the previous scenario prioritised the Earth's perspective and prompted thoughts about habitation distribution, this project proposal aims to delve further into this topic. On the overview page, the instances emphasize the fundamental themes of the relationship between the interior and exterior and the impact on the environment of the settlement.
The proposed design aims to create a roofing structure that serves as radiation protection and blends seamlessly with the environment. This is achieved by reflecting the undulating profile of the lunar terrain.
The resulting outer shell not only provides protection against radiation but also houses a covered plaza beneath it.
This common square is designed as a space accessible to all inhabitants, functioning as a transitional area between the indoors and outdoors.
It allows people to appreciate an external view and more profoundly experience communal space, which is lacking in such environments.

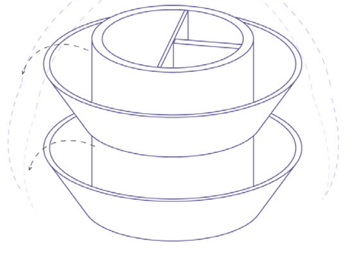
These reflections concerning the outer shell have also influenced the functional distribution of the modules, particularly their arrangement in space.
They are no longer organized in a linear pattern but are distributed around a barycentric entrance area, facing the entrances of the airlocks, evoking the theme of the semi-open courtyard and becoming a hub for vehicular and pedestrian distribution.

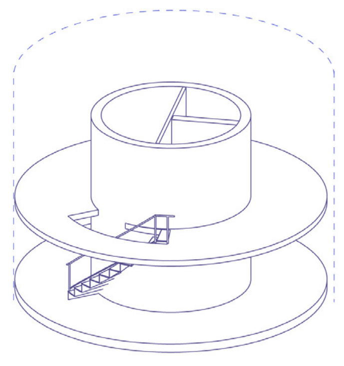
At this stage several specific considerations were made regarding the mission and the deployment mode of individual modules, including transportation and deployment.
As it well known the mean of transport that are available (ESA 2020, p. 30) are not able to transport from the Earth big or heavy elements, so the optimization of the geometry and of the design of the module is one of the most important consideration. Therefore, it was determined to reflect on the structure of the module, which are Class II modules defined as one of the paradigms by NASA (Yashar et al. 2021, p. 3).
The habitat module has a structure consisting of two main components: an external shell that acts as a deployable part and an internal support structure, which includes a cylindrical rigid element located at the module's centre.
The life-support machinery is located in a dedicated section of the structural module, and the integration of staircases boosts the overall function of the module.
This configuration not only assures stability but also enables the module to adapt to various internal functions.
The selected structure, reminiscent of TransHab (HSF -- TransHAB, n.d.), is preferred for its simplicity and minimized addition of structural elements. This design strategy optimises efficiency while maintaining the module's versatility.

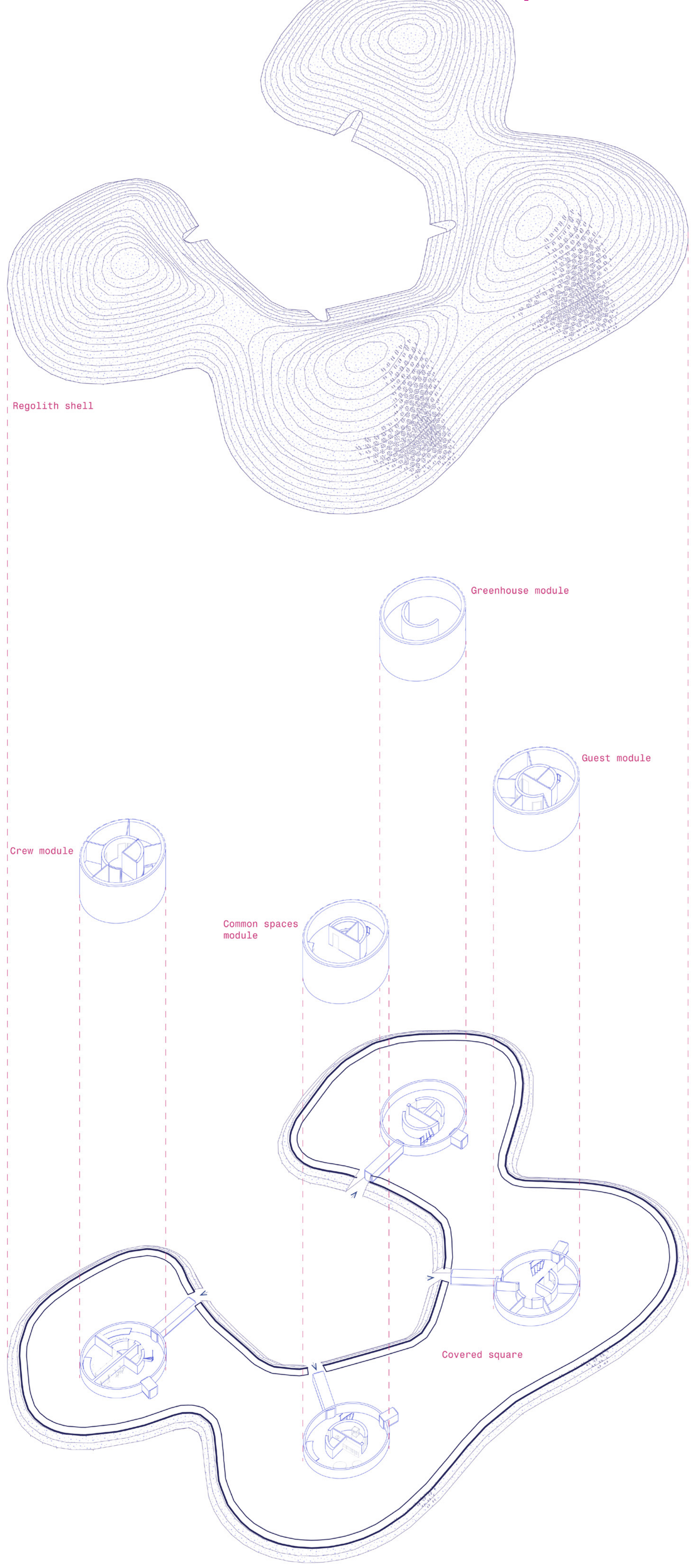
Upon arrival at the designated site, the module is extracted from the lander and precisely positioned, with the necessary airlocks installed.
Next, 3D printers construct the external protective shell, complete with windows. Only in the final stages of deployment the modules are positioned and the external membrane inflated, while the metal floors are opened. This methodical approach guarantees an efficient and organized implementation procedure for the habitat module, fusing simplicity with flexibility.


Landing


Functional core


Deployment


Final asset



2.3.1 cycle d

Mission

In this phase of the scenario, there has been a greater focus on mission design, a topic that has been a feature of previous scenarios, but one which has been largely unexplored. Understanding the various stages of infrastructure construction is crucial to the mission plan. Following an initial analysis of the selected site for infrastructure construction, it was imperative to establish the construction phases.

During the planning stages, the timeframes for transportation between Earth and Moon, as well as the timeline for construction, were carefully taken into account.
The mission plan is split into distinct phases, which are closely aligned with the documents specified in the accompanying diagram. Not only does the diagram provide an analysis of the timeframe required for each activity, but it also seeks to examine the necessary means for achieving these goals by correlating them with the document analysis.
Great emphasis was placed on selecting the appropriate machinery. It is impossible to predict the technological advancements that will occur in the next twenty years, therefore the project will utilize the equipment currently available.
The mission has two essential phases; preparatory activities and construction.
The programme utilises inflatable modules, encased by a protective coating of regolith casting, depicted as shown previously.
The molding times were determined by proportions derived from a simulated molding process carried out by SEArch+ / Apis Cor during the Mars-x project (SEArch+ & Apis Cor, 2018) in partnership with ICON, a construction company currently working on 3D printing technologies.

	Days	Activity	Machinery	Documents	
01.01.2041					01 preparatory activities
	3	**Shipment of machinery** (3d printer, robots, Orion)	Rocket Starship	a	
	2	**Machinery dispatch**	Blue Origin Orion	b	
	2	**Exavating Regolith**		c, d	
	15	**Processing of Regolith**		e	
	24	**3D printing of foundations**	Icon 3d printer	f	
23.02.2041					
24.02.2041					02 infrastructure's construction
	3	**Modules and air-locks shipment** (working and common space + Orion)	Rocket Starship		
	5	**Placing modules and airlocks on foundations.**	Orion + robots		
	8	**3d printing support structure**	Icon 3d printer	e	
	58	**Moulding the first layer of regolith**		f	
	14	**Inflatable modules dispatch**			
	30	**Supporting infrastructure construction**			
	10	**Connection of modules with supporting infrastructure**			
12.07.2041					

a: Brown et al. 2019)

b: (NASA selects Blue Origin as second Artemis Lunar Lander provider n.d.-b).

c: (Yashar et al. 2021)

d: (Coto et al. 2021).

e: (Just et al. 2020).

f: (SEArch+ & Apis Cor. 2018)

IN - DEPHT

Psychology of Space

“Human experience should not be in service to science

[on the contrary]

science is meant to serve the human experience.”

Chris McKay, Planetary Scientist, NASA Ames Research Center

The exploration of Space places humanity at the forefront, and the prospect of human presence on the Moon in the short and long term, raises questions about its psychological impact. A research study by Elizabeth Song Lockard (2006) offers an interesting way of interpreting these psychological aspects and their relationship to architecture.

As architects, the challenge is to address and alleviate the sense of alienation that individuals may experience in such a harsh and challenging environment. How do the unique challenges of life in space—different gravitational conditions, temporal cycles, cosmic radiation, absence of sound, vast distances, and temperature variations—affect the psychological well-being of humans? How can we respond to these challenges, transforming them from mere obstacles to our survival into aspects of a new way of living?

By understanding the fundamentals of how we assimilate our surrounding environment, we can better anticipate solutions for unknown or unexpected conditions, extending and revisiting terrestrial paradigms. While there is the physical world we inhabit, each person’s perceptual world is a synthesis of empathy and alienation, reflecting the degree of connection or detachment from our empirical world.
Empathy, the ability to connect with something or someone beyond ourselves, arises for familiar things that resonate within us, fostering a sense of perceptual interiority or inclusion. (Bluth 1983)
Conversely, alienation occurs when faced with the unfamiliar, leading to feelings of lack of knowledge or control, making things seem foreign and potentially threatening. The absence of conditions facilitating empathic connections can evoke nostalgia and melancholy for the past and familiar things.
Conversely, when conditions requiring imagination to satisfy our abstracting impulses are absent, we disengage from the surrounding world, and our scope of perception becomes increasingly insular and solipsistic. In essence, there is a need for a balance between passive comfort and active challenge in our living environments.

Given that Space exists entirely outside the realm of collective human experience, it appeals more to our abstracting capacity than to empathy. Therefore, reestablishing empathic connections should receive special attention in the design of space habitats.
Consequently, the design of a space habitat must consider the importance of design not only in its functional role, creating the so-called “physiological space,”(Vogler & Jørgensen 2005) but also as a combination of functionality, mental representation, and symbolic meaning, viewed in light of its anthropological significance.

As space habitats will be built in remote and extreme environments, how can architecture address the resulting issues of isolation and confinement?
Ideally, architecture should establish a dialogue between place and space, as well as between interior and exterior. While the technical requirements for supporting human life in space make direct external experiences practically prohibitive, the habitat should not reinforce the perception of isolation from the external world. Instead, architecture should serve to enhance the surrounding environment, rather than attempting to suppress it. Weaker perceptions of

IN - DEPHT

the external world lead to a greater sense of disconnection from an objective reality; thus, the external world defines the context of the inner condition we call home. (Lockard 2006)

Various architectural approaches exist to mitigate the sensations of isolation and confinement.
One conservative strategy involves creating contrasting internal spaces within the overall structure, allowing inhabitants to experience diverse qualitative zones. The aim is not to allow occupants to experience a variety of spaces contributing to greater stimulation. Creating a single large open and unmediated space does not diminish the sense of confinement but merely enlarges the prison. In contrast, a mix of intimate, enclosed, and confined spaces with relatively larger open and public spaces is more effective. Each passage through a door is a transformative passage requiring cognitive adjustment to different spatial conditions.

Additionally, to compensate for conditions taken for granted on Earth but absent in space, architecture can offer artificial devices creating a temporal infrastructure, such as lighting systems that shift angles and change intensity to simulate the sun's cycles during the day. This would provide a sense of temporal orientation, especially in distinguishing between day and night, allowing the body to develop more regular sleep patterns and function more efficiently.

Another transitional strategy to alleviate the sense of confinement involves reestablishing a direct relationship with the external environment, both through windows and by redefining what is perceived as external space. Windows ideally represent a cognitive portal through which individuals can recall relationships with people, objects, and external locations, understanding their relative position in the context.
Redefining what is perceived as external space can be achieved by drawing analogies from terrestrial counterparts.
For example, porches and balconies are transitional spaces mediating between the home and the outside.

They allow distant and panoramic views of the landscape, sounds and scents of nature, fresh air, and natural light. Although porches and balconies are essentially enclosed spaces, the experience is qualitatively different from the internal environment; on the balcony, individuals are more engaged with what exists outside. Similarly, space habitats should have some form of accessory enclosure serving the same purpose as porches and balconies on Earth.

Artificial phenomena or events can be created outside the habitat, periodically focusing perception outward. By increasing awareness of external phenomena, the architecture of the habitat can encourage extroversion, counteract egocentric tendencies, mitigate sensory deprivation, and alleviate the sense of confinement. Extravehicular activities (EVAs) provide a way to experience the "outdoors," even if mediated by cumbersome equipment.

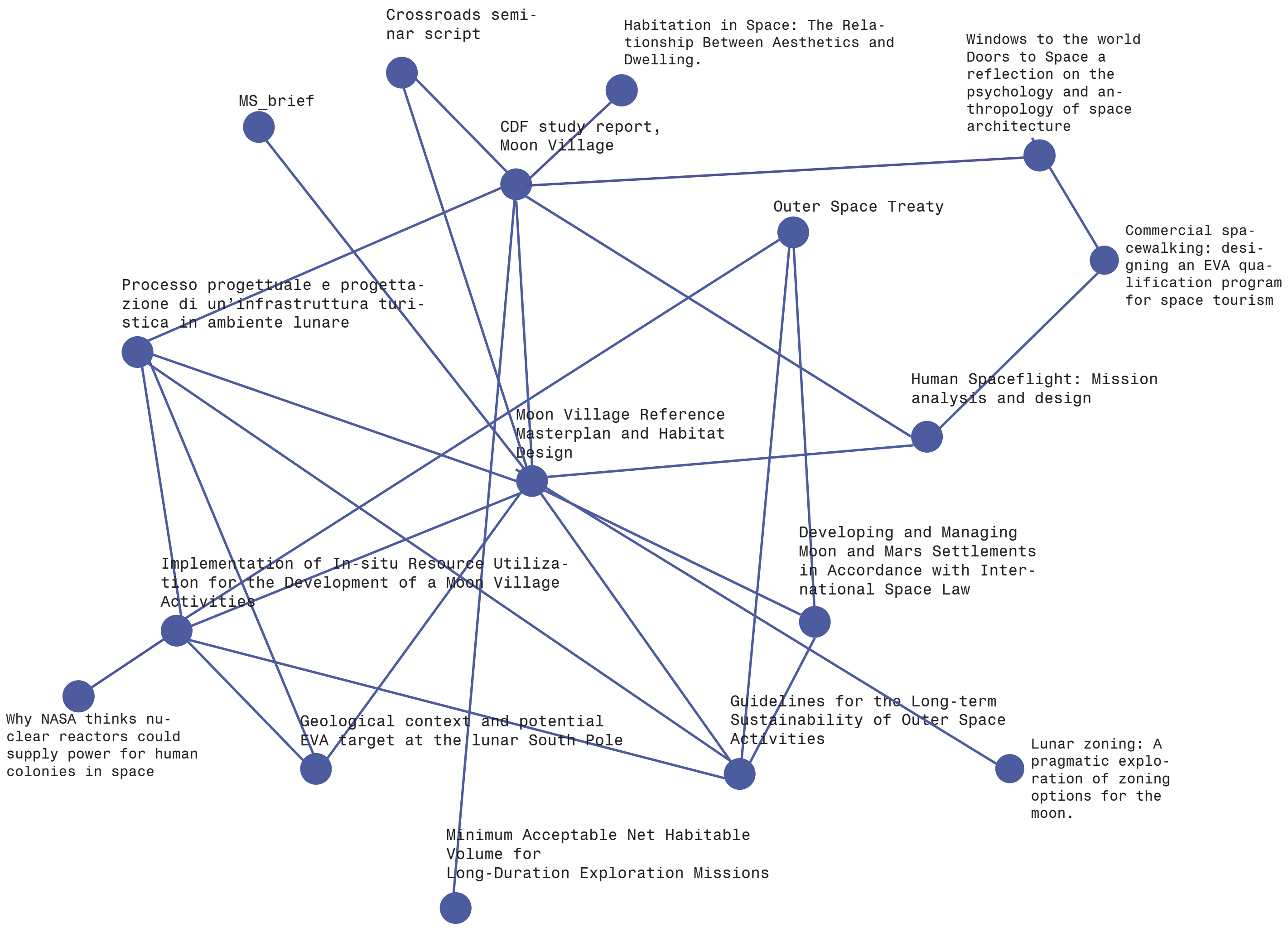
"Space isn't remote at all. It's only an hour's drive away if your car could go straight upwards."

(Hoyle 1979)

Scenario 3

An unprecedented function

2.4 Scenario 3 - *an unprecedented function*



The third scenario was developed in November after a series of meetings with the thesis collective. These sessions revealed crucial elements that enhanced considerations regarding the lunar project. Among these considerations were reflections on user experiences, including the range of sensations encountered in a unique, intricate, and thrilling environment.
There was a focused attempt to comprehend how to tackle the issue of the relationship between the interior and exterior within the lunar environment.
This research was closely tied to precise architectural decisions, including the incorporation of new features and the reimagining of certain areas, infusing them with fresh meanings. Furthermore, targeted investigations were undertaken concerning structural elements and adopted materials, with a focus on optimizing project efficiency and sustainability.

Instances overview

12) Categorization of spacewalking capabilities and minimum requirements of the various types of commercial spacewalkers. *[M. A. Gast, "Commercial spacewalking: designing an EVA qualification program for space tourism"]*

The design of a tourist facility has various user considerations. The settlement is intended to house both a crew, consisting of skilled astronauts, and tourists. The latter being non-astronauts and likely untrained, require pre-departure training.
This document outlines the comprehensive analysis of different permits required to carry out extra-vehicular activities, forming categories. Due to the analysis of this document, design factors emerged that resulted in the addition of a novel feature to the settlement.

13) Mixed-use approach in lunar zoning *[Hudgins, E., "Lunar zoning: A pragmatic exploration of zoning options for the moon"]*

The possibility of inserting itself within one of the Moon Village bands left open questions concerning the management of this band. As mentioned earlier, the band would be used by private actors who, with government authorisation, would be able to build possible further settlements. For this reason, it was assumed that an approach such as the one proposed within this study could in fact be a key element in the governance of the zone.

13d) Re-sizing of the external shell according to the function and cost - benefits analysis and lenght optimization *[from 24.10.23 meeting with Marta Rossi]*

In the previous scenario, the creation of a very large shell had entailed various considerations, mainly of a technical and economic nature.

14 d) Redudancy *[from 13.11.23 meeting with Marta Rossi and Valentina Sumini]*

Lunar design necessitates increased emphasis on standardisation and efficiency, as the harsh environment and high expenses render every decision crucial. Thus, the functional and morphological redundancy of the suggested design options becomes imperative.

15 d) At least a 1.5 m shell of regolith if the rooms are on a higher floor than the ground floor. *[from 13.11.23 meeting with Marta Rossi and Valentina Sumini]*

Radiation poses a significant threat on the Moon, as humans are not equipped to withstand it. Therefore, effective protection against it is crucial. The layer of regolith that provides the necessary shielding from radiation must increase in thickness as the distance from the ground level increases.

16 d) "There are various architectural approaches to mitigate isolation and confinement. A conservative strategy is to create contrasting interior spaces within the overall enclosure so that inhabitants can enjoy varied experiences in qualitatively different zones." *[Lockard, E. S. (2006). Habitation in Space: The Relationship Between Aesthetics and Dwelling.]*

The example quoted provides an opportunity to reflect on the design of interiors, geometry and materials. To guarantee that the interior spaces are effective and optimised, while also preventing a sense of isolation and confinement for guests and crew, it is necessary to avoid complete asepticism.

Istances | Spazializations | Conflict-Negotiation | Stabilisations

Scenario 3

Cycle e (24/10/23)

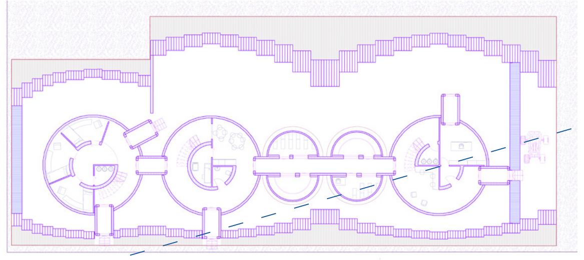
X_R Define the function of the intermediate space

12

2

1 d

|Annex 10|
|Annex 11|
|Annex 12|



X Define the relation-ship between my project and the Moon Village project

X_S The redudancy principle

Morphology
_Shell shape definition

Function
_EVA controlled space

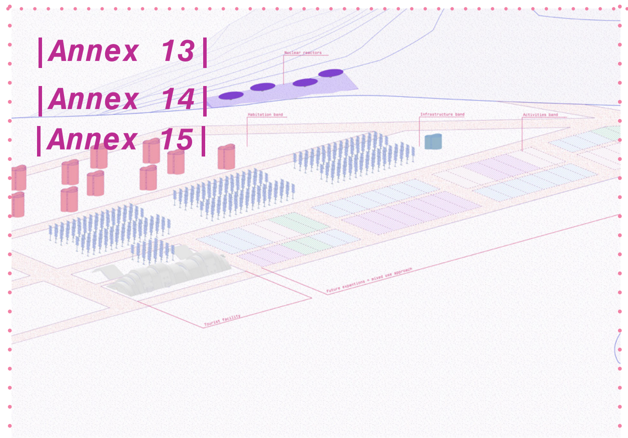
Cycle f (19/11/23)

13

14

1 d

|Annex 13|
|Annex 14|
|Annex 15|



Lunar zoning
_Development plan

Paths
_internal promenade

Istance
Module design Istance
X_n Conflict
X_D Prof. G. Durbiano
X_S Prof. V. Sumini
X_R M. Rossi
Topic
output

IN - DEPHT

EVA and tourists

Extravehicular activity (EVA) involves any tasks performed by an astronaut in the outer space environment, typically outside a spacecraft. Spacesuits are essential for EVA, providing the necessary environmental support as astronauts explore spacewalks or lunar and planetary surfaces. To date, there have been 443 EVAs (Janssen, n.d.).
When astronauts embark on spacewalks, they wear pressurized spacesuits containing oxygen for breathing and water for hydration. These suits are donned several hours before a spacewalk.
The activities performed during EVAs are primarily scientific and can vary. However, they are influenced by topographic constraints (Gawronska et al., 2020). Sampling features during EVAs are limited by range and slope constraints to ensure crew safety. Unassisted EVAs may be confined to a 2 km exploration zone on terrains with slopes <15°, expanding to 10 km and 25° with the use of a pressurized rover (Allender et al., 2019, Ohmann and Kring, 2012).

How does this relate to the design of a tourist facility?
The accessibility to space is expanding, allowing individuals with the means and desire to experience microgravity and gaze upon Earth and space. NASA has an established EVA training program for astronauts, but these standards may not apply to commercial spacewalkers. Therefore, training for those choosing to spend time in tourist infrastructure becomes crucial. Gast (2010) proposes an interesting approach to training levels.
Differentiating spacewalking capabilities into categories can establish roles, responsibilities, and minimum certification requirements for commercial spacewalkers.
Three certification levels are suggested, akin to Navy Divers:

- Spacewalker, 2nd Class: Basic certification level

- Spacewalker, 1st Class: Advanced certification level
- Master Spacewalker: Highest certification level

However, the lunar environment's inhospitality may pose challenges for EVAs due to solar winds or the two weeks of darkness.
Ensuring safe alternatives for high-risk endeavors such as spacewalks assumes paramount importance. The concept of establishing a non-pressurized yet secure environment for controlled extravehicular activities arises from the necessity to facilitate scientific operations safely and potentially extend access to space for tourists.
Considering that a significant proportion of commercial spacewalkers are likely to engage in extravehicular activities only once, or perhaps repeatedly within a single spaceflight, it becomes imperative to streamline both the level of training and the accompanying regulations. Restricting these requirements to essential elements is vital to foster a viable marketplace.
The imposition of excessive regulations could result in disproportionately expensive training programs, particularly when the majority of commercial spacewalks are anticipated to be relatively straightforward in nature.

// Conversation with

Valentina Sumini and Marta Rossi

Valentina Sumini, Ph.D., is a Space Architect and Research Affiliate at MIT Media Lab, specializing in Responsive Environments and Space Exploration. She is also a Visiting Professor at Politecnico di Milano, teaching “Architecture for Human Space Exploration.” Sumini’s work focuses on computational design solutions for sustaining human life in extreme environments on Earth and enabling space exploration. She has contributed to award-winning projects, including the Moon Village collaboration with SOM for the European Space Agency.

Marta Rossi graduated in 2021 from Politecnico di Milano with a Master’s in Architecture and Urban Design. Her collaboration with Professor Valentina Sumini began with her Mars habitat thesis. Marta is now a teaching assistant for Professor Sumini’s “Architecture for Human Space Exploration” course and a Ph.D. student at Polytechnic of Turin.

1. Do you think a more homocentric approach and less engineering-centric approach will be truly pursued in space projects? Or will everything still be heavily engineered?

V.S.: *Certainly, the pursuit of a more human-centered design approach in space projects is a compelling prospect. While engineering will undoubtedly play a crucial role in space endeavors, the integration of a homocentric perspective signifies a shift towards prioritizing human needs, well-being, and adaptability in the design and execution of space architecture.*

Like many of my generation and those following the Moon race and the initial era of space exploration, the quest for a new frontier has been a powerful motivator. The MIT Space Exploration Initiative, in particular, enhanced this stimulus, fostering the idea that realizing space exploration could be democratically achievable. Our current efforts involve actively designing technologies, tools, and human experiences for our Sci-Fi Space Future with a unique emphasis on a planet-centered design approach. This approach seeks to be respectful to the planetary body, acknowledging the significance of sustainable and responsible habitation, following the collaborative vision of the International Space Station (ISS) experience, and defining a ‘master plan’ for an inclusive and organized evolutionary settlement. From an architectural perspective, this allows us to reconsider the notion of an ‘ideal city’ in an entirely new context, navigating extreme environmental conditions as both a technological challenge and an opportunity for innovative design solutions. Therefore, designing a resilient and sustainable infrastructure for human missions on the Moon is a new challenge that requires new conceptual design approaches.

2. Is the possibility of introducing functions beyond research a truthful and achievable prospect, or will lunar and Martian research be the only functions pursued?

M.R.: *The main function in the first period of exploration of these two celestial bodies will certainly be research-related and will concern a small segment of the population consisting of scientists and experts. Possible different functions related to tourism or definitive establishment outside the terrestrial boundaries, I believe, could be realised over a longer time span than the research function. However, the actual realisation of all this depends on purely terrestrial economic and political dynamics, as well as on overcoming certain technical and technological challenges to ensure the sustenance of human life.*

3. How long do you think it will take for humanity, not just astronauts and the very wealthy, to be ready to become a multiplanetary generation?

V.S.: *The timeline for humanity to transition into a multiplanetary generation is challenging to predict precisely. Technological advancements, increased accessibility, and the development of sustainable infrastructure will influence the pace of this transition. It could span several decades, with ongoing efforts aimed at democratizing access to space and ensuring the viability of human settlement on other celestial bodies.*

4. What are the most important concepts that need to be reconceptualized when transitioning from a project done on Earth to a project done on the Moon, from an architectural standpoint?

V.S.: *Transitioning from Earth-based projects to lunar projects necessitates a reevaluation of fundamental architectural concepts. Key considerations include adapting designs to lunar gravity, mitigating radiation exposure, and leveraging available lunar resources for construction (ISRU) for a sustainability-by-design approach. Furthermore, the architectural response should account for the unique environmental challenges, emphasizing modularity, sustainability, and efficient use of space.*

5. Could proposing a hypothetical EVA zone in a secure setting offer a resolution that concurrently tackles issues surrounding the safety of tourists and re-examines the connection between interior and exterior spaces?

M.R.: *The division between indoor and outdoor environments is crucial in spatial projects due to security concerns. Thus, it’s necessary to re-evaluate the relationship between the two. One potential solution is a protected outdoor area which could be a step towards rethinking the way we conceptualise indoor and outdoor spaces. However, it’s important to consider the environmental and technical restrictions that such a project presents.*

6. How can the relationship between interior and exterior be reconceptualized in such an extreme environment?

V.S.: *In an extreme lunar environment, reimagining the relationship between interior and exterior becomes paramount. Architects must design with a focus on creating a seamless yet adaptable transition between the enclosed habitat and the lunar exterior. This involves strategic use of materials, innovative structural designs, and possibly incorporating technologies that provide a sense of connection to the lunar landscape while ensuring the safety and comfort of inhabitants.*

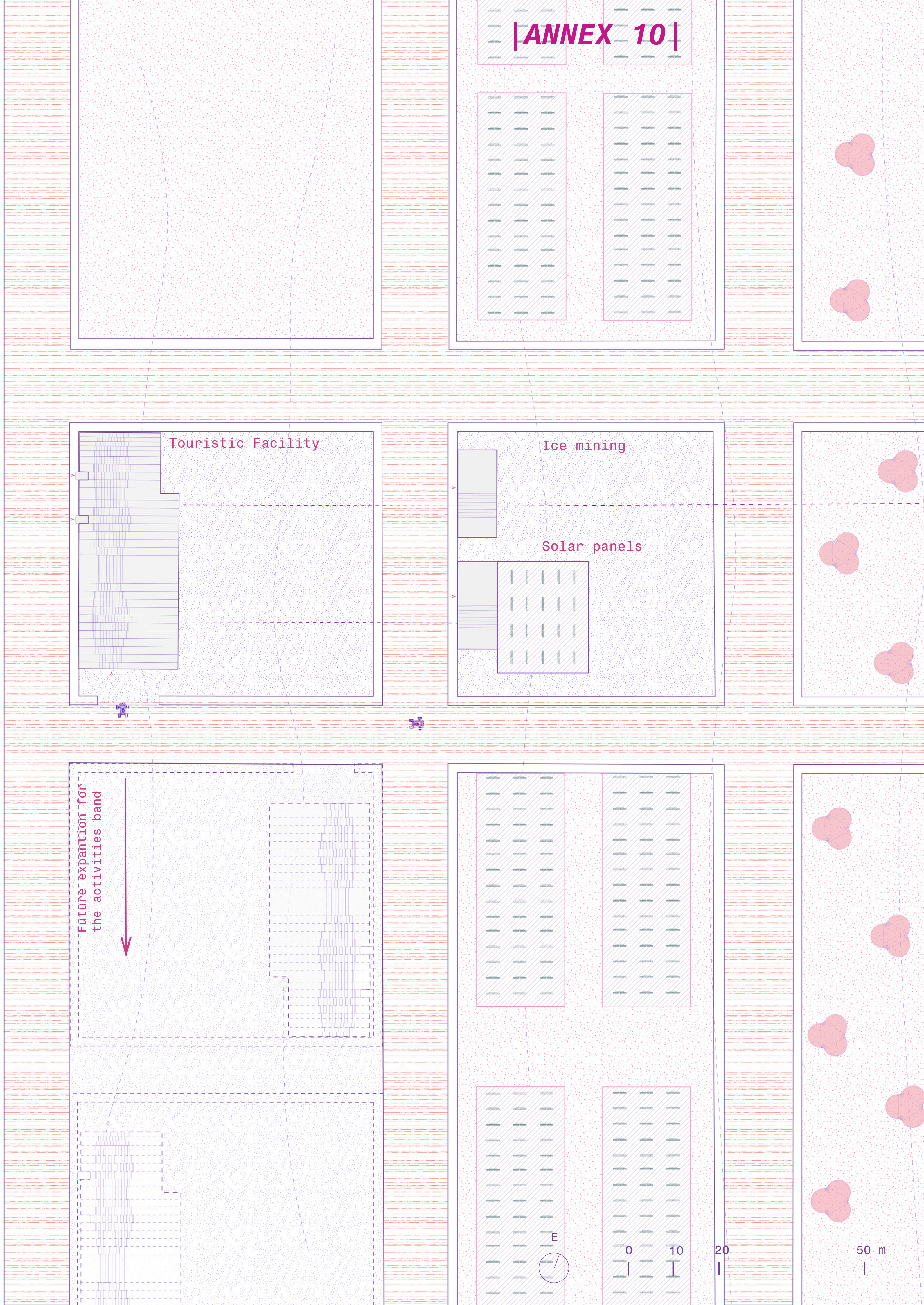
2.4.1 cycle e

Linearity

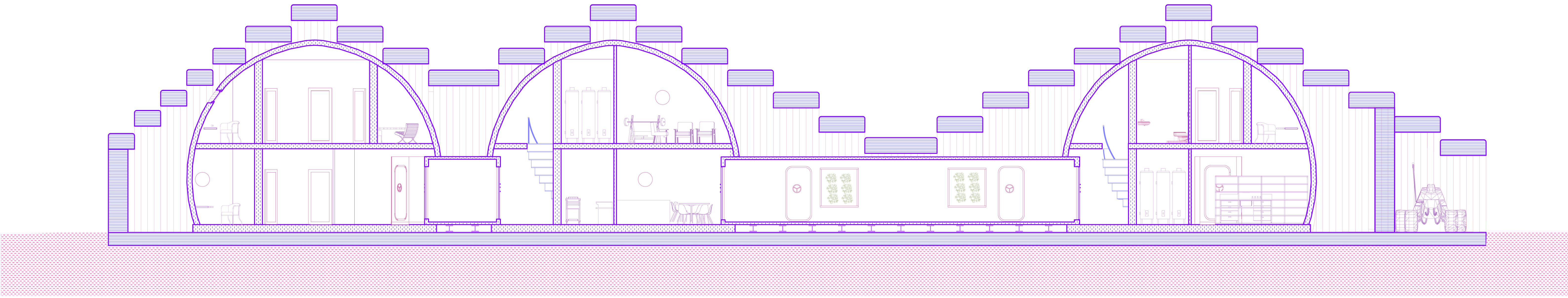
The design proposal for cycle e underwent a modification in the habitat distribution. Initially conceived with a C-shaped configuration, concerns were raised during discussions with Marta Rossi about the potential drawbacks of excessively long connections between modules.
This raised the prospect of increased costs and the creation of less livable and comfortable connections.
In response to these considerations, a decision was made in this design proposal to adopt a linear distribution system, aligning all modules along a single main axis.
This strategic choice aims to optimize connections, offering both economic and technical advantages while bolstering safety.

Given that the proposed facility falls within the Moon Village project, careful consideration was given to its placement within the overarching masterplan.
This involved not only determining the location of the tourist facility but also strategically placing associated support infrastructure, including roads, solar panels for energy production, and infrastructure for ice extraction.
At this stage, it was envisaged that the infrastructure supporting habitation would be situated within the dedicated infrastructure zone outlined by the Moon Village master plan.

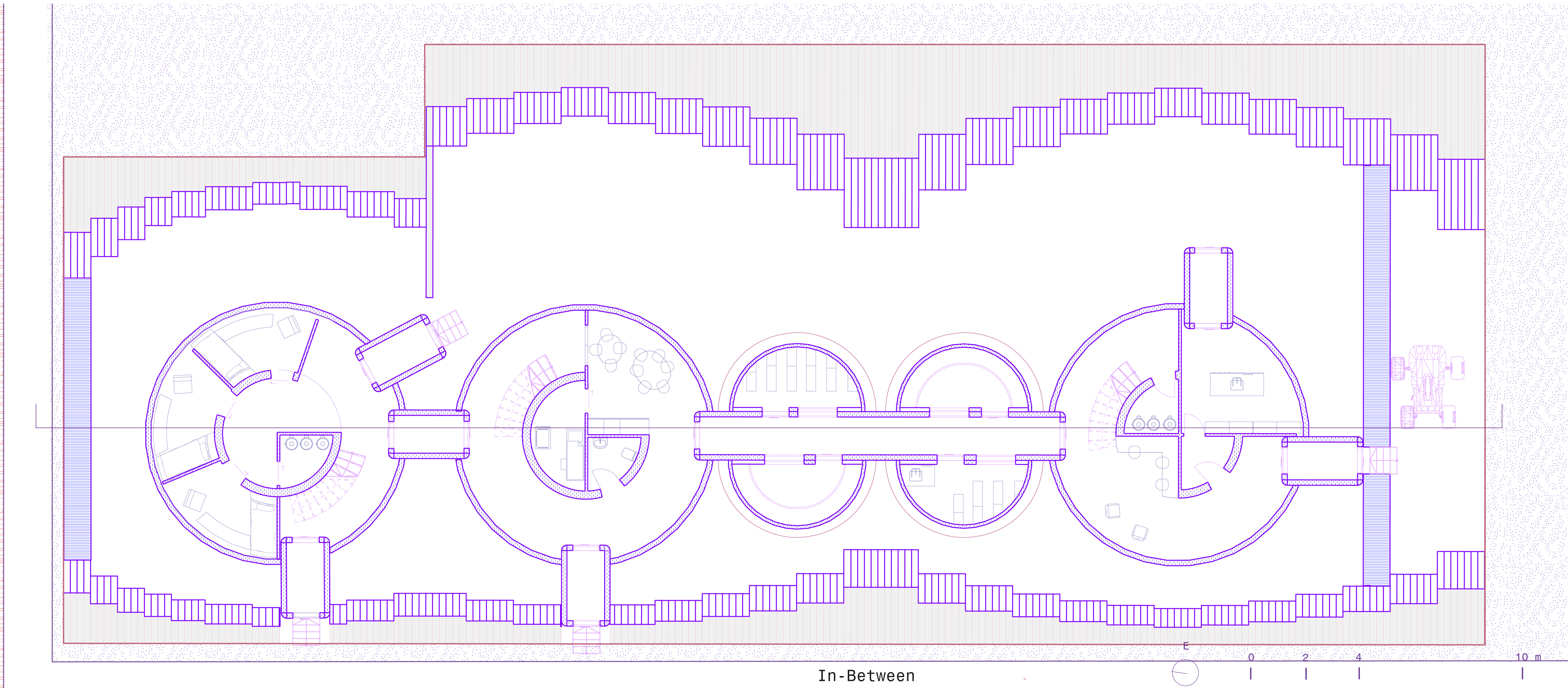
The adjacent plan illustrates the above points, distinguishing the Moon Village project in pink and the proposal from this thesis in purple. An attempt was made to outline a potential expansion framework for future participants seeking to integrate into this context.



|ANNEX 11|



|ANNEX 12|



2.4.1 cycle e

The protective shell is made up of a series of arches with a special geometry, their succession in sequence is able to generate the effect of a mountain, typical of the lunar landscape and which greatly mitigates the landscape impact of the settlement.
The arch was a parametric tool that allowed it to be managed in order to be able to create an interesting and also luminous interior space thanks to the succession of slits that characterise the space between a lower and a higher arch placed in succession.

Considerations were also made regarding the hierarchical categorization of modules, which were divided into three types: the first hosting fundamental functions, the second housing greenhouses, and the third handling connections. During the previous exchange, the presence of an intermediate space between the interior and exterior was a topic of discussion. However, the absence of a specific function for such a large space raised doubts.
The complex relationship between the interior and exterior in such a hostile environment was a subject of exploration in the in-depth "psychology of space".
This led to the idea of an intermediate exchange zone that could somehow evoke the experience of being outside without actually being there. However, the absence of a well-defined function for such a large space, made justifying this space challenging.
Following these reflections, efforts were made to identify a function for a space with these characteristics. A study by Gast (2010) inspired the idea of a space that could host extravehicular activities (EVAs) in a protected environment. [in depth "Eva's and tourists"]
The presence of openings towards the outside would provide a similar sensation.
The presence of this space is deemed essential due to the potentially hazardous nature of Extravehicular Activity (EVA) for even seasoned astronauts, and it becomes even more critical for tourists. Introducing a novel and interactive experience for tourists to assume the role of researchers for a day could be enticing. Moreover, the space could serve the crew by providing a laboratory for conducting research activities in a secure environment.

Furthermore, as suggested by Professor Valentina Sumini, the walls of the shell could serve as a canvas for interactive projections. These projections could showcase, for instance, earthly landscapes or other images, possibly incorporating technologies that establish a connection to the lunar environment while ensuring the safety and comfort of the occupants.

One of the four modules seen in previous design hypotheses, particularly the greenhouse module, underwent modification. As known (Häuplik-Meusburger & Holzgethan, 2011), the greenhouse is a fundamental element providing essential resources and sensory and spatial benefits. The improvement stems from plant presence and cultivation, offering significant engagement through individual interaction, contributing to the overall well-being of astronauts.
While greenhouses are not easily accessible to tourists due to stringent control environments, it was decided to divide the greenhouse module into smaller modules with windows overlooking the connection corridor. This decision aims to create the perception of a view of something alive for all habitat inhabitants.
The theme of windows and views is crucial. Windows facing the greenhouses allow inhabitants to observe the greenery and its evolution, fostering a connection with life.

The second window regime faces the external view. During Cycle C, the grid processing identified the view towards Earth as a fundamental axis due to the positive impact it has on astronauts (White 2021).
This principle was not previously incorporated into the design. The design proposal implements this concept by including windows in every bedroom and communal area.
The structure also uses this as an architectural feature, with openings in the shell at each variation level to allow natural light to enter the space in between.
The structure features a double layer, with one comprising a pressure membrane. An inflatable ETFE, reinforced with Dyneema imported from Earth, constitutes the other layer. The windows consist of double-glazed panels and a second layer of regolith created in situ using 3D printing.
As a result, solving the issue with the outer layer's windows was of utmost importance. Since it is preferable to avoid transportation of materials from Earth to the Moon whenever possible, a 3D-printed enclosure was thought to be the right solution.
However, to address openings, it was necessary to establish the 3D-printable material. Schleppi et al.'s (2021) investigation clarifies this issue, suggests that the ability to produce transparent glass on the lunar surface could be a significant enabling factor.

2.4.2 cycle f

Urban redefinition

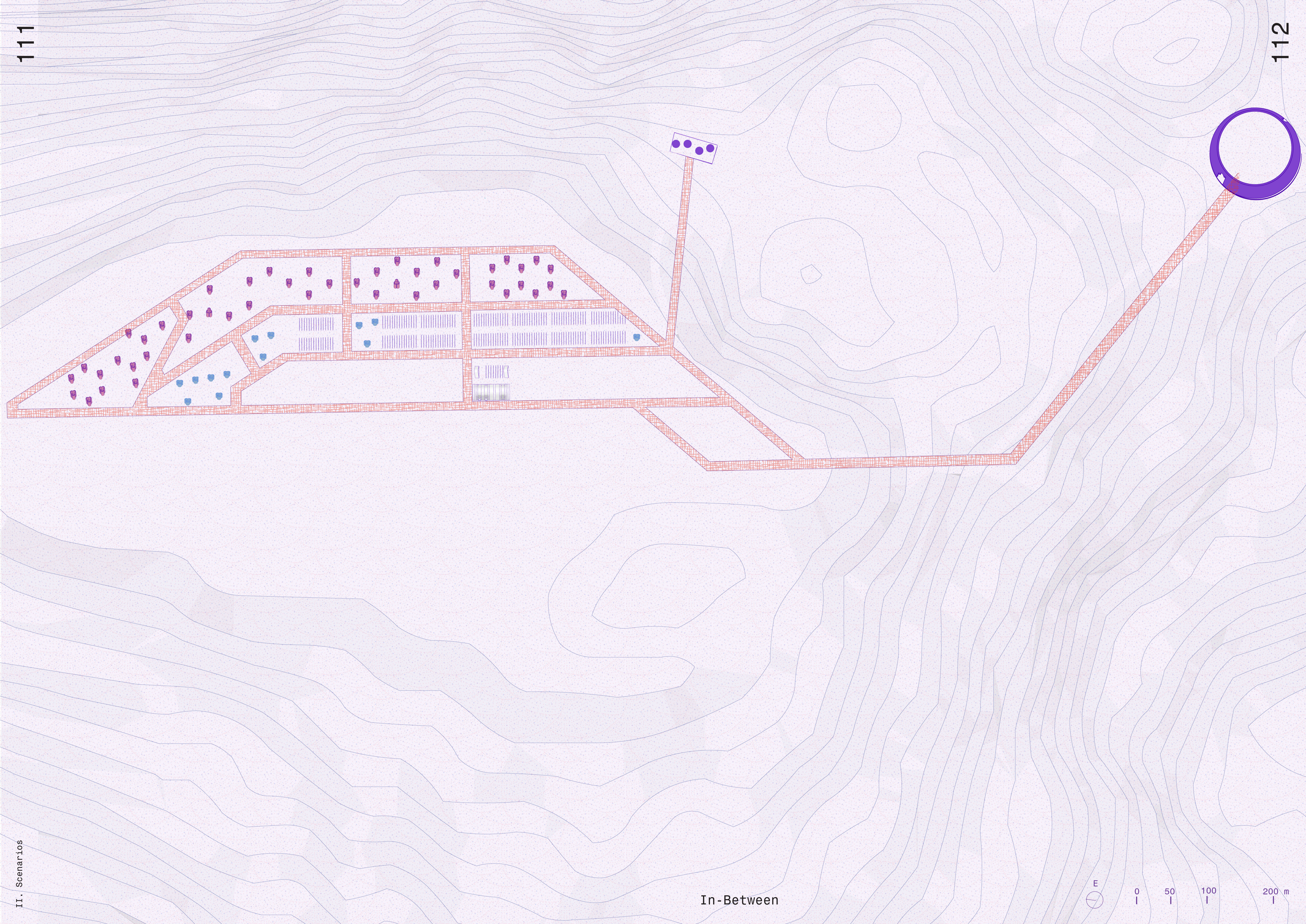
During this stage, the formulation of an expansion strategy was deemed essential, wherein land use and zoning policies have a significant impact on shaping the built landscape and setting up a structured framework for business operation.
It is worth noting that the proposed project is associated with a wider program, Moon Village, which envisages a practical distribution system based on different bands.
This thesis project fits into the context by suggesting a precise plan for the area it is integrating into. The plan includes defining categories of use for lots. Since this particular area has not been assigned a function, there is an opportunity to intervene in this uncertainty.

To seamlessly integrate into this location, I formulated a realistic zoning plan for the area.
The selected methodology is inspired by a multifunctional perspective, as demonstrated by Ethan Hudgins (2021).
Hudgins' analysis highlights the efficacy of a mixed-use approach, which considerably reduces the average distance between assigned usage categories as plot sizes become more detailed and denser.
This is particularly evident when activities are randomly assigned in a mixed-use fashion instead of being strictly separated. Zoning for dense, mixed-use development enables the fortuitous co-location of activities driven by stakeholders, leading to a significant reduction in average trip distances of up to 88%.
The plan highlights the possibility of cost savings through reduced travel, and the benefits that mixed-use zoning can bring about (Hudgins, 2021).

To secure the support of stakeholders for international organization and zoning policies, it is essential that said policies promote a productive and efficient urban settlement.
This necessitates the development of compact, co-located infrastructure over a shared system of scaled infrastructure.

Collaboration is a fundamental criterion of success, which is why the project aligns with the Moon Village initiative, which underscores this concept in the zoning plan.
Additionally, being positioned within the same area would enable not only scientific research in neighboring areas but also ensure that constructions are confined within defined perimeters, avoiding extensive and scattered creation of micro-cities on lunar soil.
Although construction on lunar soil is currently a topic of interest, this thesis does not aim to support the creation of a megalopolis in an extreme environment, which could introduce similar issues to those present in certain terrestrial areas.

Essentially, by participating in international organizations and adhering to zoning authority policies, stakeholders should be able to avoid independently constructing their infrastructure.
The cost of independent private infrastructure should be outweighed by the opportunity for specialization at a lower cost overall.
This strategic alignment ensures not only the success of the lunar settlement but also the economic viability and attractiveness for all parties involved (Hudgins, 2021).



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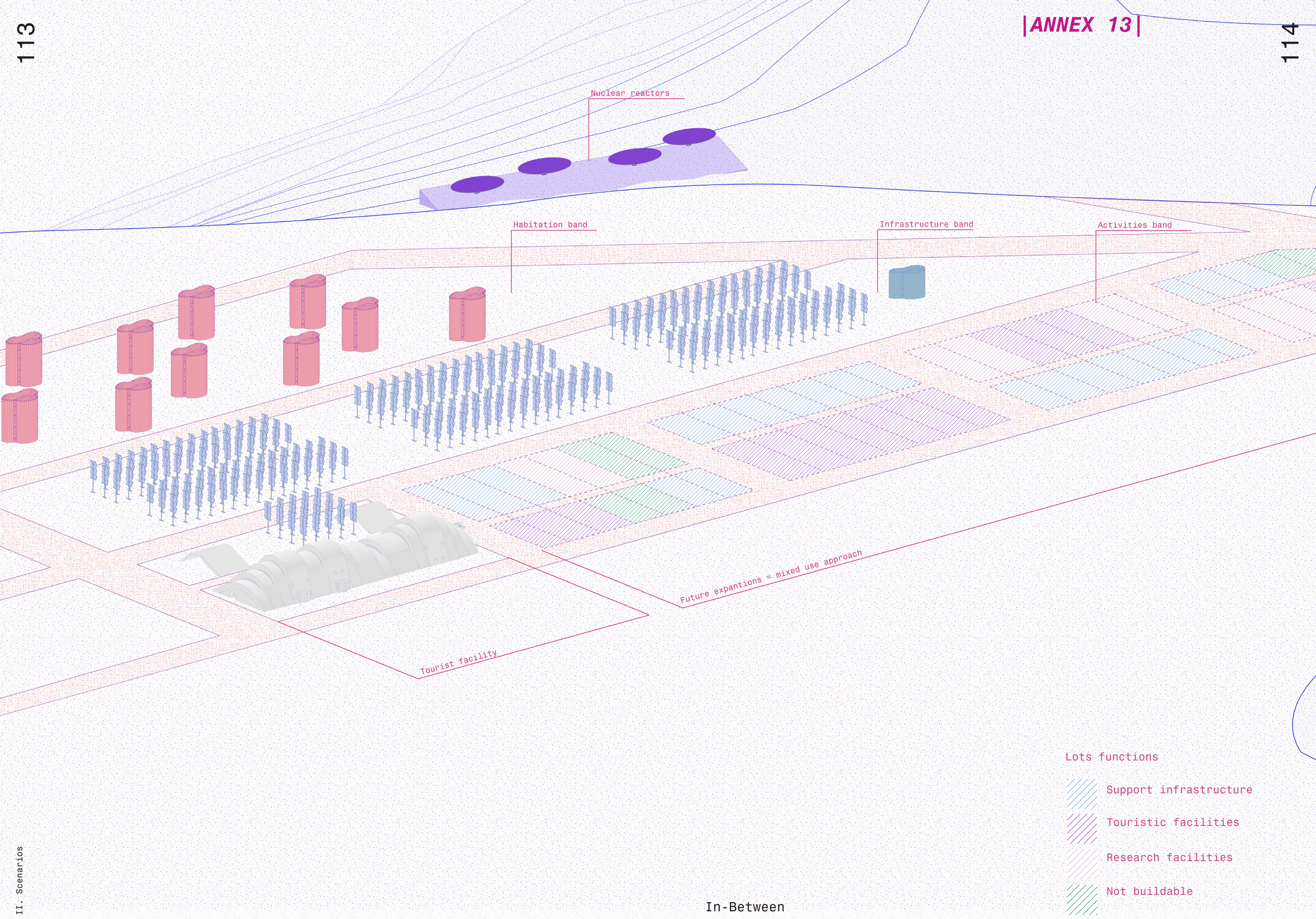

Nuclear reactors
Habitation band
Infrastructure band
Activities band
Future expantions = mixed use approach
Tourist facility
Lots functions
Support infrastructure
Touristic facilities
Research facilities
Not buildable

2.4.2 cycle f

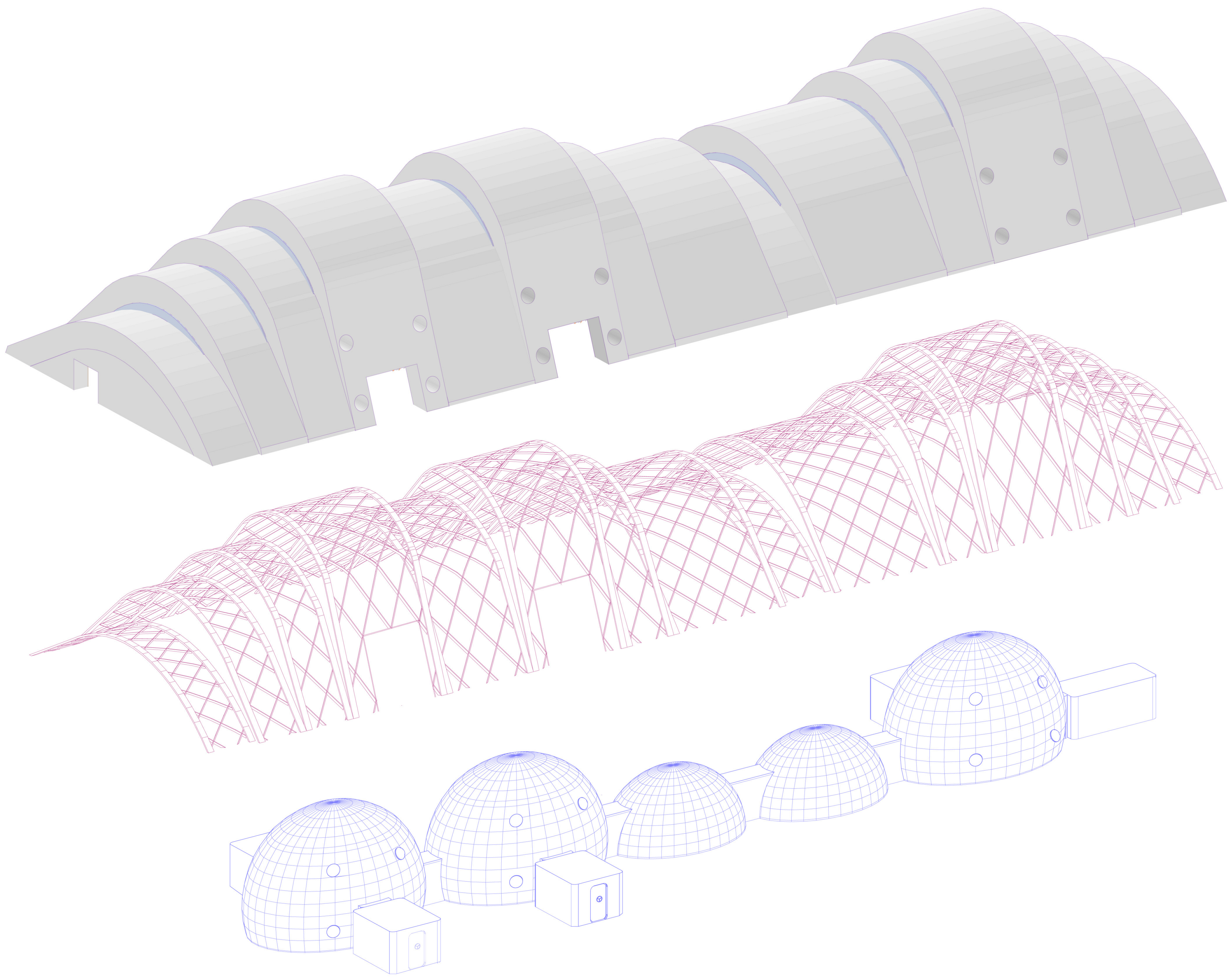
Reconfiguration

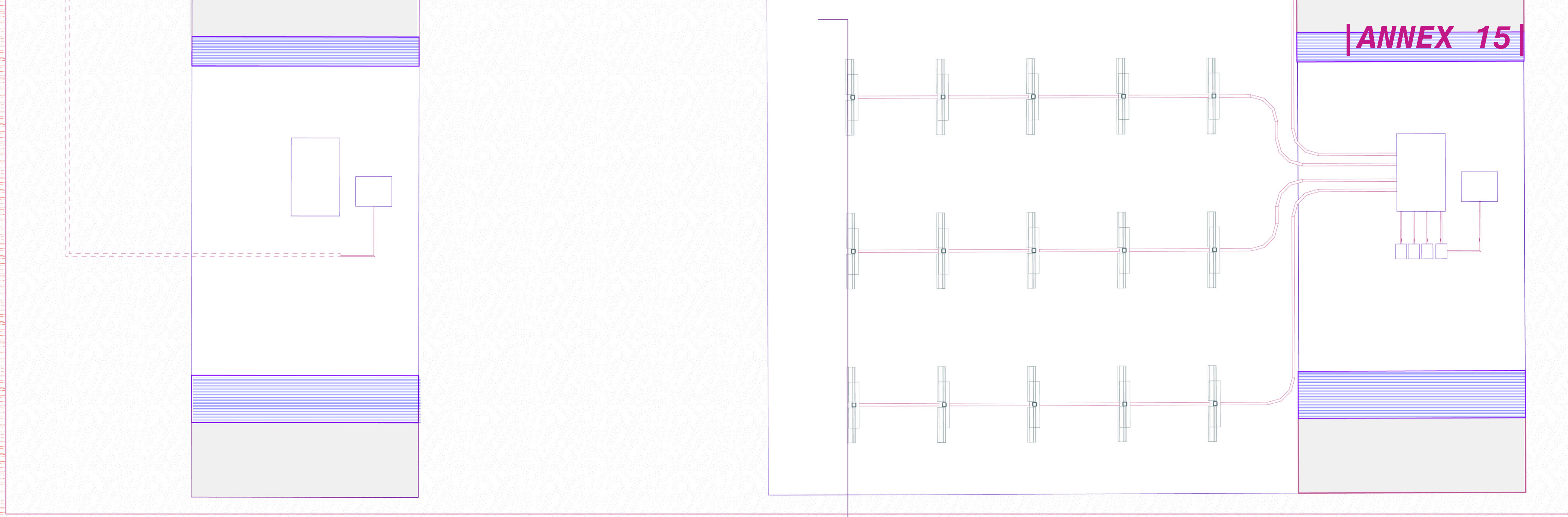
Subsequent to the meeting convened on November 13th with Professor Valentina Sumini and Marta Rossi, a more extensive set of considerations and refinements were deliberated upon in relation to the lunar project.
A notable focal point of these discussions centered around the intricate concept of redundancy within the settlement, an indispensable facet in spatial design. The antecedent design hypothesis had not comprehensively embraced this principle, prompting a conscientious effort to integrate redundancy across diverse dimensions.

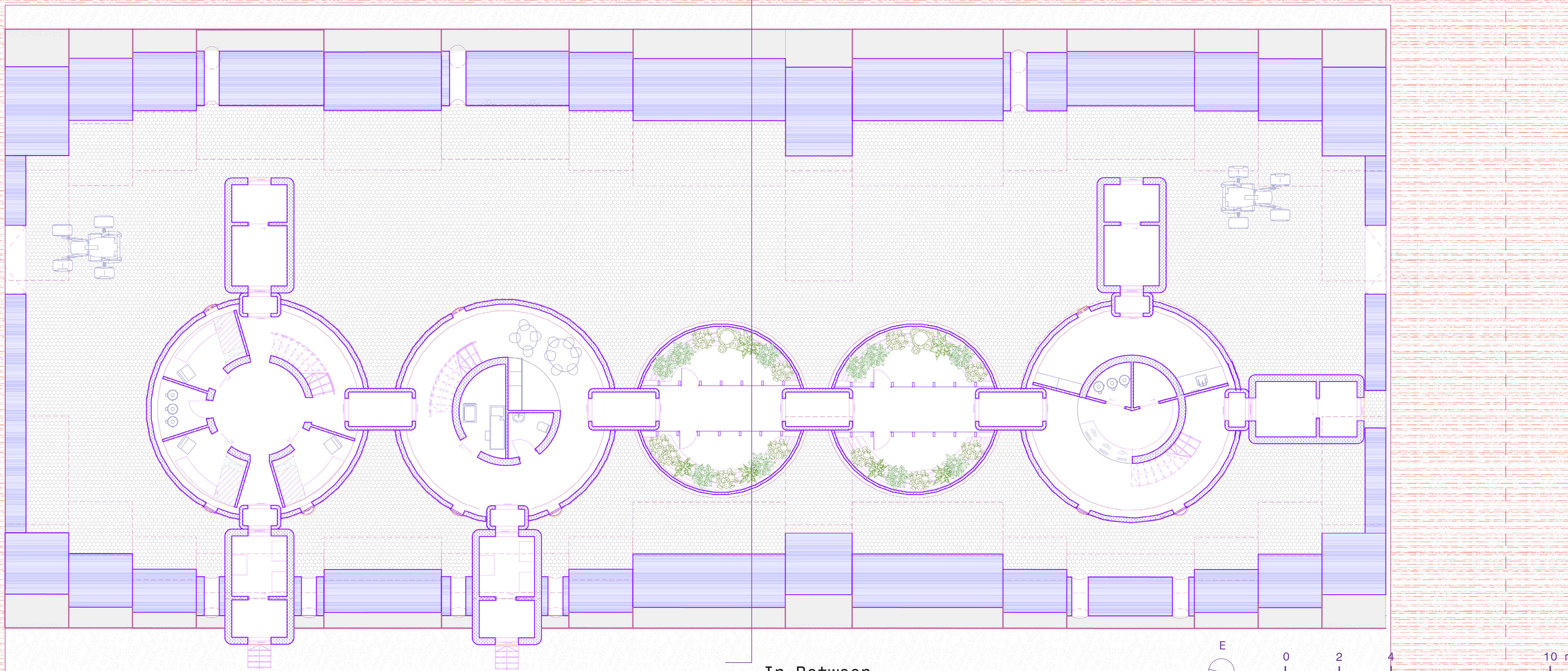
At a dimensional level, meticulous attention was directed towards the identification of four distinct modules, each conceived to be prefabricated on Earth and subsequently transported to the lunar surface.
These modules encompass the primary functional module, the greenhouse module, an airlock module facilitating the connection between pressurized and non-pressurized environments, and a second airlock module designed to link two pressurized environments seamlessly.
Operational considerations were also diligently addressed, with each module meticulously designed to incorporate sleeping quarters.
This inclusive approach extended even to the module dedicated to communal spaces, ensuring adaptability in the face of potential depressurization events within either the tourist or crew modules.
The adopted solution involved the integration of foldaway beds discretely concealed within partitioned furniture, allowing for their deployment as needed.

Beyond the spatial and functional dimensions, thorough reflections were devoted to technical aspects inherent to the varied functionalities distributed across the different floors of the modules.
A pivotal decision to include chambers on the first floor necessitated a consequential adjustment in the thickness of the regolith shell. The meeting underscored that the initially specified thickness was deemed insufficient for the intended function.
Additionally, structural integrity concerns were articulated, prompting a recognition that the regolith shell alone may require fortification.

In response to these concerns, a comprehensive strategy was devised. A carbon fiber skeleton was strategically incorporated between the inflatable modules and the regolith shell, introducing an additional layer of structural support. Significantly, the incorporation of a carbon fiber skeleton was envisaged to transpire concurrently with the 3D printing process of the regolith shell, thereby fostering synergy within the overarching construction methodology. This integrated approach aimed to optimize the efficiency and structural integrity of the lunar habitat, capitalizing on the inherent advantages offered by both the regolith shell and the carbon fiber reinforcement.
In summation, the post-meeting deliberations and refinements underscored a commitment to enhancing both the robustness and adaptability of the lunar settlement, ensuring its resilience in the face of unforeseen challenges and contributing to the broader objectives of lunar habitat design and sustainability.







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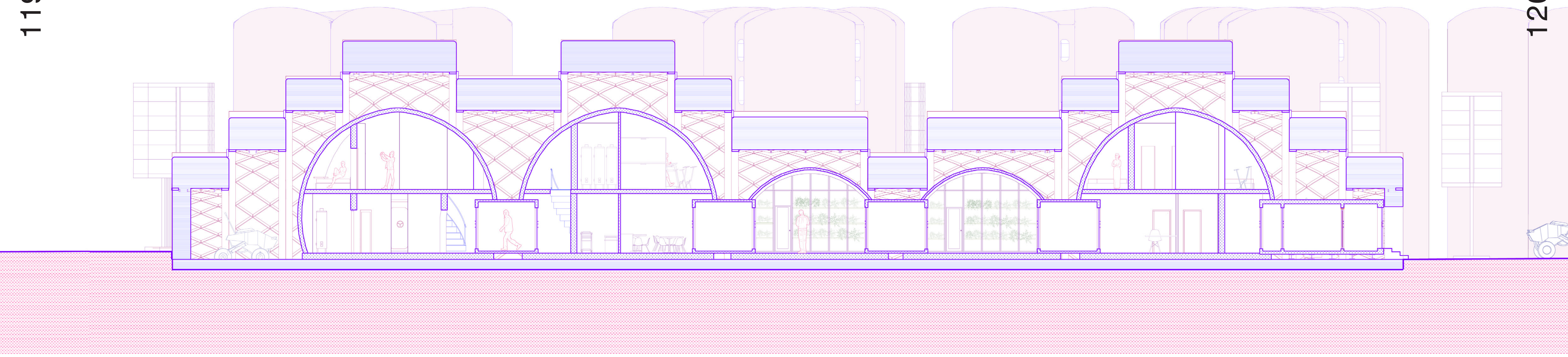

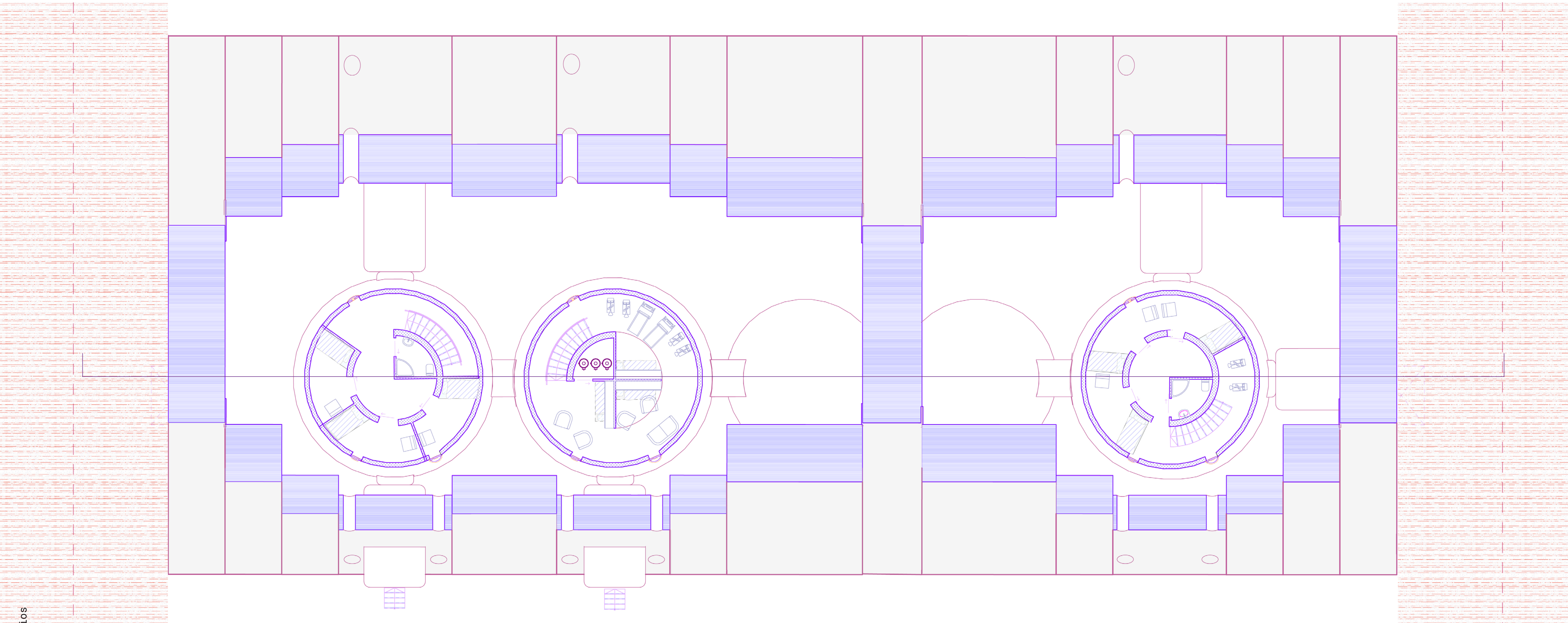

E

0 2 4 10 m

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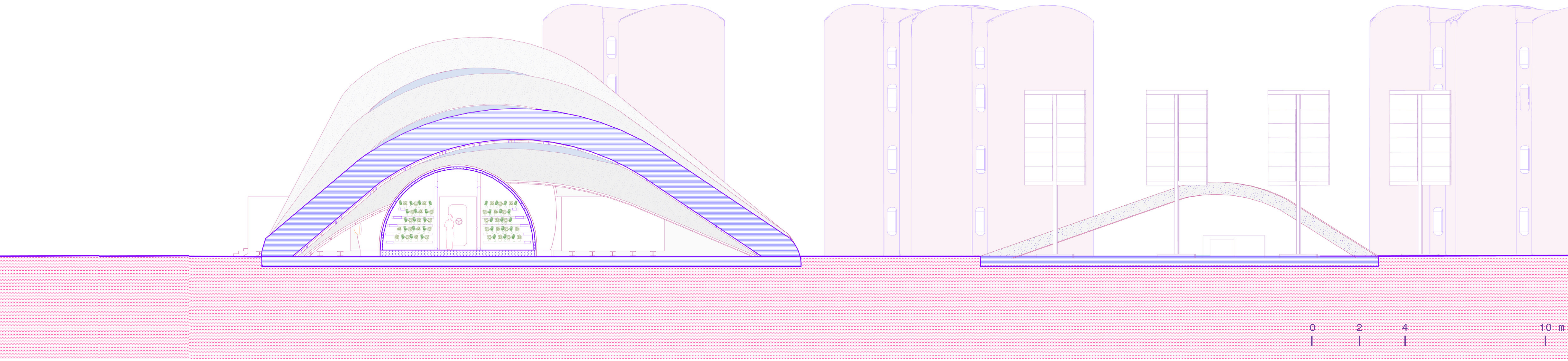


The above cross-section demonstrates the interconnections among the interior, intermediate space, and exterior within the lunar settlement. This portrayal centers on the thematic consideration of pedestrian movement and the incorporation of different spatial typologies. The importance of walkability and the variety of spatial experiences takes on utmost significance. The proposal for a verdant walkway is based on the strategic positioning of the two modules that house the greenhouse, ensuring a harmonious interplay between the built environment and the natural elements.

The recommendation has, at its core, the goal of providing accessible and user-friendly amenities for all. This pedestrian thoroughfare not only serves as a conduit for functional purposes but also enhances the overall wellbeing of the lunar habitat's inhabitants.

The inclusion of greenery in the walkway design is motivated by its psychological impact, rather than solely functional considerations. The integration of plants and natural elements provides a visual and sensory respite, reducing potential feelings of confinement experienced by lunar inhabitants. The incorporation of outside views, combined with the presence of greenery, becomes crucial in cultivating a more holistic and pleasurable living experience.

This integration of functionality and human-centric design principles highlights the project's dedication to creating a lunar settlement that meets essential needs whilst also enhancing the quality of life for its occupants.

3.

Tracing the process ex-post

The 'Tracing the process ex-post' section, which draws together the threads of the thesis, aims to systematise the information gathered throughout the process and to provide an extended analysis of the specific issues that have emerged.

Up to this juncture, the entire effort has been directed towards establishing a correlation between the terrestrial and lunar contexts. The objective is to create sturdy connections from the standpoint of architectural practice.

In this work, a social reality has been crafted, originating from the documentation of encountered particularities. The analysis of specific issues has resulted in a gradual augmentation of relationships among the various components under scrutiny.
This concluding section accentuates distinctive conditions encountered throughout the journey, emerging in individual cycles and shaping the developmental trajectory of the project.

The overarching objective of this research extends beyond envisioning a settlement on the Moon; it aims to glean insights from that experience on how social and physical realities can undergo transformation.

The thesis offers a methodology aimed at creating one possible scenario among many, which, thanks to the various actors and their systemisation, succeeds in taking on a performative dimension, although this performativity is not only the result of these relationships, but also of the ability of the design proposal to be realised in the established framework.

3.1 Methodological problems

Throughout the intricate process of constructing the thesis, a myriad of questions emerged, spanning technical, design, and methodological dimensions.
One of the initial challenges revolved around a paradigm shift induced by the comparison between Earth's established conventions and unprecedented lunar context with its specific physical reality.
Elements considered secure and validated on Earth underwent modification on the Moon, posing a distinctive challenge in adapting terrestrial architectural design, along with its rules and governance instruments, to the lunar context.
This process involves redefining the foundational assumptions of reality and, consequently, the approach to architectural projects.

In this context, the architect played a crucial role in comprehending these facets and discerning which clear and assimilated paradigms from architectural, technical, and bureaucratic perspectives on Earth required new connotations in the realm of space design.
Given the unique lunar context, a thorough investigation into established Earth paradigms was imperative, as they proved to be unstable on the Moon.

The ascertaining of the degree of separation from the traditional bureaucratic context, as defined within the commonly shared terrestrial paradigm, has engendered a contemplative exploration and critique of the constraining conditions.
These conditions are, in essence, the culmination of extensive prior stratifications that have contributed to the perception of such constraints as fundamental principles of reality.

The analysis presented in this thesis does not seek to deny their existence; instead, it adopts an inquisitive position regarding their unquestioned acceptance.
The investigation has led to the development of a new bureaucratic context based on a different physical and social reality.

A significant finding has arisen, highlighting the necessity for incorporating governance tools, which are absent on the Moon but critical on Earth.
Terrestrial instruments have been introduced to reassess this emerging context with a partial redefinition being the intended outcome.
As a result of the need for reassessment in the face of a physical and social reality different from the one in which they were first introduced - the earthly reality - it was necessary to grasp both their intrinsic power and the underlying conditions.

Within this context, the architectural project is perceived as a meticulous and verifiable documentation. The suggested project acted as a tool for scrutinizing terrestrial environments, conducting in-depth examinations, and fostering critical thinking about terrestrial architectural practices.

3.2 Issues reconceptualization

Designing in extreme conditions, such as the lunar environment, poses challenges that are often taken for granted on Earth due to their assimilation.
Throughout the design process, I critically examined elements that are commonly assumed in architectural design on Earth. When comparing the design for lunar environments with those for terrestrial environments, I identified a catalogue of issues requiring reconceptualisation, specifically when transitioning from Earth to the Moon. Occasionally, ideas acquire new characteristics, which may contrast with their terrestrial equivalent, while in other cases, terrestrial criteria can be applied with necessary adaptations.

Charting all the issues, along with their implications and connections contributing to the composition of social reality, proved to be a complex task. Nonetheless, a diagram was generated to schematize the crucial issues, serving as an extremely condensed summary of the comprehensive analysis conducted cycle after cycle. Even if all issues were then described in more detail on the following pages.

Despite the differing assumptions, the design process found it intriguing and beneficial to experiment and assess various earthly tools and rules.
This exploration aimed to discern their effectiveness and identify areas of success or limitations. Among the governance tools examined were an urban development plan, land use mapping, and regulations providing details on minimum internal square meters.

The accompanying graph aims to elucidate the challenges and associated design solutions that have arisen.

Scenario 1

ISSUES!

! radiations

! dwell times

! functions and related square meters.

*There is a **deficiency in minimum dimensional and qualitative standards**, specifically the absence of a document outlining the required minimum quantities, expressed in square meters per inhabitant, allocated to each function.*

! private - public relationship

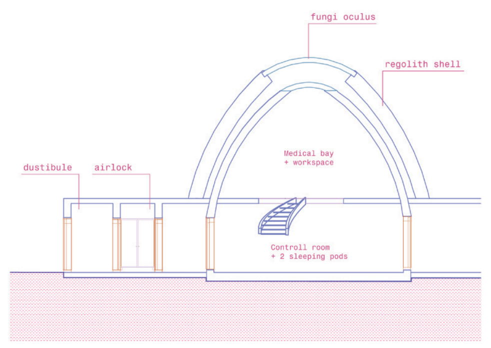
PROJECT RESPONSE

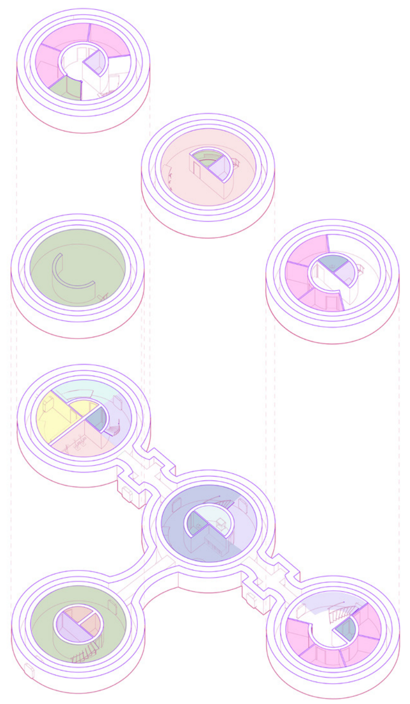
\ regolith protective shell

\ each module has a main function

\ definition of minimum sqm for each internal space

DRAWINGS





Scenario 2

ISSUES!

! (ISRU) resources location and utilization

! safety distances

! energy production

*There is a **lack of a regulatory plan**, meaning the absence of a tool to regulate building activities.*

! cooperation

! transport and construction

PROJECT RESPONSE

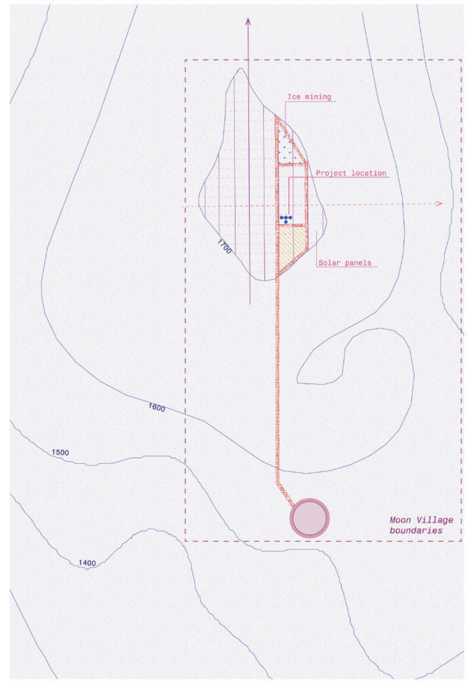
\ settlement pattern (main axes)

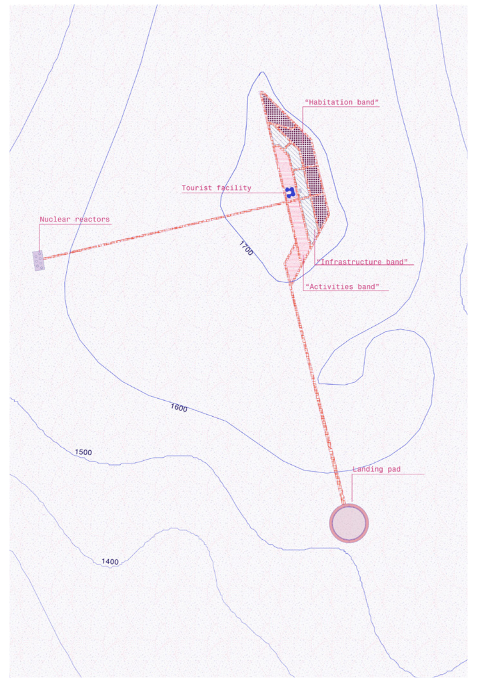
\ infrastructure plan

\ specific location within the master plan of the Moon Village idea

\ mission plan definition

DRAWINGS





Scenario 3

ISSUES!

! users safety

! interior - exterior relationship

! possible future expantion

***lack of an allotment plan** for the band in which the project is inserted*

! exterior environment relationship (not safe)

! confinement

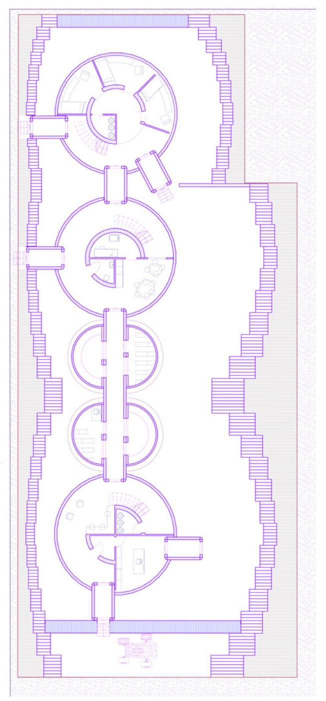
PROJECT RESPONSE

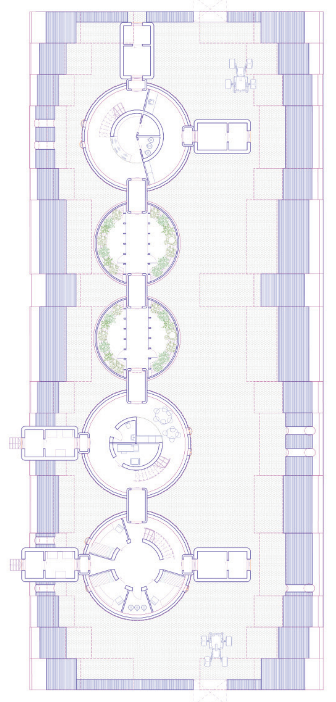
\ introduction of an intermediate space not pressurized but closed for EVA's activities

\ designing varied interior spaces to offer inhabitants diverse experiences within the overall structure.

\ always trying to have a view to the external space

DRAWINGS





3.2 Issues reconceptualization

Scenario 1

During the initial phase of design, paramount attention was directed toward addressing the difficult environmental challenges inherent to lunar conditions, such as the nearly non-existent gravity on the Moon, temperature variations, and light-night cycles. These factors, among others, require reassessment of current terrestrial practices and guide designers towards a new perception of architectural design and practise. Notably, the initial design proposal highlighted radiation as a crucial factor. The elevated levels of cosmic radiation prevalent in outer space render human endurance unattainable without adequate protective measures. Consequently, a primary concern was the implementation of shielding, leading to the conceptualization of dwell times. In fact, the prolonged habitation of humans on the lunar surface necessitates a substantial quantity of lunar regolith. The endeavor, at this stage, aimed to facilitate human presence on the Moon for durations surpassing three months, and consultation of official documentation from the European Space Agency (ESA) enabled a precise determination of the requisite shielding thickness. The distinctive exigency for shielding against radiation in lunar and outer space environments arises from the absence of an atmosphere, distinguishing it markedly from terrestrial considerations.

Subsequent design iterations focused on functional and distributional aspects. Lunar design presented intricate challenges in transportation due to the high costs and constraints posed by limited vehicle dimensions. A detailed literature analysis was required to address the lack of specific regulations pertaining to assigned square metres for each function, as is the case on Earth. This required a comparison between the minimum standards for each function on Earth, and the dimensions discovered in the researched documents related to space design. As a result, internal dimensions were defined to provide comfort while fitting within modules that align with available transportation methods. As the infrastructure is aimed at tourism, it is crucial to comprehend the interdependence of spaces and to determine the level of permeability in each module. Consequently, a primary function was assigned to every module to ensure safety requirements and facilitate communication among users through identification of common areas, private spaces, and semi-private areas.

Scenario 2

While the first scenario considered settlement characteristics more specifically, the second delved into urban issues, particularly how the settlement is connected to other necessary elements. Questions arose concerning proximity and availability of resources, safety distances from elements such as the landing pad, and the connection of the settlement to support infrastructures like energy production and ice extraction. In the absence of regulations regarding usable surfaces or settlement principles, reliance was primarily on morphological and physical conditions of the territory for settlement planning.

The following hypothesis highlights the crucial importance of cooperation in extreme environments, where successful outcomes depend on collaborative efforts despite the significant costs and implementation hurdles. Accordingly, the proposed project in this thesis closely aligns with a broader undertaking - specifically, the development of the Moon Village. This analysis prompts thoughts regarding the correlations between the two areas, including spatial distribution, time sequencing, and practical interdependence. This situation offers an exemplary demonstration of how the planned project can be efficiently carried out in conjunction with other tasks, showcasing its ability to function independently without reliance on them.

Scenario 3

In the third and final scenario, additional concerns arose regarding future expansion and the need for an urban instrument to regulate it. As a result, an allotment plan hypothesis was proposed. Furthermore, the interaction between the user and the surrounding space was also taken into consideration. As previously discussed, the lunar environment is inhospitable, requiring strict measures to ensure user safety, especially for inexperienced individuals such as tourists who may use this settlement. Therefore, an intermediate space of sociability was established for the settlement's inhabitants. This includes the creation of a non-pressurised but protected environment for extravehicular activities, using the regolith shell.

Additionally, the latest design proposal has tackled concerns about the visual and physical connection with the outside area. If external space on Earth has positive connotations associated with open spaces, social interactions, and a sense of community, the same cannot be said for lunar environments where it can be extremely hazardous. This raises another critical issue, that of confinement. The feeling of confinement experienced in sterile environments cut off from the external environment is paramount. Solutions should be devised to address these concerns and aimed at reframing the commonly held perception of external space on Earth. Interiors have a twofold purpose: to function as indoor spaces and to facilitate external space experiences, such as strolling, socializing etc.

3.3 Conclusion

This experience led me to challenge preconceived notions in architecture and re-evaluate the architect's function. The ideas gleaned from this project must not be treated as simply an exercise - they should be put into action.
Achieving this has necessitated a heightened awareness of architectural design.
Numerous themes, most notably sustainability - which concerns not only the environment but the economy and politics as well - prove to be crucial.
The careful management and conscious utilization of resources is a vital lesson gleaned from exploration, aiding in the reduction of energy consumption.
These principles can be easily implemented on Earth and have become central concerns.

The issue of the connection between the interior and exterior has gained a unique perspective where experiences usually reserved for outdoor spaces on Earth are now transposed onto the internal environment.
The proposed project of this thesis and other projects in extreme environments allow for a comprehensive reimagining of architectural design and human life, which fosters a critical outlook on conventional architectural practices on Earth.

This project experience has enabled me to cultivate a critical mindset towards the construction of conventional practices. Examining the underlying rationales for proposing one approach over another can significantly alter the definition of the methods employed. Through analysis of legislative, geopolitical, and technical contexts, I have come to appreciate the multitude of ways in which conventions can be conceived.
Design methodologies can be shaped by diverse influences, including political, economic, and technical values. In my thesis, I endeavored to merge two specific conventions: the technical and the social. The project was examined within the societal context, offering a platform to delve into current conditions and contemplate their reimagining. This exploration provides an avenue for reconsideration and potential reshaping of prevailing norms.

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