



**SAFE HARBOR**



# Safe Harbor

## An Exploration in Lunar Habitation

Cameron James Gahres

Thesis submitted to faculty of the  
Virginia Polytechnic Institute and State University  
in partial fulfillment of the requirements for the degree of

Master of Science in Architecture  
Urban Design Concentration

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## **An Exploration in Lunar Habitation**

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### **ABSTRACT**

This thesis posits the creation of a lunar settlement, examining the practical and theoretical challenges of urban design in a space environment. Analysis of the lunar environment aided by data and imagery from the Lunar Reconnaissance Orbiter allows the project to narrow focus on site selection while simultaneously capturing the bizarre and beautiful landscape. Intensive site study becomes the framework of a uniquely tailored, imaginative design emphasizing an urban fabric that is sensitive to astrological presences through passive and reactive design.

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## **An Exploration in Lunar Habitation**

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### **GENERAL AUDIENCE ABSTRACT**

Whether it be through accident, conquest, or expedition, humanity has long held an innate desire to root itself in new environments that challenge us. The sky has proven to be no limit, the 20th century has shown that the exploration and colonization of space is inevitable. The question is where will we begin the first colony in space and what form will it take? This thesis posits the creation of a lunar settlement, examining the practical and theoretical challenges of urban design in a space environment.

Site selection is crucial with the birth of any new city or civilization. Much like settlers of the past, a thorough understanding of constraints and strategic positioning is necessary to ensure the growth and survival of a colony. The accumulative site knowledge presented with this thesis is the framework of a uniquely tailored design to sustain long-term inhabitation on the moon. While this project can make no bold claims to predict the intentions of future colonists, it does serve to create an imaginative urban form to begin this journey, derived from grounded research and intensive site study.

This thesis adds new perspectives beyond conventional engineered plans, to explore the potential of an immersive, reactive urban fabric with sensitivity to astrological presences. Urban design recommendations are made to enhance day to day livability in space, offer a sense of time and place, foster meaningful interaction among colonists, and consider growth beyond the initial settlement. While such a colony will undoubtedly serve as the staging area for the next steps in space exploration, it foremost will be a testament to what we as a people choose to collectively bring with us to the moon.

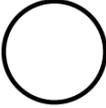
I would like to thank my committee, Susan, Nate, and David, for all of their guidance, patience and time spent with me during this project, and for allowing me to pursue my interests.

I would like to thank my friends who have unknowingly been a source of endless enjoyment and sanity.

Lastly, to my parents for their unconditional love and unwavering support, I wouldn't have made it without you.



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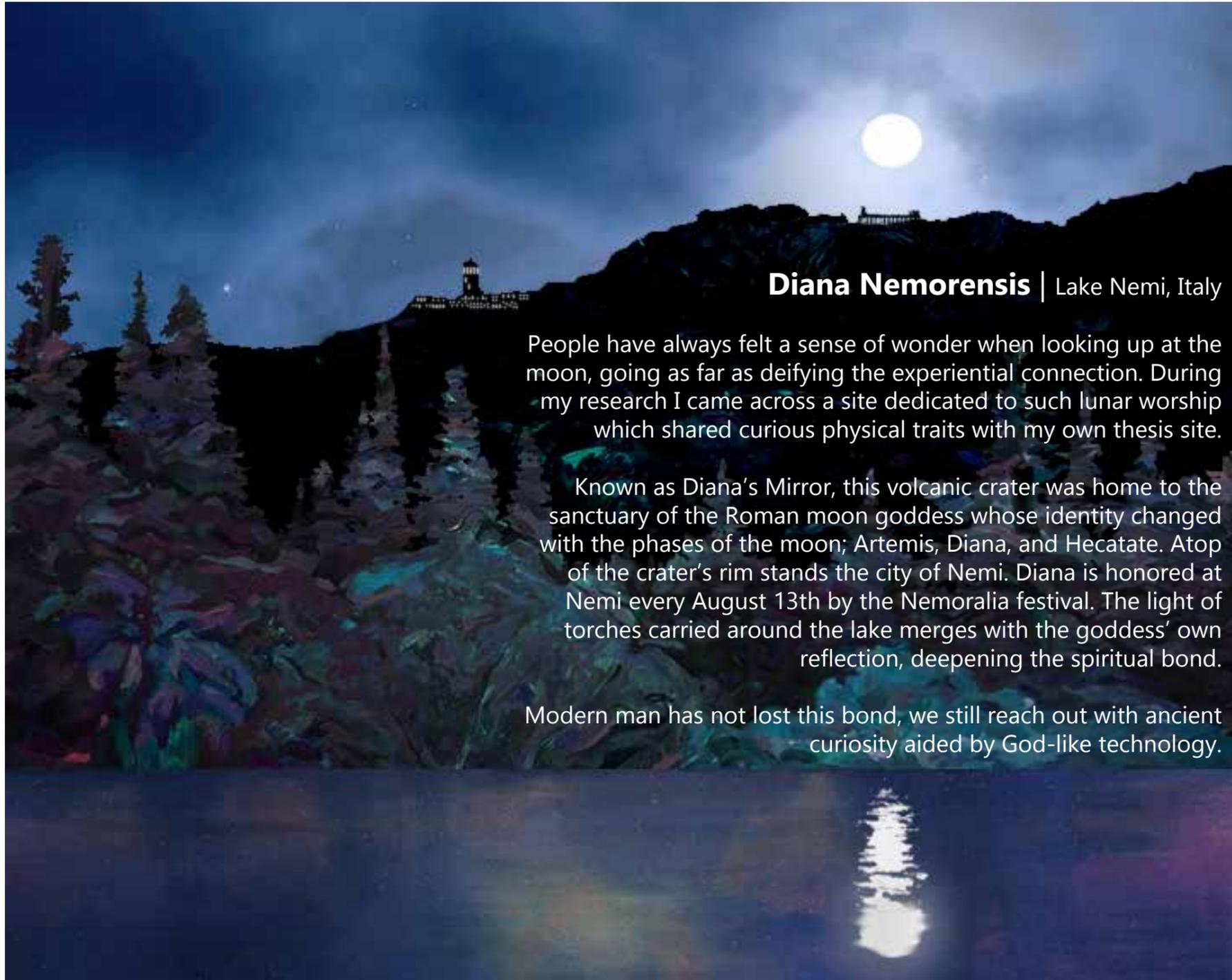
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Where Do We  
Boldly Go?

"Let's Go!"

- Yuri Gagarin

Uttered before  
becoming the first  
human in outer space



### Diana Nemorensis | Lake Nemi, Italy

People have always felt a sense of wonder when looking up at the moon, going as far as deifying the experiential connection. During my research I came across a site dedicated to such lunar worship which shared curious physical traits with my own thesis site.

Known as Diana's Mirror, this volcanic crater was home to the sanctuary of the Roman moon goddess whose identity changed with the phases of the moon; Artemis, Diana, and Hecatate. Atop of the crater's rim stands the city of Nemi. Diana is honored at Nemi every August 13th by the Nemoralia festival. The light of torches carried around the lake merges with the goddess' own reflection, deepening the spiritual bond.

Modern man has not lost this bond, we still reach out with ancient curiosity aided by God-like technology.



49  
YEARS OF  
GOING TO  
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- LAUNCH FAILURE
- SHUTTLE FAILURE
- PARTIAL FAILURE
- SUCCESS
- MANNED MISSION
- FUTURE MISSION

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MISSION  
FAILURE

LANDER  
IMPACTOR  
ORBITER  
FLYBY

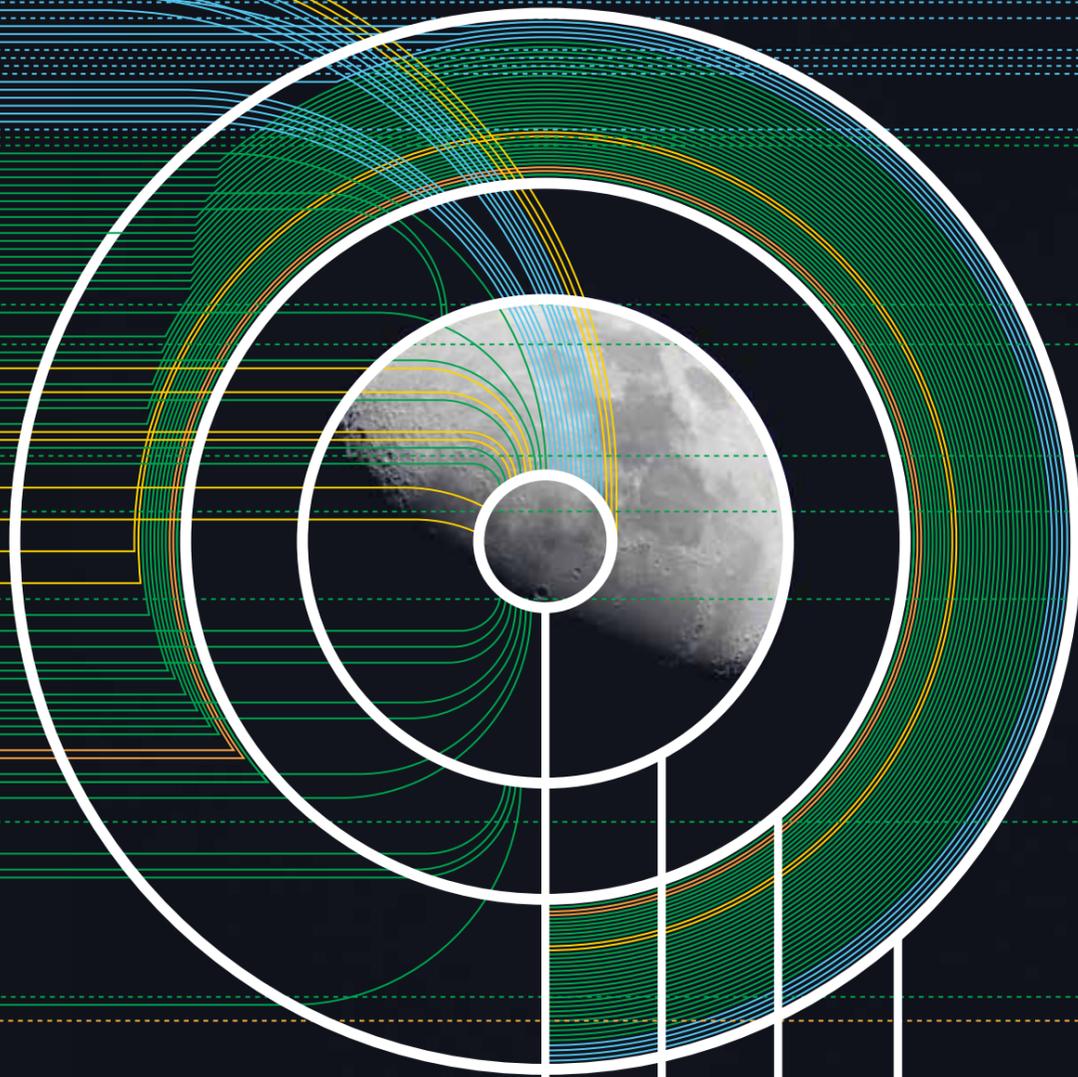
First Flight  
1903

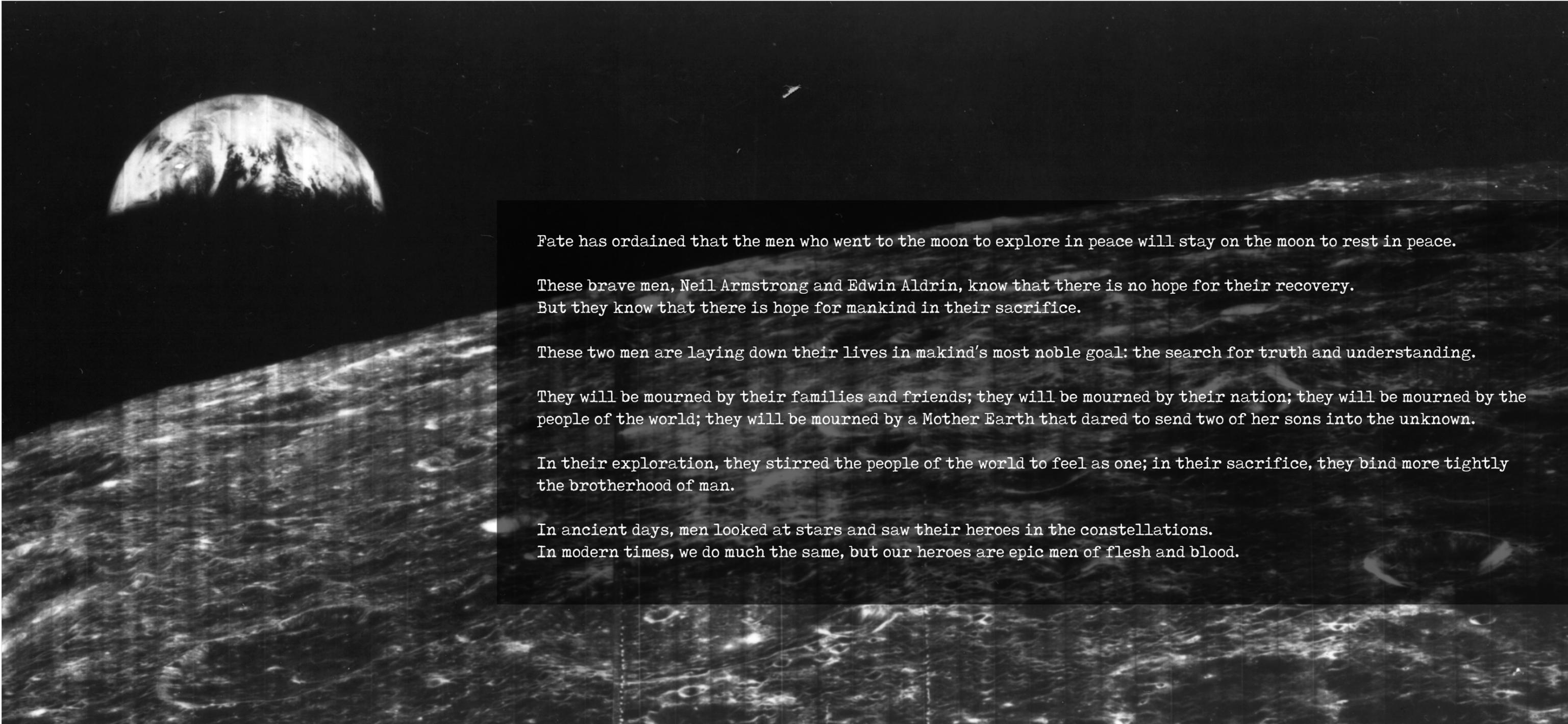
66y

Apollo 11  
1969

49y

Present  
2018





Fate has ordained that the men who went to the moon to explore in peace will stay on the moon to rest in peace.

These brave men, Neil Armstrong and Edwin Aldrin, know that there is no hope for their recovery.  
But they know that there is hope for mankind in their sacrifice.

These two men are laying down their lives in mankind's most noble goal: the search for truth and understanding.

They will be mourned by their families and friends; they will be mourned by their nation; they will be mourned by the people of the world; they will be mourned by a Mother Earth that dared to send two of her sons into the unknown.

In their exploration, they stirred the people of the world to feel as one; in their sacrifice, they bind more tightly the brotherhood of man.

In ancient days, men looked at stars and saw their heroes in the constellations.  
In modern times, we do much the same, but our heroes are epic men of flesh and blood.

### **"In Event of Moon Disaster"**

Written in 1969 by William Safire, to be read by Richard Nixon in the event Apollo 11 was stranded on the moon.

Even in the face of utter defeat, the goal of putting a man on the moon was so monumental and unprecedented the very attempt would immortalize those who dare try. From the previous graphic it is evident this endeavor has been fraught with failure but never did we consider laying to rest thoughts of ensuing attempts.

From Romans dancing around lakeside reflections to Americans skipping with glee on its surface, the moon has always captivated our spirit and curiosity. Without fear of failure, it is time to envision what part the moon has yet to play in humanity's evolution.

First photo of Earth from the Moon  
Aug. 23, 1966

To leave our atmosphere you have to push a rocket weighing more than 2 blue whales to travel 16xs faster than a bullet and each pound of that whale costs roughly \$10,000. Earth's massive size is not on our side.

While Mars is undeniably in our future, I believe the moon is the crucial precursor. Three short days away, access to ice water which can be refined into rocket fuel, and 1/6th the escape velocity makes the moon the perfect orbiting launch pad for humanity to begin settlement, following the fabled first step with a second. The moon is but the first milestone on the road to the stars - our safe harbor.

German rocket-propulsion engineer and advocate for space exploration, Krafft Ehrlicke once said:

"If God wanted man to become a spacefaring species, he would have given man a moon".

Image taken by Voyager 1 probe after traveling 13 years and 3.7 billion miles (0.6 light-year). It was ordered to turn around to take one last photo of our solar system before connection was lost. The circled Earth can be seen as "a mote of dust suspended in a sunbeam"

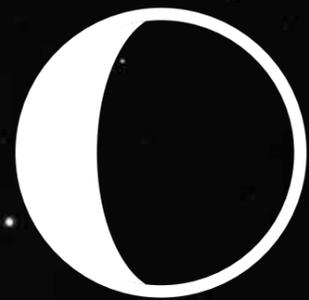




11 Acrylic: Origins by self

4.5 billion years ago a rogue alien planet the size of Mars collided with an ancient Earth. The cataclysmic destruction ripped apart and forged together the magma flesh of the two planets. The moon we see in the night sky today is the fusion of their celestial bodies.

Beyond space exploration, this thesis is fundamentally built upon reunification. Beneath the soil that is both alien and familiar, we begin our journey into the stars, giving common cause for nations to cooperate in what will become man's greatest endeavor.



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# Out of the Cradle

“The Earth is the cradle of humanity, but mankind  
cannot stay in the cradle forever”

- Konstantin Tsiolkovsky  
Soviet rocket scientist

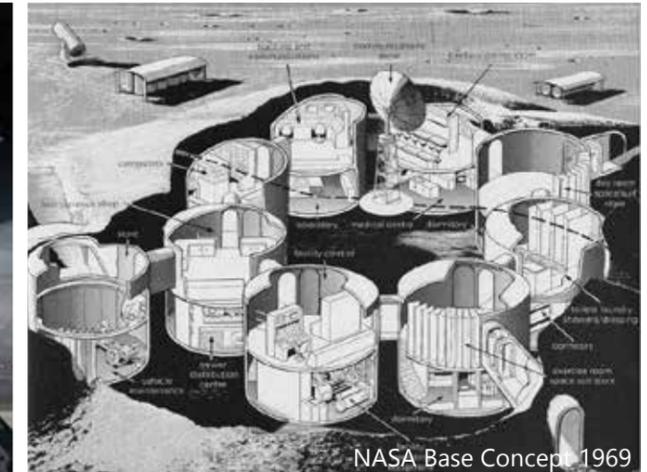
Since the Space Race of the 20th century we have pondered what shape lunar life will take. Early designs were drawn as strategic military bases while present concepts prefer a more cooperative exploratory tone. Rarely have lunar projects been thought out in detail beyond a small initial colony and those which do are often heavily based in science fiction.

In the world of space exploration site selection is an early life or death decision. The two most developed and widely accepted construction techniques suggest using the lunar regolith (soil) to shelter inhabitants from the extreme temperature fluctuations and solar radiation. One suggestion is the use of modular structures brought from earth to be buried underground while recent designers have sought to 3D print the regolith directly into building material. The second method explores the moon's ancient lava tubes, which due to low gravity, can support cavernous sizes, some as large as six miles wide. Both realities trade protection for access to daylight, an important resource in space.

This thesis opts to break the previous strategic molds to explore a third alternative.



3D Printed | Foster + Partner : ESA contract



NASA Base Concept, 1969



Modular | 1st Place Moontopia Competition



Downtown Philadelphia inside lava tube

Lava Tubes | People's Choice Moontopia Competition



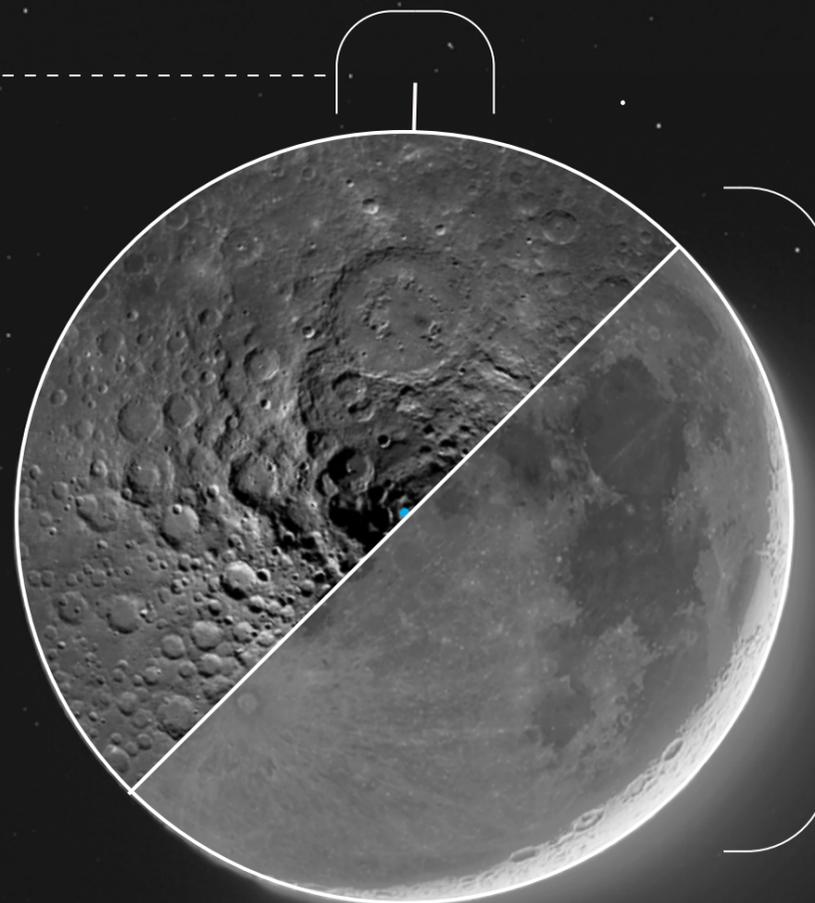
**НАВИГАЦИЯ В КОСМОСЕ ОТКРЫТА!**  
 12 апреля 1961 года гражданин Советского Союза летчик-космонавт майор ЮРИЙ АЛЕКСЕЕВИЧ ГАГАРИН совершил полет вокруг земного шара на космическом корабле-спутнике «ВОСТОК-7».  
 8 августа 1961 года гражданин Советского Союза летчик-космонавт майор ГЕРМАН СТЕПАНОВИЧ ТИТОВ совершил полет вокруг земного шара в течение 23 часов 38 минут.  
 «ВОСТИ» Soviet Propoganda to colonize the moon

## Lunar Poles

-10 | 26F  
334 days / 31 nights

Mild Radiation

Abundant Cold Traps  
aka: ice



Shackleton Crater  
South Pole

1.5° Tilt  
1/6 Gravity  
1 Lunar day / 27 Earth

-298 | 224F  
13.5 day D/N Cycle

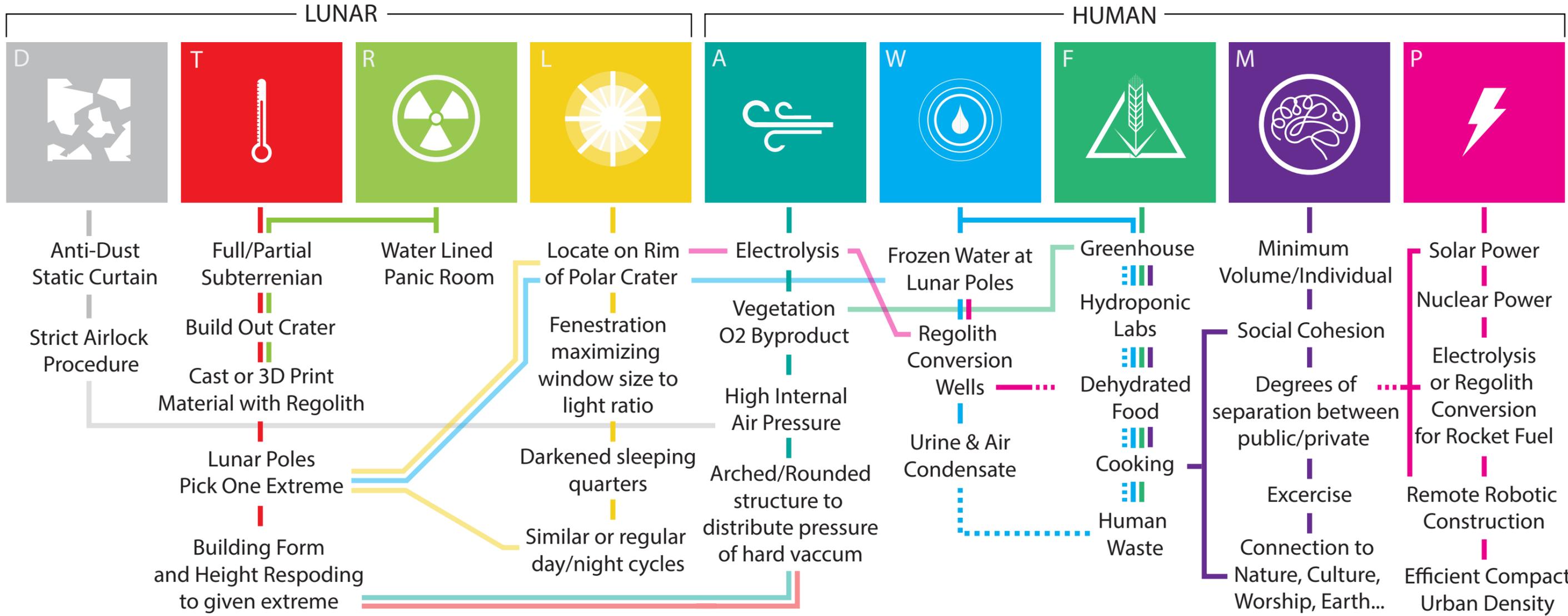
No Magnetic Field  
No Atmosphere  
Extreme Radiation

Luna

Because of the lack of atmosphere, the surface temperature is dependent on solar exposure. One lunar day consists of two weeks of consecutive daylight followed by two weeks of night. With the rise and fall of the sun, temperature swings to the extremes causing inconsistent power supply, stress on building materials, and potential psychological strain to inhabitants. The danger is doubled by the moon's lack of magnetic field which leaves colonists vulnerable to solar radiation.

The poles offer a more hospitable beginning for our brave explorers. The moon has nearly zero tilt, meaning solar rays that strike the poles bathe the site in a near constant yet weak light. Imagine getting a suntan in Brazil which lies on the equator, versus Antarctica in the summer time. In lunar geography this means thermally benign temperatures and severely reduced radiation. The south pole was chosen over the north due to the greater potential for ice water to be found in craters.

CHALLENGES

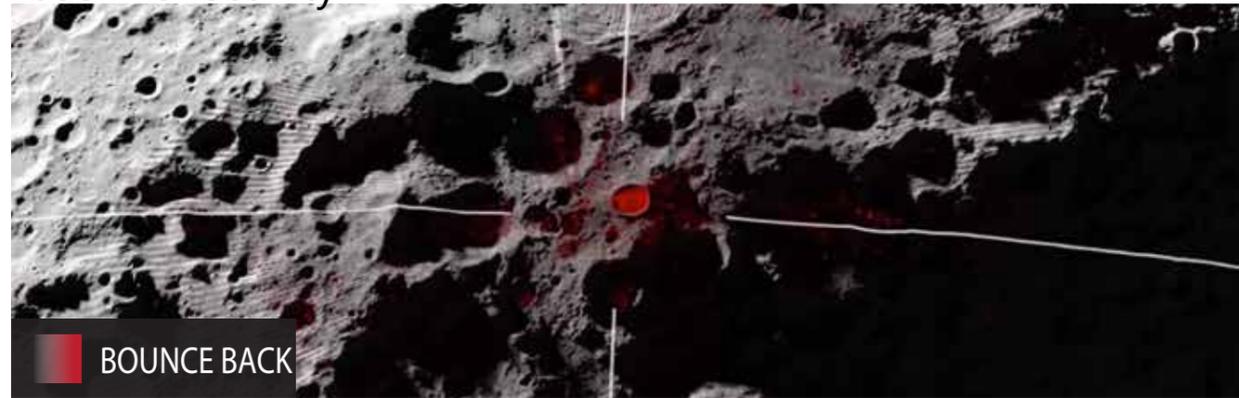


SOLUTIONS

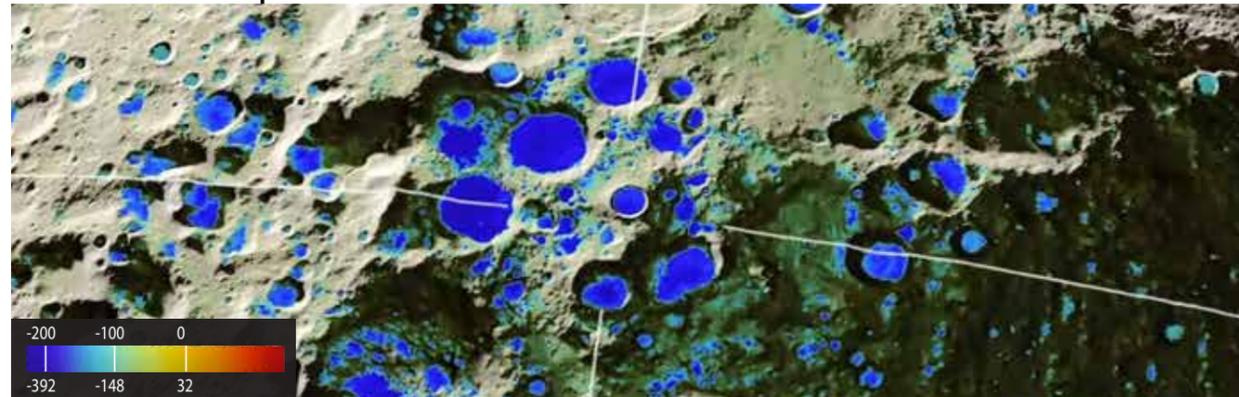
Every obstacle and resulting solution will begin to dictate the form of the colony as it evolves to accommodate future needs

**SHELTER**

## Laser Reflectivity



## Ground Temperature



## Probable Locations

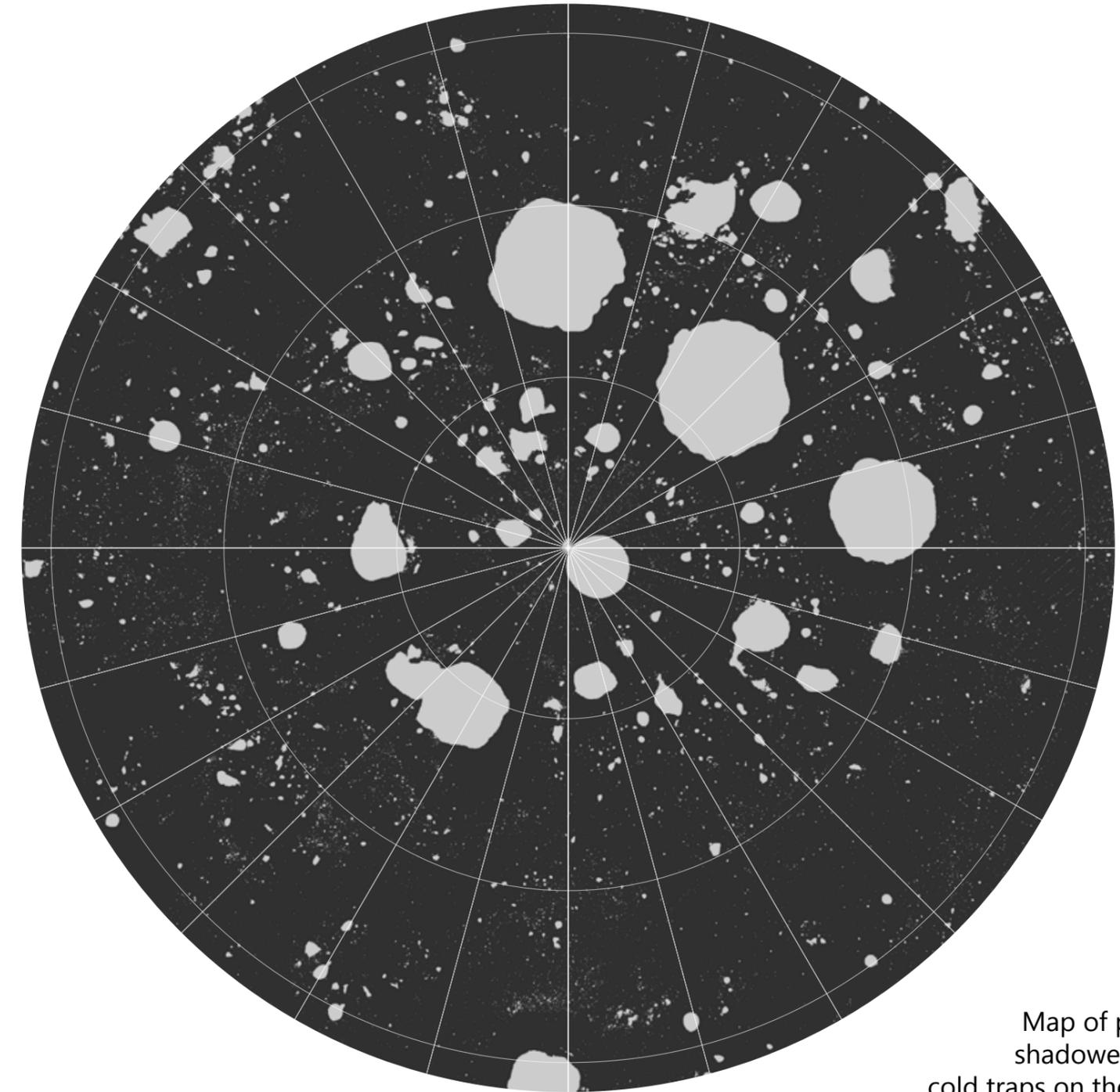


NASA Ice Video

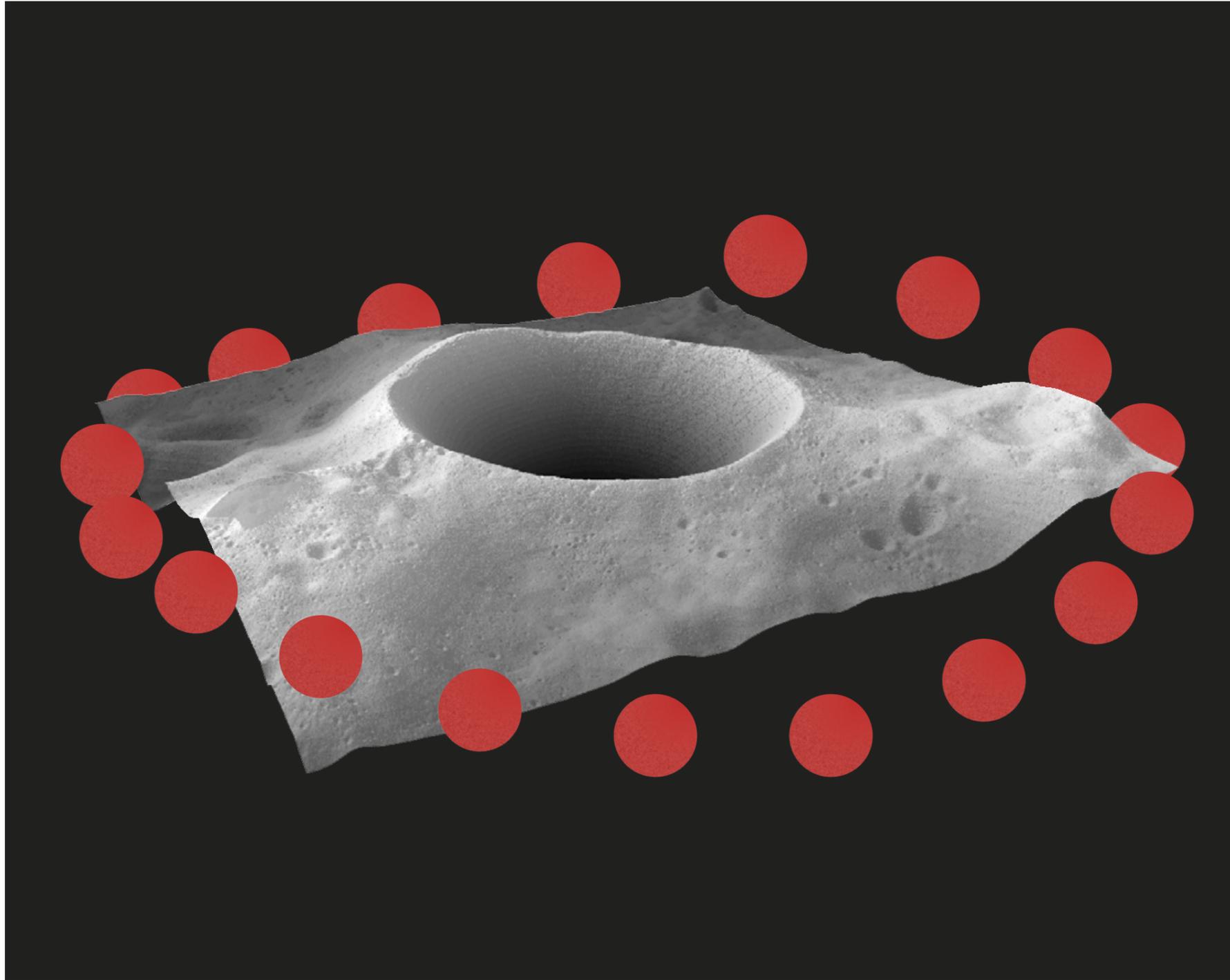
A combination of laser reflectivity and temperature readings were used to posit the possibility of water within the lunar pole craters.

On August 20, 2018, NASA confirmed that ice water was found on the lunar south pole.

Water carries a greater importance on the moon. Not only is it used for drinking and irrigation, it is split apart through electrolysis to become the air breathed. It can be refined to become fuel for rockets which will use the moon as a low-G springboard for deep space exploration and future colonization.



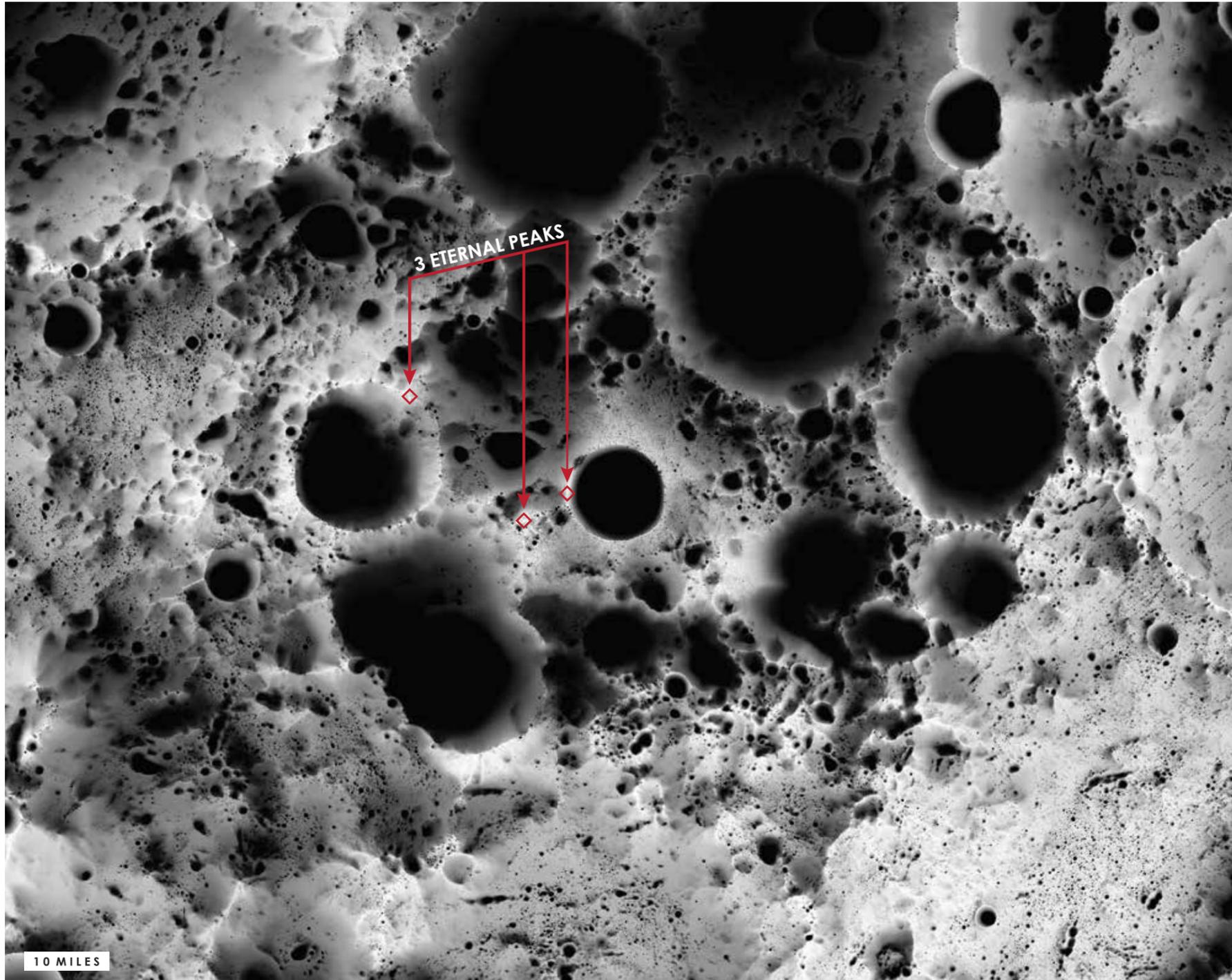
Map of permanently shadowed regions or cold traps on the south pole



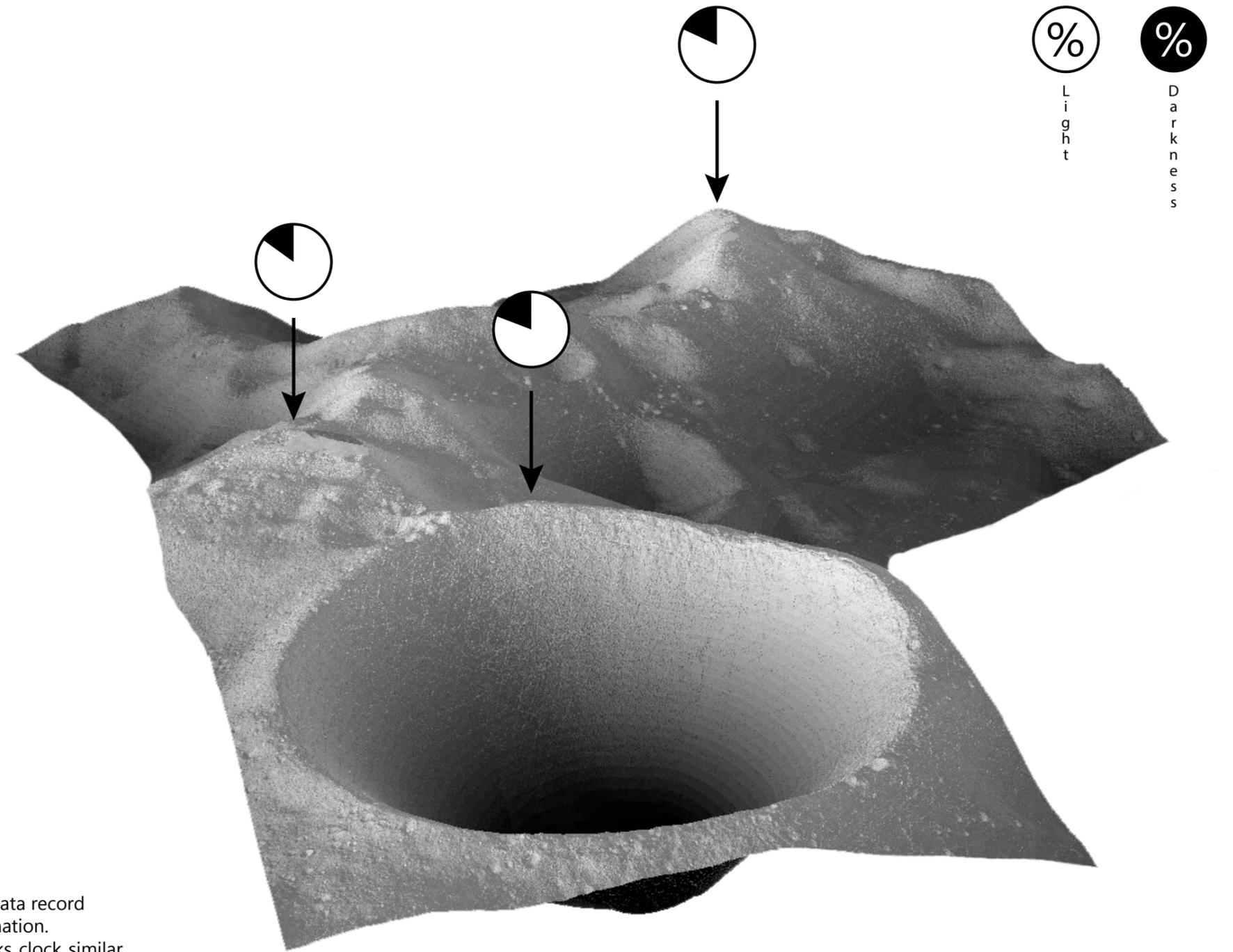
3D rendering of Shackleton Crater using GIS software

A “peak of eternal light” refers to a hypothetical location on an astronomical body which is always illuminated. To our knowledge no such location exists within our solar system, with four close exceptions. One is on Mercury, the other three are on the south pole of our Moon.

Because of the  $1.5^\circ$  tilt, the Moon’s south pole rotates almost completely on itself, receiving near constant horizontal sunlight year-round. The sun only rises or falls a maximum of  $\pm 2.0^\circ$  on the horizon making the largest source of darkness the shadows cast by distant mountains.



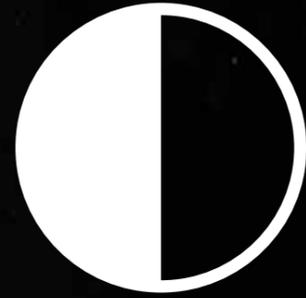
Both sets of data record annual illumination. All three peaks clock similar 87-90% sunlight year round.



For its benign temperatures, weak radiation, near constant illumination, and abundance of ice water, the glowing rim of Shackleton Crater will be the site this thesis proposes for future colonists to begin their journey.



Rim of Shackleton Crater: NASA Lunar Reconnaissance Orbiter

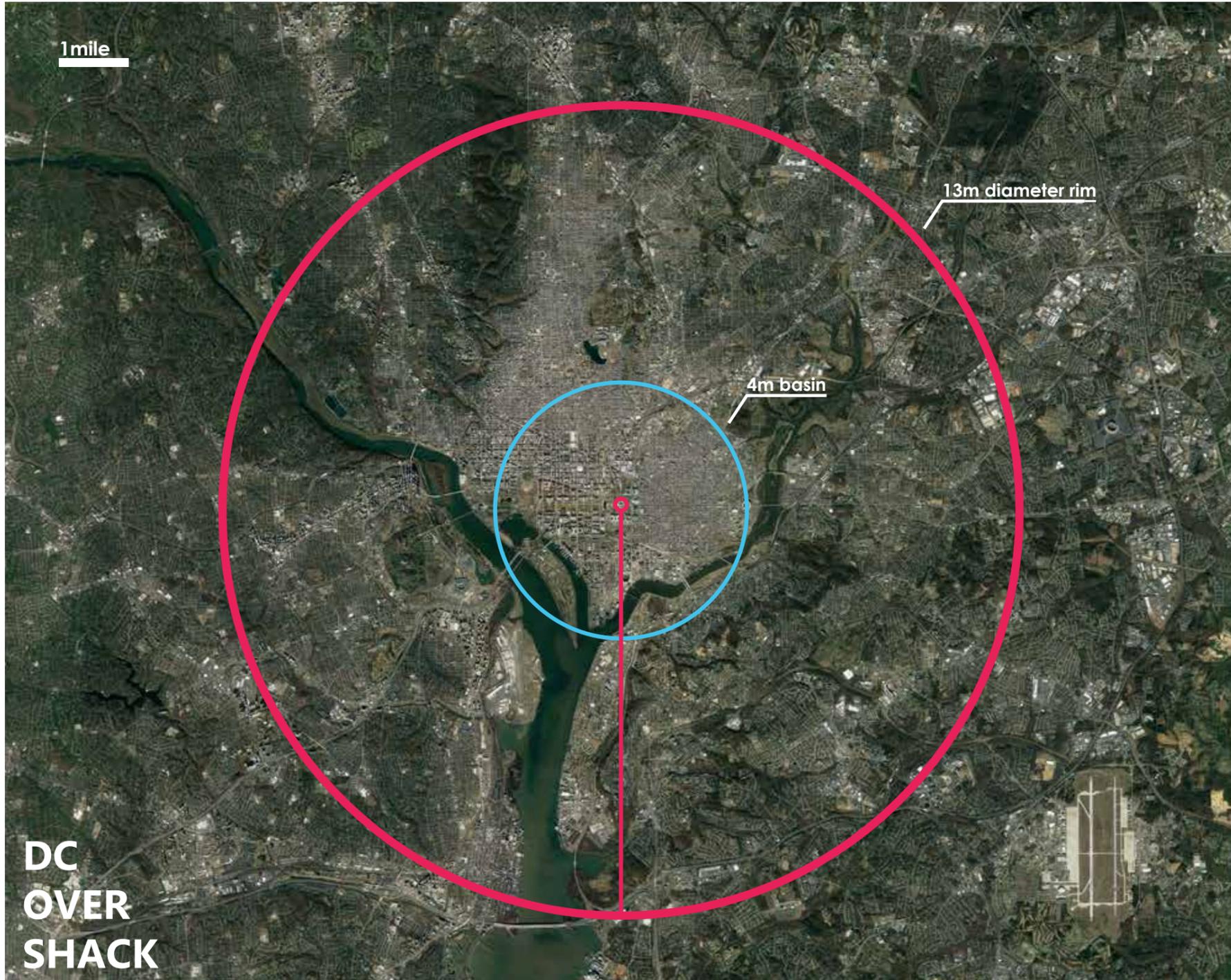


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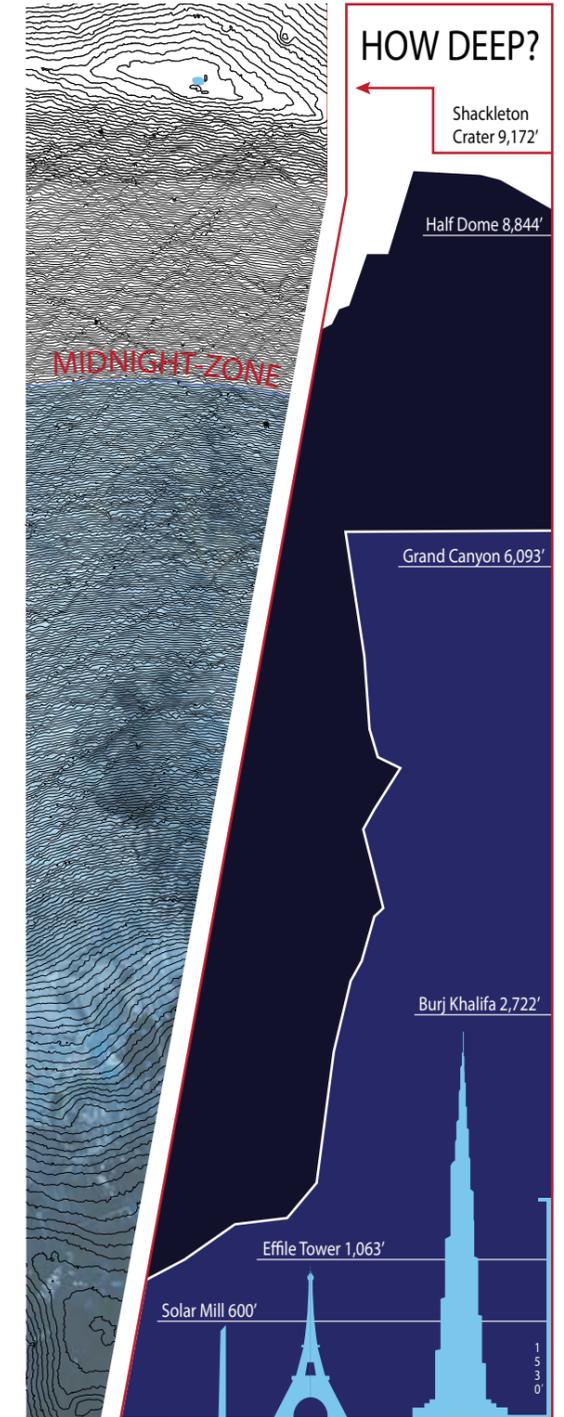
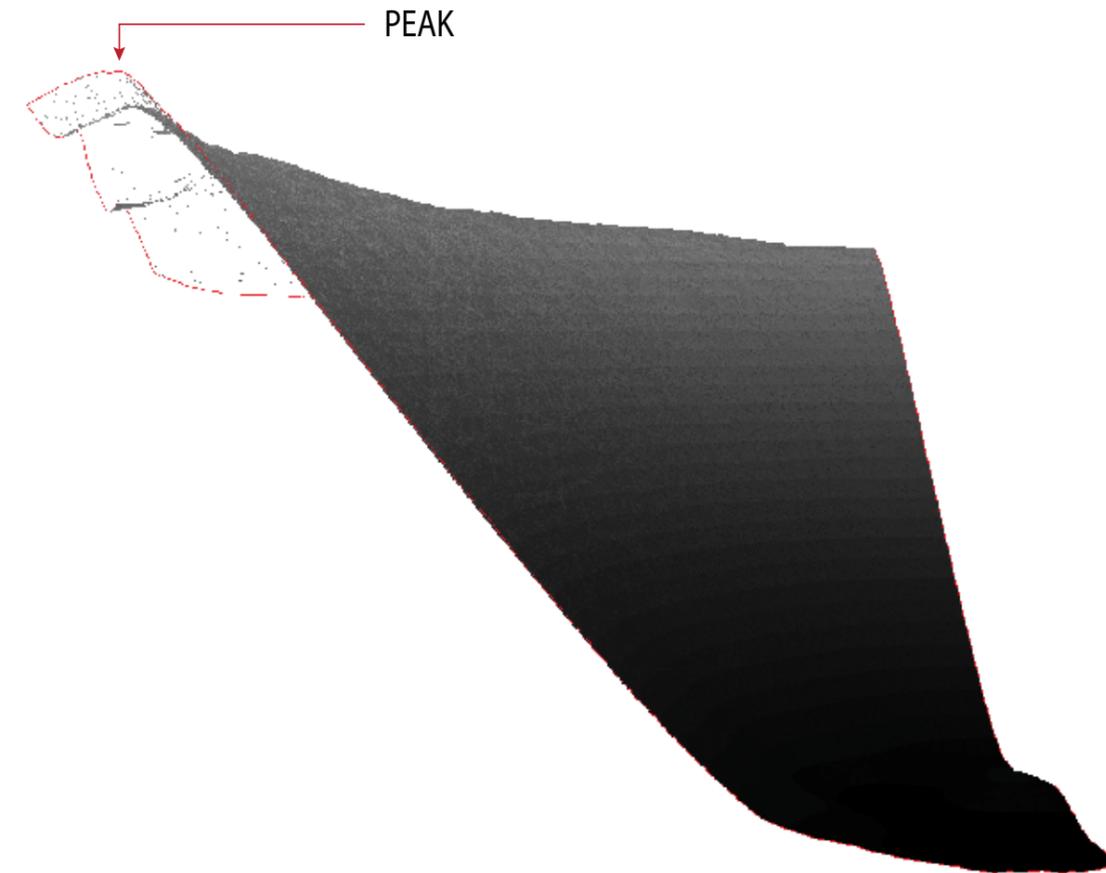
# To Know Something Alien

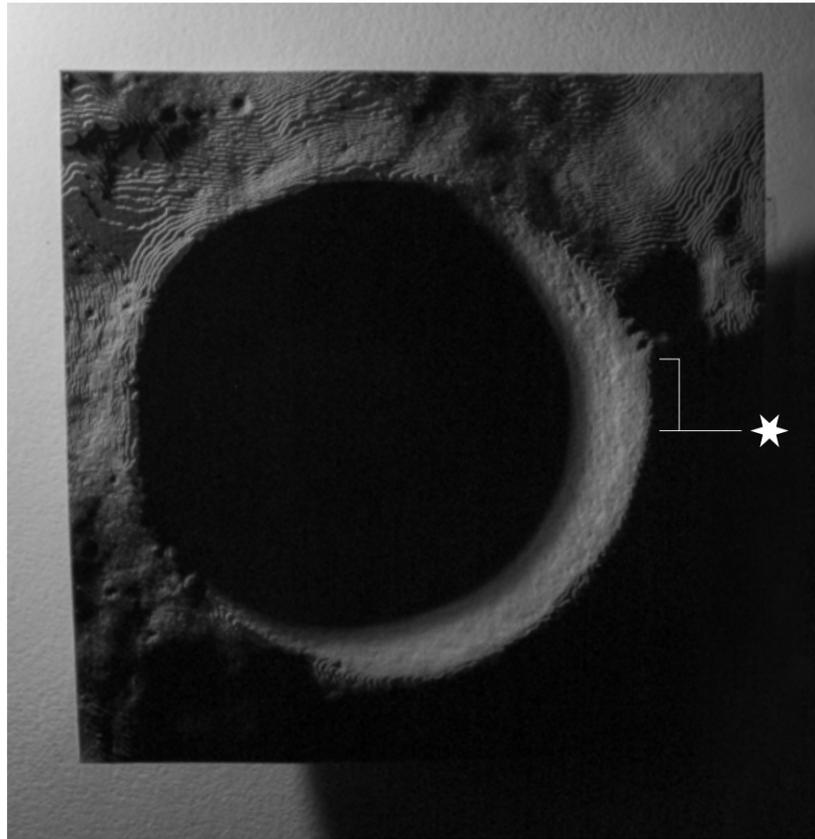
"It is a beautiful and wondrous sight to behold the  
body of the Moon"

- Galileo Galilei  
first man to view the  
moon through  
telescope



It's hard to imagine what object left the impact crater that our future lunar colonists will call home. The rim which basks in the southern light has a circumference of 41 miles while its interior drops to a depth of 1.7 miles. Aside from small shadowed lake-like craters along the rim, no light has ever touched deeper than the "Midnight Zone" which lies about 1,300' below the peak. Any regolith below this point holds the potential for ice water. The flat 4-mile bottom will likely be an ideal site for processing the ice as well as a landing pad and refueling station for shuttles coming and going.



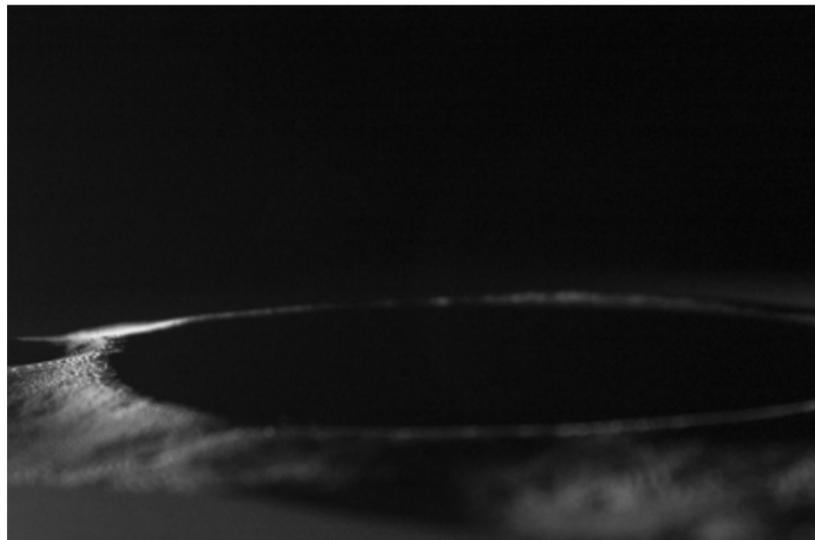
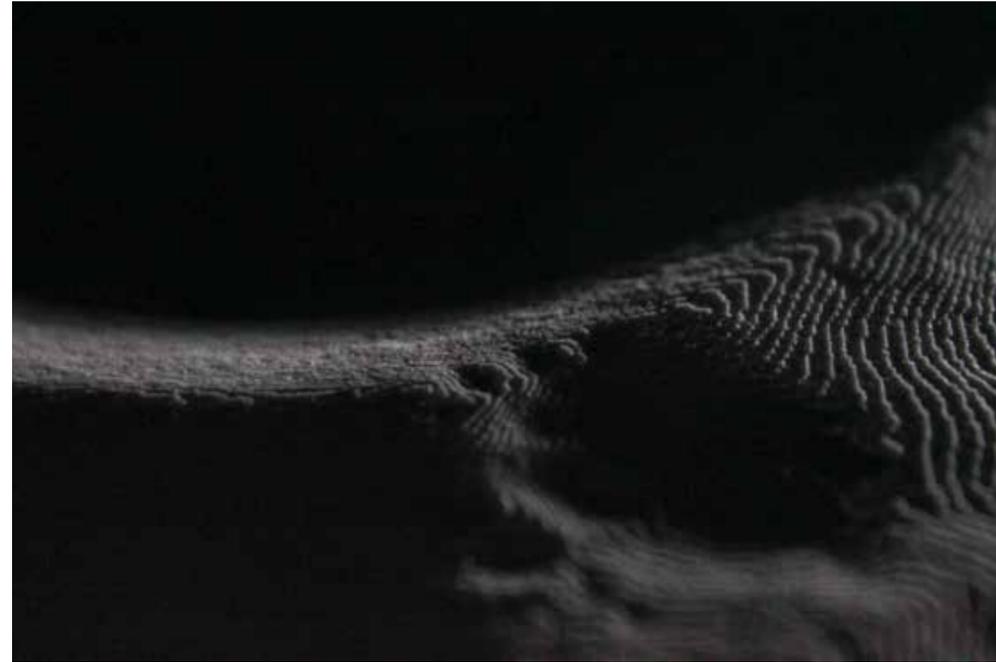


1.8 miles between two the ridges - rim width varies from 1/4 to 1/2 mile

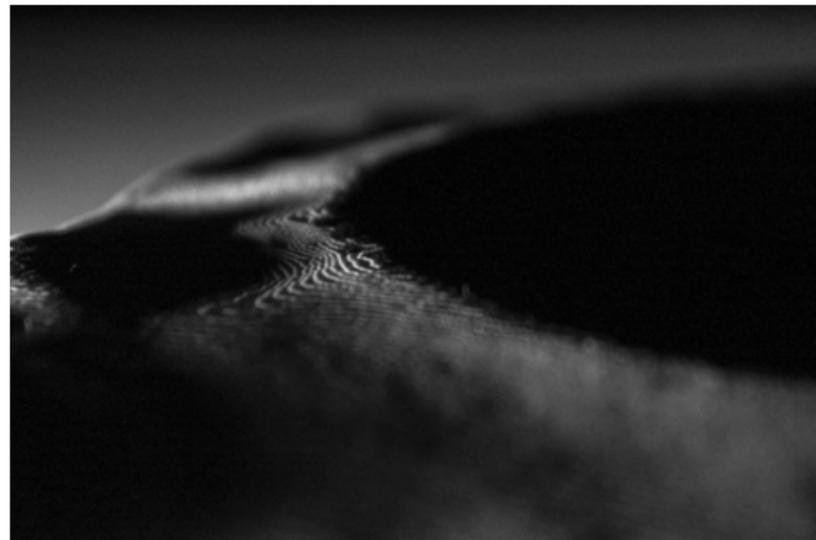


Hollow stars mark other potential landing sites and future growth

Solid white star marks Shackleton's "peak of eternal light"

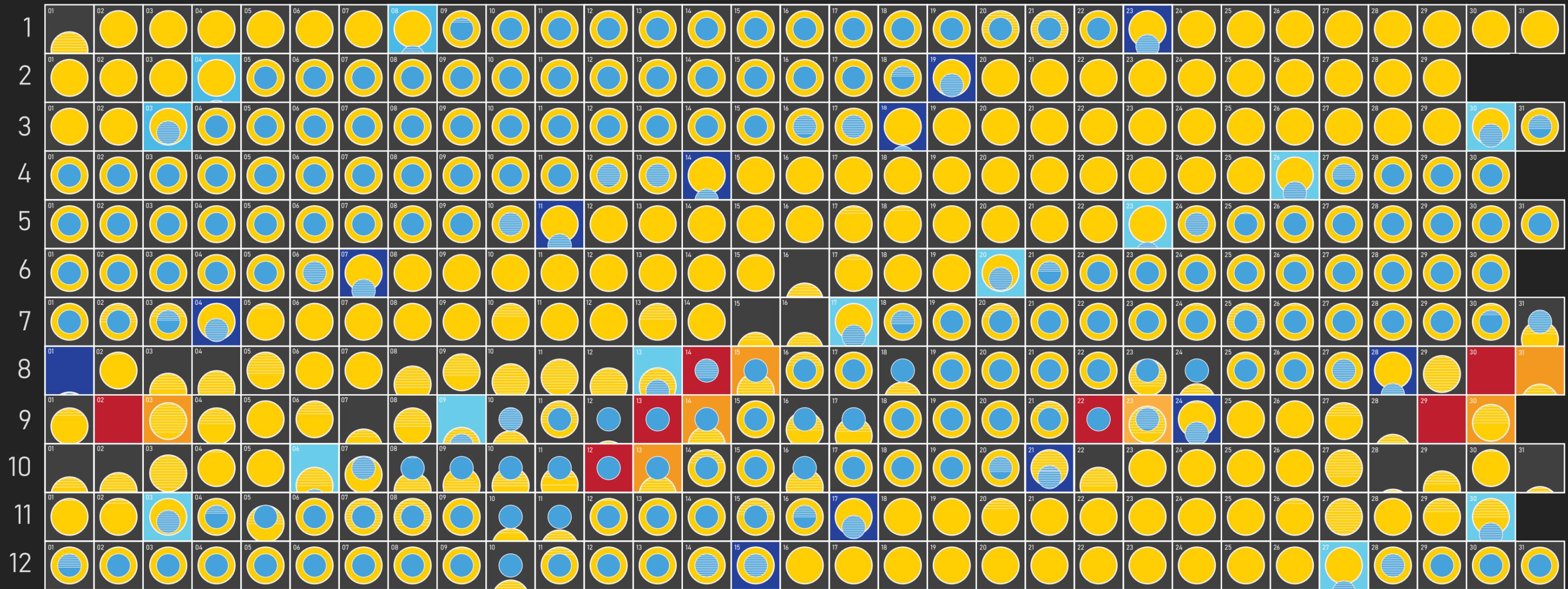


Photographed 3D printed model created from NASA topographic data



Because of the sun's position low on the horizon, only the lip of the crater's bowl is illuminated. The crater's inky black interior evades the sunlight.

# 2020 SOLAR & EARTH CALENDAR



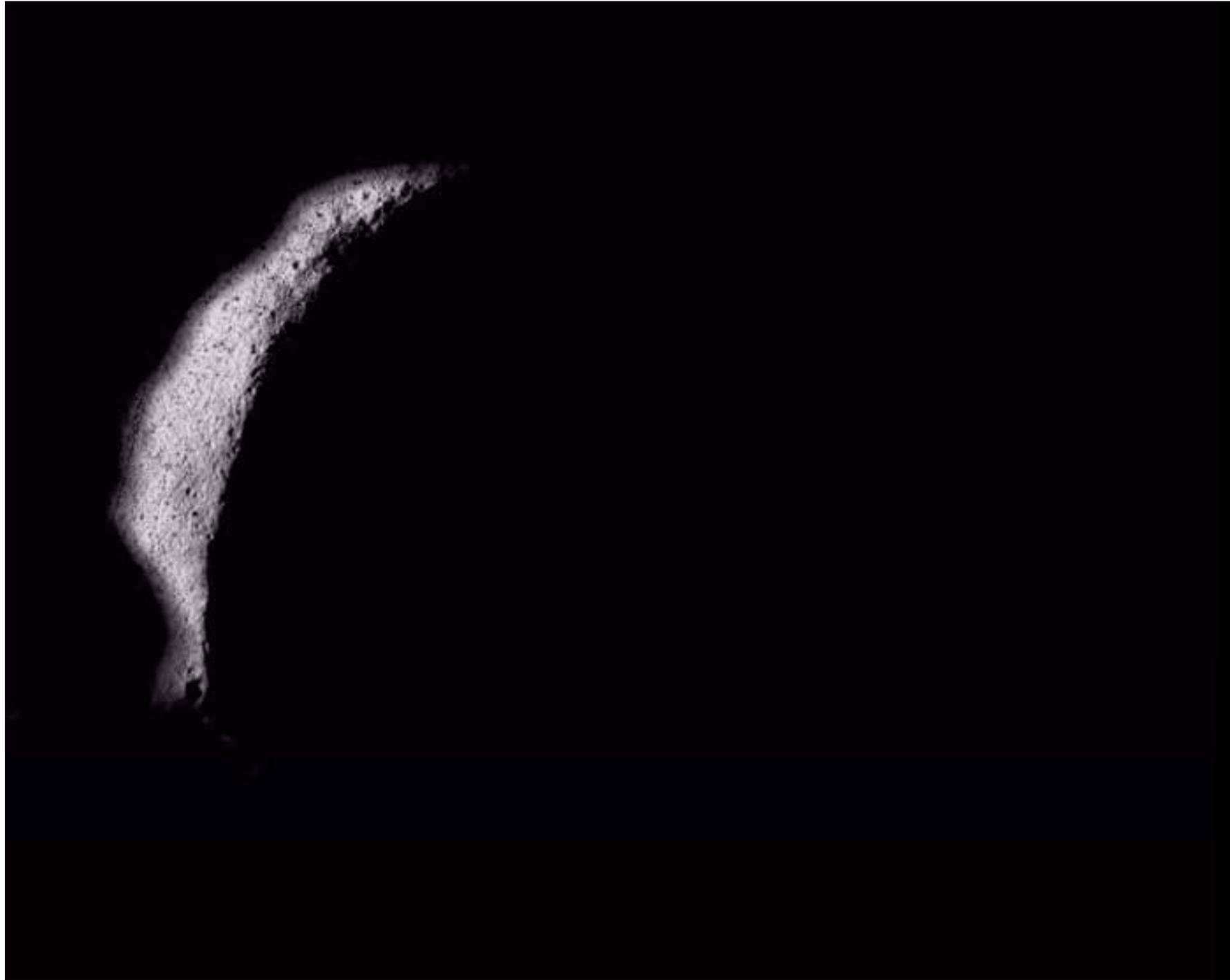
Perhaps the most bizarre and fascinating aspect of the site is the rhythmic rising and setting of the sun and earth, encircling Shackleton in an endless dance.

To better understand the site a graphic calendar was created using predictive NASA data of the year 2020 on the specific coordinates of the eternal peak. Because of the nature of the south pole, simply walking down the ridgeline would drastically change visibility, creating an entirely different calendar.

Earth rises and sets are consistent year-round; however, the sun goes through an erratic phase three months annually. During this period sunsets occur (red), never lasting for more than 24 hours. These are the few times when the true splendor of the milky way will be visible in a way no star gazer has ever witnessed.

**Linked below** is a video visualizing Aug 2020 through solar simulation. 1 second = 1 Earth day

<https://vimeo.com/291206029>



**July 16, 2020 | Solar Simulation**

Only the ridgeline between the two highest peaks remain illuminated. Corresponds to previous calendar.



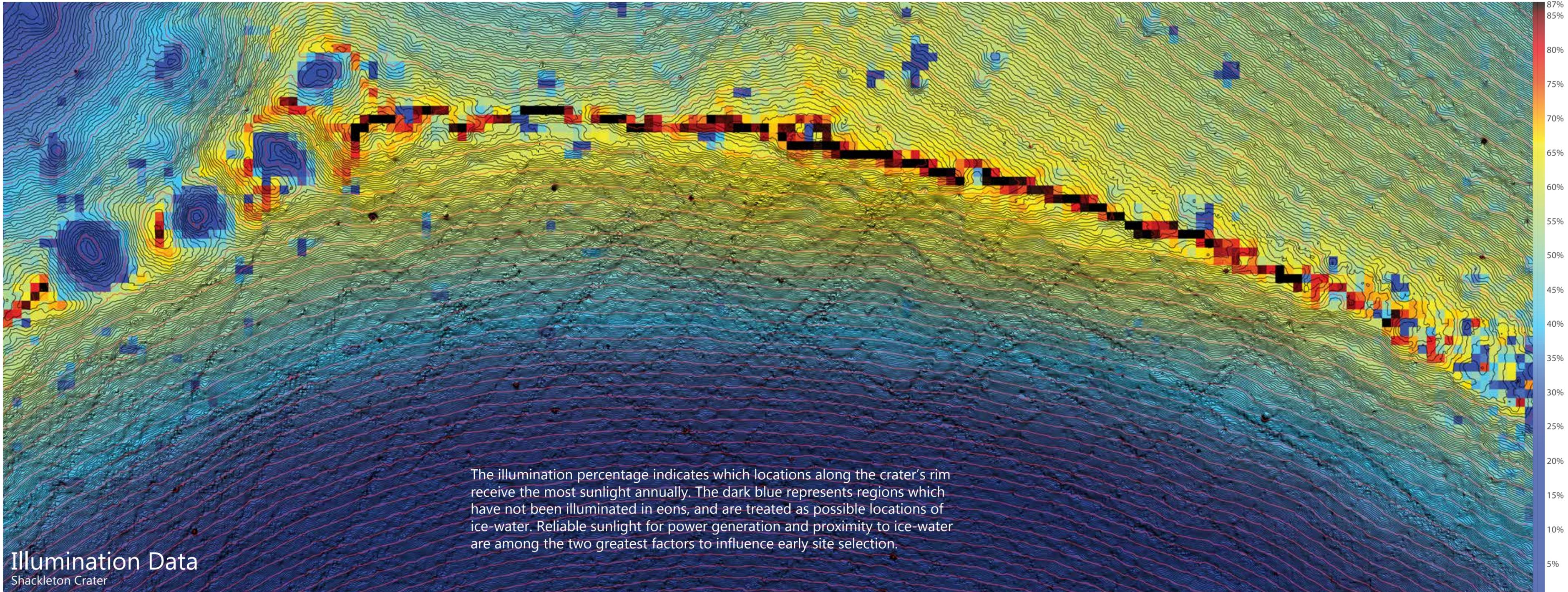
Earth appears and disappears in regular  
13-16 day cycles



-  163 days of full visibility
-  33 days of partial visibility
-  169 days absent



the Earth as we know it will appear geographically upside down and will go through phases not unlike the moon

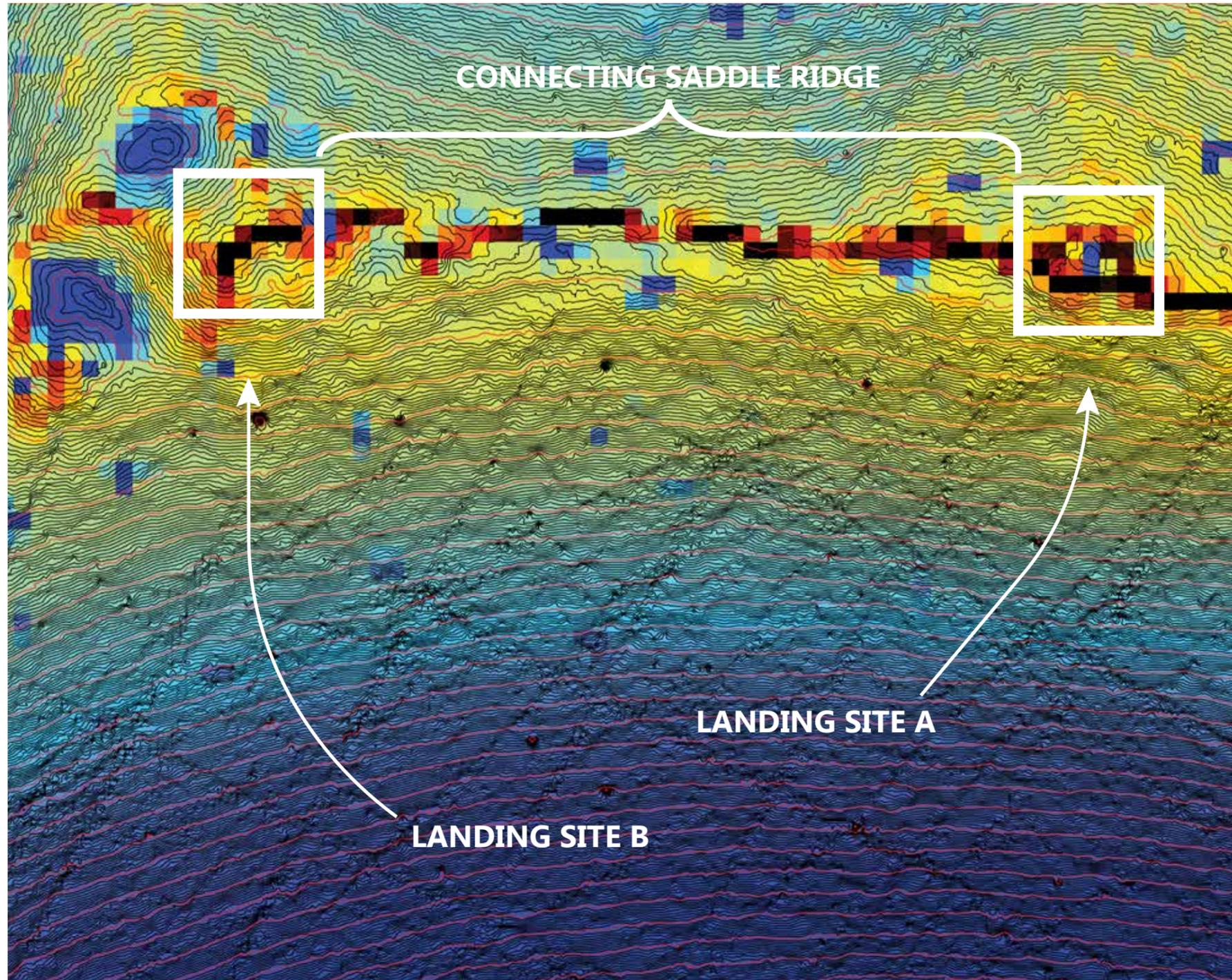


The illumination percentage indicates which locations along the crater's rim receive the most sunlight annually. The dark blue represents regions which have not been illuminated in eons, and are treated as possible locations of ice-water. Reliable sunlight for power generation and proximity to ice-water are among the two greatest factors to influence early site selection.

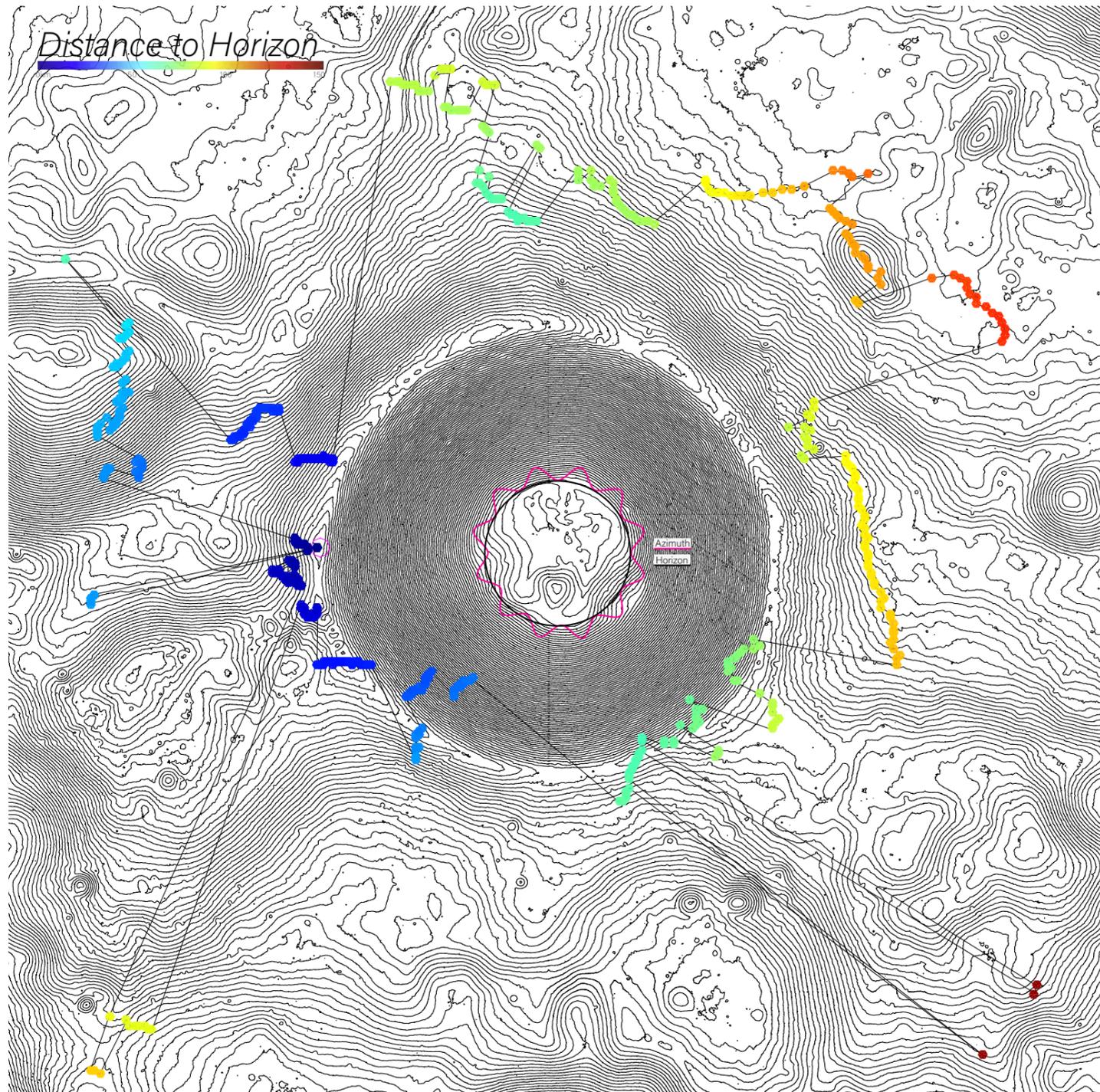
# Illumination Data

Shackleton Crater

Created in GIS using NASA south pole illumination data



Two landing sites stand out amongst the data. Both are located upon the crater's tallest ridgeline. Elevation changes of only 25' easily alter annual illumination by +/- 20%, producing a unique design challenge when creating a colony with equitable solar exposure.

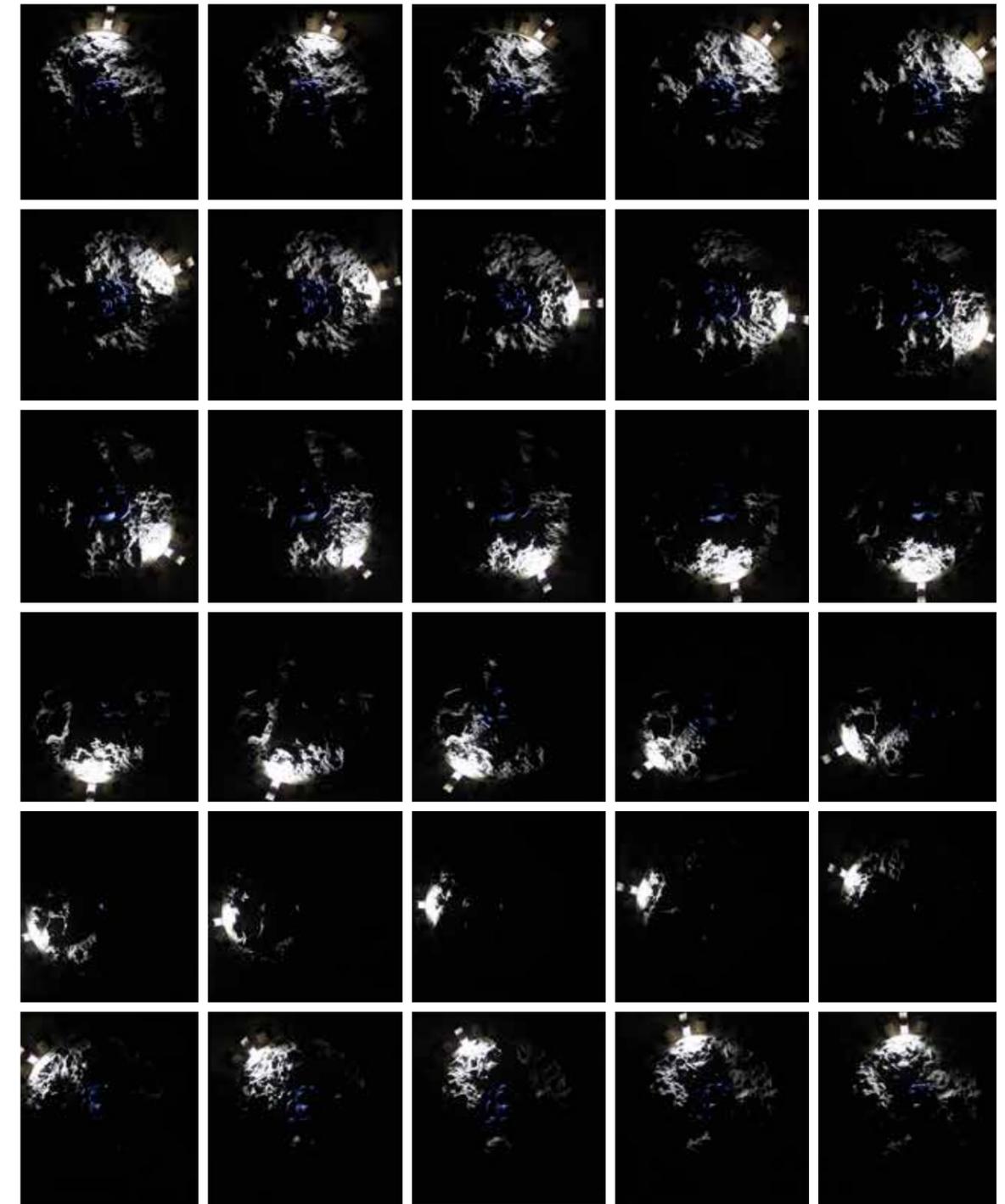
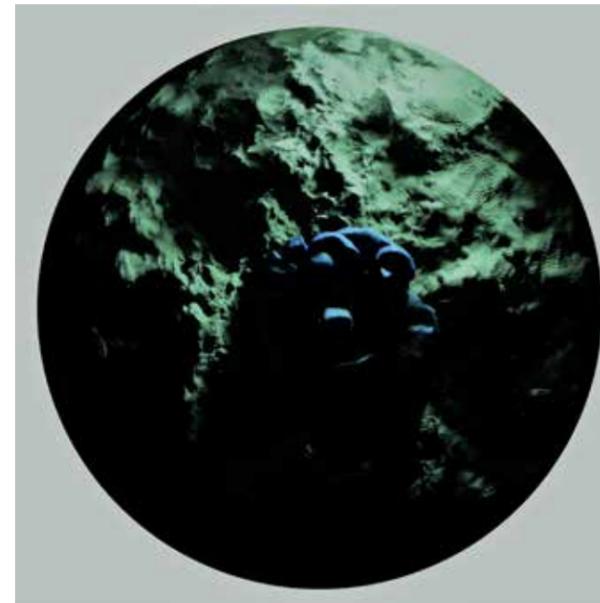


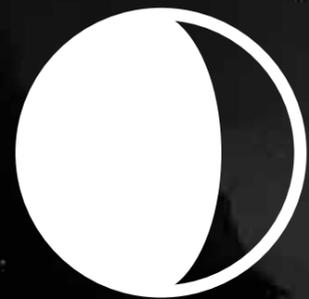
Although the sun rarely sets, intermittent periods of darkness occurs as the sun, low on the horizon, is blocked by distant mountains.

The graphic (left) illustrates the nearest obstacles that could potentially shadow site-A. Dark blue indicates adjacent peaks while red shows the relatively flat open solar avenues.

(Right) Model of approximate topographic conditions using a clay medium. 30 rotating solar positions were tested to mimic the sun's pattern over a month. A figure was placed in the center to investigate how the light would strike facades of varying size and height. Even small changes in height yielded increases in light.

The figure below represents a rough estimate of solar accumulation on the site in a 30-day period. As the data predicted, the less mountainous "northeastern" portion of the site is the most illuminated.





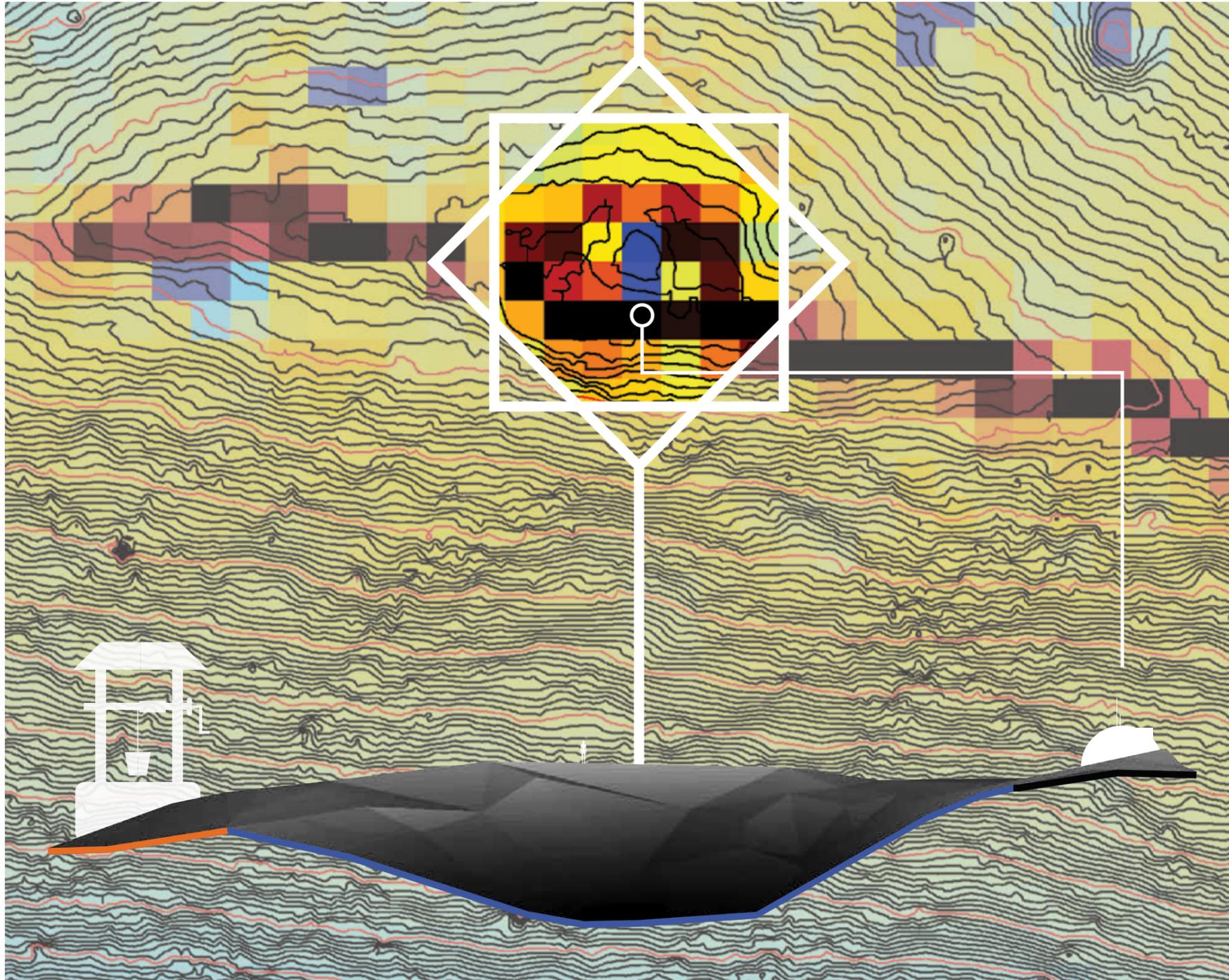
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# Beginnings, Growth, and Purpose

“People try to typecast astronauts as heroic and superhuman.  
We’re only human beings”

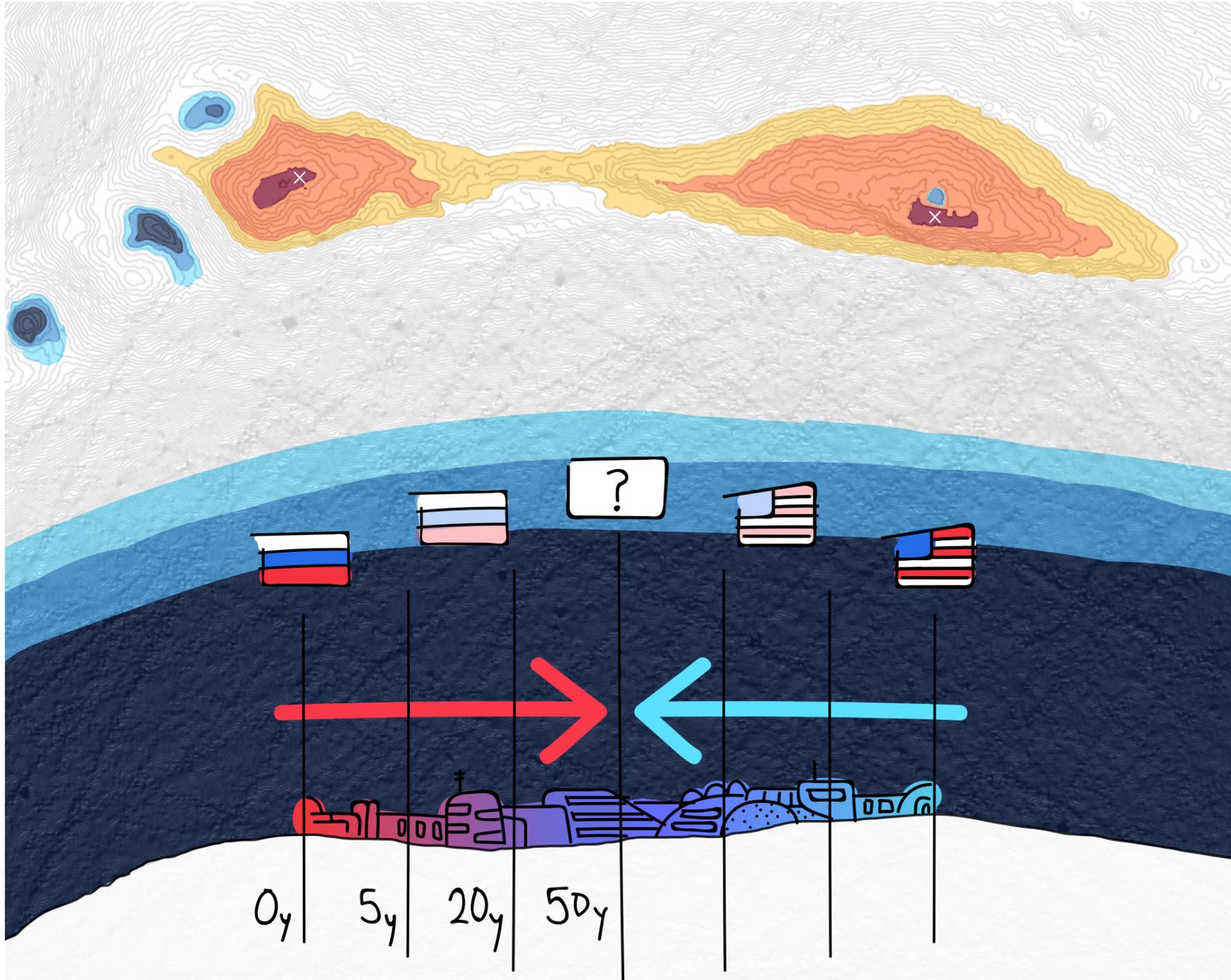
- Gene Cernan

Apollo 17 astronaut  
Last man to walk  
on the moon



The location our explorers will first beach their space shuttle sits atop of Shackleton's eternal peak, receiving sunlight 90% of the year.

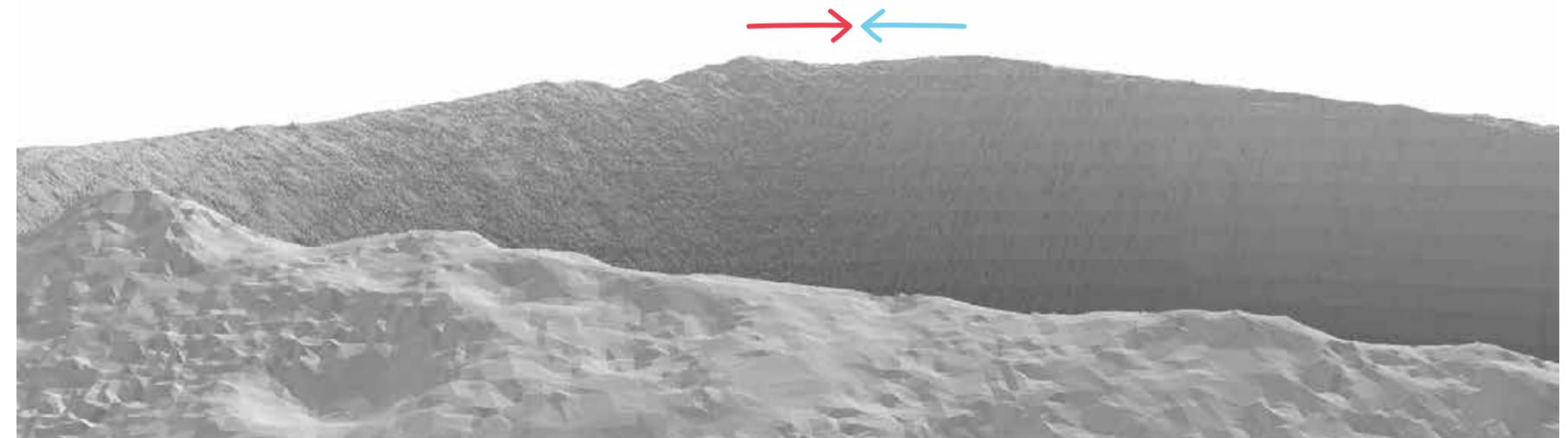
90 feet away from the peak lies a small crater (blue center), 200' in diameter and 40' deep, shrouded in constant darkness. It will likely serve as the colonists' resource for "well water" before the bounty of ice hidden within Shackleton's depths is attainable.

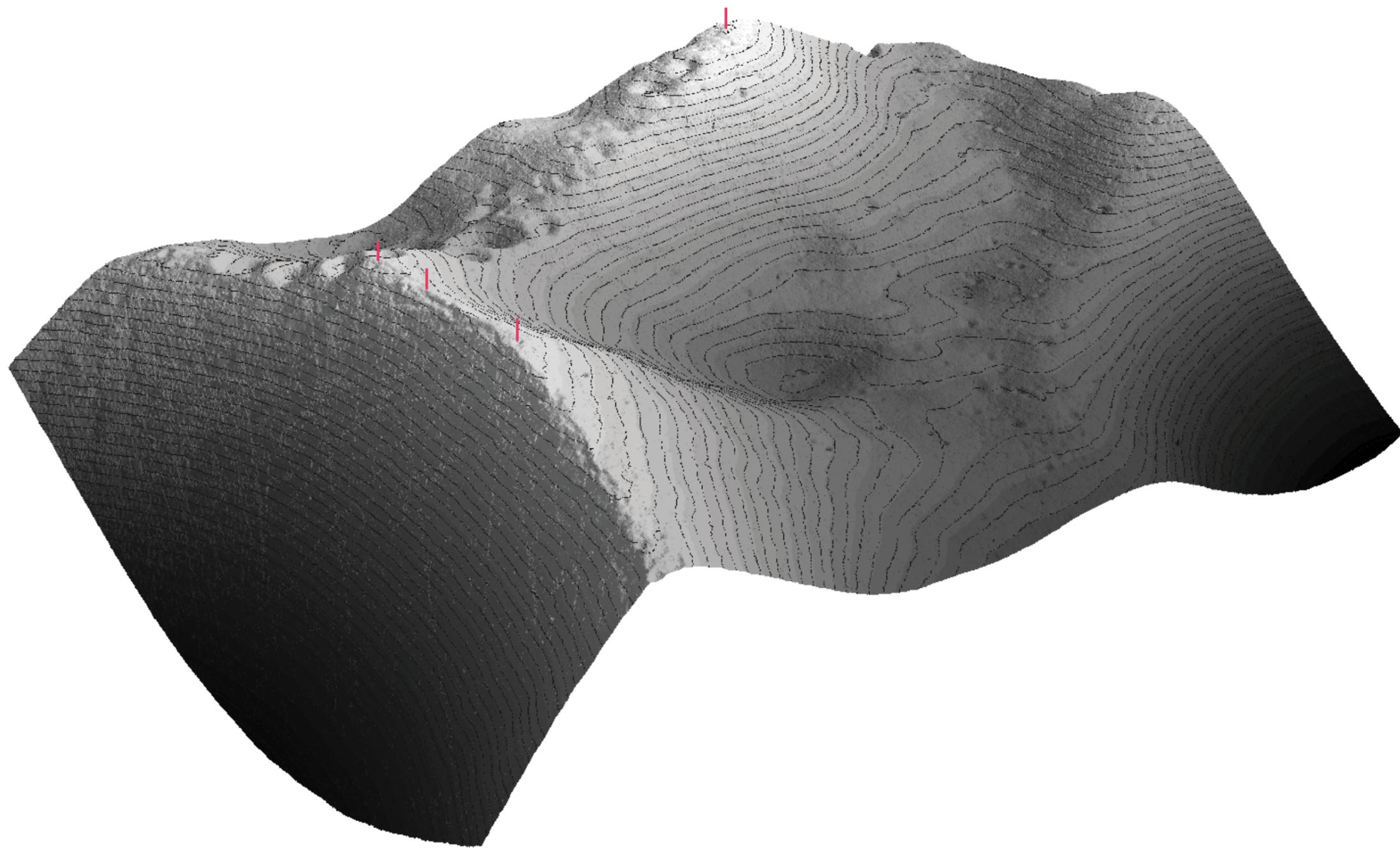


Ideally two colonies will begin their journey simultaneously, perhaps as part of a cooperative international settlement; operating similar to the International Space Station. Each landing site has its own inherent strengths and weaknesses.

The southernmost site and focus of this thesis (blue arrow) has the best annual illumination and rests on a slightly higher peak, meaning fewer hours of darkness and greater visibility of Earth. Its drawback is that its immediate source of ice is limited. What the adjacent site lacks in height it makes up for with several large cold traps, meaning greater potential for water reservoirs.

As the cities expand, the most likely path urban growth will take is linearly along the crater's rim. The interior saddle between the two peaks will become the site of dense conurbation as the two settlements merge in not only structure, but in people, perhaps creating a new identity.



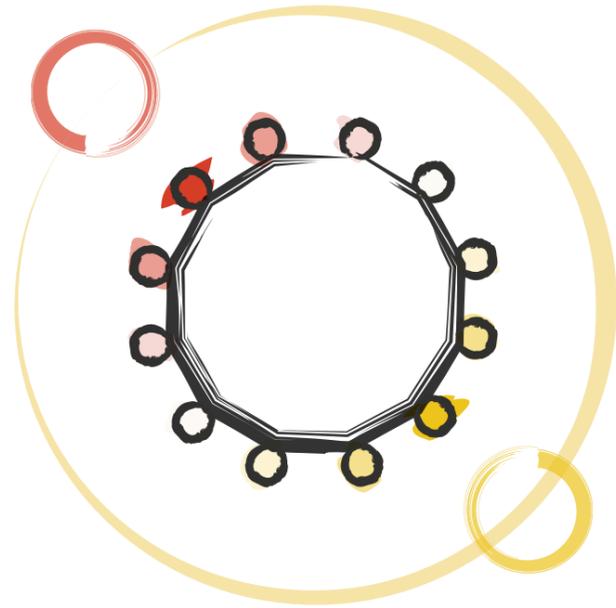


Once the two colonies have merged, expansion of a matured lunar civilization may continue along the rim of Shackleton or possibly join to the adjacent ridgeline which connects to the south pole's next eternal peak. The relatively gentler slopes of the crater's backside may also allow for non-residential urban growth that is not as dependent on constant sunlight.

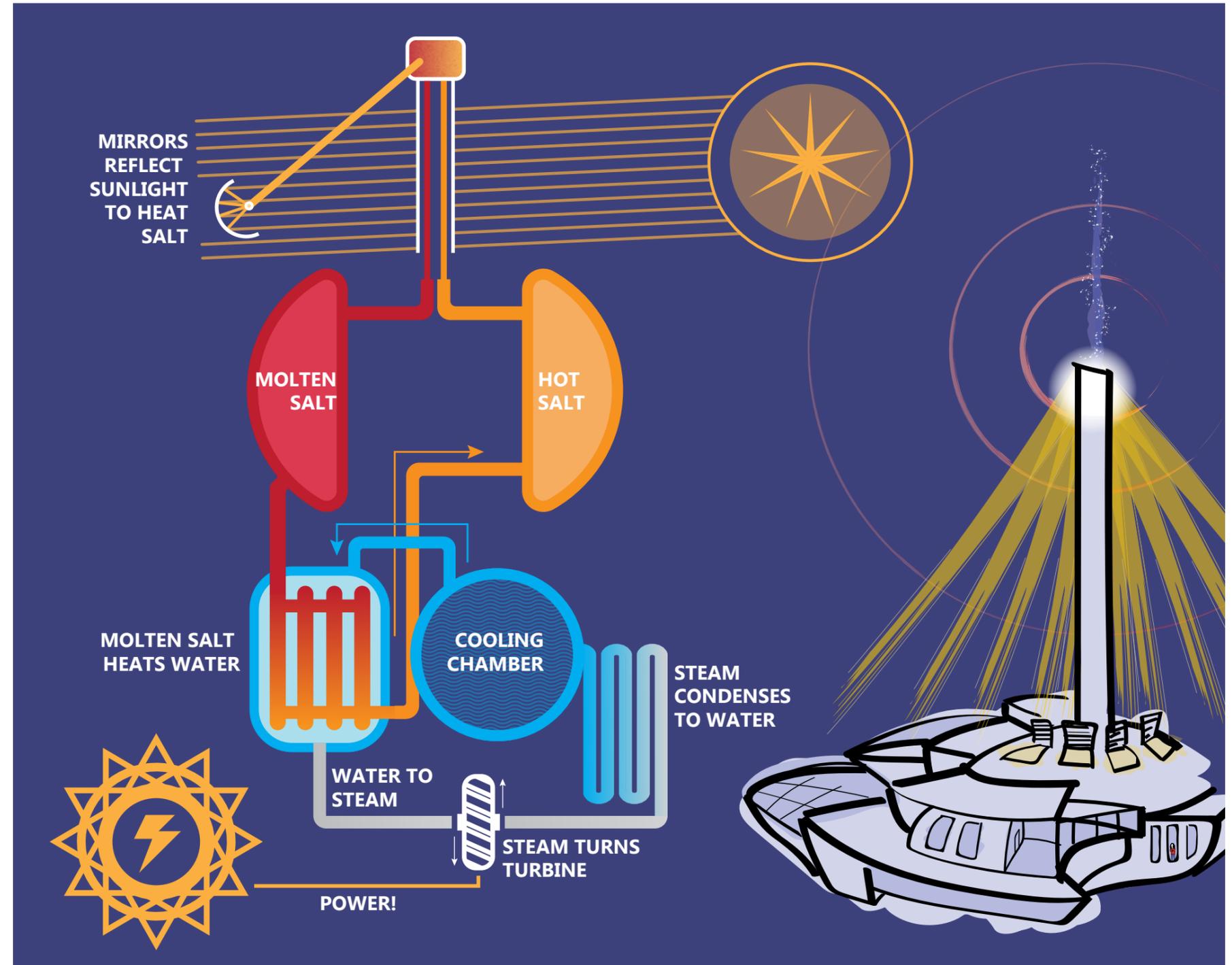
The initial outpost will likely rely on photovoltaic solar panels to keep the lights on but as demands grow a more powerful and reliable method will be needed.

At the center of the city stands a solar mill which uses concentrated solar power to keep the civilization running and its inhabitants alive. Mirrors on rooftops bloom like flower petals, reacting to the 360° solar presence, closing when no longer needed so as not to cast long shadows in the horizontal light. Unlike photovoltaic, this method allows energy to be stored and used during the rare hours of darkness.

Standing nearly 600' high and visible from anywhere in the city, it will become the first object to exist within the mythic "eternal peak", its pinnacle bathed in sunlight even when everywhere else appears to be in night. More than a tool for power or a space for social gathering, it is a symbol, a beacon for all of those who find refuge in the lunar harbor.



Crescent Dunes Solar Plant - Las Vegas, Nevada



It is impossible to sum all that which a city contains. It can never be planned in its entirety and whatever is created is always subject to change by future generations and unforeseeable intentions.

These are a sampling of considerations that this thesis has attempted to address whether actively through visible design or passively in research and thought.





## LABORATORY

**Scientific Research** | testing, honing, and perfecting our skills of cosmic habitation; from methods of construction, power production, and agriculture, to day to day challenges. The base is welcomed to all who are able to donate resources, funding, or crew.

**Outpost:** 50 +

An extension of representative nations which relies on the direct cooperation of participating countries. Crew live and work together - mission leaders are elected in pure democracy.



## METAMORPHOSIS

**A Place for Staying** | a transitional period where mastery of space habitation techniques creates comfortable living, encourage migration, growth, and greater self-reliance. Families are introduced to the colony, along with a large variety of new services to transition a single minded outpost into a diverse colony.

**Colony:** 1,000 +

Premeditative separation begins to occur mirroring the colonies' growing self-reliance. Basic social codes and inviolable rights are framed, enacted, and enforced. Generational colonists strengthen and improve upon social and political identity.



## THE HARBOR

**Port City** | just as coastal cities were the gateways to the world in the past, the moon will serve as the safe harbor for cosmic sailors to launch from and find refuge in. While the lunar colony has reached maturity, the cycle is destined to repeat on ever distant planets for as long as human curiosity persists.

**Settlement:** 20,000 + per city (3)

Recognized as a new territory with an independent political system, united under Earth's banner. It is the hub of all future space exploration.

The journey we begin on the lunar surface to become a spacefaring species will be long and unpredictable. The early years are easy to envision; however, looking ahead decades or even a century later invokes the imagination. What identities, ideologies, and connections will a 3rd generation child born on the moon develop when their own parents have been absent from Earth? What memories and traditions will be kept?

From a geopolitical perspective, what fate do the two initial colonies hold? Will one nation seek dominance to gain a competitive advantage or will humanity use this blank slate as an opportunity to dissolve earthly divisions? Politics, religion, vices; it is the things we carry with us that will shape our new identity. What will we bring to the moon or leave behind?

The moon becomes humanity's crucible in which we not only test our technologies and resourcefulness, but ourselves as a people.



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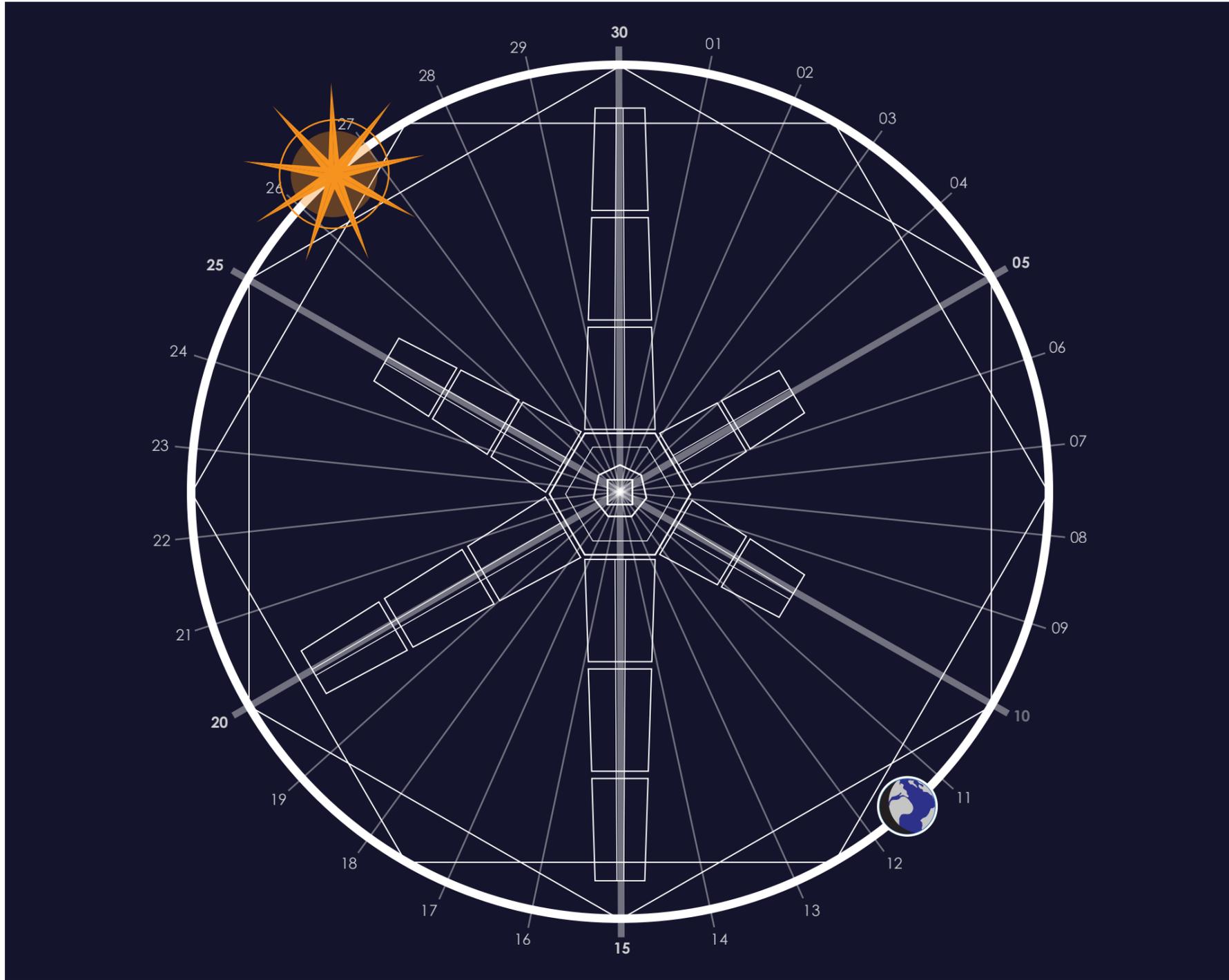
## Centered Cosmic Consciousness

"A vaccination against negative parochialism is to realize our infinite smallness containing the enormous power of mind.

We would therefore like to cultivate an environment wherein structures and grids would make astronomical sensitivity a normal presence"

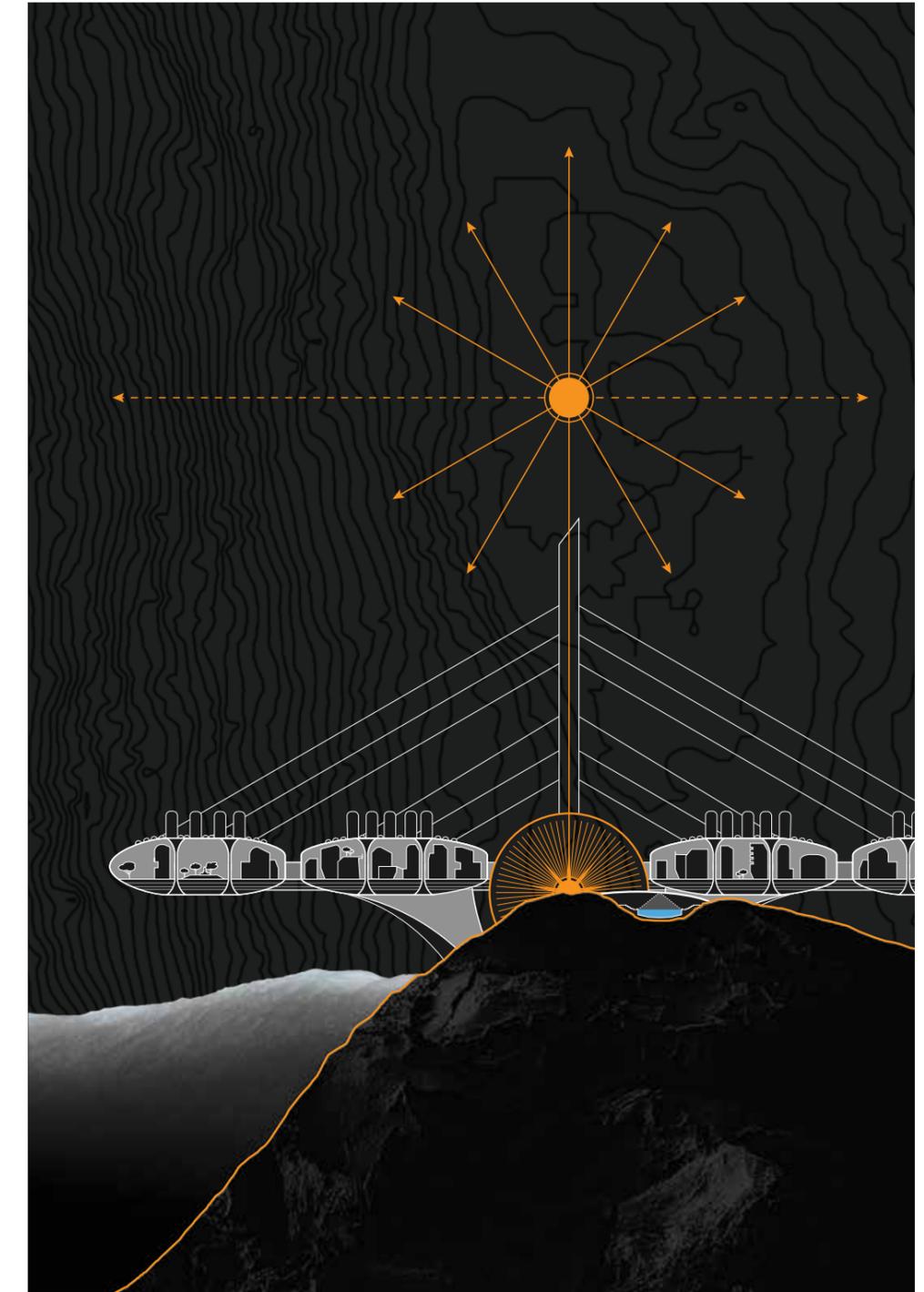
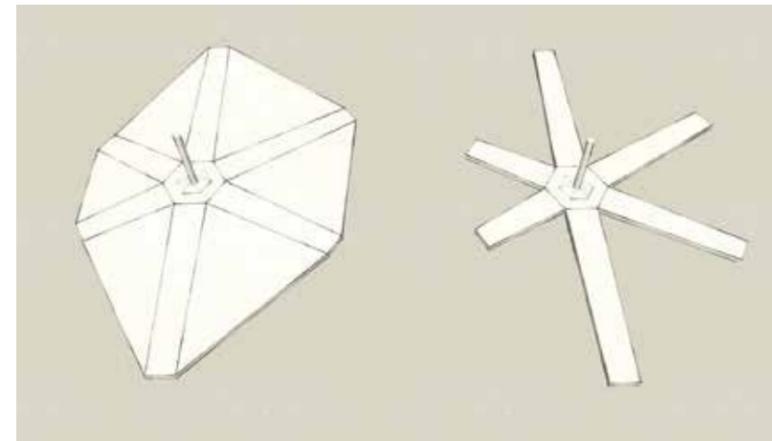
- Paolo Soleri

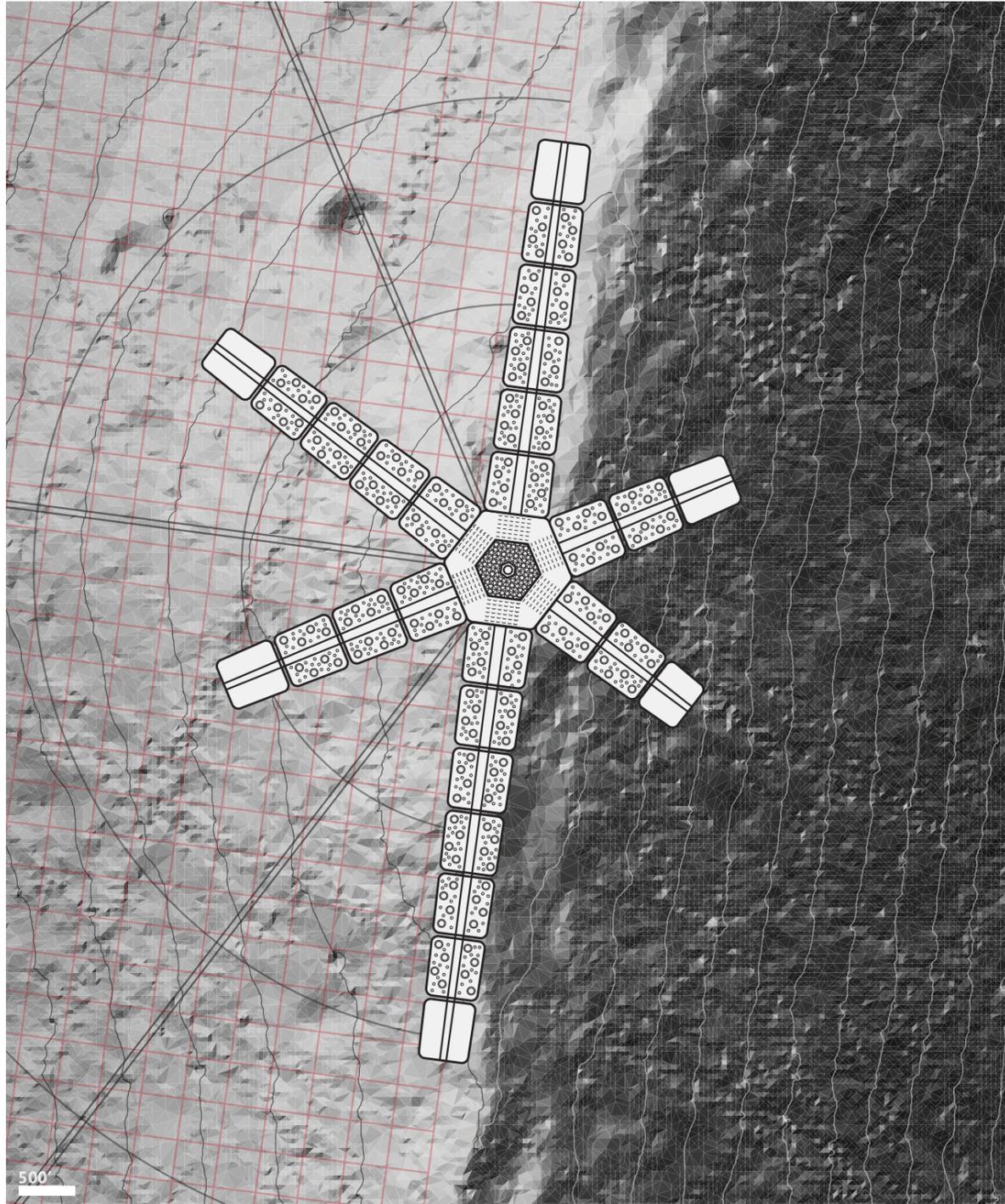
architect and advocate  
of arcology



The design (right) focuses on taking the exact point where the 'eternal peak' resides and raising it up from the lunar surface. This will become the foundation of the solar mill as well as the civic and cultural heart of the city. From this central point the urban fabric expands outward in rays above the extreme topography. The solar mill additionally acts as a cable-stayed bridge, supporting horizontal piers which soar above the darkened landscape kept high in the southren sunlight.

The hexagonal form (left) serves to mimic a 30-day calendar month following the circular path of the south pole sun. Each arm is five solar days apart, allowing residents to know the date based on their own orientation within the city and the sun's relative position. Interior voids between the piers sacrifice a larger urban population for longer, fuller, and more equitable solar exposure.



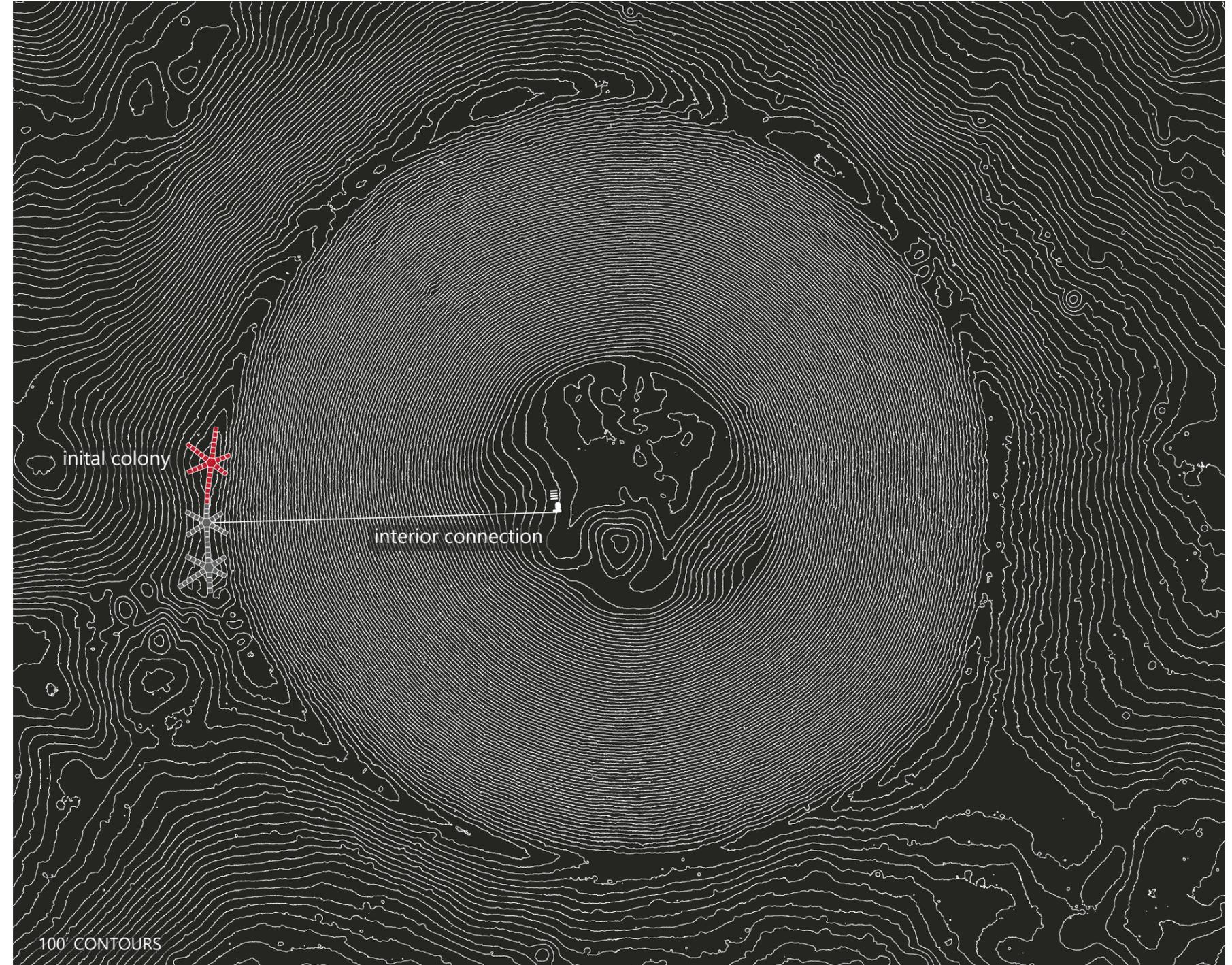


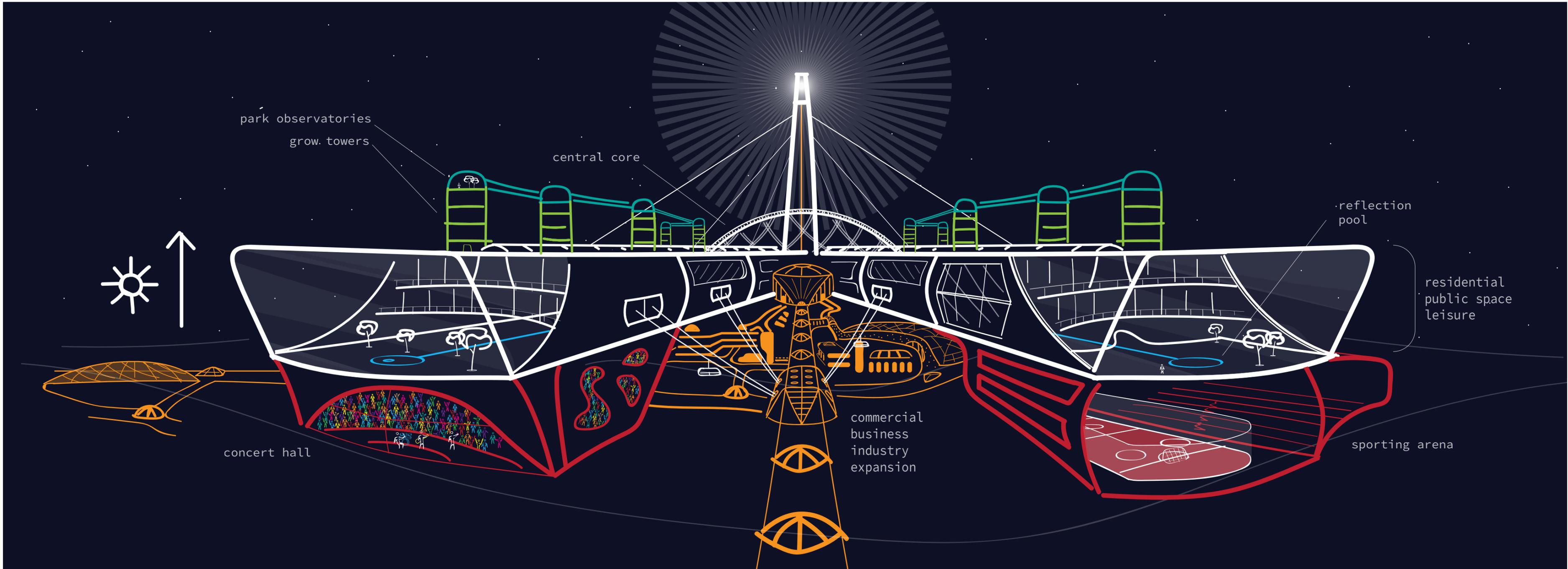
The heart of the city is programmed to facilitate major civic functions, as well as a public space for assembly. The exterior roof of the core holds parabolic mirrors arranged to reflect sunlight to the solar mill no matter the sun's position.

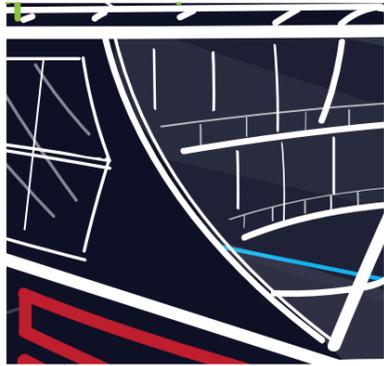
The rooftops of the piers will remain in near, if not constant, daylight. Because of this fact they are dotted with agricultural grow towers to create a steady supply of food year-round. Individual private domes attached to each living space connect the residents to a nearby grow tower, encouraging a sense of stewardship over the crops.

The residential piers which extend from the core are composed of modular urban blocks to suggest a slow growth outward, prioritizing connection with the adjacent colony along the ridgeline. Modular design also serves as a failsafe. In the event of disaster other blocks could be isolated not unlike compartmentalization within a battleship.

Heavy industry and refinement of ice into potable water and rocket fuel occurs in the crater's basin.



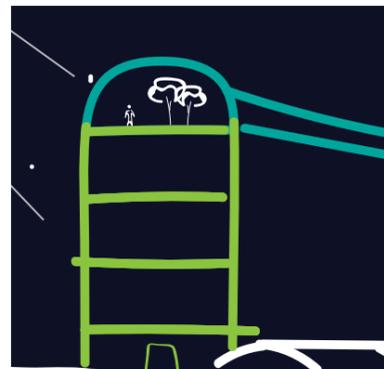




The previous illustration shows the division of space within the city from the point of view of the crater's backside. The suspended piers [white] kept in near constant sunlight are programmed to be the primary living spaces within the settlement, accommodating moderate commercial and public spaces on the bottom levels (1-2 stories), leaving the upper levels (4 stories) primarily residential.



At the end of each pier is a reflection pool [blue] and small "stream" that connects to the city center. Just as the moon's gravitational pull effects our Earthly tides, an even greater effect will be felt by Earth. The Earth's presence will be observable through tidal forces pulling water to the end of the pier that the Earth is aligned with at that particular moment. The linkage does not need to be a single unbroken stream but can be represented by the manifestation of water through a visually connected sequence of engaging features; potable water, fountains, art installations, as well a more naturalistic stream.



Above the piers [green] is a network of community agricultural towers and connecting park observatories. This park system is an alternative to other interior public spaces, placed on top of the grow towers for unobstructed viewing without taking away additional roof space. Surrounding the towers are private residential spaces that act like a small sunlit balcony and personal observatories.



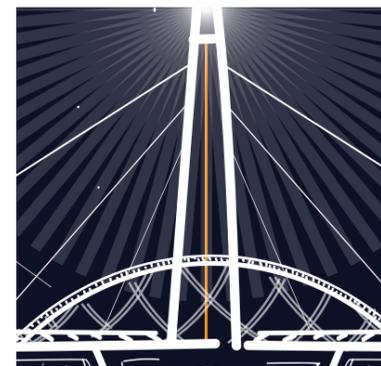
As the piers extend outward, without change in elevation, an extraordinary amount of underutilized space is created underneath. These spaces [red] could be used for amphitheaters, sport, and all manner of entertainment.

Here the lunar environment can be used to an advantage. As long as there is empty exterior space between the ceiling of the entertainment and the floor of the piers, even a fraction of an inch, no sound will be able to be heard due to the lack of air. A concert hall could be below a garden and no one would be the wiser. Vibrations can be minimized through engineering and by carefully placing where the connections between the two spaces occur.

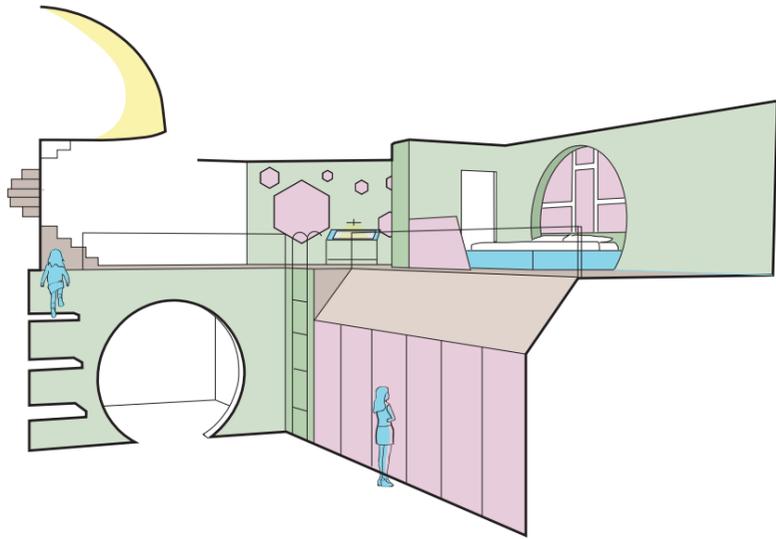


Below the piers the city expands [orange] following the darkened lunar surface. This is seen as the core commercial, business, and industrial area. Spacious bazaar-like streets connect the expanding urban development. Central roads extend from the joints of the hex design creating a connective urban grid that is primarily orthogonal in pattern.

This also allows for the colonists to enjoy the freedom of choice. To be able to reside outside of the solar piers, purchase land, and start businesses while still being connected to the greater urban fabric.

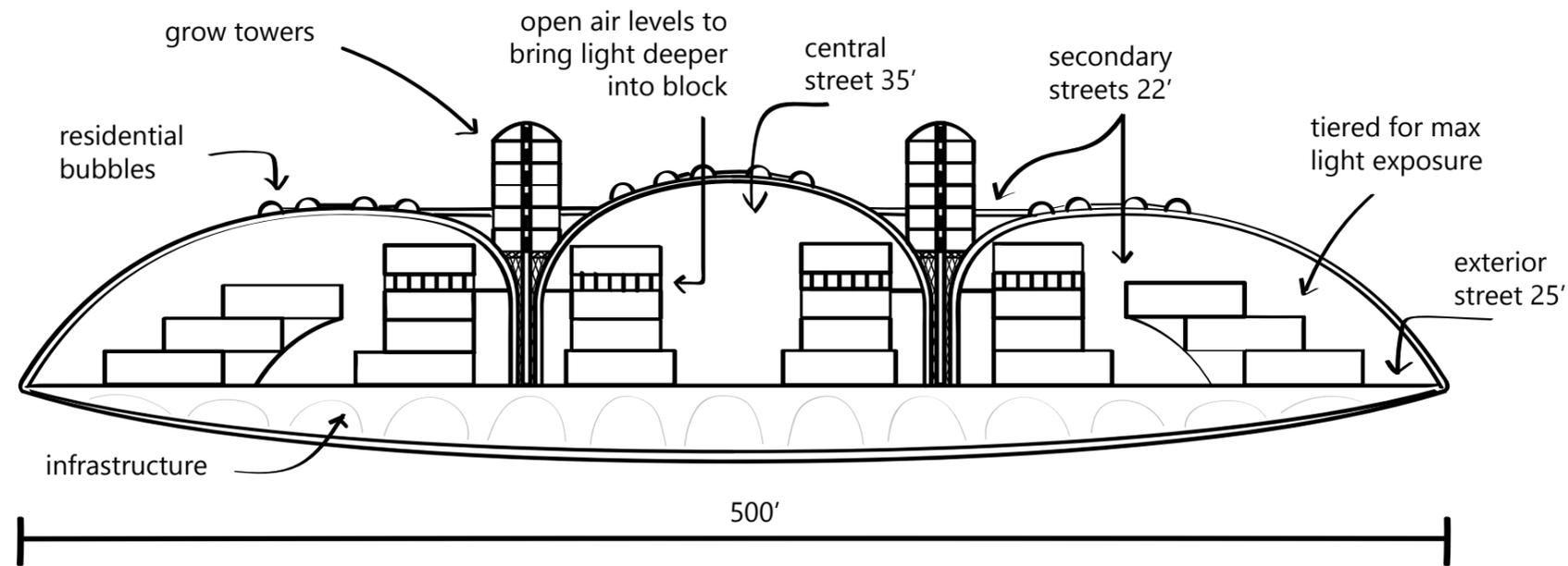


The central core of the city is the junction of the six horizontal piers, facilitating civic buildings, regional transit, and public space for assembly and recreation. The interior is wrapped around the solar mill which stands exposed at its center. This pivotal space is the subject to further programming throughout this thesis.



[Left] Potential interior of an outward facing living space within the upper decks of the piers. While interior is speculation it emphasizes connection to exterior spaces.

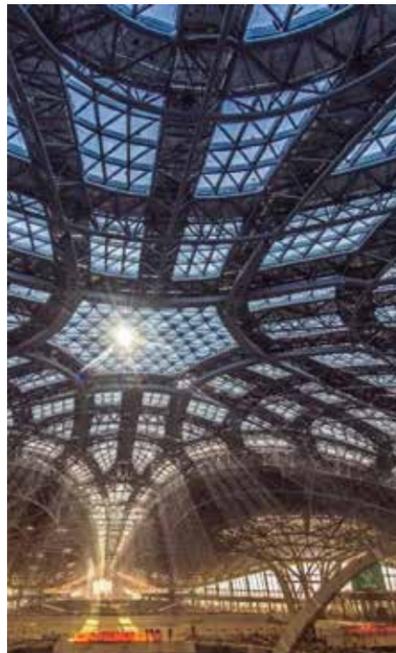
[Top Right] Example of a semi-private flexible program space within residence giving views of the stars above. While spatially private, they are visually connected to the rest of the community through a field of residential bubbles and local grow towers.



## Interior Structure

Piers would be spatially divided by massive interior archways to distribute pressure along the mega structure. An inner skin functions as a semi-permeable latticework akin to jali screens used in Islamic architecture. The pattern of windows would be smaller on the ceiling, becoming increasingly light permeable and larger towards the exterior edges where the horizontal rays will be direct. Particulates within layers of glass scatter light simulating familiar Earthly atmospheric light.

Street patterns and interior configuration could be highly diverse but is illustrated above in mirrored simplicity to investigate urban dimensions. The core patterns that will not likely change from module to module are the structural bases of the archways, which allow access to the grow towers, and the central/exterior streets. Strong paths leading inward to the blocks center may also become regular practice to bring in sunlight. Aside from these considerations, interior space may opt for a more meandering pedestrian driven pattern opposed to the western orthogonal grid.



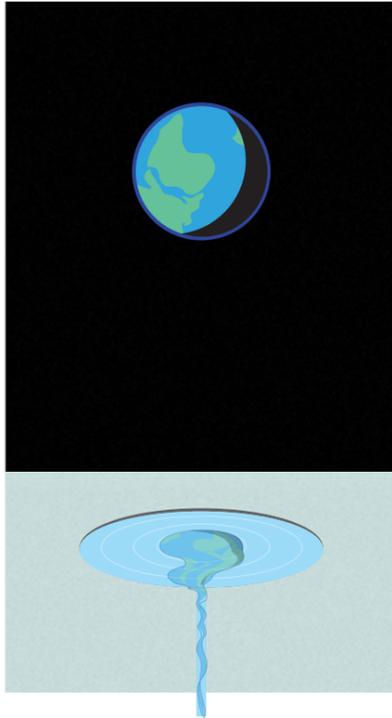
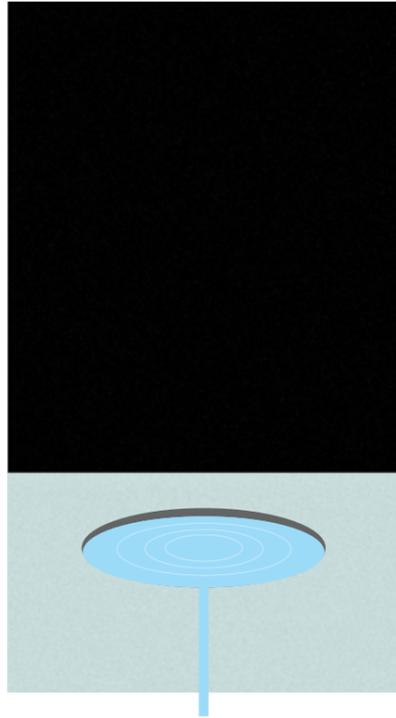
Light Permeability: Beijing airport

Jali screen

Collage (right) depicting the codependence of community and linkage between grow tower, living space, and food distribution. This collage also addresses a fundamental question which perhaps needs a subsequent thesis to explore fully; what is urban form/life like inside the piers? Is there freedom in construction and personal aesthetic taste, or are living arrangements predetermined by the constraints of living within a highly engineered city?

Within the enclosed 500x500' modular blocks a great deal of flexibility and freedom could be given, if designs adhere to a prescriptive lunar form-based code. Some requirements would be more crucial than others, such as floor area ratio and allowing light to permeate as deeply into the block as possible. I believe that lunar citizens will not crave a sci-fi setting but rather a more familiar architectural vernacular.

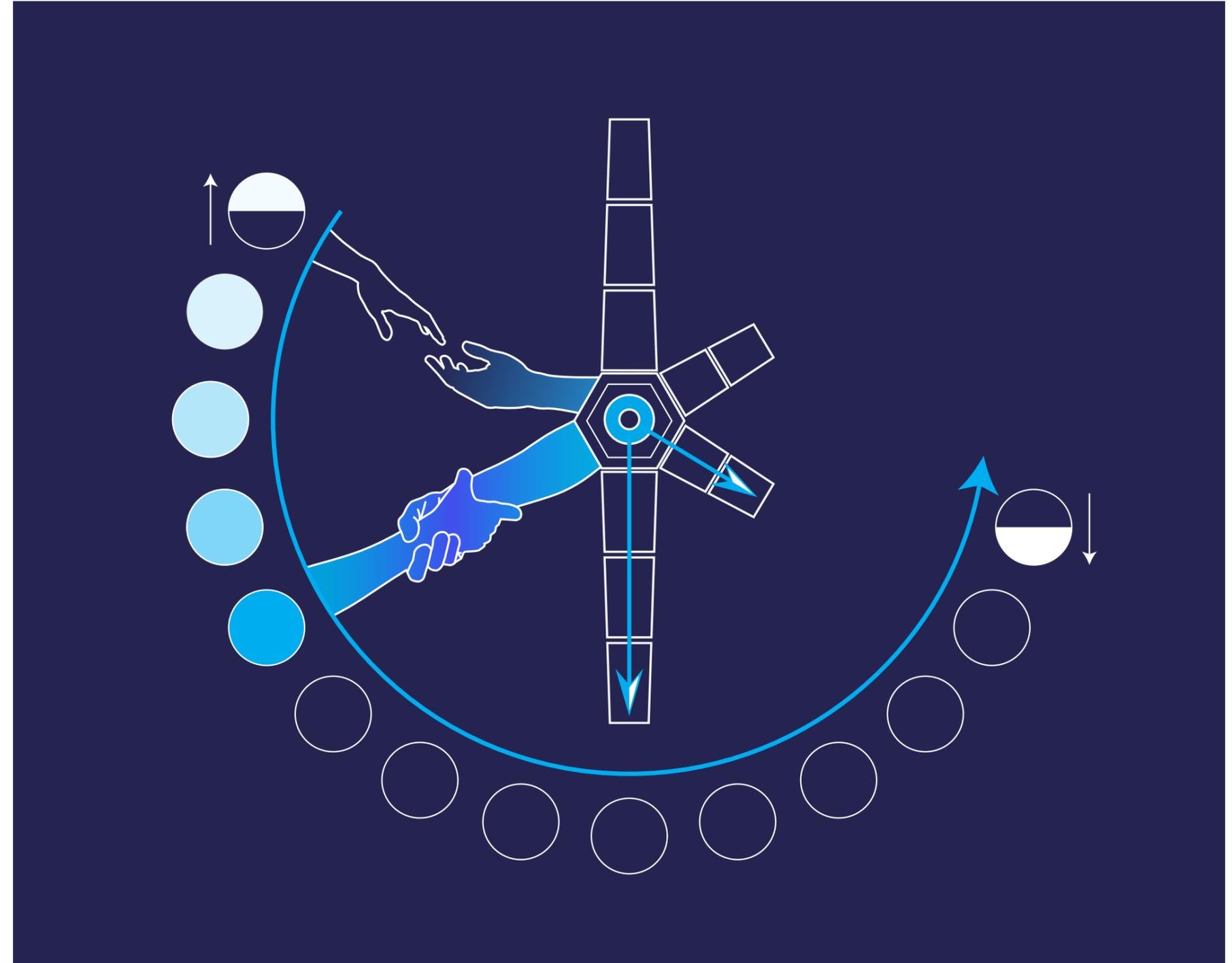
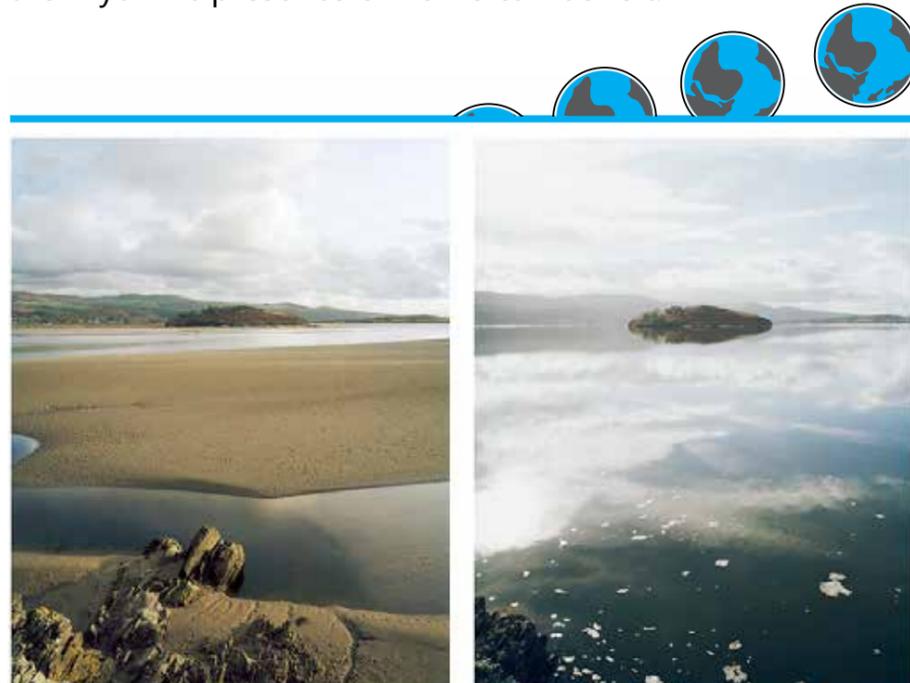
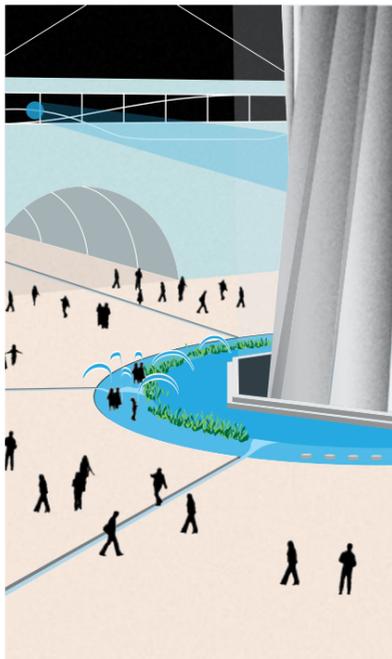
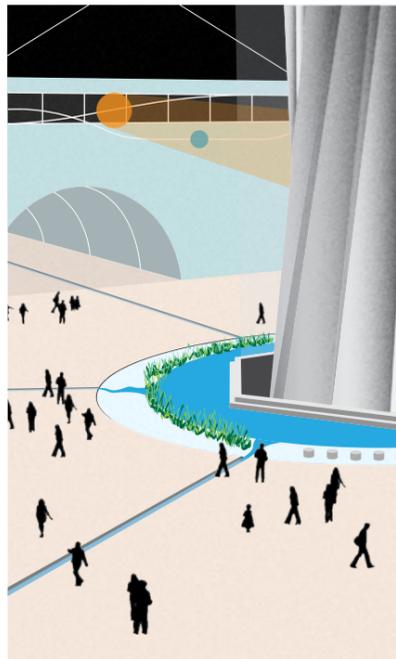




## Familiar Sights

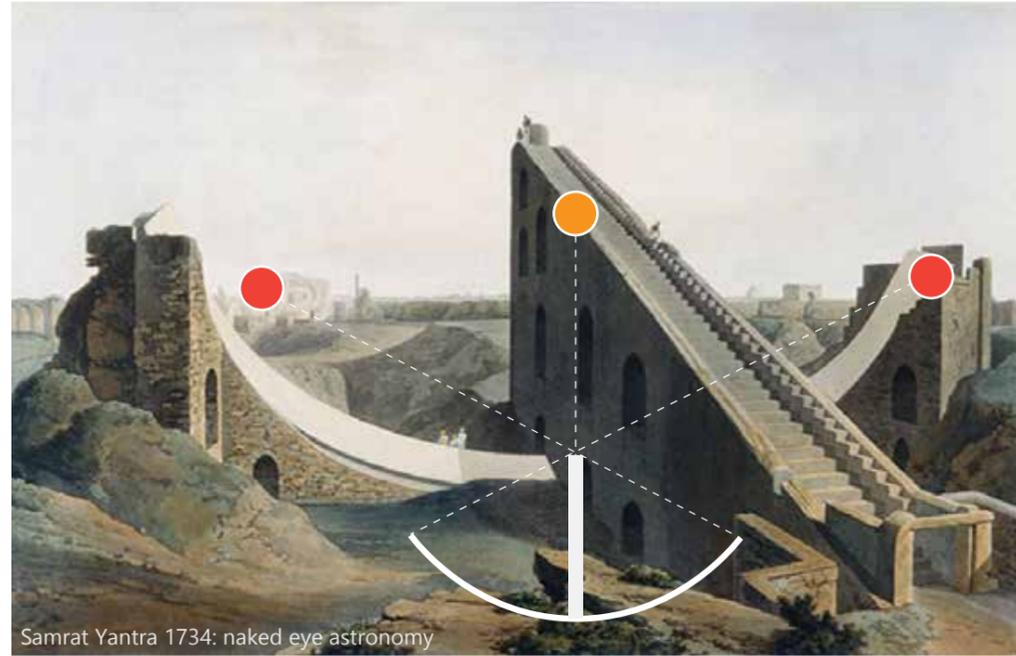
Present or hidden, Earth's gravitational pull beckons to the lunar colonists. Just as the moon effects our Earthly tides, a much greater strength will be felt by Earth. At 81 times the size, it exerts a force 6 times greater.

As the Earth rises, rotates, and sets around the site its physical presence will be observable through the tidal forces. Although not always visible within the city, the Earth's location will be known by observing the flow of water. The heart of the city (concept left) contains a central plaza which houses a large basin of water around the solar mill. The Earth draws from the basin pulling the water to whichever pier it is most strongly aligned with. As the planet continues its rotation, the bond between one pier weakens as the succeeding pier strengthens. At all times the rhythmic presence of home can be felt.





Sundial designed for South Pole



Samrat Yantra 1734: naked eye astronomy



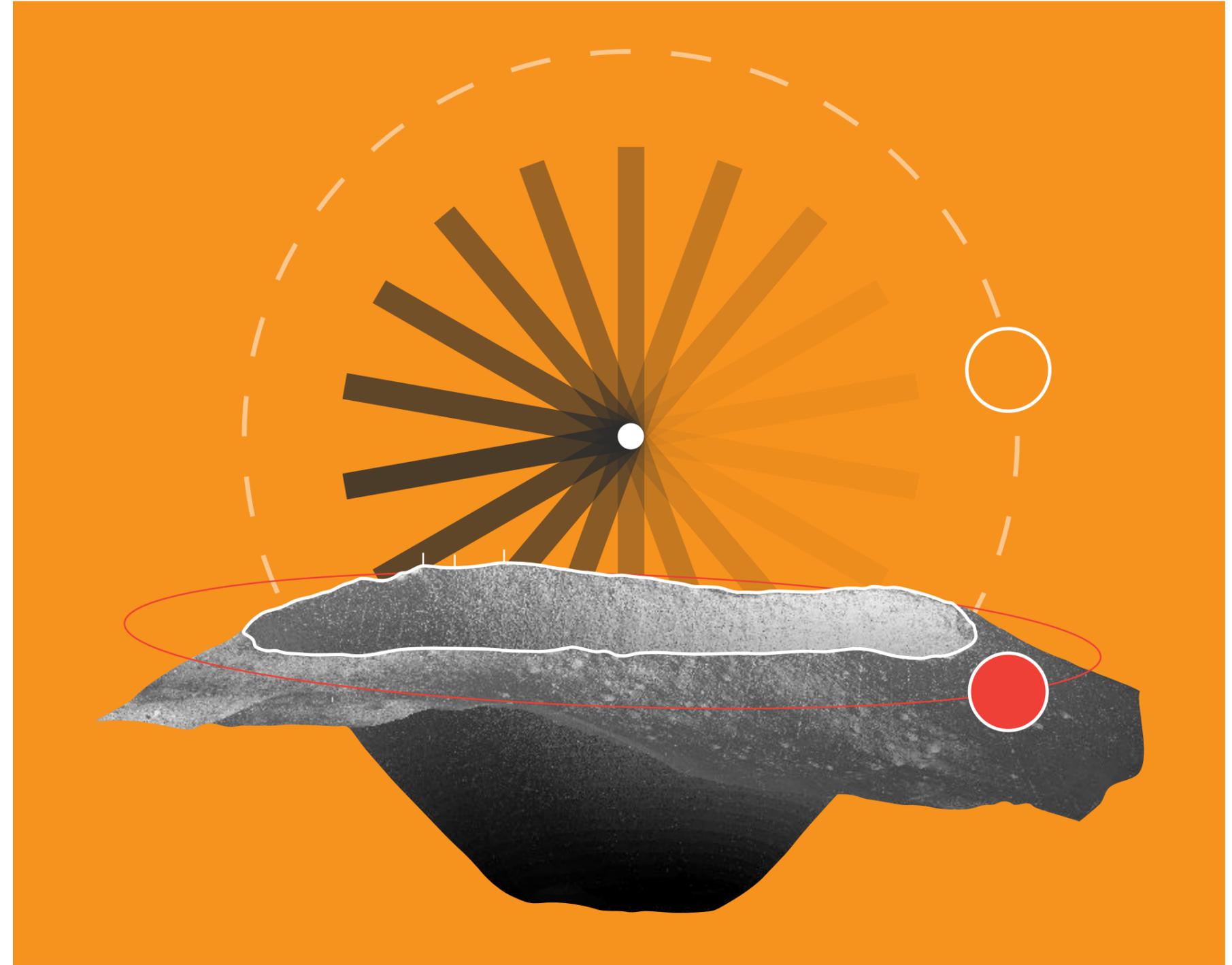
PS10 Solar Plant  
Spain

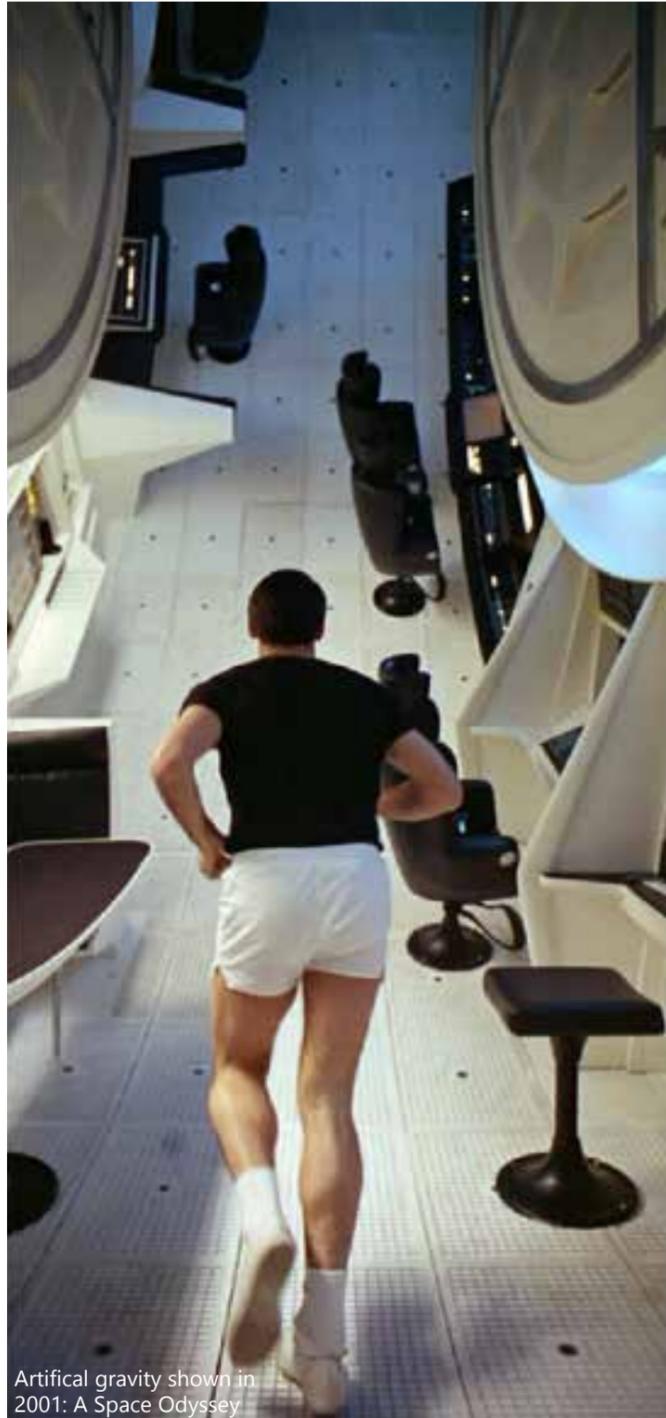
## Consciousness of Time and Movement

While the geometric shape of the city gives citizens a gradual awareness of the passage of time, another opportunity for timekeeping presents itself.

Architects have always been fascinated by the challenge of making astronomical orientation visible to the naked eye. One method was to construct massive sundials built to geographic specification. Samrat Yantra's central piece (pictured above), called a gnomon, was designed with a 27-degree slope, reflecting the latitude of Jaipur, India. The sun's shadow cast against the gnomon indicates the time of day, the center representing noon.

Such an instrument on the south pole, latitude 90 degrees, would simply be a straight, erect structure. Our colonists reside 0.03 degrees from the lunar south pole. As the sun circles our solar mill, powering the colony, it effectively becomes a passive sundial. With additional markers and design considerations the rotating shadow of the solar mill could transform the city's heart into a living chronograph.





Artificial gravity shown in 2001: A Space Odyssey



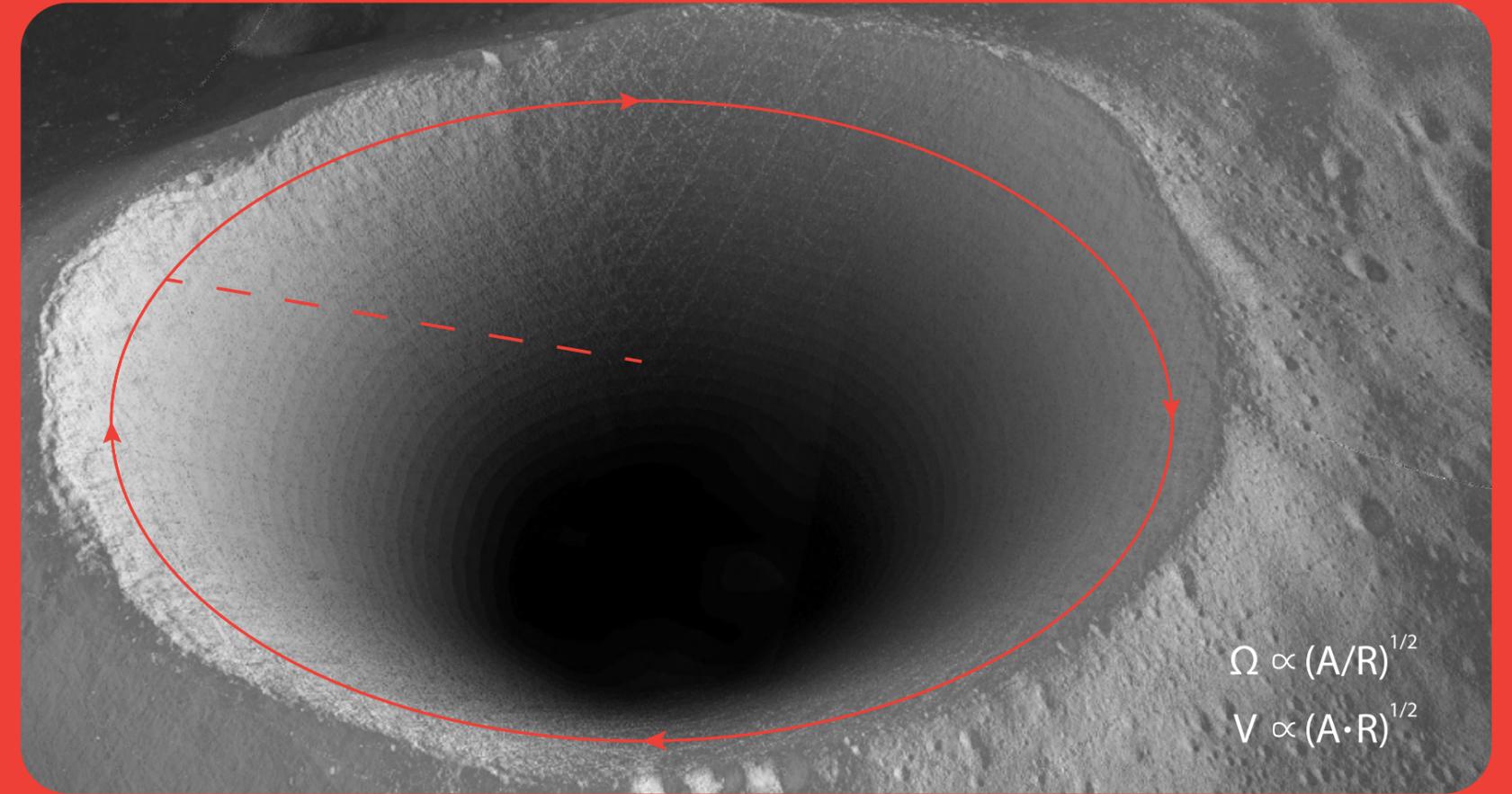
L0 Maglev  
**375 mph**

### The Gravity Problem

Lunar gravity is a blessing and a curse. 1/6 G allows for stronger, more ambitious construction methods. It gives the average person the ability to jump nearly 10', surely giving rise to new sports. The moon may even become a haven for the physically handicapped, healing, and elderly as movement is easier and joint pain is greatly reduced. We may feel superhuman but our bodies work less, becoming weaker. Those who are born or live long periods of time on the lunar surface may not be able to physically return to Earth.

While not the immediate priority of initial settlers it will have to be addressed by the lunar civilization. The solution may lie in centrifugal forces to create artificial gravity. A maglev train accelerated along a circular track following the crater's rim could create a comfortable 1G environment in which to exercise. If colonists can be kept in terran-shape, life on the moon will not become a one-way trip.

Japan houses the fastest maglev train at 375mph. A future more advanced train that is 6xs lighter and operating without air resistance may be able to achieve the necessary 688mph.



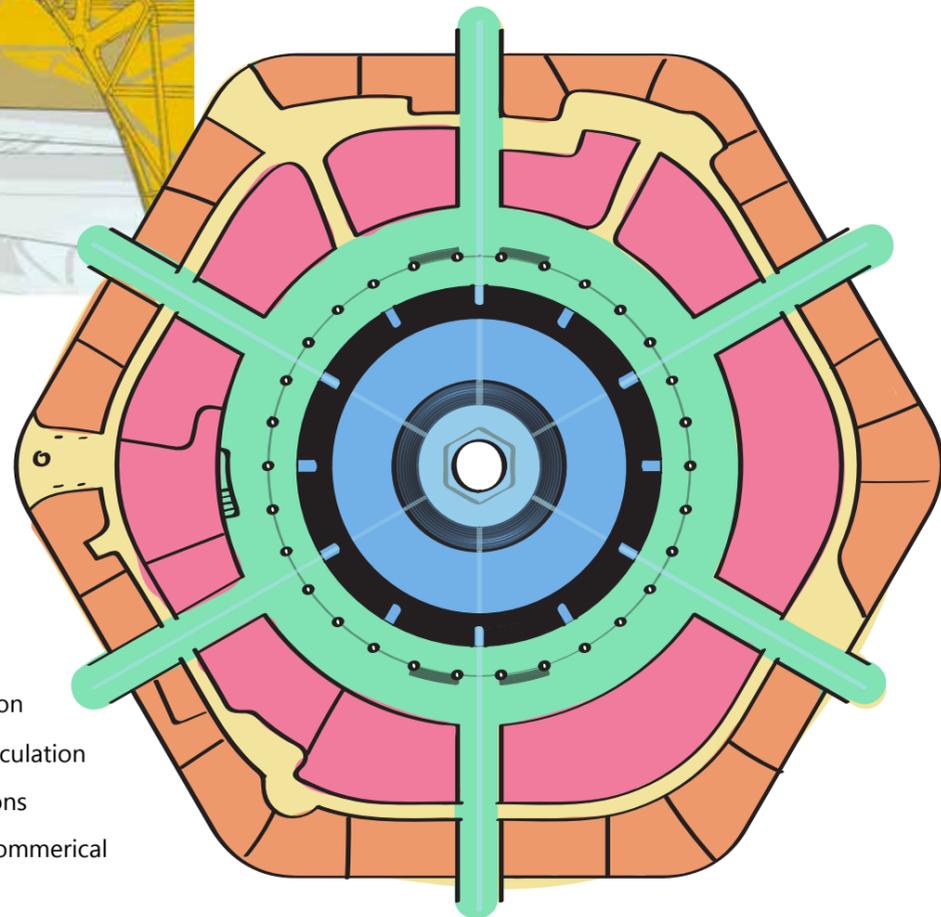
$$\Omega \propto (A/R)^{1/2}$$

$$V \propto (A \cdot R)^{1/2}$$

- R - radius (center of rotation): **6 miles**
- $\Omega$  - angular velocity (spin rate): **0.3 rotations/minute**
- V - tangential velocity (rim speed): **688 miles/hour**
- A - centripetal acceleration (gravity): **1G**



Exterior of city's core illustrating the partially open array of mirrors reflecting sunlight towards the solar mill.



The ground floor of the city's core is programmed primarily for circulation between the six residential arms, as well as housing the city's major civic institutions. At six stories in height, the colony's cultural and governance center creates a strong presence along the central public space.

- Liquid Heart
- Core Circulation
- Secondary Circulation
- Civic Institutions
- Supporting Commerical

### ROOFTOP REFLECTORS

a light-permeable dome which encases the previous two levels. The array of parabolic mirrors are situated around the solar mill, flattening when not needed, and blooming like petals when needed for solar reflection.

### SOLAR CALENDAR

one level above the observatory, this canopy-walk doubles as a functional sundial. The shadow of the solar mill passes over the 30 markers, one full solar rotation indicating one month. The windows on this level are intentionally particulate free to produce unnaturally crisp shadows.

### CELESTIAL OBSERVATORY

eye-level with the piers, this elevated floor provides 360° views to observe all possible earth/sun rises and sets, becoming a space for celebration and festivals. A planting of shade trees lines the exterior edge.

### LIQUID HEART

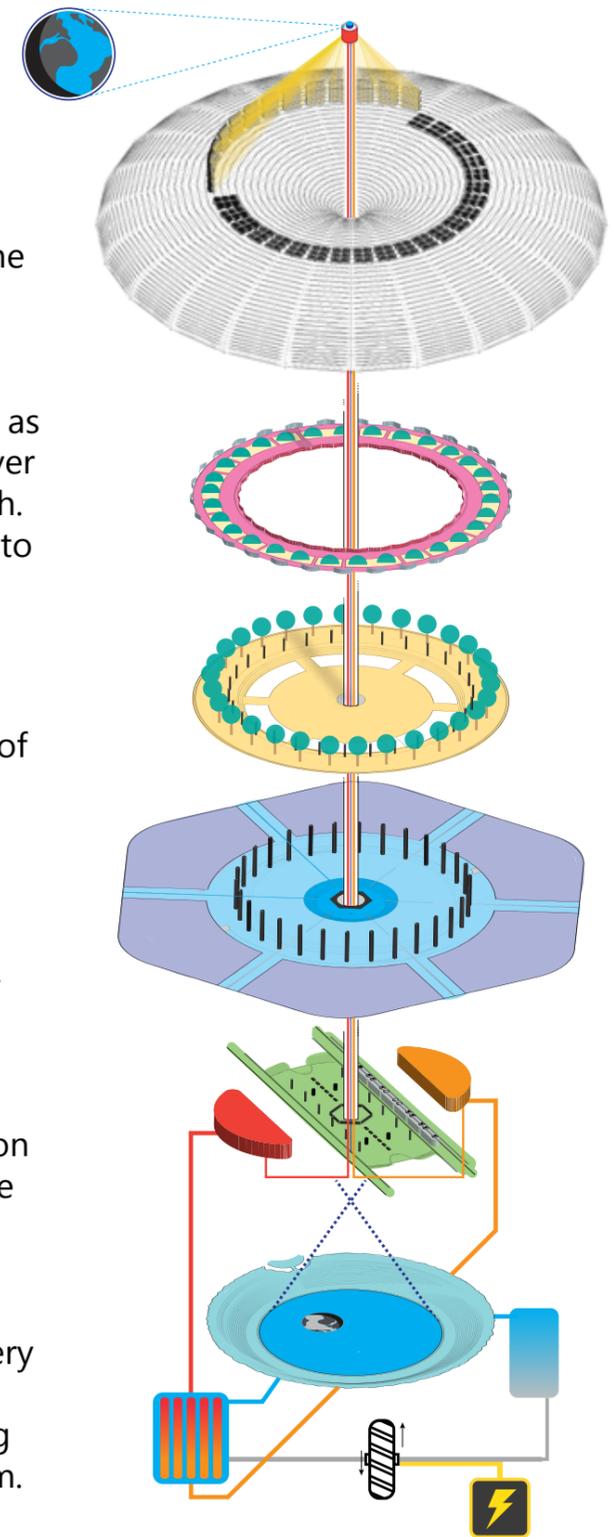
ground floor of the core public plaza within the city, connecting all six residential piers. The perimeter is programed for civic uses such a government, emergency response, library, e.g. A basin of water resides in the center which reacts to the position of the Earth.

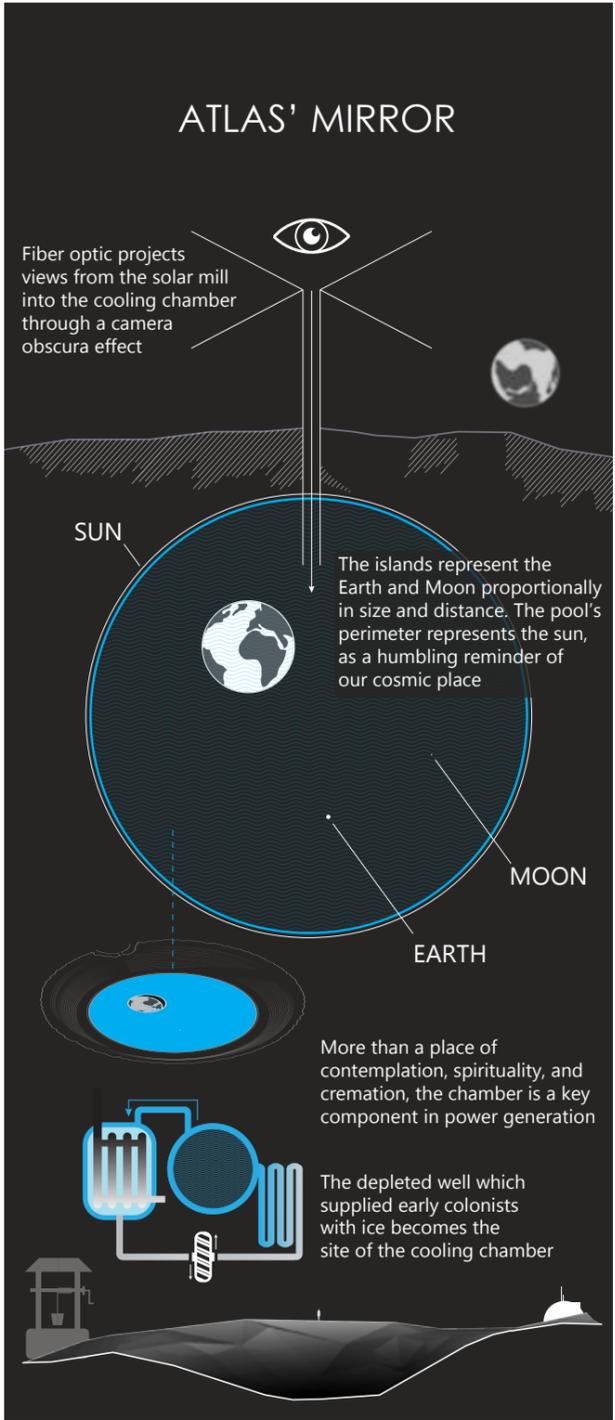
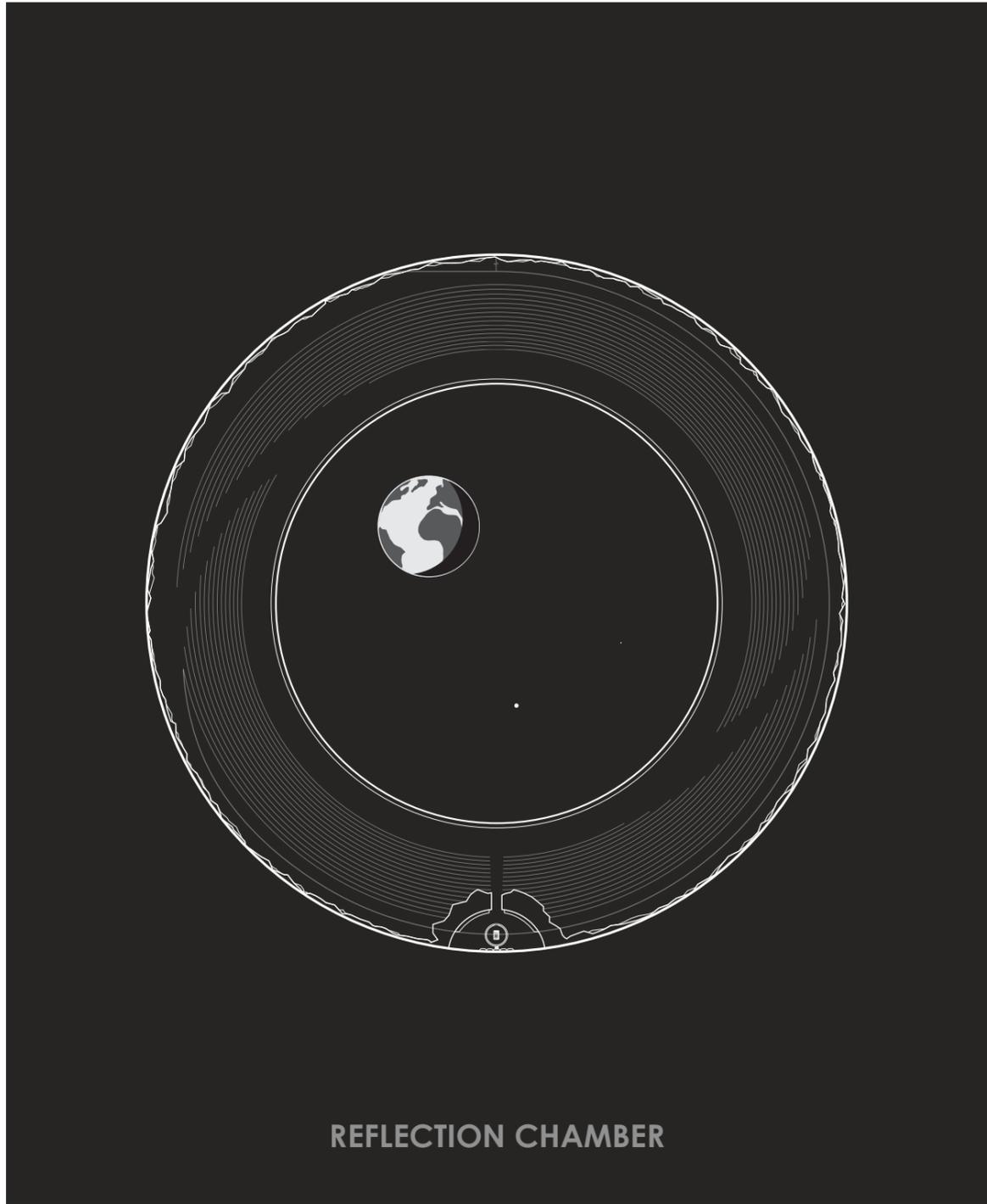
### TRANSIT STATION

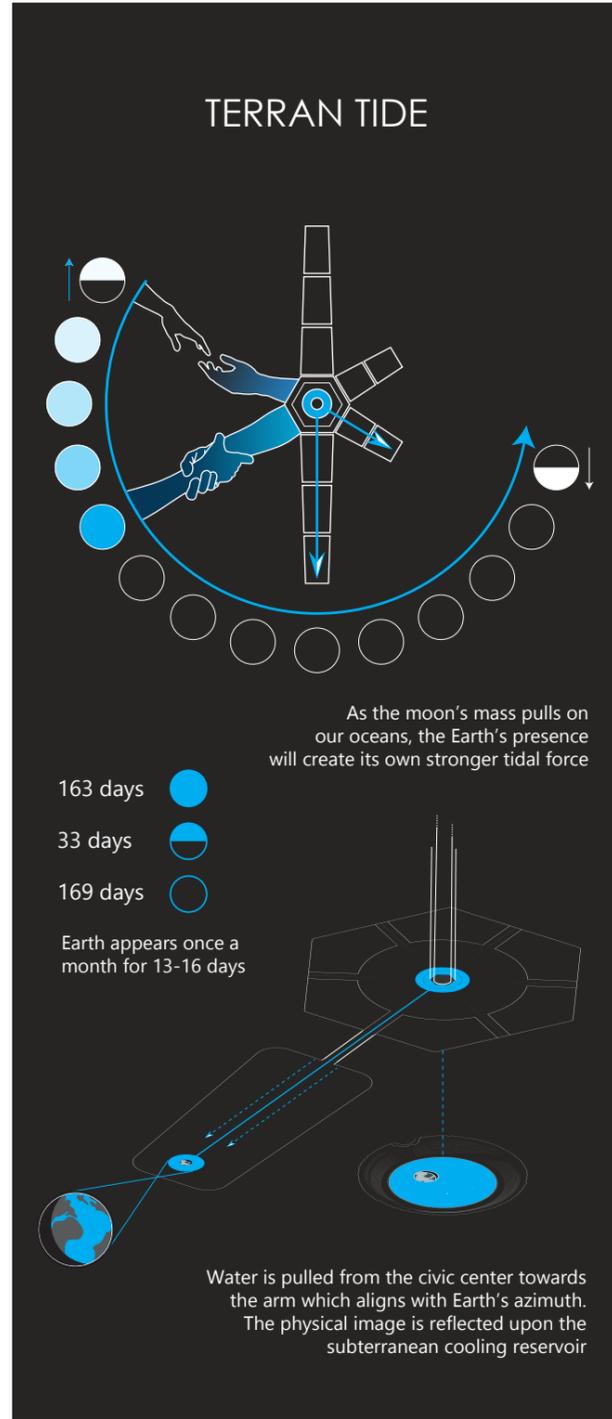
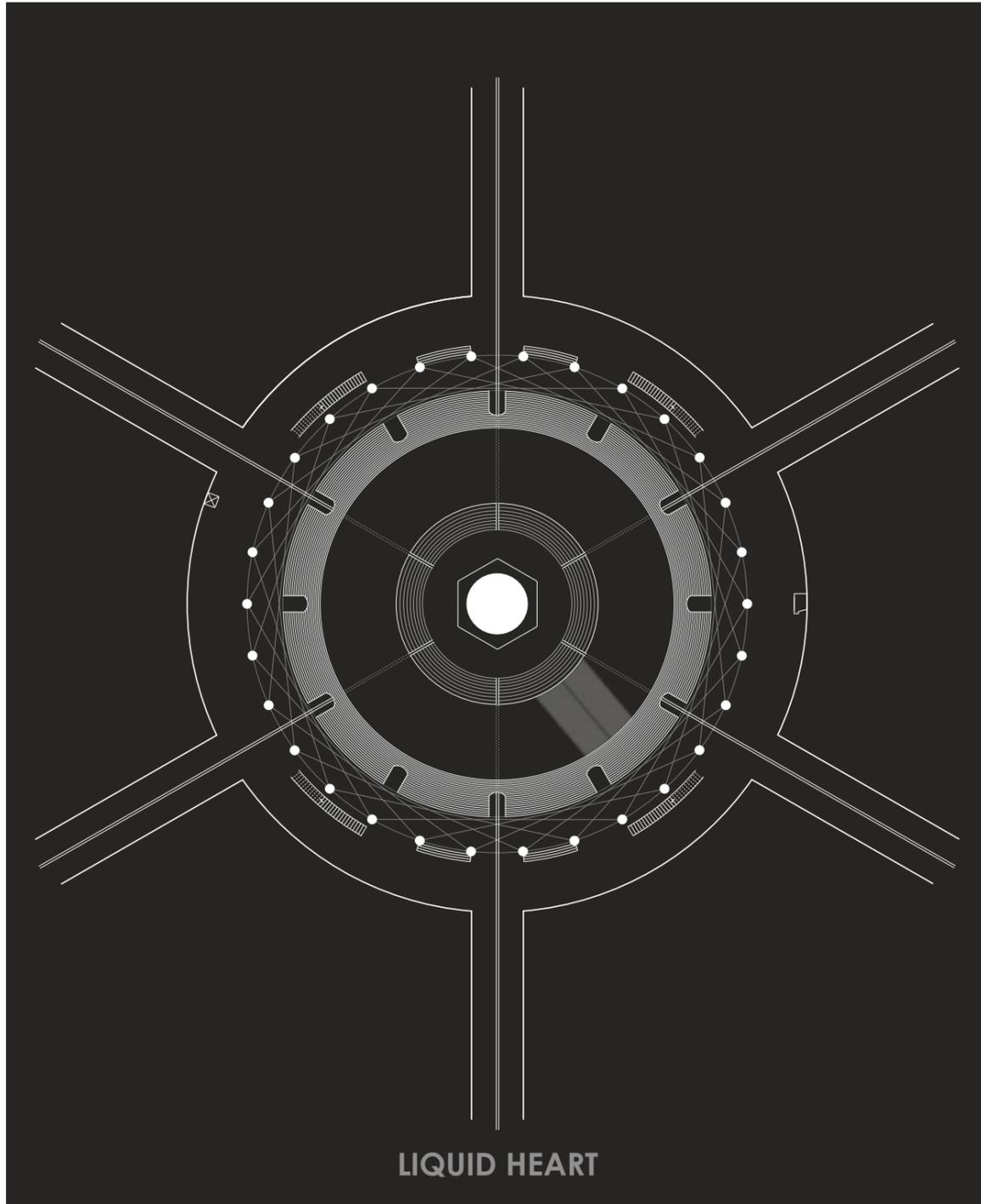
directly under the central plaza, a small platform holds two light maglev rails which connect the three cities. If expansion occurs along the crater's rim the rails will follow to continue the flow of resources and citizens.

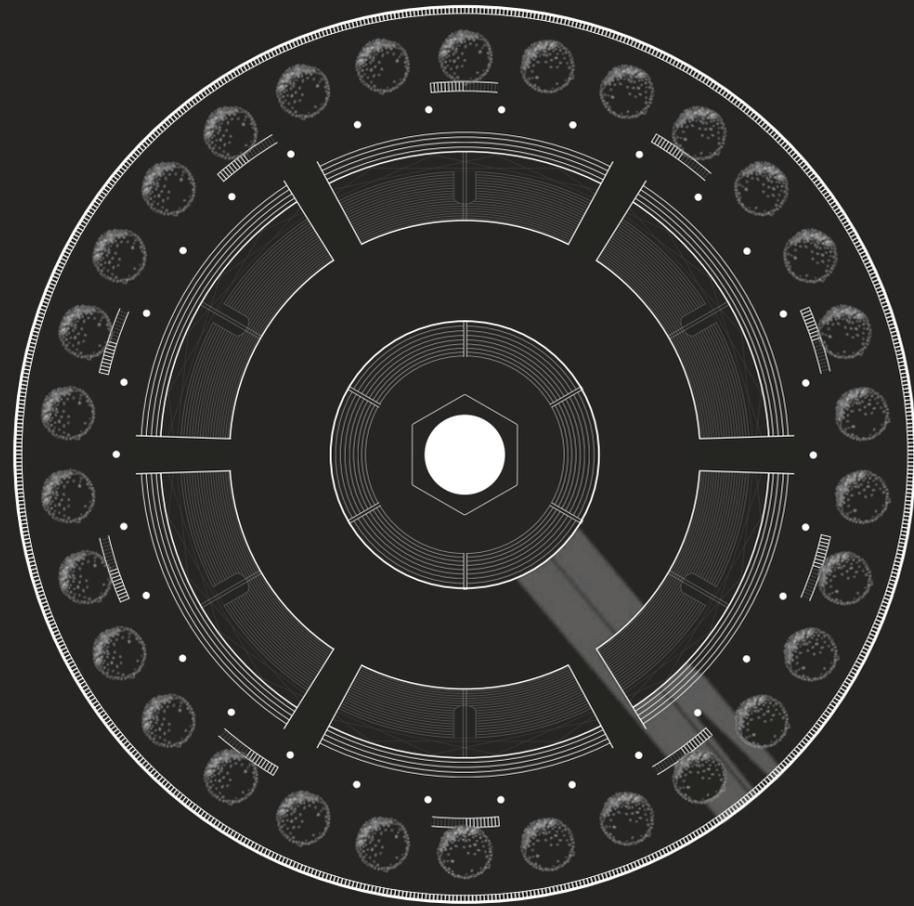
### REFLECTION CHAMBER

a subterranean secular temple constructed in the hollowed shell of the colony's initial crater well, now depleted. Imagery from the exterior cosmos is projected onto the still water. The basin plays an integral role in power production, acting as a reservoir for water that is to become heated into steam.





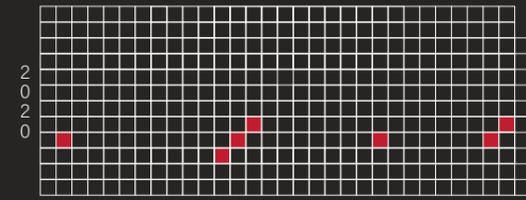
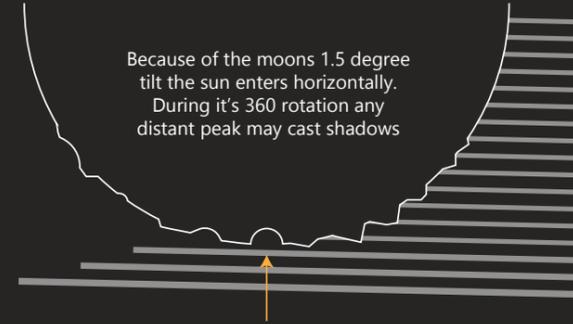




CELESTIAL OBSERVATORY

## THE DARK MONTH

Because of the moons 1.5 degree tilt the sun enters horizontally. During it's 360 rotation any distant peak may cast shadows



Throughout the year the sun will only set 7-10 times

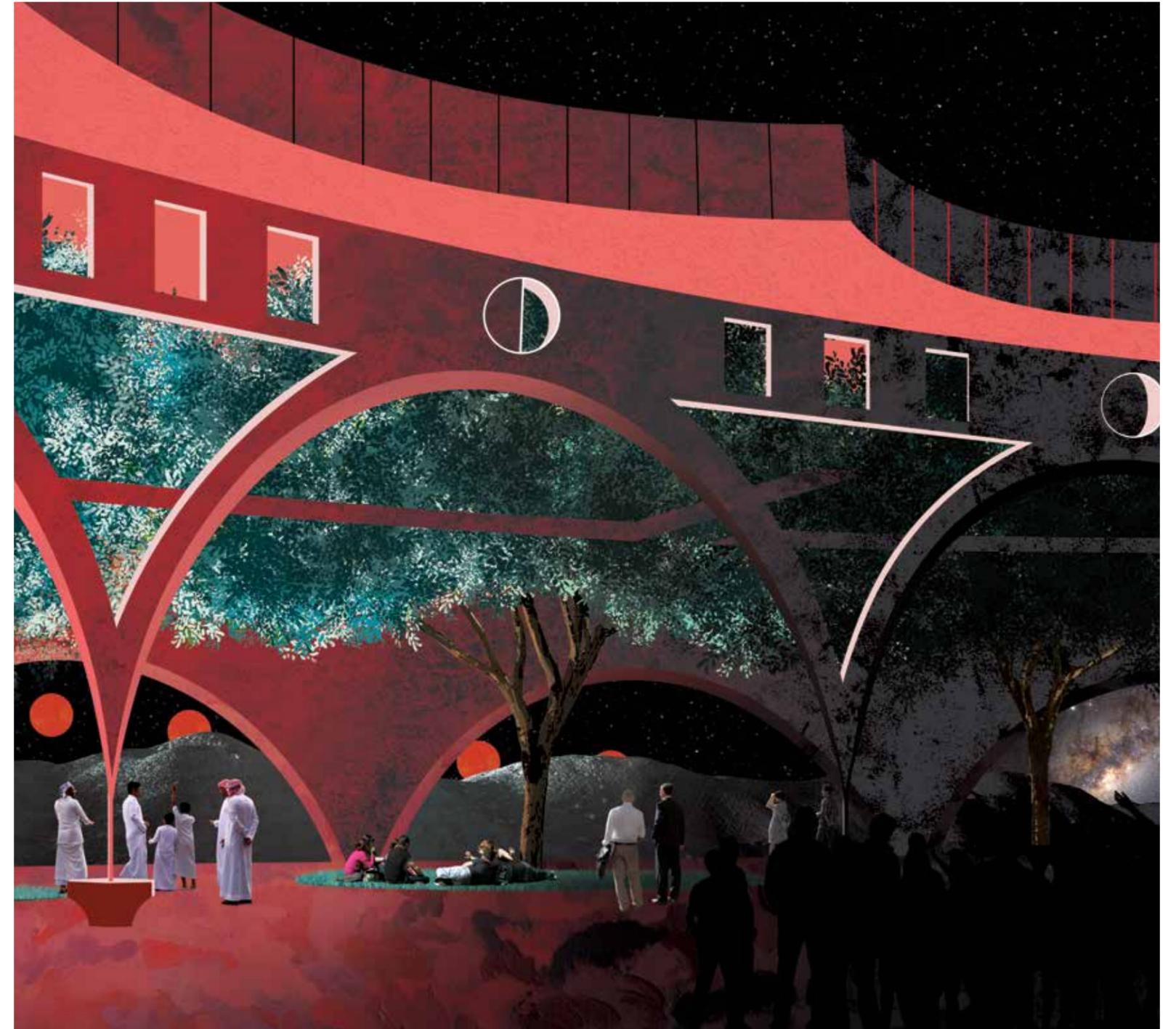
Each city, block, and level will have its own illumination microclimate.

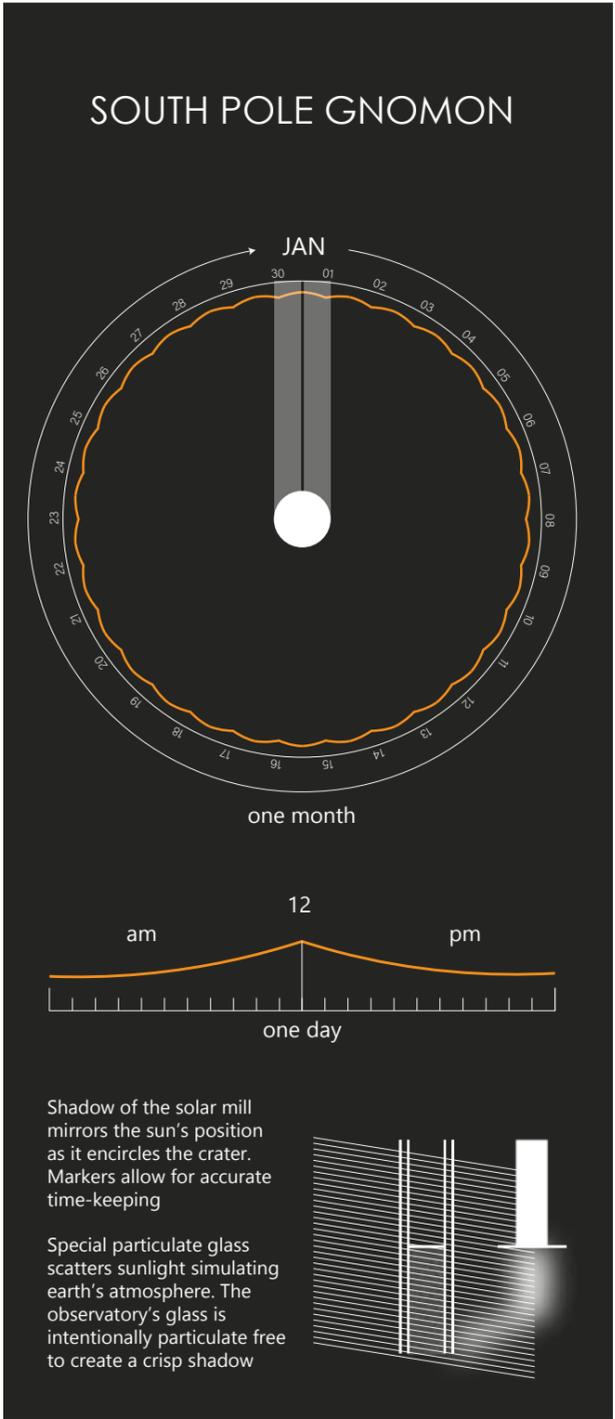
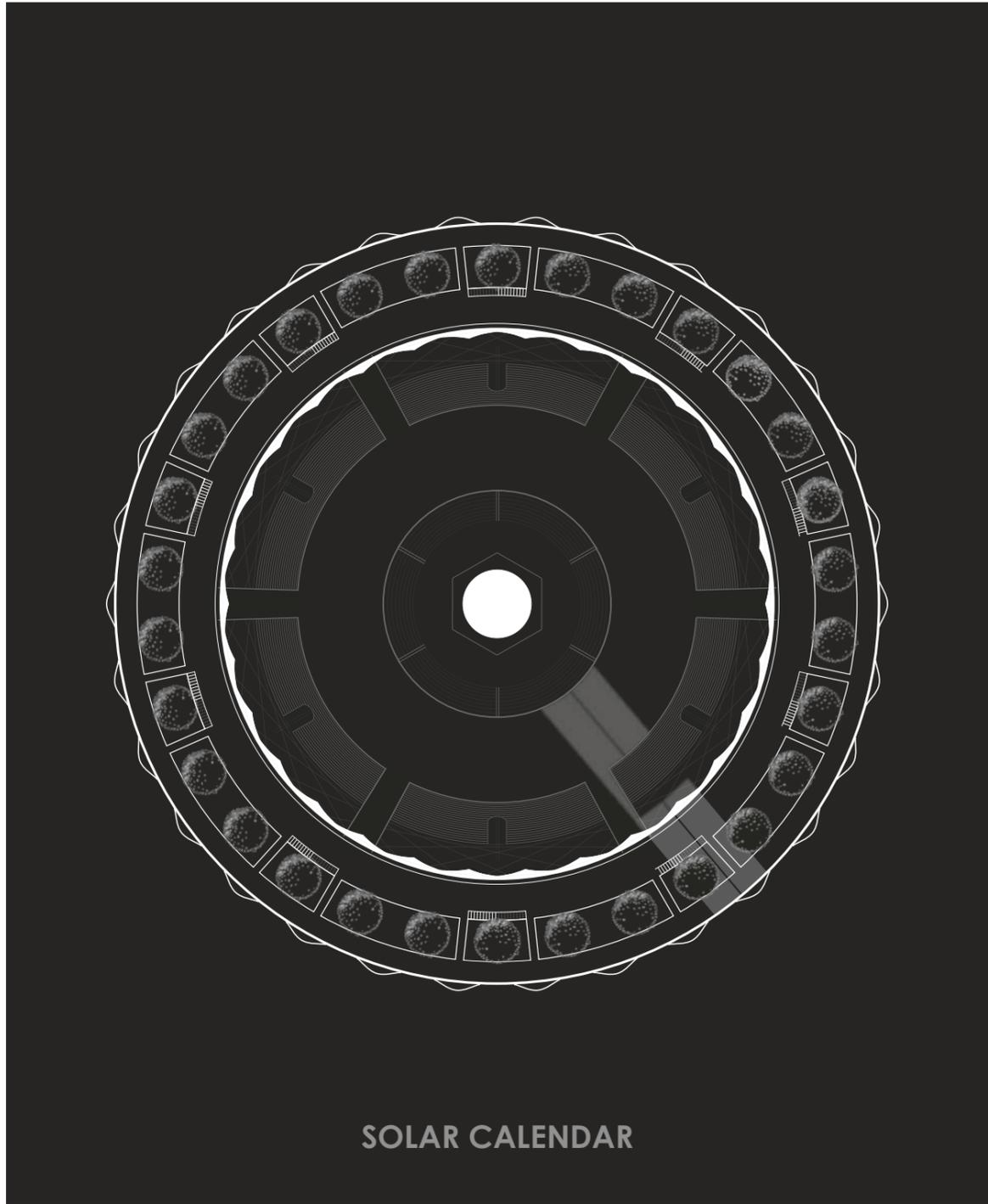
- 302 days  day
- 32 days  intermittent
- 31 days  night

The celestial observatory is a constant centerpiece among the flux.



Sun's path only varies 2 degrees above or below the horizon.





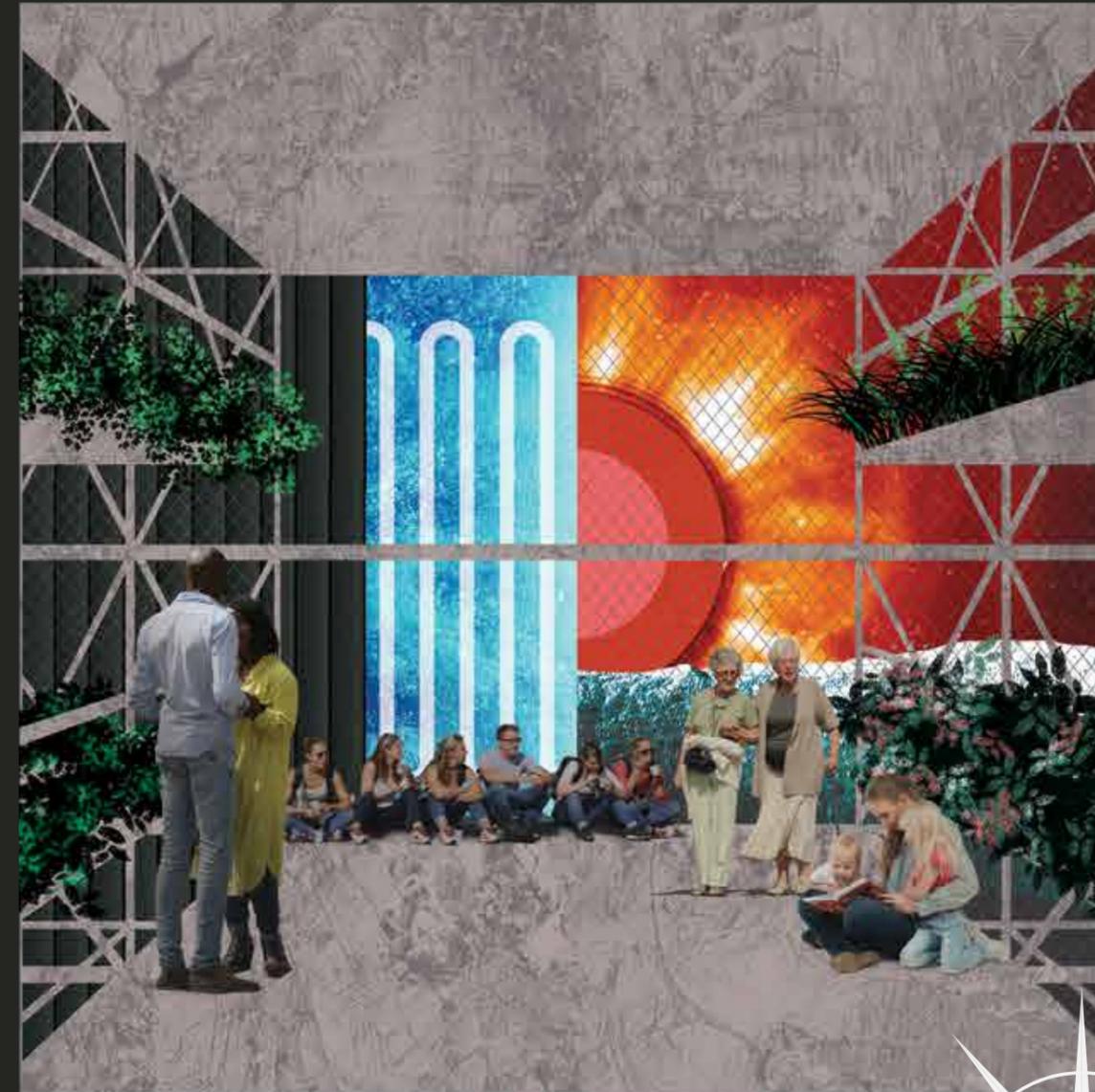
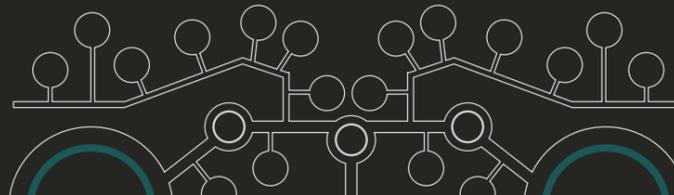


**BOUNTIFUL HARVEST**

Nearly 333 days of constant sunlight to cultivate crops



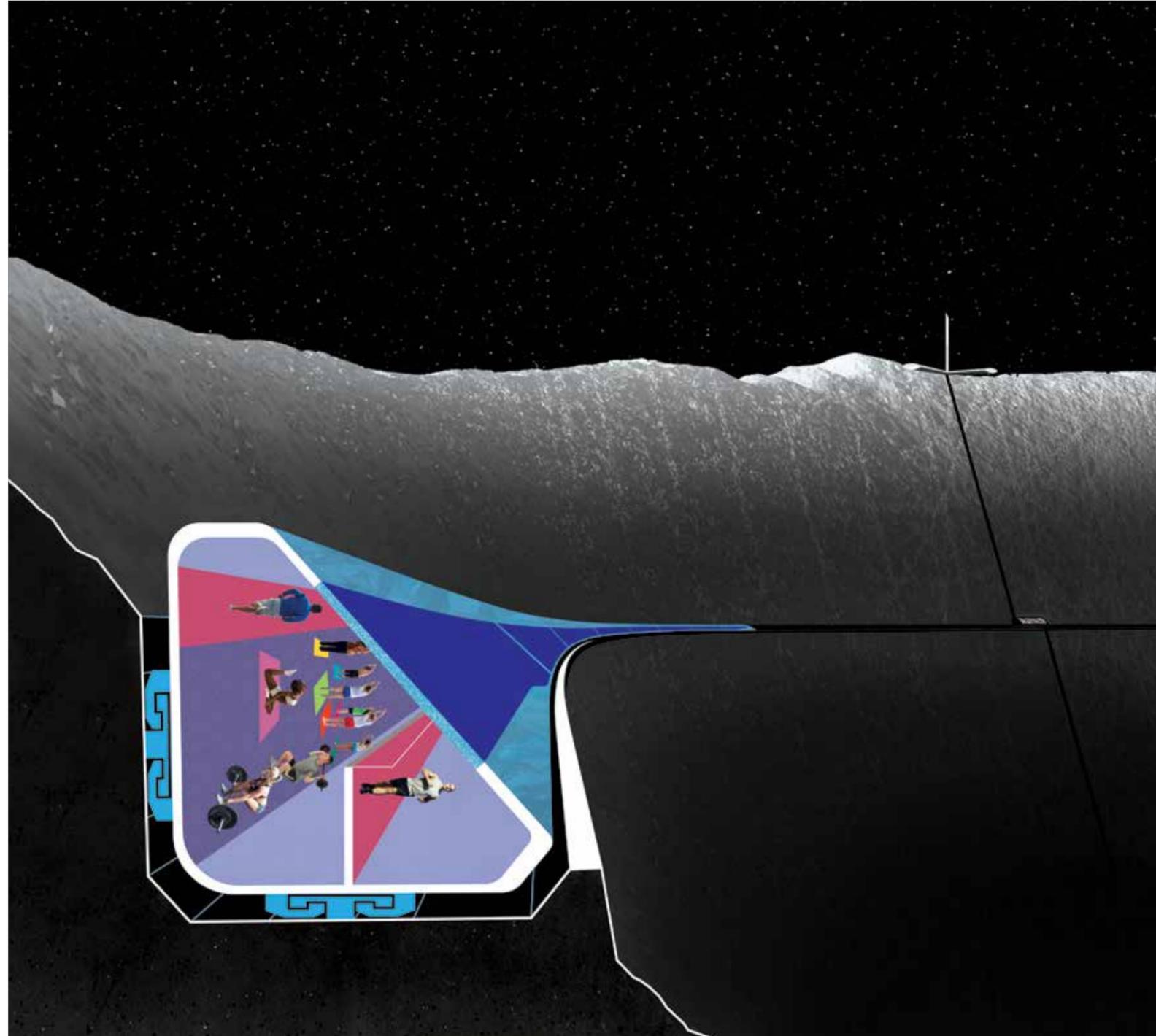
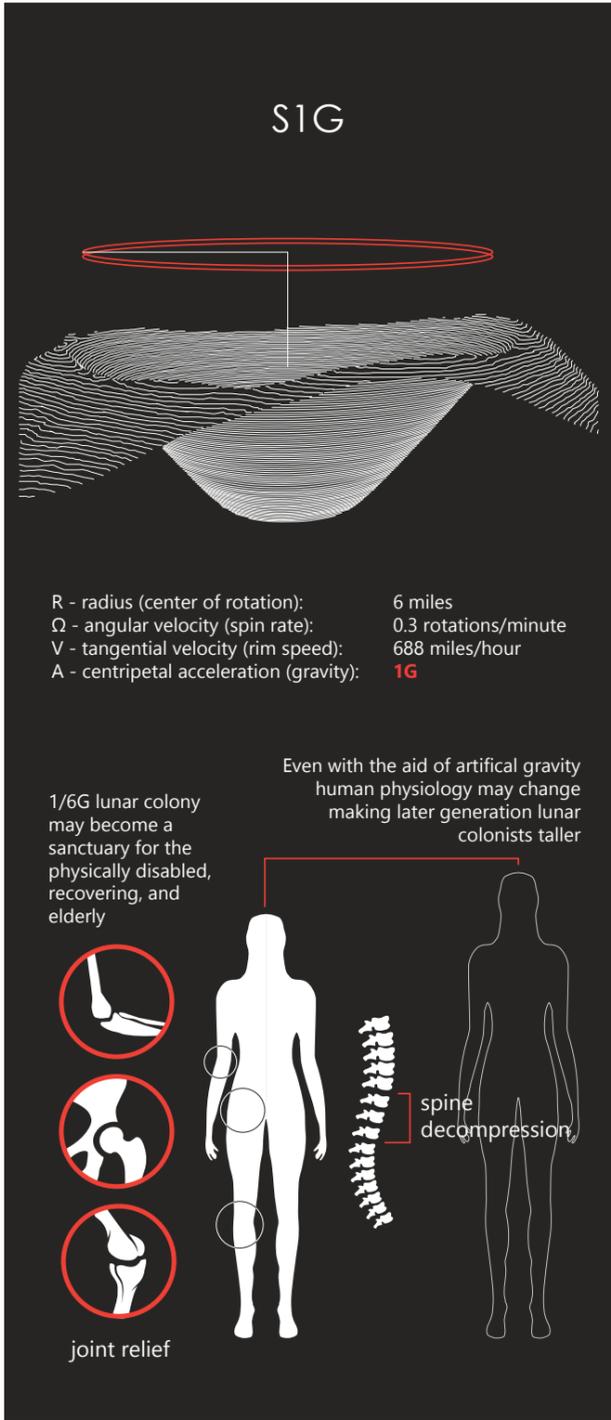
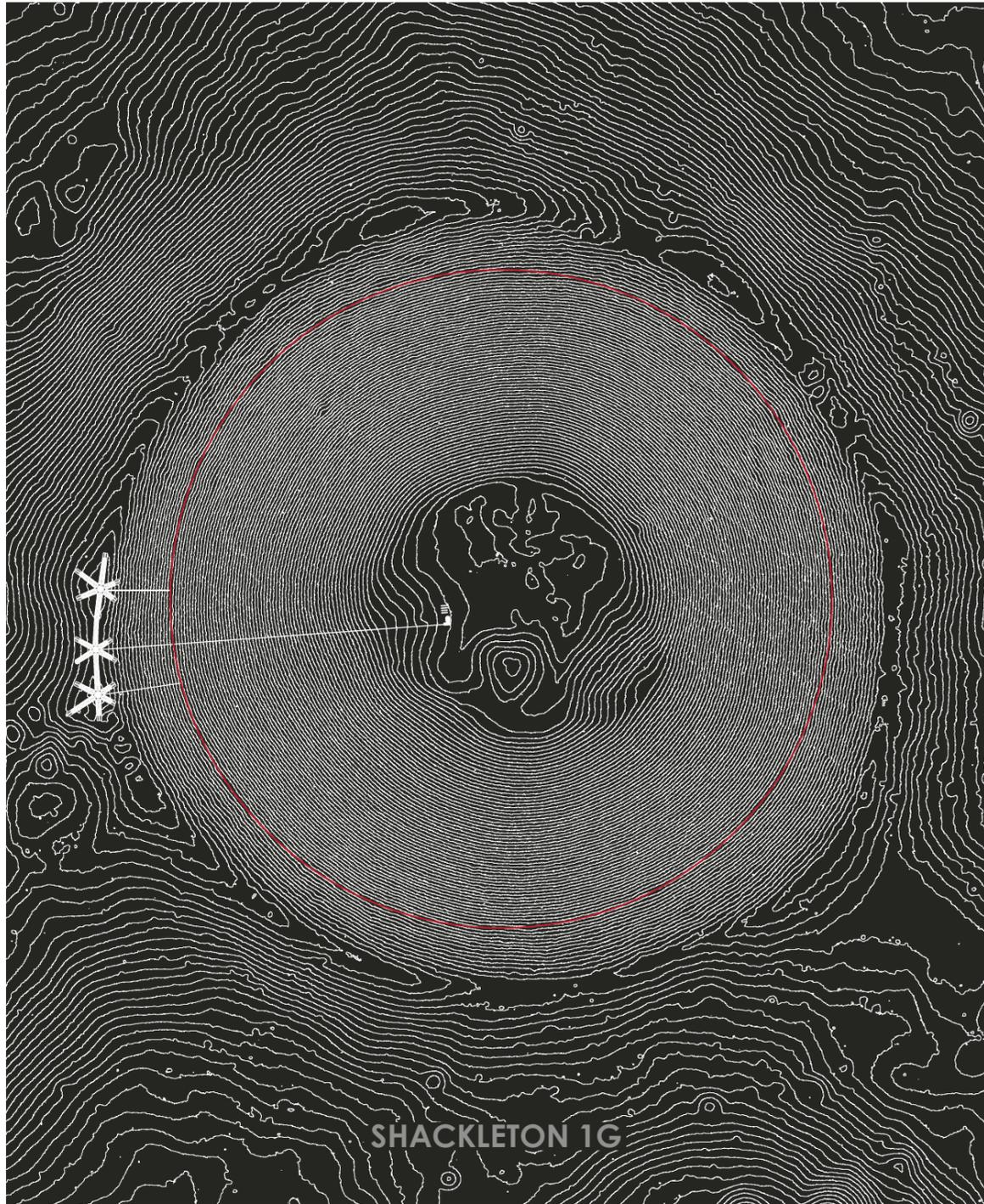
Private spaces connect communities to their local grow tower



Every 11 years our sun discharges deadly solar flares

Lead curtains filled with irrigation water absorb the deadly radiation providing shelter





## AN UNPRECEDENTED CITY - REUNIFICATION OF PEOPLE - A NEW IDENTITY

Any flag left on the moon has long since been bleached white by the sun. Overtime the divisions between the codependent multinational populous may too be dissolved by the lunar environment. The moon is no utopia, it is no guarantee, but it is however a blank slate full of hope and opportunity.

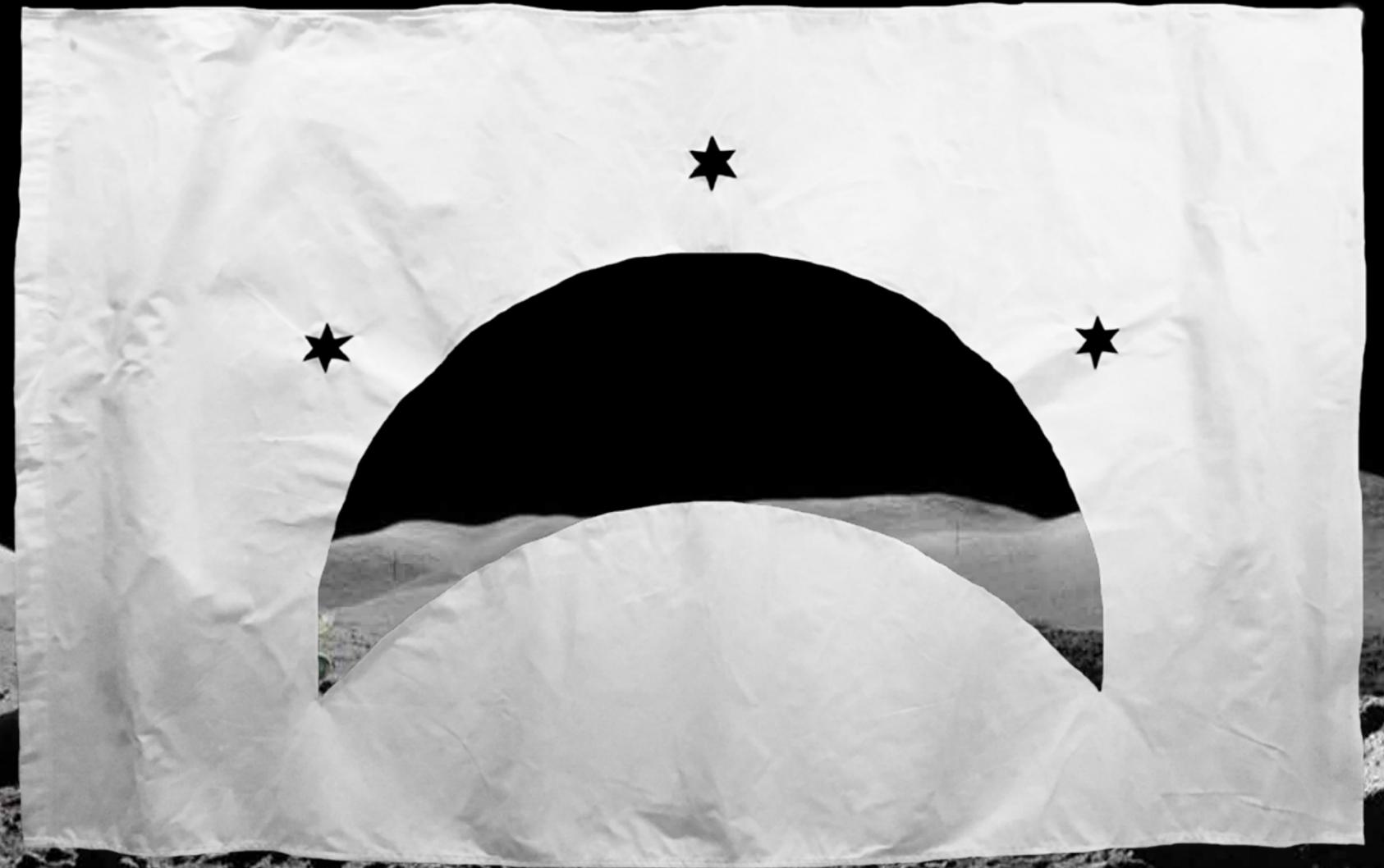
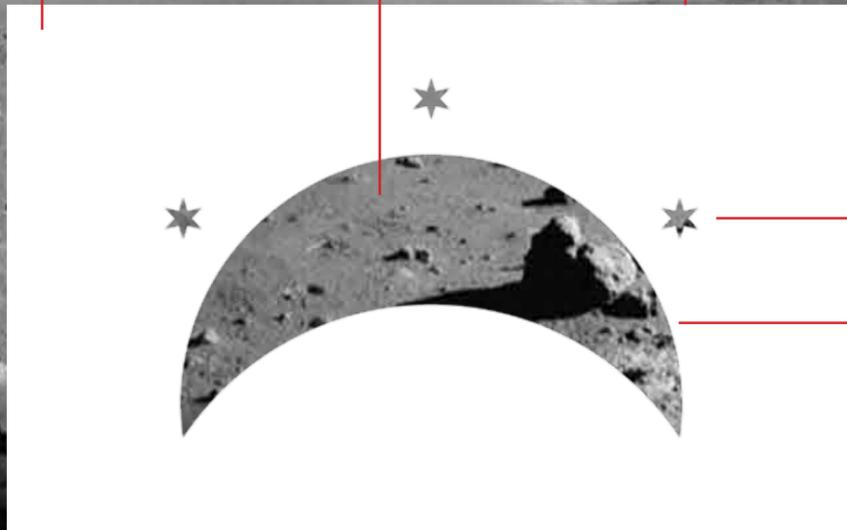
Colors will become bleached white by the solar radiation

Removing material from the flag, utilizing the natural landscape as part of the design

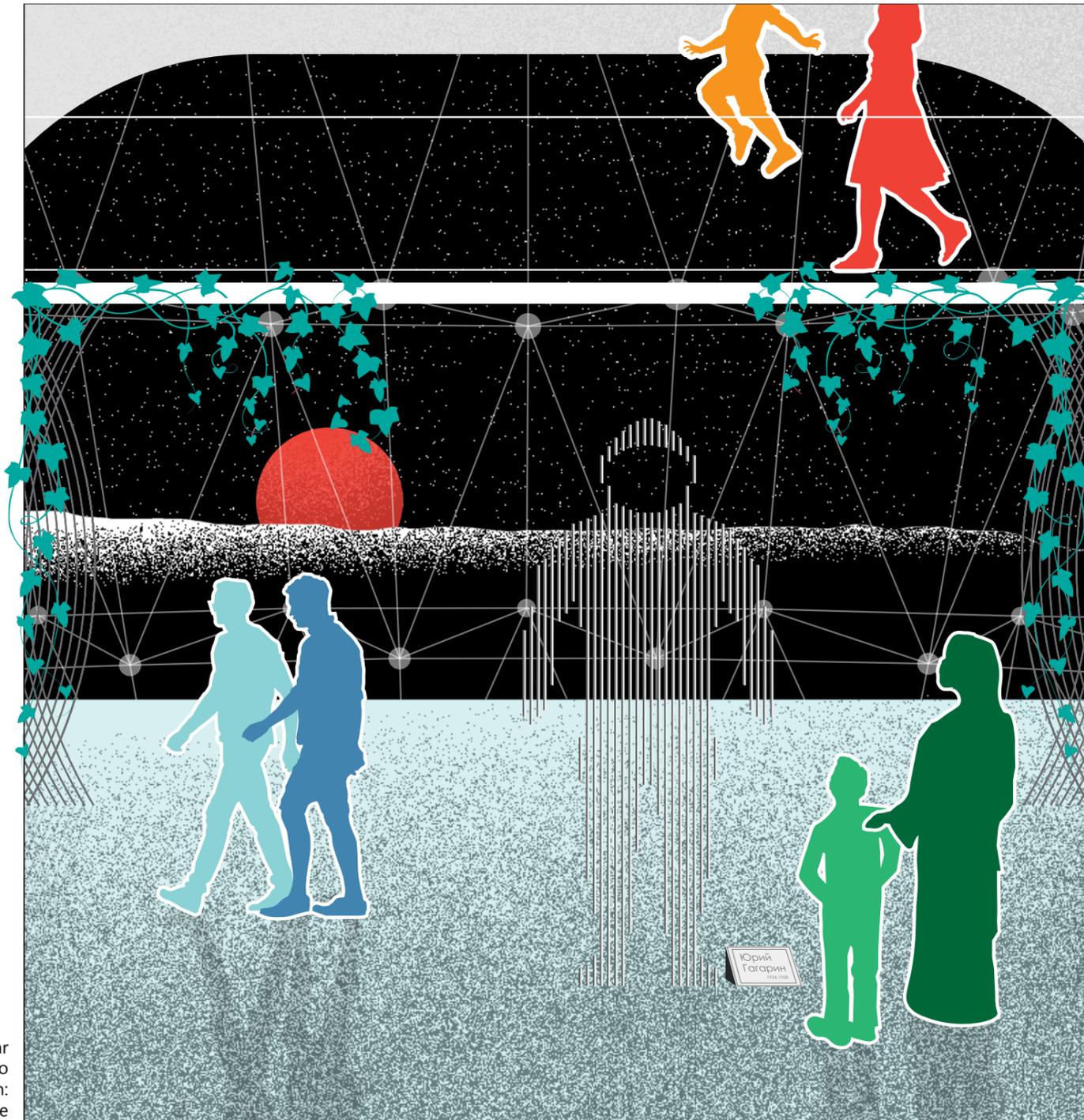
Mesh between layers of fabric allow the flag to hold shape

3 stars for each city proposed, and the three eternal peaks future expansion may reach. 6-pointed stars to symbolize the hexagonal form of the city

Not only resembling a waxing crescent moon, the design represents the glowing ridge of the colony atop of Shackleton Crater. It stands alone in daylight when elsewhere is shrouded in night.



Imagined lunar monument to Yuri Gagarin: first man in space



## CONCLUSION

From our origin as a species to our planet's distant and destined end, the moon will forever be a part of our identity. For centuries its pale glow has inspired us as we've dreamt what life upon it would be like; from myth, to literature, to film. Today we have the remarkable opportunity to witness dream become reality as we push the boundaries of foregone impossibilities. Incredible technologies allow us to go beyond questions of how to make life on the moon simply survivable, to how it can become pleasant and meaningful. Urban design allows us to find beauty in the bizarre and fascinating landscape as well as discover new ways to incorporate ordinary urban functions into daily interactive experiences. Fundamental connections to our environment can be brought to life through imaginative design.

Throughout this thesis I have been constantly reminded of the project's relevance and importance as both governments of the world and private corporations make regular news in attempt to move humanity out of the cradle of Earth. The future, as it often does, comes swiftly and does not wait for the unprepared.

For as long as people find new places to call home, architects and urban designers will be needed to provide structure and meaning, even when that home is no longer on Earth.

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Lunar Flag designed by self

