M O O N S T A T I O N

GROUP 3

Analysis_ Rhizome 1.0 Human-Robot-Interaction

Human-Robot Interaction (HRI) part is described as having three main aspects:

1. Designing a controller for physical HRI during a pick-and-place task
2. Designing a trajectory learning and optimization based on human preferences
3. Conducting a feasibility study for attaining robot mobility

1. Four identified sub tasks:
- Pick-up
- Carrying
- Alignment
- Stand-by

Five designed modes

- Locked
- Free
- Main
- Orientation
- Lift & lower

2. Four main preferences that are fundamental to the construction task

- Carrying velocity
- Height from the ground during the carrying
- Minimum distance to obstacles during the carrying
- Side on which the obstacle is passed.

3. Best options for mobile platforms?

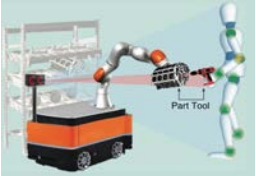
- Collaborative robotic arm
- Legged mobile platforms
- Wheeled mobile platforms
- Custom-designed mobile platform for a rough environment

Battery vs cable:

- Advantages and disadvantages


1


2



3

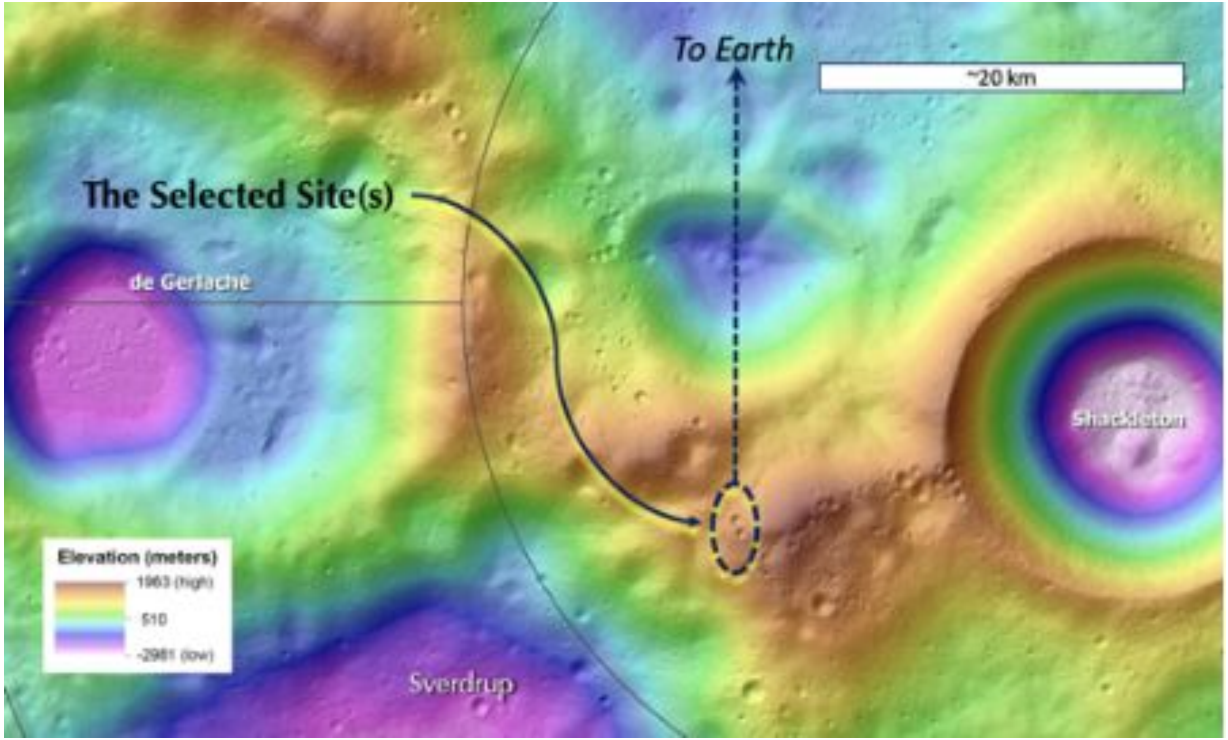
Site Selection

Site 2:

The Lunar south polar ridge on the left of Shackleton Crater

Station Site:

Along the Earth-facing slope of the Lunar south polar ridge, along the upper edge of an approximately 800m diameter crater there, facing downslope and toward Earth (which should be occasionally low on the south polar horizon).

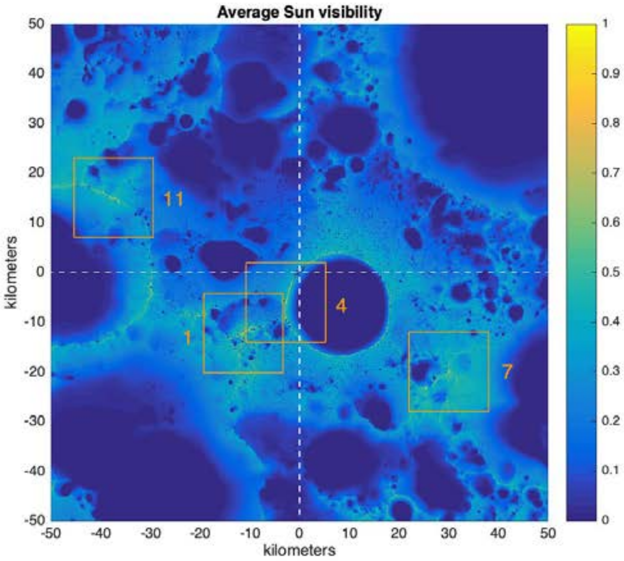


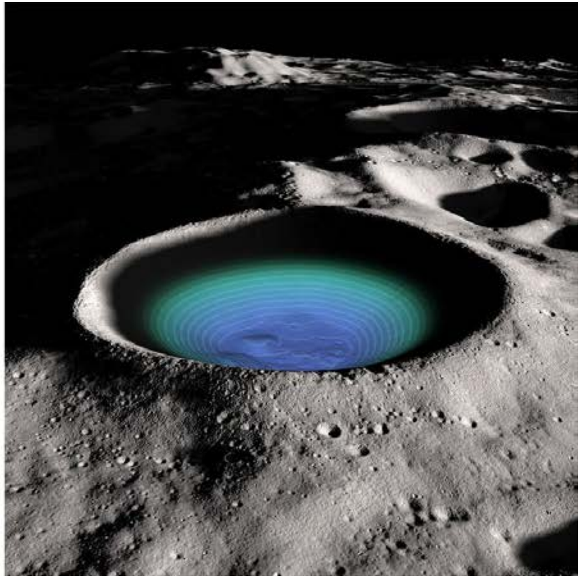
Site Selection_Considerations + Opportunities

+ The ridge along the crater's rim is exposed to almost continual sunlight

+ The interior of the crater is perpetually in shadow that may indicate the presence of water ice.

+ The variance in sunlight and resource quality allows for spaces of different functions



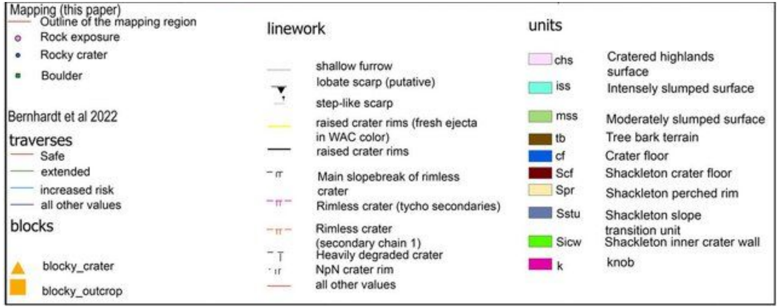


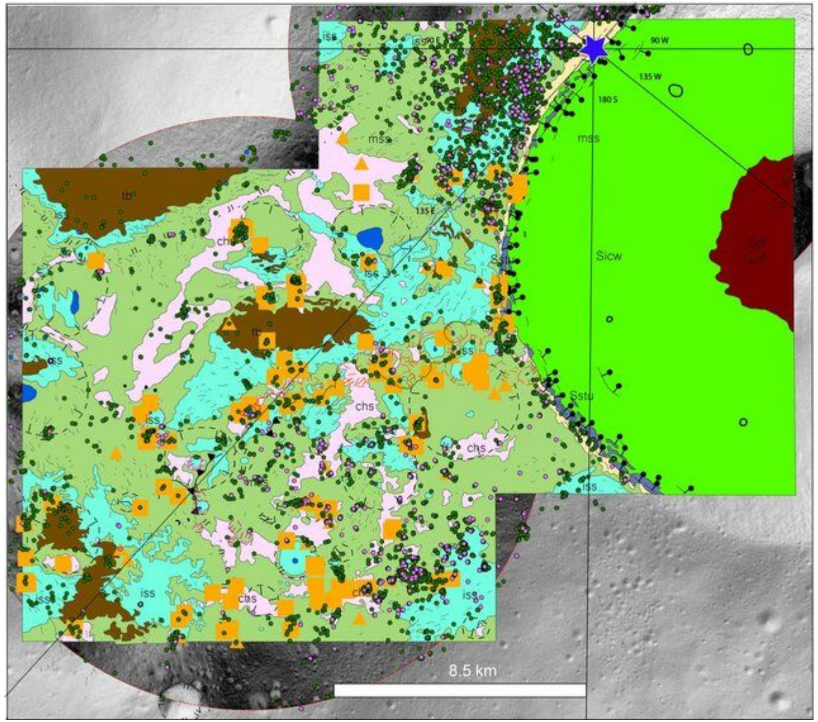
Barker, M.K., E. Mazarico, G.A. Neumann, D.E. Smith, M.T. Zuber, and J.W. Head, 2021: Improved LOLA Elevation Maps for South Pole Landing Sites: Error Estimates and Their Impact on Illumination Conditions. Planetary and Space Science, 203, 105119, doi:10.1016/j.pss.2020.105119.

Site Selection_Features

Features mapped (isolated boulders, rock exposures, rocky craters) overlaid on geomorphological map.

Distribution of features in relation to the geomorphic units can be seen, including around the "Connecting Ridge" the moderately slumped unit aligns with the mapped features.





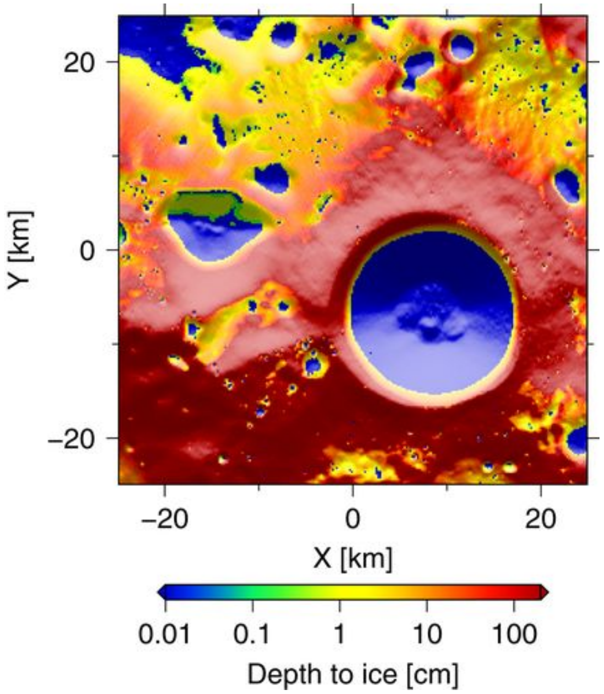
Sarah. J. Boazman et al., "The Distribution and Accessibility of Geologic Targets near the Lunar South Pole and Candidate Artemis Landing Sites," The Planetary Science Journal 3, no. 12 (December 1, 2022): 275, https://doi.org/10.3847/PSJ/aca590.

Site Selection_Features

Depth of ice in the area mapped

Provides insight into possible water collection and system to be implemented, as well as water that can be used for in-situ material use

Also gives insight on ground composition for foundations and excavation

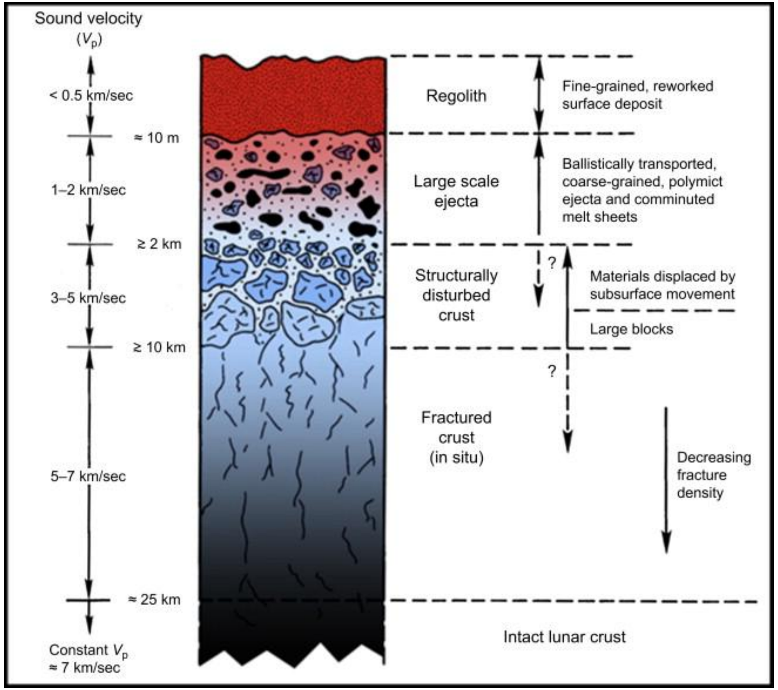


Sarah. J. Boazman et al., “The Distribution and Accessibility of Geologic Targets near the Lunar South Pole and Candidate Artemis Landing Sites,” The Planetary Science Journal 3, no. 12 (December 1, 2022): 275, https://doi.org/10.3847/PSJ/aca590.

Site Selection_Features

Assumed ground composition of the site area.

Shows depth of excavation possible,
And potential material collection for in situ construction



Sarah. J. Boazman et al., “The Distribution and Accessibility of Geologic Targets near the Lunar South Pole and Candidate Artemis Landing Sites,” The Planetary Science Journal 3, no. 12 (December 1, 2022): 275, https://doi.org/10.3847/PSJ/aca590.

Theme 1. Lunar Architecture_Analysis

CONSIDERATIONS

- low gravity (1.6m/s2)
- Extreme thermal cycle (-173°C to +117°C)
- 29 days for one lunar day
- Limitation to access to liquid water
- Lack of atmosphere
- Higher seismic activity than for Earth
- Micrometeoroids
- High level of galactic cosmic radiation (GCR) and infrequent but very intense solar particle events (SPEs)
- On the poles: better temperatures (-50°C to 0°C)
- No weather = no wind = no wind turbines

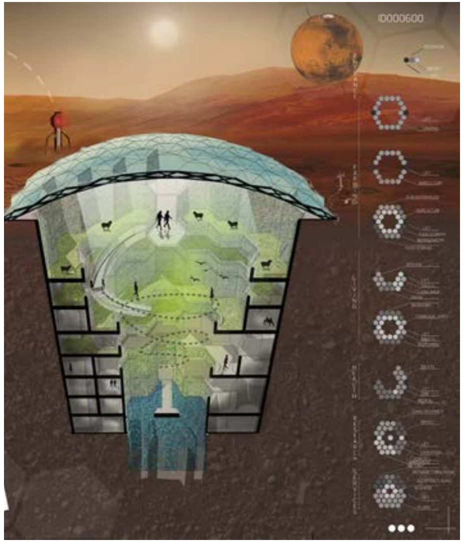
NEEDS

- Eating/sleeping areas for 3-6 people
- Grow food
- Research and experiments
- Communication with earth
- Computer rooms
- Workout room
- No stairs needed outside, gravity

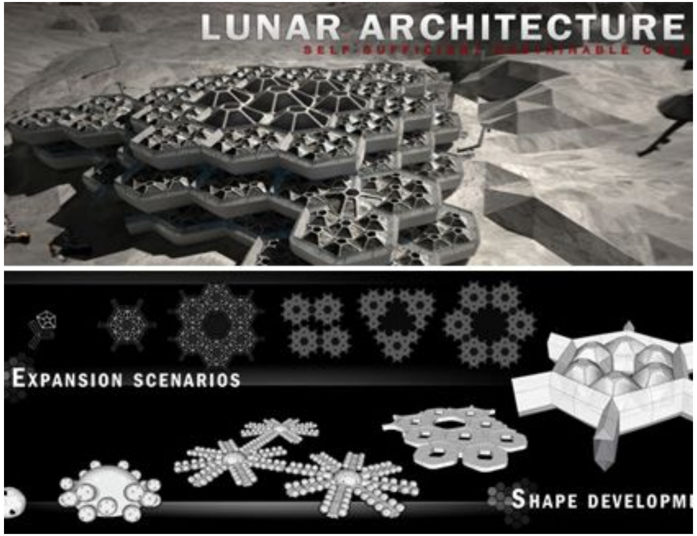
MATERIALS

- In-situ resources (lunar soil) for 3D-printing
- Modular systems
- Interlocking parts of 3D-print (flexibility)
- Smaller/ lighter and maybe inflatable
- Airtight at all times
- Airblocks as doors
- Protection from the radiation
- Protection from meteoroids
- Polyethylene for protection= 10-20 cm shielding is enough for protection

Theme 1. Lunar Architecture_Space Precedents



central atrium for light distribution



node system for possible expansion

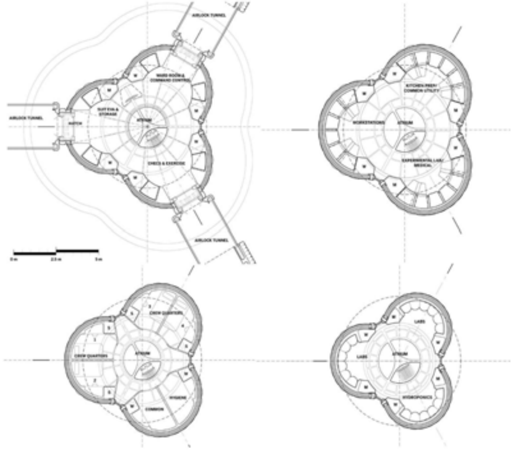
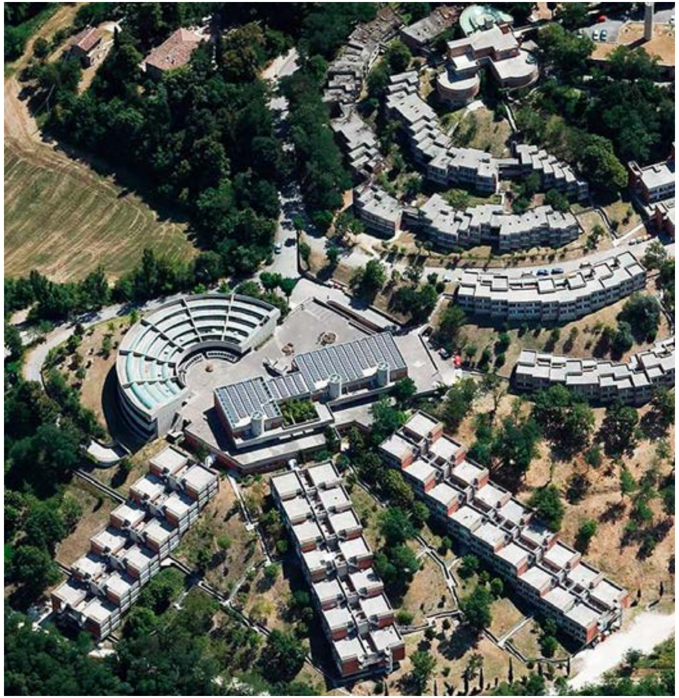


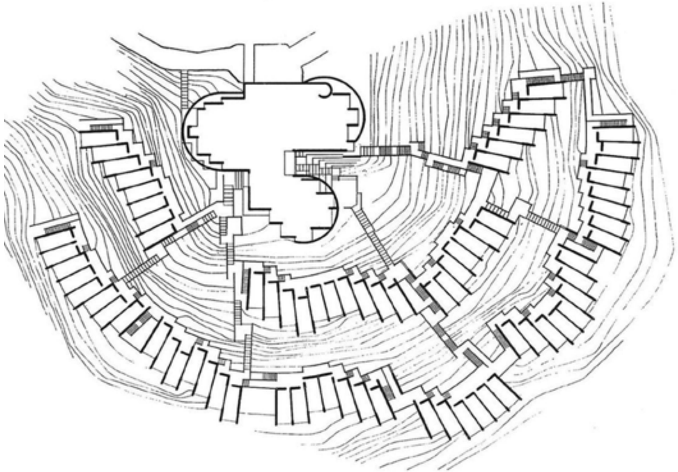
Figure 11. Vertical habitat plans.

stacked structures

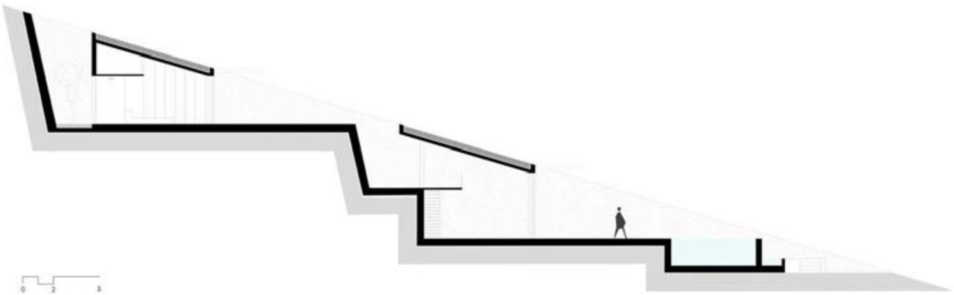
Theme 1. Lunar Architecture_Concept Design



University of Urbino, Italy. Residences.



Theme 1. Lunar Architecture_On Earth Precedents



NCave House. Agios Sostis, Greece

Theme 2. Lunar Energy & Health and Life support

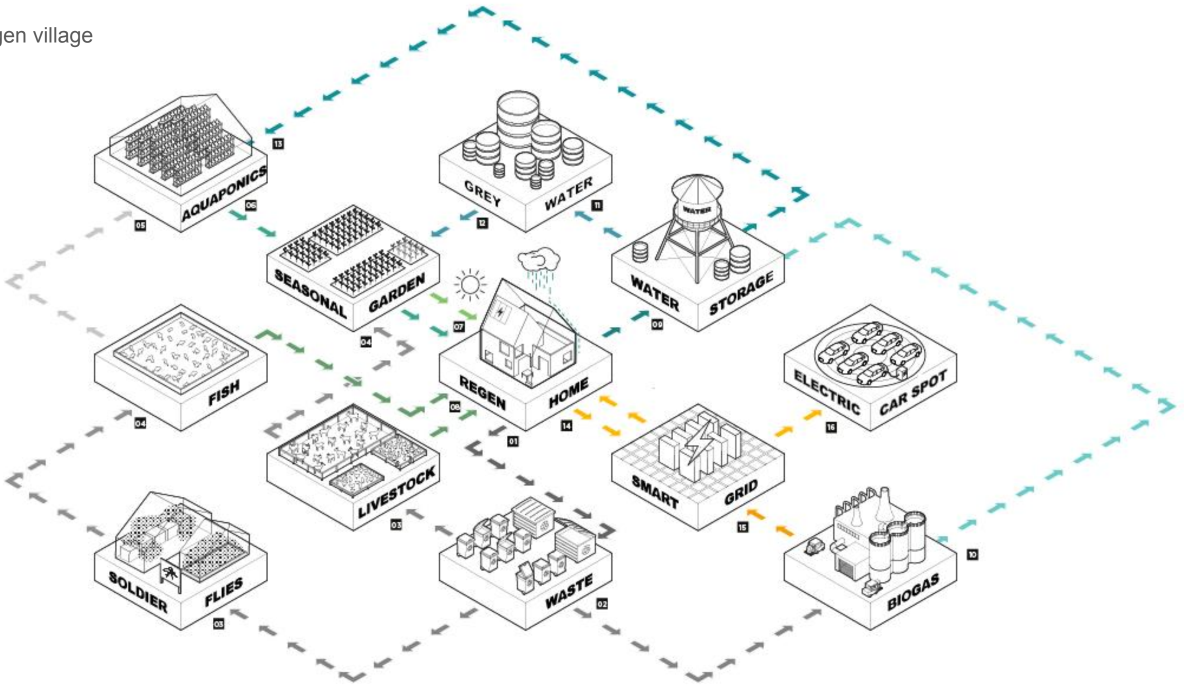
Self-sufficient case Study

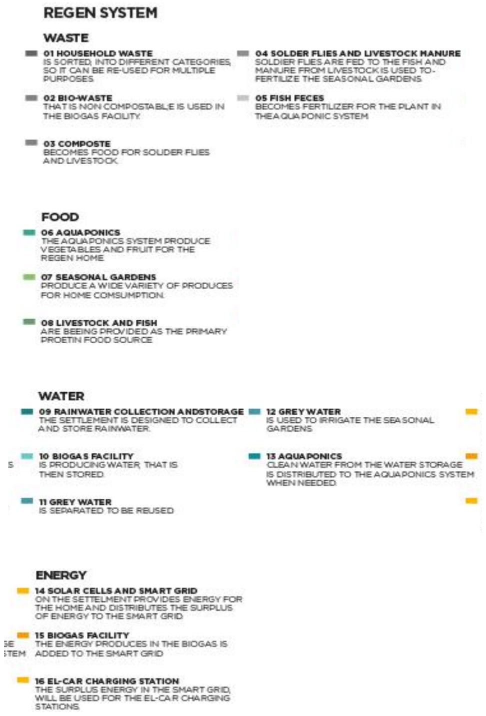
a) Energy system
b) Water recycle system
c) **Air revitalization**
d) Food production

Theme 2. Lunar Energy & Health and Life support

Self-sufficient system

Regen village

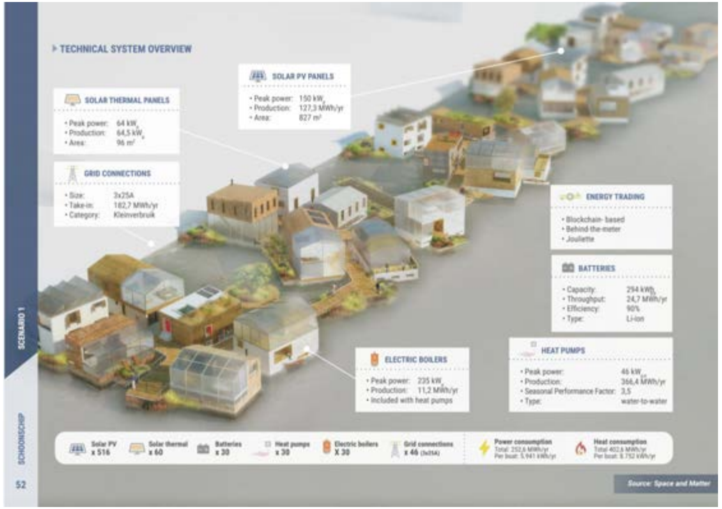


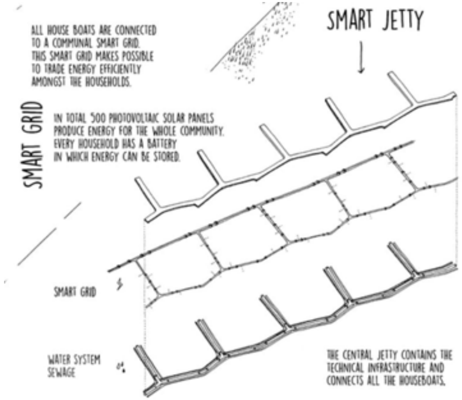


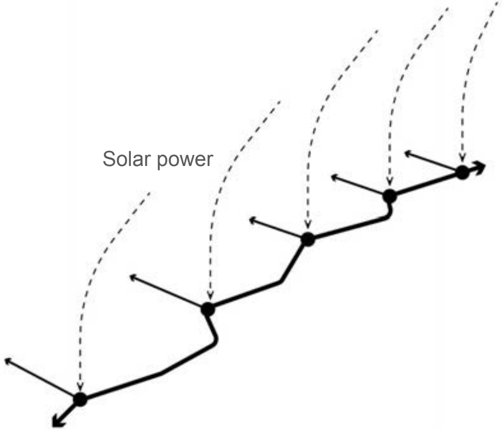
Theme 2. Lunar Energy & Health and Life support

Self-sufficient system- smart grid system

Schoonship self-sufficient village







Smart grid

Energy transmission + Water sewage system

Power station (pv solar panel)

Smart grid system

Theme 2. Lunar Energy & Health and Life support

a) Energy system

Solar power plant

CubeRovers

(power transmission for grid within **100m**)

Wireless charging robot

Methane and Oxygen from Lunar Soil and Water

CH_4

[(https://weather.com/en-IN/india/space/news/2022-11-04-scientists-have-created-methane-and-oxygen-from-moon-soil)](https://weather.com/en-IN/india/space/news/2022-11-04-scientists-have-created-methane-and-oxygen-from-moon-soil)

Energy generation → Energy transmission → Energy storage → Energy recycle

Energy Station

Wireless charging Path for robots

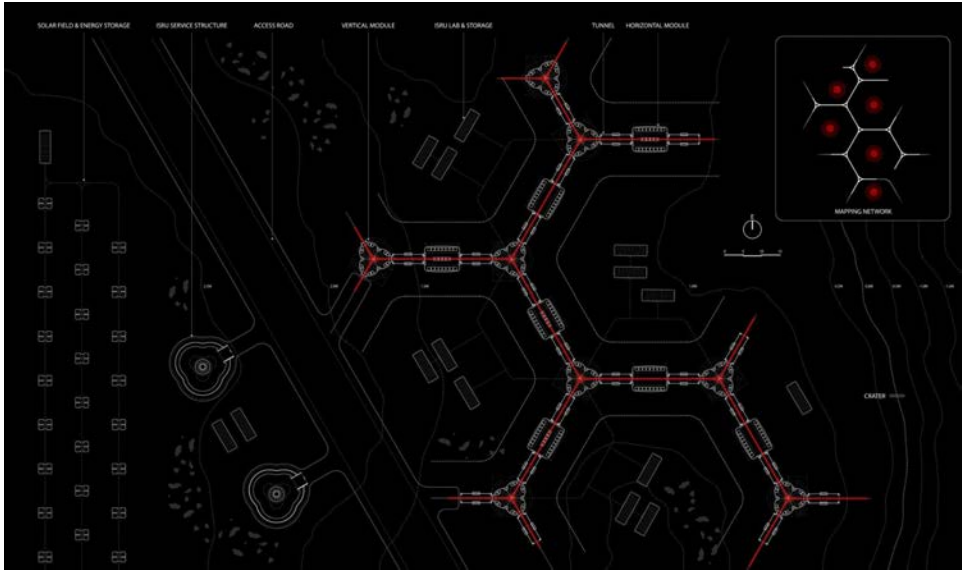
Livestock & sanitary facilities

Biogas station

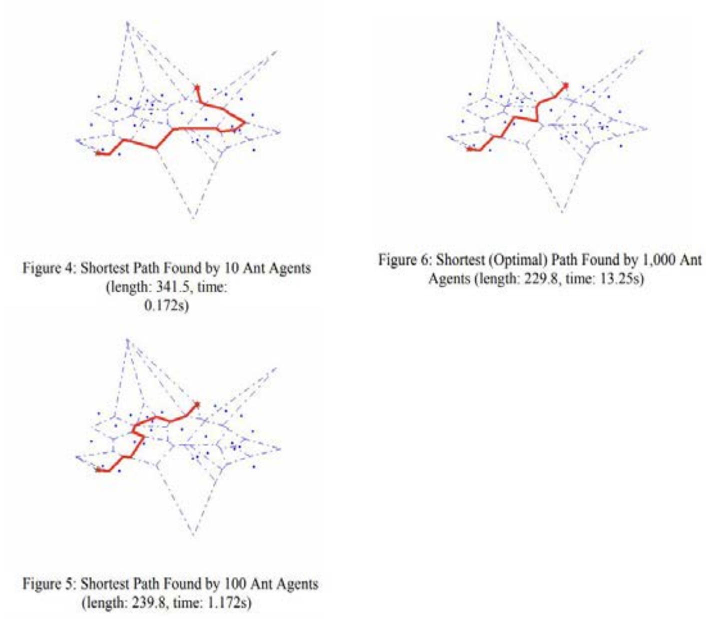
Human & Livestock waste

Theme 2. Lunar Energy & Health and Life support

a) Energy system



Linear Growth of Moon village



Shortest path finding in Voronoi shape via Galapagos

Theme 2. Lunar Energy & Health and Life support

b) Water loop system

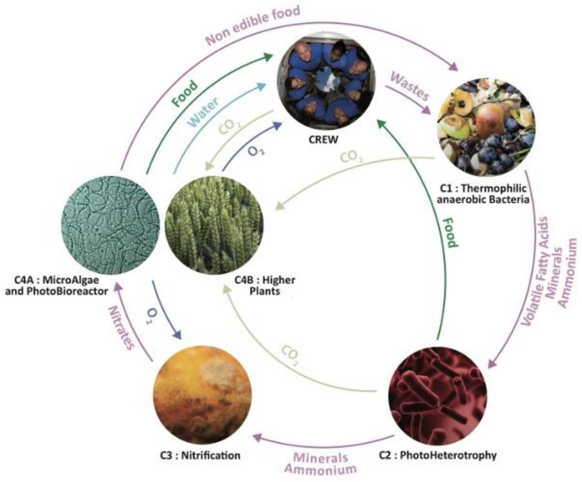
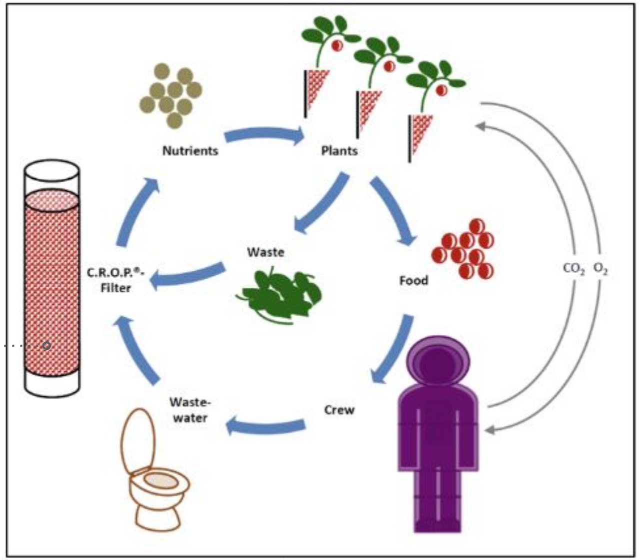


Figure 7. A schematic representation of the MELiSSA loop (courtesy of the MELiSSA Foundation)

Microorganisms in lava stone as bio filter

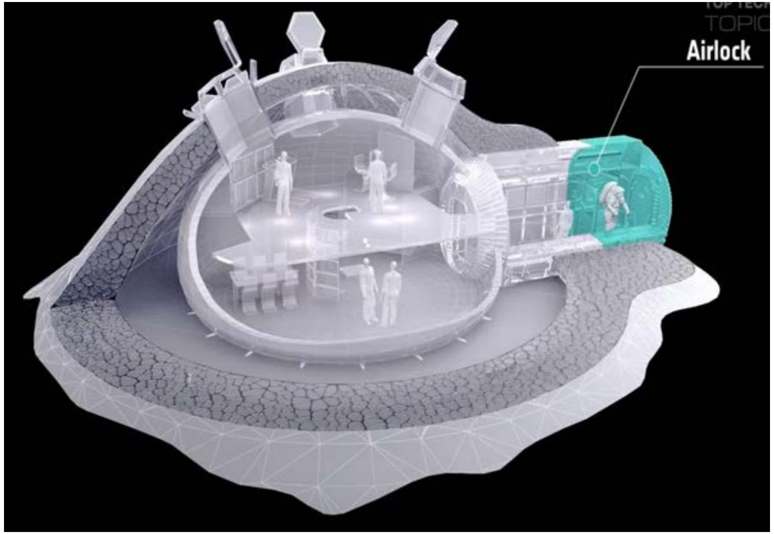


- Water: 3 kg/day/crewmember
- Treatment 1. membrane based filtration
- Treatment 2. Photosynthetic reactor
  - chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.som.com/wp-content/uploads/2021/07/20191213_som_research_iac_paper.pdf

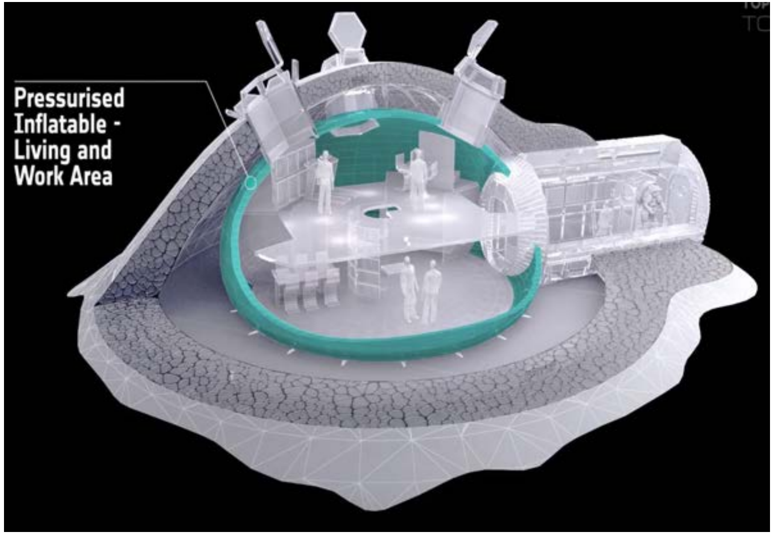
- membrane based filtration
  - https://blogs.esa.int/exploration/spaceship-eac-recycling-water-on-the-moon/

Theme 2. Lunar Energy & Health and Life support

c) Air revitalization



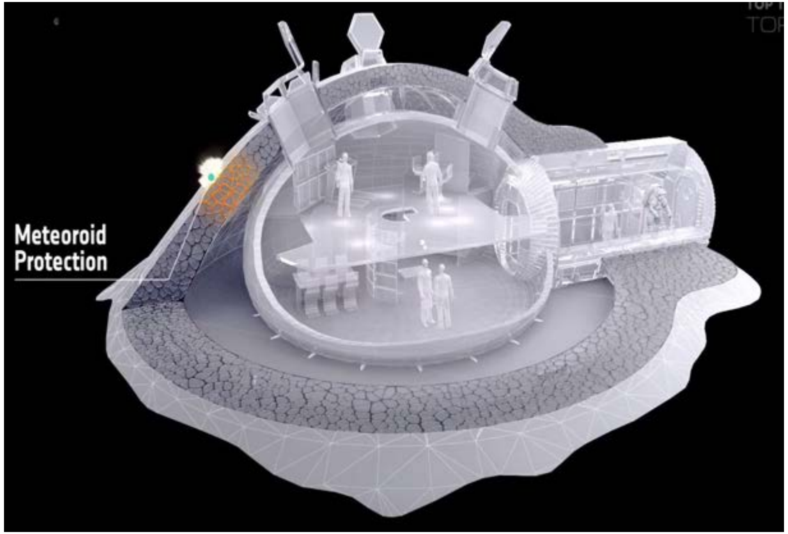
Original capsule function as airlock and technical support modular

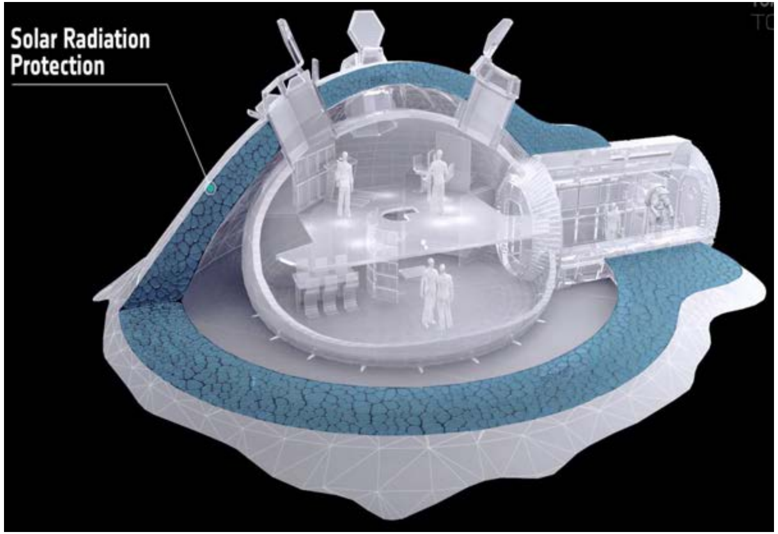


Foldable membrane as boundary for pressurised enclosure

Theme 2. Lunar Energy & Health and Life support

c) Air revitalization

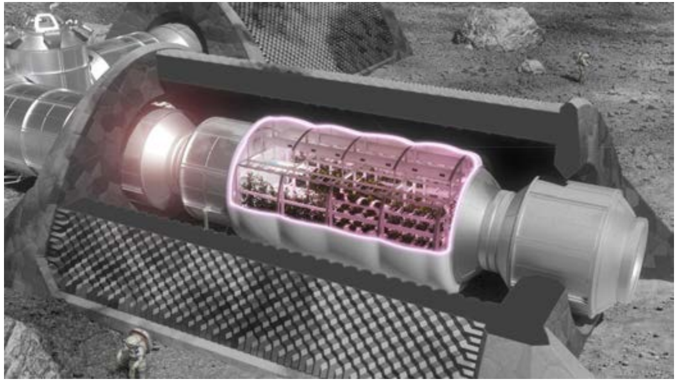




3d printing dome as protection for solar radiation and meteoroid protecture

Theme 2. Lunar Energy & Health and Life support

d) Food Production



- 30 sqm greenhouse needed for six-member crew
- Use artificial light
- Embedded with [biofilter system (C.R.O.P.)]

https://www.dlr.de/en/latest/news/2019/03/20190823_project-eden-iss-presents-results

Theme 2. Lunar Energy & Health and Life support

d) Food Production

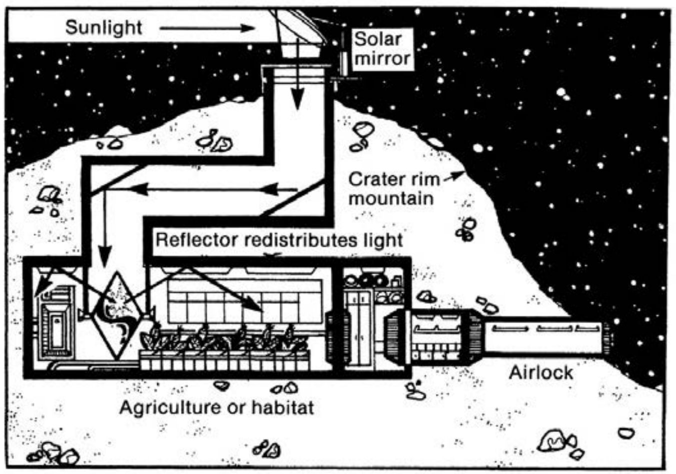


Fig. 1. Sketch of the design for a lunar polar habitat as suggested by Burke (1985).

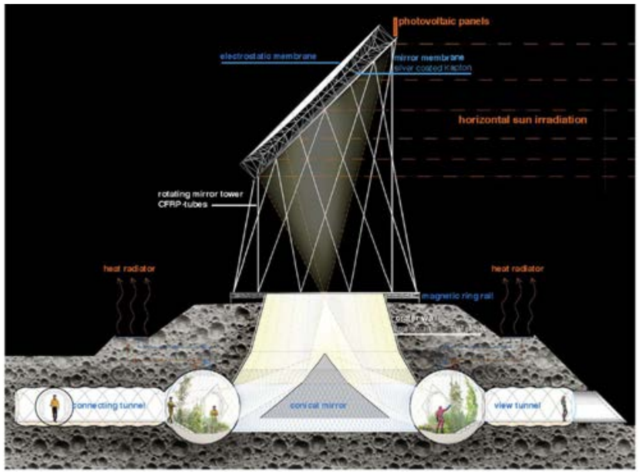


Fig. 6. Crossection of a greenhouse unit including tunnels, solar towers and mirrors.

Strategy to reflect natural light into the greenhouse

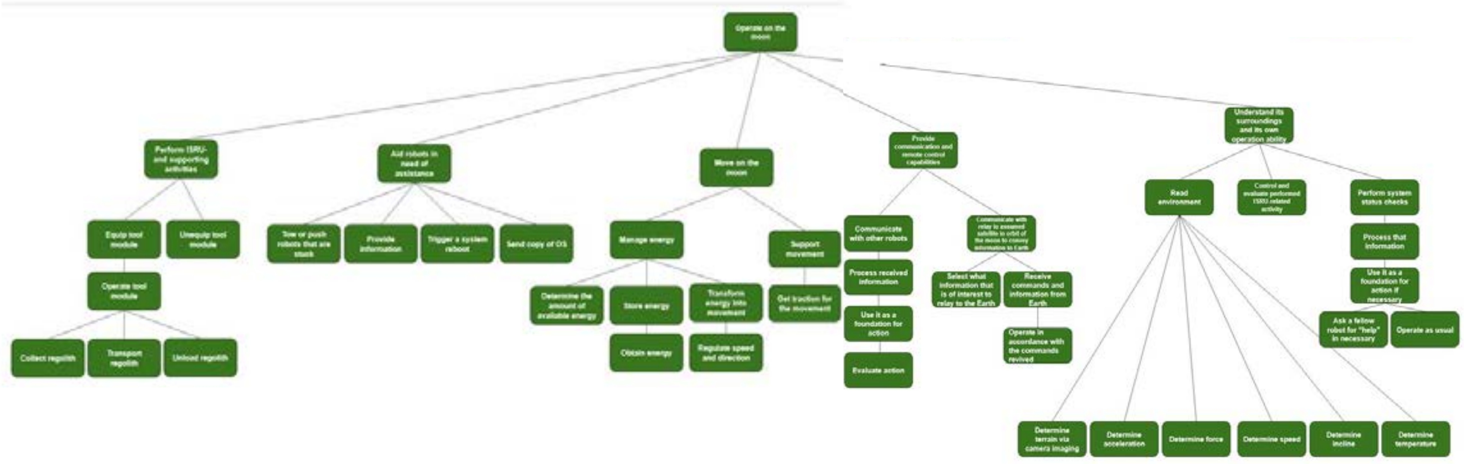
- Embed the mirror tower strategy to voronoi shape
  - chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.nasa.gov/wp-content/uploads/2011/08/396719main_wlmr_educator_guide.pdf?emrc=459cb8

Theme 3. Robot and Mobility

a) Initial machine for inflatable expansion / membrane structure
b) Water collection
c) Regolith collection
d) 3D printing robot for construction and how would the robot construct interlocking (Feng)
e) Electrical Charging for Robot

Theme 3. Robot and Mobility

a) Robotic tasks



Robotic Operations on the moon such as regolith collection, 3D print, perform status checks, AID robots

Theme 3. Robot and Mobility

a) Construction Process for Robots

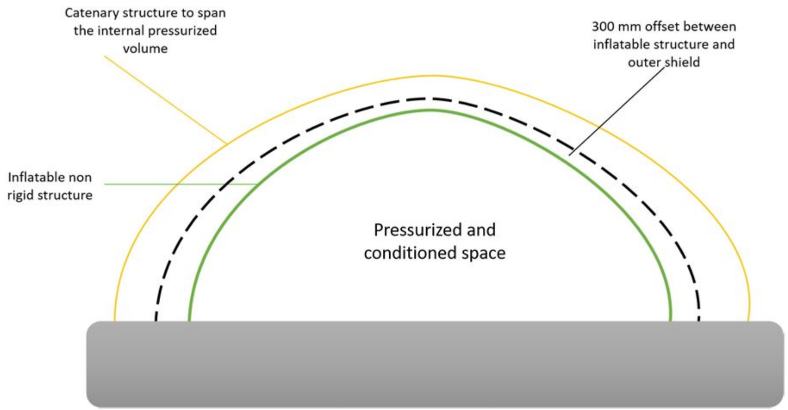


Figure 10. Proposed design for an inflatable Lunar habitat with a regolith shield. Imaged drawn based on [48].

Construction Sequence for the proposed Lunar habitat design

- Inflation
- 3D print around the inflation membrane

The possible construction sequence for the Lunar base is presented in Figure 11. The deployment of the airlock module, which is responsible for maintaining the inside atmosphere, is followed by inflating the inner part of the structure. After the inflation is complete or even during it, one or multiple mobile printers follow the circumference of the building, depositing raw regolith and then binding it layer by layer. It is expected that multiple smaller mobile printers are more beneficial overall for the needs of the mission, despite the energy requirement to move the printers during construction. Another important constraint that rises during the deposition step is the maximum angle at which regolith is able to maintain the shape and not collapse under its own weight during the curing process, which might be considerably slower due to low pressure and temperature [49,50].

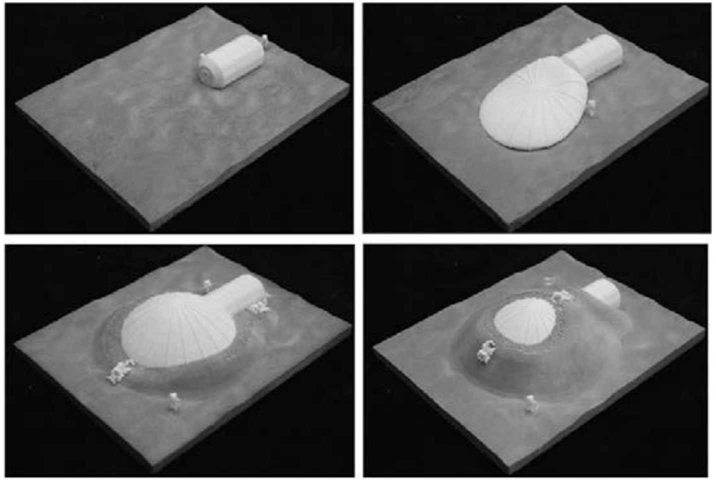
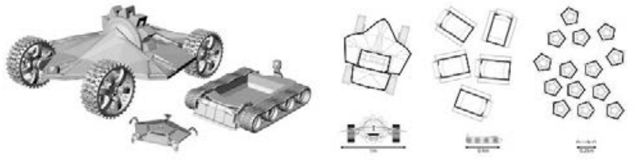


Figure 11. Construction sequence for the proposed Lunar habitat design [48].

Theme 3. Robot and Mobility

b) Types of Rovers and purpose



(a) (b)

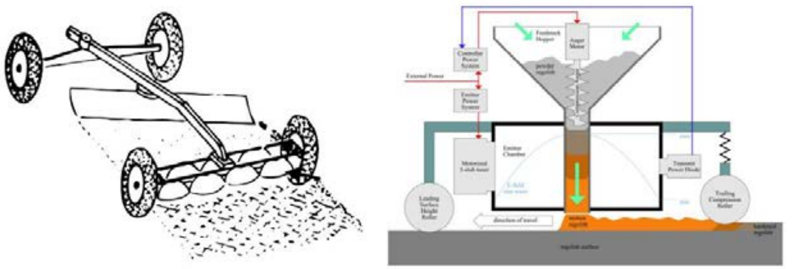
Figure 6: Robot design: (large to small) RAC-D, RAC-T, RAC-M

Table 1: Construction robot specifications

Name	*Function*	*Size*	*Quantity*	*Movement*
RAC-D	'Digger', regolith excavation using a perpendicular bucket-wheel	1.00m	1	Wheels
RAC-T	'Transporter', moves and deposits regolith into thin layers	0.40m	5	Tracks
RAC-M	'Melter', microwaves patches of regolith in desired position	0.25m	10	Legs

Three types of Rovers (large, medium, small
Purpose of digger, transporter and melter

As classified in the earlier taxonomy, there are two methods to applying this either internally or externally. The first involves placing a layer of material and sintering it in-situ Taylor and Meek (2005). For example, the 'lunar road-paving wagon' can move back and forth with its magnetrons (microwave generators) that can be set to various frequencies and power, in order to effectively sinter the lunar regolith, thereby constructing a traffic-able road or launchpad.



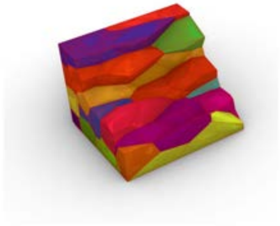
(a) (b)

Figure 5: Regolith sintering in-situ: (a) 'Lunar Road-Paving Wagon' designed by Taylor and Meek (2005); (b) Microwave printer concept by Barmatz et al. (2014)

In the second case, regolith is collected into a reservoir and fed through a microwave oven where it becomes molten and is subsequently extruded out into position (Barmatz et al., 2014).

Lunar material collecting wagon

Theme 3. Robot and Mobility



c) Construction Process for Robots

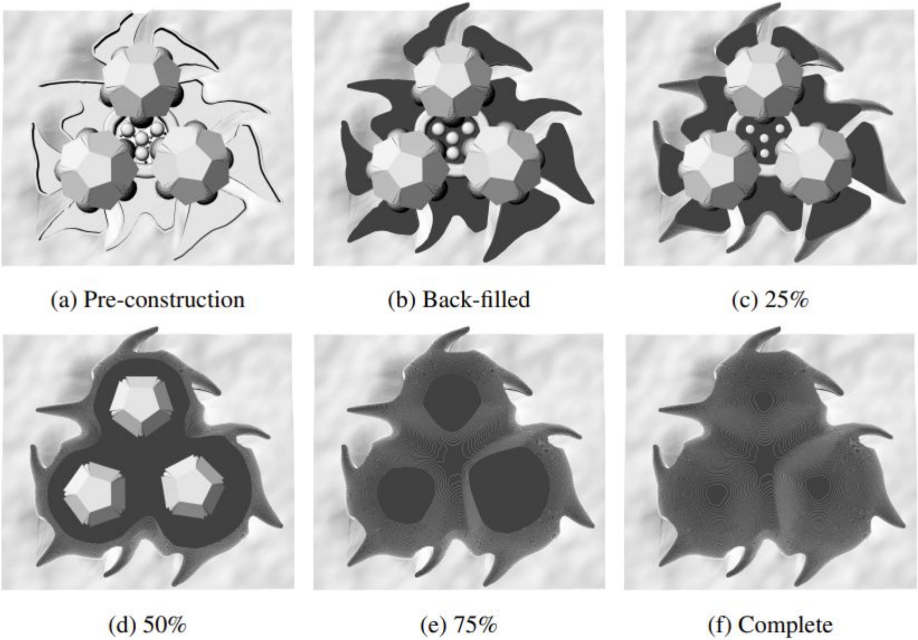
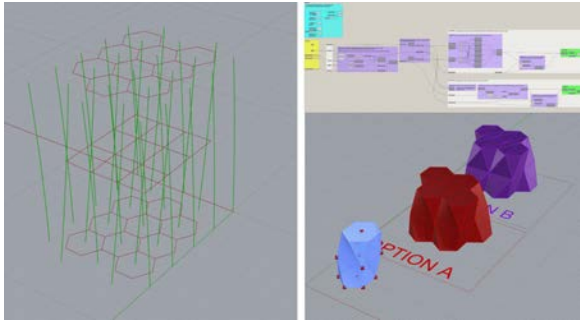
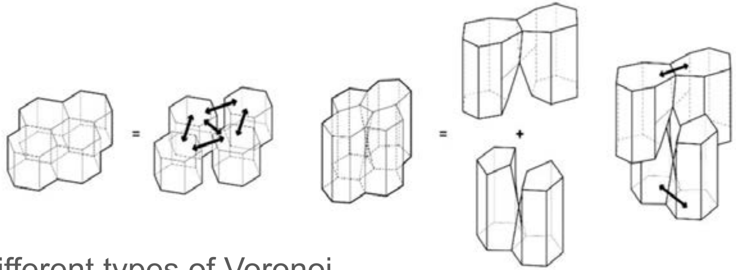


Figure 2: Plan view of progressive regolith construction





Different types of Voronoi
- Original
- Scutoid
- Voronoi Tessellation

For different types of interlocking

B

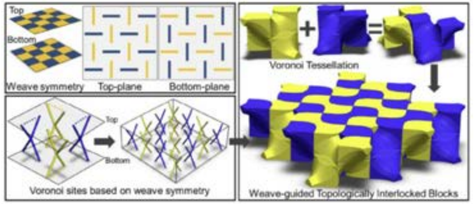
Review Article

Design of architectured materials based on topological and geometrical interlocking

Yuri Estrin[a,b] · Vinayak R. Krishnamurthy[c,*] · Ergun Akleman[d,e]

Abstract

In this article we present a design principle based on segmenting a structure into a set of topologically or geometrically interlocked elements. None of these designs was borrowed from Nature and yet there are some parallels between these structures born in the minds of researchers and Nature's designs. We give some historical background, describe the different kinds of interlocking structures, and discuss the ways in which they can be generated. Based on the beneficial features of the proposed structures, such as a great tolerance to local failures, enhanced bending compliance, high sound and energy absorption, ease of assembly and disassembly, and nearly full recyclability, we discuss possible applications of the concept of topological and geometrical interlocking design.

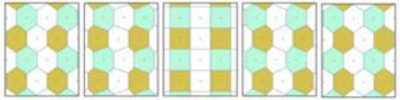


(a) Voronoi tessellation of a set of sites (red)

(b) Line arrangement for Delaunay Lofts

(c) Delaunay Lofts after layer-wise Voronoi tessellation

(d) 3D printed assembly of Delaunay Lofts



(e) Voronoi tessellations for five selected layers used in Delaunay Loft construction.

(a) Topological interlocking is directional for 6-4-6 hex-quad-hex Delaunay Loft

(b) Topological interlocking is complete for 5-4-5 pent-quad-pent Delaunay Loft

Conference Paper | Full-text available

Scutoid Brick: The Designing of Epithelial cell inspired-brick in Masonry shell System

September 2020

DOI: 10.52842/conf.ecaade.2020.1.583

Conference: The 38th eCAADe Conference of eCAADe - Education and Research in Computer Aided Architectural Design in Europe - At: Berlin, Germany

Lab: Jenny E. Sabin's Lab

Teng Teng · Mian Jia · Jenny E. Sabin

This paper focuses on the design of individual bricks in a masonry shell system that is inspired and informed by the reorganization of epithelial cells within tissues. Starting from a newly discovered shape called "Scutoid", we first investigated how epithelial cells within living animals are packed three-dimensionally within tissues. We focused on the living mechanisms within these cells that facilitate tissue curvature in the creatures' organs, skin, and blood vessels. By utilizing this generative geometric approach, we created a series of parametric generators and modeling kits to represent this mechanism and process. We then explored the potential for adopting this mechanism into larger scale settings. Meanwhile, we discovered that the deformation of individual epithelial cells during the bending process generates an intriguing triangular connection along the bending direction. We managed to translate this unique feature to the architectural scale as a joint system for connecting bricks in a masonry shell structure. Based on the above findings, we designed and fabricated a set of models for the masonry shell structure that are generated from scutoid bricks and this unique joint. The geometrical characteristics of scutoid bricks allow the packing of four bricks with just two joints. The work tha we have generated thus far contributes to solving issues of shell design and fabrication from the perspective of individual units. The result of the shell structure model demonstrates that applying the epithelial cell inspired-block masonry system is a feasible approach for the construction of shell structures.

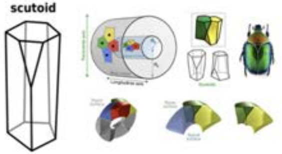
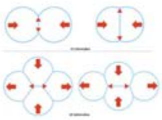
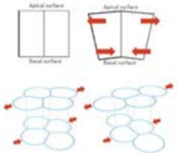


Figure 6
Cells vertically revolve along the horizontal axis resulted in different movement tendencies on apical and basal surfaces.

Figure 2
1 and 2-dimensional deformation of cells

Figure 3
The tissue is bent toward the basal surfaces





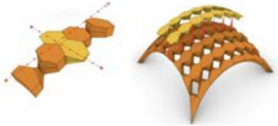


Figure 14
The connected scutoid bricks on both directions act like multiple arches that are perpendicularly mortising together

Theme 3. Robot and Mobility

d) printing pattern and algorithms

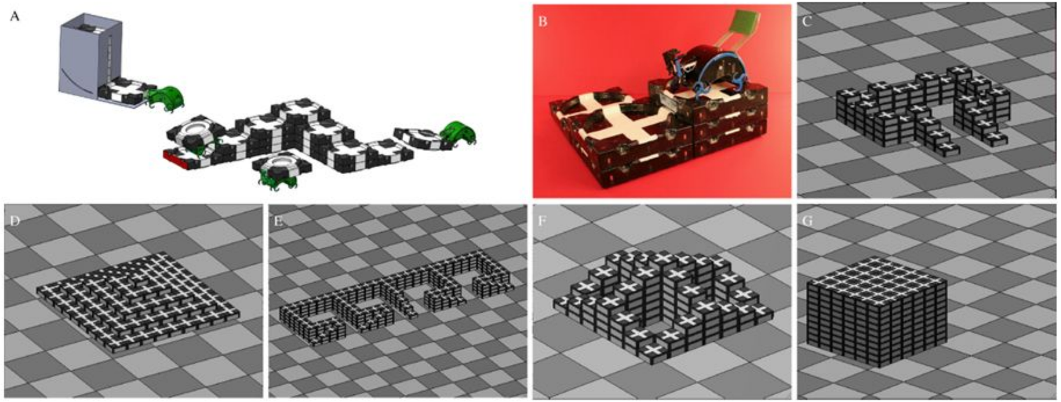


Fig. 1. (A) Overview of proposed system. Robots collect blocks from a cache (at left) and use them to build a desired structure starting from a marker block (with red face). (B) Hardware implementation. (C–G) Examples of structures buildable by the system, demonstrating single-path additive structures (C,D), splitting (E,F) and merging (F) paths, and a structure requiring a temporary staircase as scaffold (G).

Inspired by Termites building technique

Distributed Multi-Robot Algorithms for the TERMES 3D Collective Construction System

Justin Werfel, Kirstin Petersen, and Radhika Nagpal

Abstract—**The research goal of collective construction is to develop systems in which large numbers of autonomous robots build large-scale structures according to desired specifications. We present algorithms for TERMES, a multi-robot construction system inspired by the building activities of termites. The system takes as input a high-level representation of a desired structure, and provides rules for an arbitrary number of simple climbing robots to build that structure, using passive solid building blocks under conditions of gravity. These rules are decentralized, rely on local information and implicit coordination, and provably guarantee correct completion of the target structure. Robots build staircases of blocks (potentially removable as temporary scaffolds) that they can climb to build structures much larger than themselves.**

I. Introduction

In nature, there are many examples where relatively simple and limited individuals coordinate to self-assemble large-scale structures. A classic example is termite mound construction [1], [8]. Millimeter-scale insects build meter-scale mounds, with complicated architecture including features such as specialized nest chambers, fungus gardens, and self-regulating ventilation systems. Termite colonies achieve tremendous complexity, parallelism and robustness, with individuals that are simple, decentralized, and expendable. Engineering can draw inspiration from these natural systems with the research area of collective construction, whose goal is to develop robot swarm construction systems in which large numbers of autonomous robots build large-scale structures according to desired specifications. Such artificial construction systems have potential for application in many settings difficult or dangerous for humans, e.g., construction of levees, structural support elements, or temporary shelters in disaster areas; or construction of underwater or extraterrestrial habitats. Eventually such systems could increase automation in the construction industry and reduce accidents, as well as enable automated long-term repair and maintenance in dynamic environments.

A key challenge to the realization of collective construction systems is algorithmic: how do robots coordinate to construct a large-scale structure correctly, while retaining a high level of parallelism and simplicity at the single robot level? Another challenge is physical: how do we design robots and modular building materials such that robots can construct structures much larger than themselves in the presence of gravity? These challenges are not entirely separable, e.g., physical constraints have to be taken into account by the decentralized algorithms.

In this paper we describe an algorithmic approach to 3D collective construction, as part of a project called TERMES, which is inspired by the building activities of termites and other social insects. In this system, autonomous robots build structures using passive modular building blocks, climbing over structures that they themselves build. Robots operate under conditions of gravity, constructing staircases of blocks as scaffolds to allow them to reach heights and build structures larger than themselves. Elsewhere we introduced a hardware system that implements a climbing robot and blocks it can manipulate to build large structures [5]. Here we focus on the high-level algorithmic approach, by which an arbitrary number of such robots can build 3D structures, using decentralized control and implicit coordination. We show that this system can autonomously build arbitrary user-specified structures from a large class of possibilities. We prove the correctness of the algorithm, and show how robots can use simple rules to avoid the construction of intermediate deadlock structures or structures that can no longer be traversed by the robots.

II. Related Work

Algorithmically, the problem of collective construction is closely related to lattice-based self-reconfiguring modular robotic systems and programmed self-assembly [2], [6], [12]. Typically in such systems all modules are intelligent, communicating, and mobile. Collective construction can be thought of as an example of a bipartite self-assembling modular robot system, where there are two types of "elements": robots (self-mobile) and building blocks (passive, non-mobile, designed for attachment). This bipartite separation lets blocks be optimized for structural properties and low expense, and robots be specialized for mobility and reused for other building projects.

Unfortunately, this separation also increases the complexity of algorithm design beyond that for traditional modular robots. Robot movement constraints can be quite complex, especially when carrying blocks, and the use of passive blocks without embedded electronics implies that information needed for coordination in the self-assembly process is more difficult to propagate through the system. Further, if

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Theme 3. Robot and Mobility

d) printing pattern and algorithms

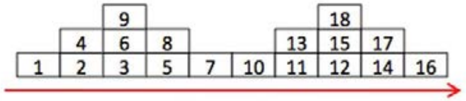

Fig. 4. Side view of a linear structure in which blocks will be added in the order shown as robots enter from the left and leave to the right.

Algorithm 1 Robot routine for single-path additive structure.

loop
  get new block from cache
  go to structure
  follow perimeter clockwise until entry point found
  climb onto structure
  while on structure **do**
    follow structpath
    if holding block
    and plan specifies block here
    and next site along path is at same level
    and (just descended from higher level **or** previous site is at same level and supposed to be empty) **then**
      move to next site along structpath
      attach block at site just vacated

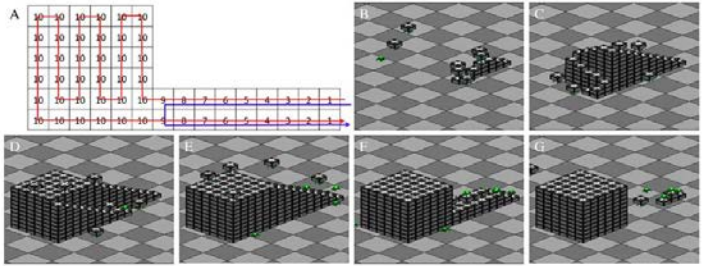

Fig. 7. (A) Compiled paths for the structure shown in Fig. 1C: full path for structure plus staircase in red, staircase-only path in blue. (B–G) Snapshots of ten robots building the structure and removing the staircase after the tower is complete.

Algorithm 2 Robot algorithm for removing a temporary staircase.

start by following Alg. 1 (construction)
if reach end of full path without having attached block
or reach site where the full path and staircase-only path split, and encounter an unclimbable cliff in the direction of the structure path **then**
  leave structure and discard current block
  while staircase not entirely removed **do**
    go to structure
    follow perimeter clockwise until entry point found
    climb onto structure
    while on staircase **do**
      go to next site along staircase-only path
      if just descended step **and** not carrying block **then**
        turn and pick up the block just descended from
    discard block

could be realized for instance by creating "unfolding" blocks that robots can carry in a compressed state) could enable features like short roofs and overhangs, thus dramatically increasing the space of interesting structures the system can create.

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Theme 3. Robot and Mobility

e) electrical charging

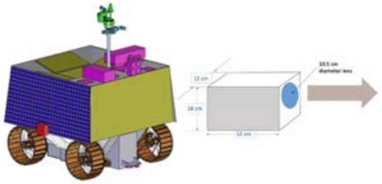

Figure 2 (left): Visualization of the power beaming experiment mounted on a rover. The elements relating to the power beaming experiment are shown in purple. In this image, the wheels are retracted for storage. *Figure 3 (right):* dimensions of the laser and beam director (not including gimbal elements for pointing).

Figure 4: artist's conception of the rover beaming power

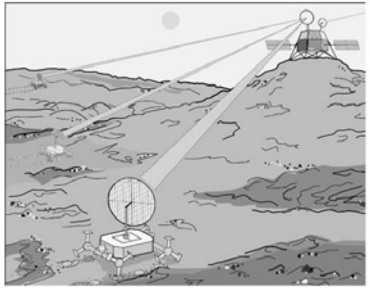

Figure 1: **a sketch of the possible use of a base station on a crater rim beaming power to multiple rovers ploring the permanently shadowed craters of the moon.**

Laser Power Beaming for Lunar Polar Exploration

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NASA Glenn Research Center, 21000 Brookpark Road, Cleveland OH 44135

Advances in laser technology now makes it reasonable to use a laser to beam power directly from a power source at the illuminated rim of the crater to a photovoltaic laser receiver on a rover exploring inside the permanently shadowed region. To move this technology from the conceptual design to a system that can be implemented for exploration, it will have to be demonstrated, both with ground- and space-based prototype systems. A conceptual design was done of a possible flight demonstration of laser power beaming. The design envisioned the demonstration as an addition to a proposed flight demonstration of the Kilopower space reactor, on a proposed lunar lander.

I. Introduction

Systems to provide electrical power are a challenge for lunar polar operations. Specifically, exploration of the ice-bearing permanently-shadowed craters near the lunar poles, in which the complete absence of sunlight means conventional solar power systems cannot operate, have been identified as a significant technology challenge for NASA's future exploration (for example, in STMD Strategic Thrust D, "Sustainable power in extreme lunar surface environments".)

Enright and Enright and Carroll [1] and others [2-5] have proposed powering a rover in such conditions has been to utilize a laser to beam power directly from a power source (either a solar array or a nuclear reactor) at the illuminated rim of such a crater to a photovoltaic laser receiver that converts the optical energy to electrical power to recharge a rover exploring inside the permanently shadowed region.

Recent advances in laser technology now make this approach seem to be feasible. However, the gap to be addressed between needs and capability is that while such systems have been previously proposed, a demonstration of power transfer at high enough power to operate a rover has never been done, and this will be critical before any such system can be used on the moon. To move this technology from the conceptual design to a system that can be implemented for exploration, it will have to be demonstrated, both with ground- and space-based prototype systems. The project goal is to develop and demonstrate this capability: surface to surface laser-power beaming, at a level capable of powering a lunar rover.

Laser power beaming has been proposed before, including significant work done at NASA during the 1990s [6-9], culminating with a centennial challenge resulting in a demonstration of an optical power transmission system capable of beaming power over ~km scale distances [10], but there has not previously been a compelling need for the capability. The current NASA objective of developing technologies for lunar polar exploration provides the need, and the evolution of higher-power and more efficient lasers provides the opportunity. This will put together several disparate technologies: the recent development of high-efficiency fiber lasers, along with solar cells capable of operating at the laser wavelength.

Optical power beaming using a laser power can be compared to using microwaves , which has also been proposed for long-distance beaming of power. The wavelength used for optical beaming, a factor of about ~10^4 shorter than microwaves, makes the spot size correspondingly larger, and hence systems for optical beaming are much more compact. On the other hand, generation of microwaves using vacuum tubes can be done at efficiencies of 85% or higher, considerably more energy efficient than lasers, which typically have electrical-to-light efficiency of 50% at best. Likewise, the conversion of the beam to electrical power at the receiver is higher for microwave systems, again about 80% conversion efficiency under ideal conditions (the record conversion efficiency, by Brown, is 90.6% [11]). This compares to efficiencies on the order of 50% for the photovoltaic converters [12]. In the real world, both of these conversion efficiencies will be lower.

A peripheral advantage of laser power receivers is that the same photovoltaic panel that converts laser radiation

[1] Researcher, Photovoltaic and Electrochemical Technology Branch. Associate Fellow, AIAA.

Theme 3. Robot and Mobility

e) electrical charging

Laser Power for UAVs

A White Paper
By T.J. Nugent and J.T. Kare
LaserMotive, LLC

Summary: Lasers can transmit power to UAVs in flight, giving them potentially unlimited endurance aloft. Silent, refueling-free laser-electric UAVs are practical with current technology and could be developed and deployed quickly.

Background

Unmanned aerial vehicles (UAVs) are seeing increasing use as demand for them explodes[1], but their range and sortie duration are limited by their on-board energy storage (either in the form of batteries or fuel). Landing UAVs to refuel them not only takes them off-station, but requires skilled manpower and adds risk: even more than manned aircraft, UAVs are most likely to crash when taking off or landing.

The longest-endurance fuel-powered UAVs have stayed aloft is only 80 hours.[2] Electrically-powered UAVs have many advantages, including quiet operation and low maintenance requirements, but have much more limited range and endurance, even with the best foreseeable batteries. Even a solar-electric UAV has to date only remained aloft for 82.5 hours.[3] Solar-powered "eternal" UAVs and lighter-than-air (LTA) platforms are bulky, fragile, and expensive, and so far have very limited payloads and operational envelopes.

WHAT IF we could have robust, high-performance UAVs that never needed to land?

System Concept and Technology

A laser power link for UAVs is shown in schematic in Figure 1. The laser transmitter converts power from a primary source (battery, generator, or AC line power) into a monochromatic (single-wavelength) beam of light.

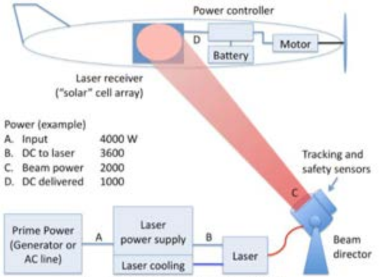


Figure 1. Schematic diagram of power beaming to UAV.

The preferred laser technology for most near-term applications is arrays ("stacks") of near-infrared laser diodes (see Figure 2). Laser diode arrays are efficient (>50% DC power in to light out[4]), compact, and relatively inexpensive, and are now sufficiently robust and reliable (>20,000 hour operating life) for field use. For some low-power or long-range applications, other lasers, notably diode-pumped fiber lasers, can provide a brighter (lower divergence) beam, which permits the transmitter optics to be much smaller, at the expense of higher laser cost and lower efficiency.

A beam director or beam-steering mirror directs the laser beam at the UAV receiver, under control of a pointing and tracking system. A UAV is a cooperative target, so optical tracking is straightforward, but can be supplemented with RF or GPS-based methods for acquisition and tracking through clouds or past obstacles.

There does not need to be a one-to-one ratio between beaming stations and UAVs. One beaming station support multiple UAVs which rotate in and out of recharging mode. A network of beaming stations can support a large number of UAVs with flexible flight paths.

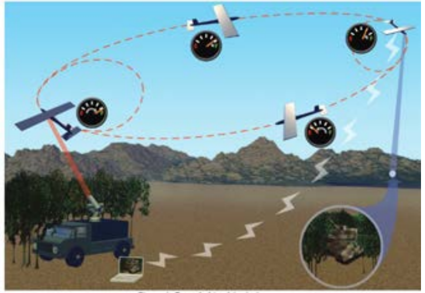


Figure 4. Extended/multi-mission ops.

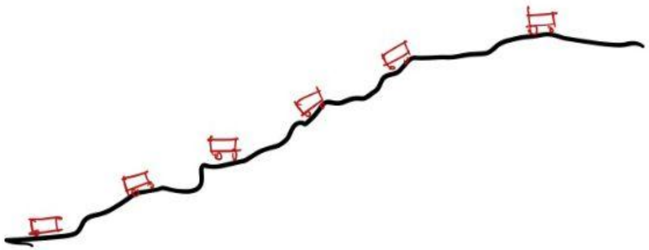
Another example of recharging for extended missions is relatively small UAVs flying within a few kilometers of a base, e.g., for perimeter patrol. Many UAVs could be rotated between recharging near a beaming station and out to near-base missions.

Because in-flight recharging can be done at relatively short range, optics requirements are modest, and the impact of clouds and other beam obstacles is reduced. However, both transmitter and receiver must handle much more than the mission-average power.

Theme 3e: Water Collection

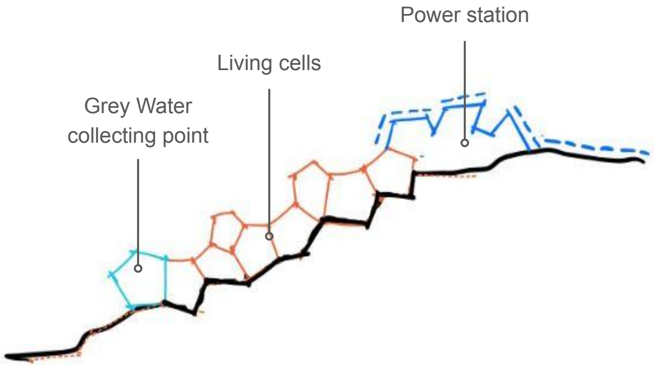
This work covers the simulation and comparison of three different thermal water extraction methods: 1) in-situ surface heating, 2) heated drills, and 3) heating inside a crucible after excavation.

Preliminary Concept

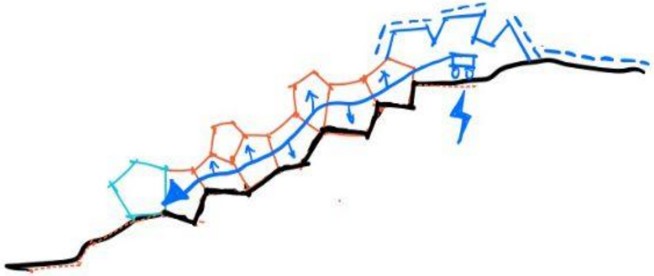


Step 1. lunar robot for geographical exploration

Step 2. Optimize geographical shape for voronoi interlocking foundation

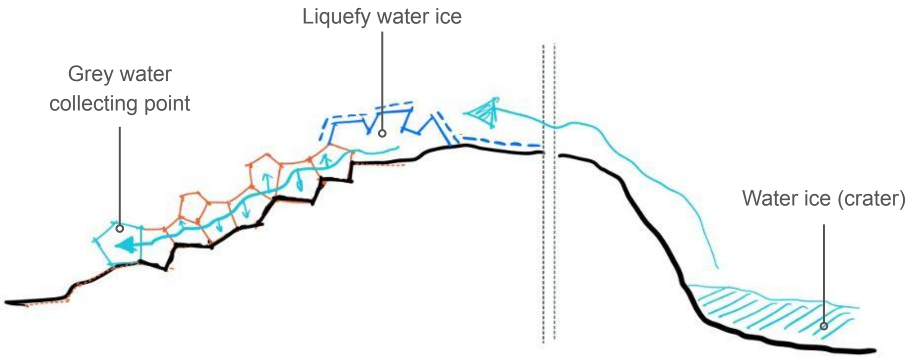


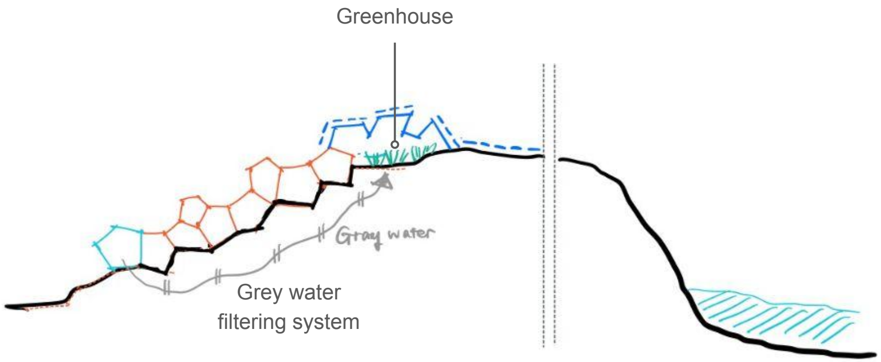
Step 3. Semi-buried Voronoi cells



Energy system: Path for wireless charging robot embedded in the voronoi cells for living

Preliminary Concept

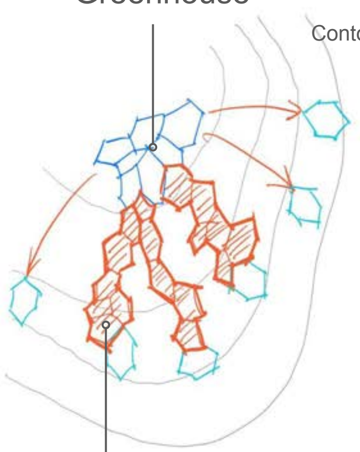


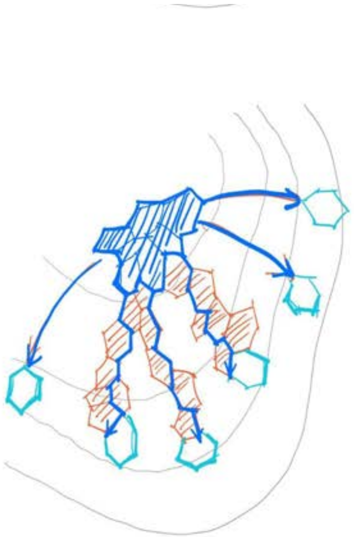


Water recycle loop: Sewage system embedded in voronoi living cells

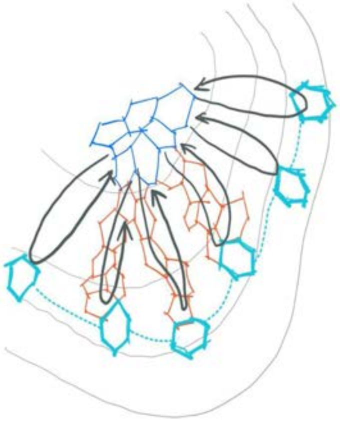
Water recycle loop: Grey water get filtered when pumping back to the top for greenhouse irrigation

Preliminary Concept





Energy transmission path



Water recycle loop

Lunar Architecture_Space Requirements

- Communal Space
- Sleeping Space
- Support Functions

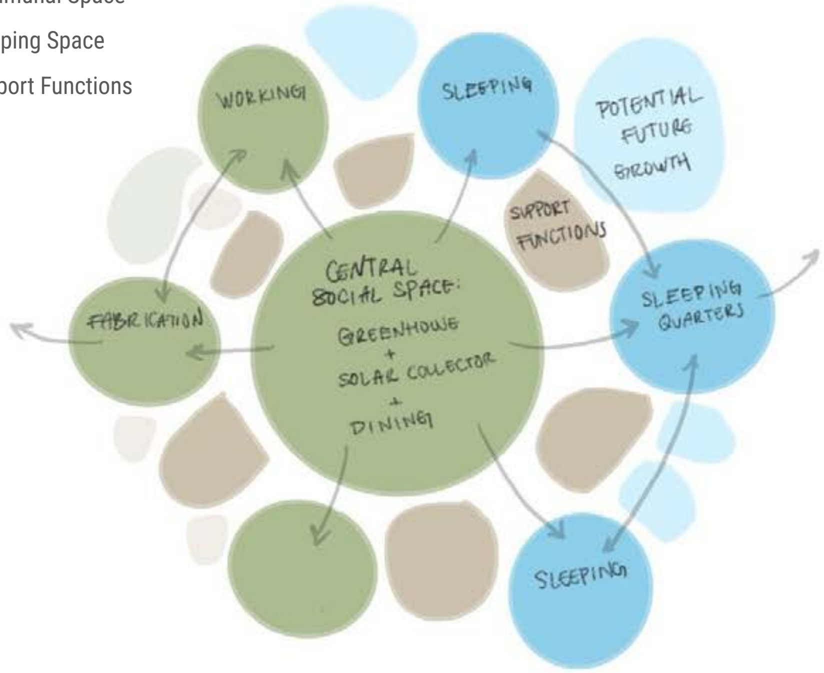
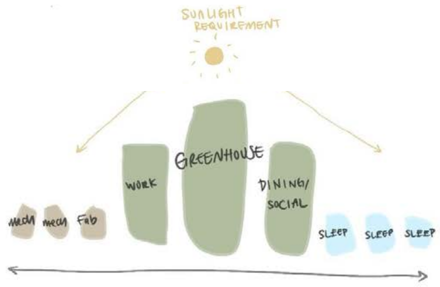


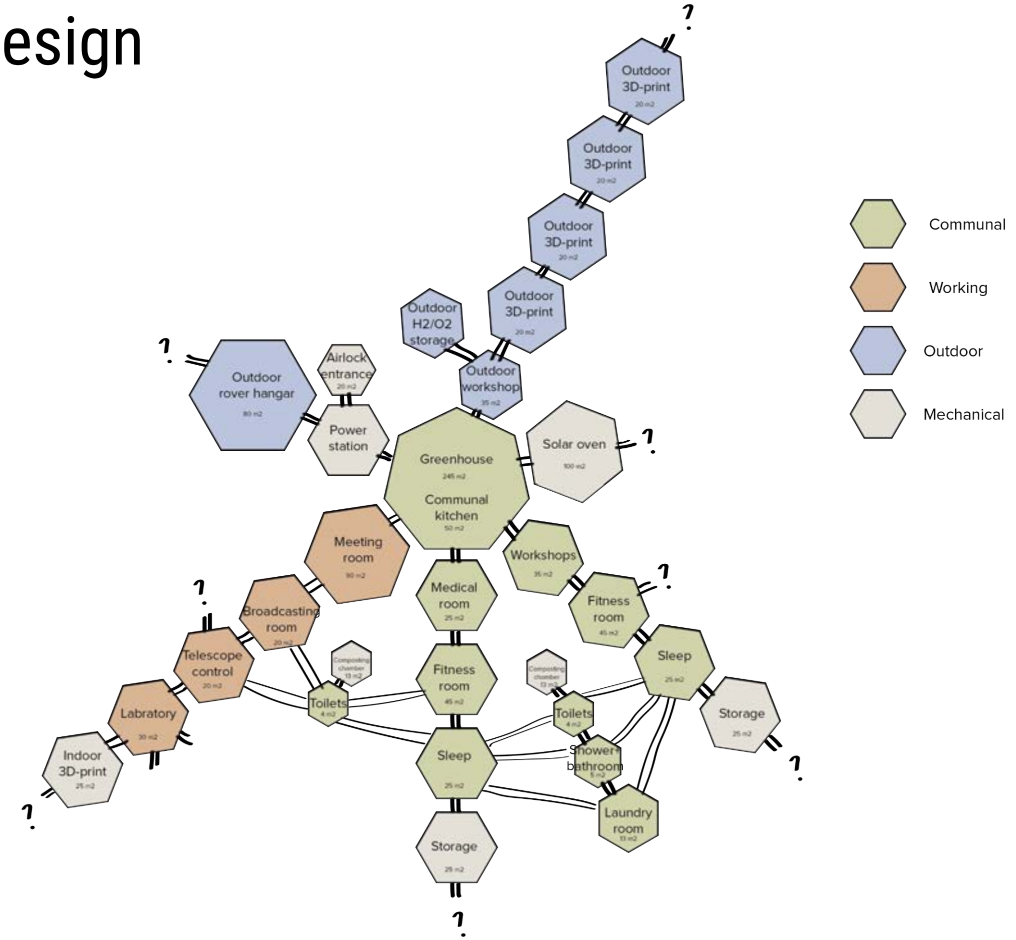
Table 1
Facilities of a single greenhouse unit which can nourish 2 persons.

Nr.	Facility	Area	Nr.	Facility	Area
01	greenhouse	245 m^2	16	fitness room	090 m^2
02	composting chamber	013 m^2	17	voltage converter	–
03	sleeping compartment	013 m^2	18	battery	–
04	kitchen	025 m^2	19	fuel cell	–
05	toilet	002 m^2	20	electrolysis	002 m^2
06	shower & bathroom	005 m^2	21	frozen CO_2 storage	–
07	laundry washing room	016 m^2	22	view tunnel	–
08	medical room	025 m^2	23	airlock & entrance	020 m^2
09	meeting room	090 m^2	24	solar oven	100 m^2
10	broadcasting room	020 m^2	25	outdoor H_2 storage	–
11	telescope control	020 m^2	26	outdoor O_2 storage	–
12	avatar control room	025 m^2	27	outdoor workshop	035 m^2
13	laboratory	030 m^2	28	outdoor 3D-printing	080 m^2
14	indoor workshop	035 m^3	29	outdoor rover hangar	080 m^2
15	indoor 3D-printing	025 m^2			



Lunar Architecture_Concept Design

Here is a schematic layout of our concept. Green represents communal spaces, orange indicates work areas, blue indicaties outdoor spaces, and grey designates technical areas. Various modular structures are interconnected through passageways, all linked to the central communal space. The power station is located there, distributing energy to the branches. The chosen structure aims to foster future growth, allowing shared support functions between two branches. This system can expand both horizontally and vertically in the future.



Lunar Architecture_Next Steps

Voronoi structures can be optimized to fit in digital mapping of terrain from high res images

Explore openings in the voronoi spaces

Opportunities for individual nodes to connect through interior or exterior bridges or fit together