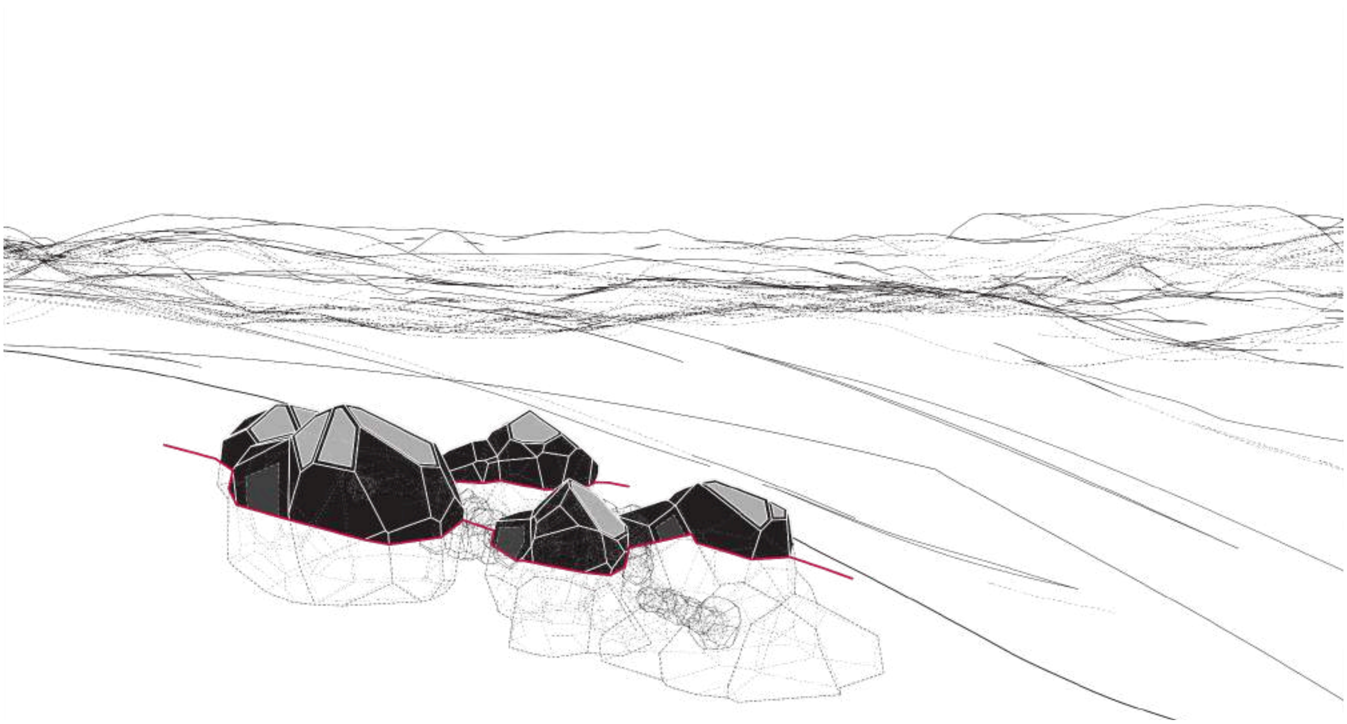
AR0122 1:1 Interactive Architecture Prototypes Workshop (2023/24 Q3



Housing Typology in Lunar Habitat

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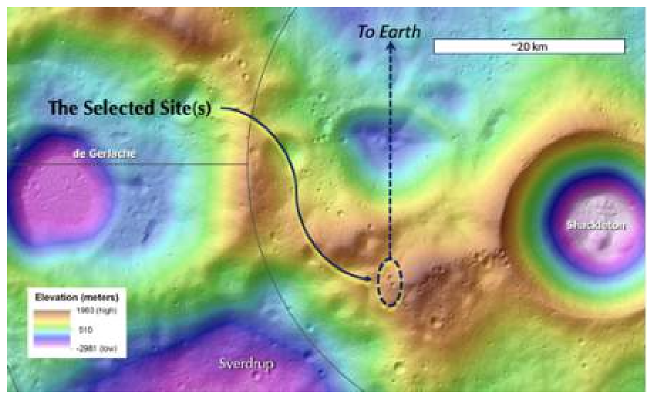
Part I. Introduction

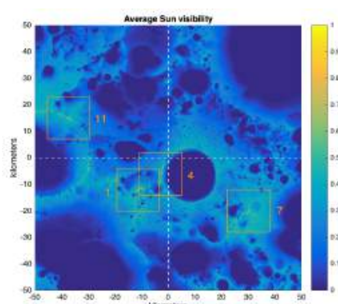
Living on the Moon has become a current exploration with the advancement of aerospace technology. As human effort, material, and supply are limited on the Moon, this project aims to provide a Voronoi housing scheme for 3-6 astronauts using human and robot collaboration. The project was initiated through Lunar site selection through researching environment and terrain challenges, Lunar Energy and Health and Life Support systems, and construction robots; then explore the design of communal living units using local materials(regolith); and finally explore ways to realize the design using technologies of Design-to-RoboticProduction-Assembly(D2RP), Computer Vision(CV) and Human-Robot Collaboration(HRC)

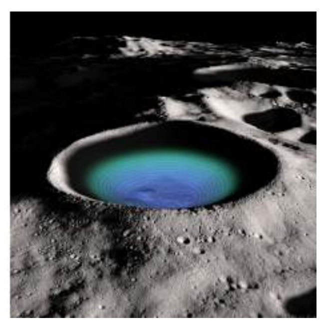
Part II. Site Selection and Challenges on the Moon



Alongside the 1:1 Prototype Workshop, we have entered the Moonstation2050. The competition gave two options for the site selection. We have decided on site 2, located at the Lunar south-polar ridge on the left of Shackleton Crater. Along the Earth-facing slope of the Lunar south polar ridge, along the upper edge of an approximately 800m diameter crater, facing downslope and toward Earth (which should be occasionally low on the south polar horizon).

Station Center Coordinates: 89.45°S, 222.69°E





Area Specificities: The reason for the chosen site is because the ridge along the crater's rim is exposed to almost continual sunlight for solar charging, human health, and greenhouse, while the interior is perpetually in shadow, which indicates the presence of water ice for water collection as well as water that can be used for in-situ material use. The landing and launch facilities could be located on the far side of the south polar lunar ridge line to minimize the risks due to 'ejecta' produced during arrivals and/or departures from the settlement. The slopes near the ridge appear adequate for surface mobility to facilitate access by surface transportation to permanently shadowed regions (PSR) where ice has been detected during recent years.

Apart from the lack of construction materials and human labor forces, this project aims to cope with four main challenges in the Martian habitat environment:

- 1. The average radiation level on the Moon is 200-1000 times that of Earth. The living space and glass openings must be protected from radiation for human health through film and technology.
- 2. Consider the Vaccum Atmosphere on the Moon poses challenges for material durability and protection against radiation
- 3. The average ground temperature on the Moon swings from 123 Celsius in the daytime to -233° Celsius at night.
- 4. Compared to Earth, the Moon is farther away from the Sun. The design needs to balance light gain and protection from radiation.

Part III. Design

Case Studies

Firstly, the design references the study of rhizome 1.0 by an architectural and aerospace team in Tudelft, which suggested underground constructions using local regolith for radiation and temperature protection. Our projects also look into other literature reviews and case studies and have considered three main points:

- a Central Atrium for light distribution
- a node system for possible expansion through modular housing
- a stacked structure that is built underground

After studying the terrain, we will utilize the slope of the terrain. The project also references the University of Urbino. Italy. It is a residential project with a central core placed at the top of the ridge, and it is modular.

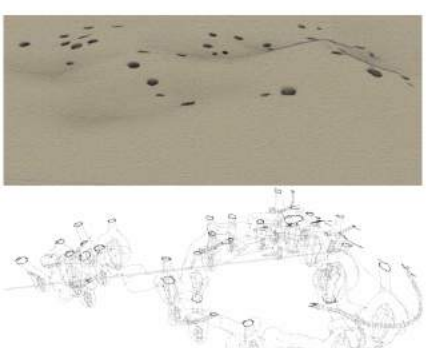
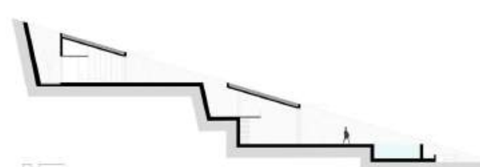
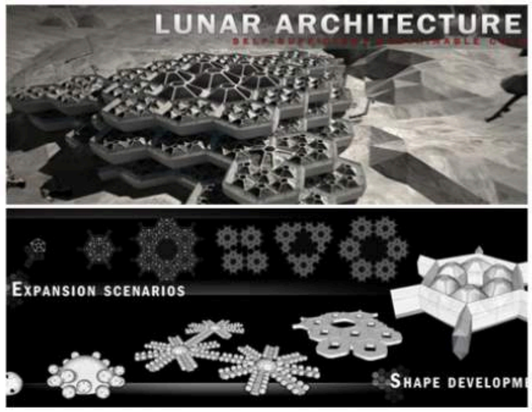


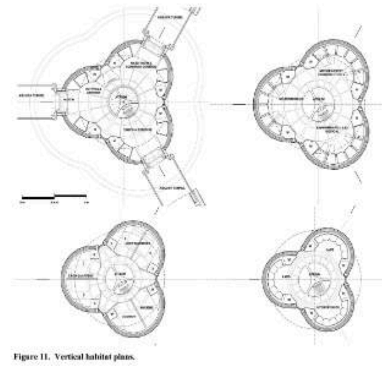
Fig. 1: Underground rhizomatic structure with skylights



central atrium for light distribution



node system for possible expansion



stacked structures

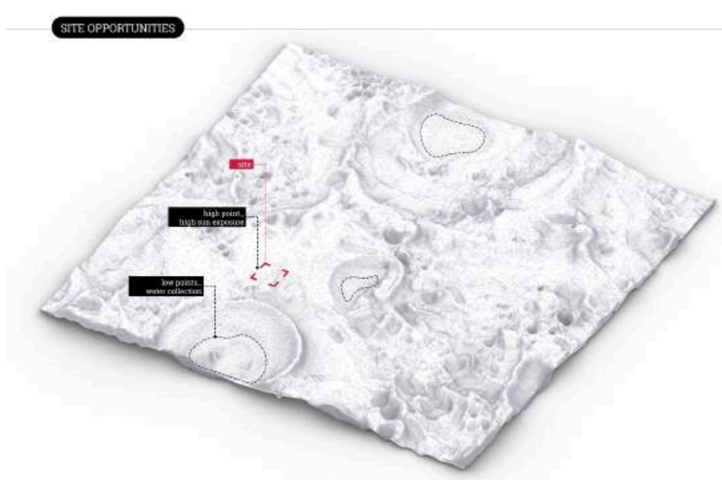
Concept

The project has designed a lunar base to house three to six people, which can offer protection from meteorites, gamma radiation, and high-temperature fluctuations. The base is first unfolded from a tubular module that can be transported by a space rocket. An inflatable dome then extends from one end of this cylinder to provide a support structure for construction. Layers of Voronoi-shaped regolith are then built up over the dome by a robot-operated 3D printer to create a protective shell, demonstrating the potential of 3D printing to create structures close to natural biological systems. Each house has its electrical core in the design, and the overall circulation depends on the electrical and health/ life support flow. Several underground individual houses are connected with the electrical core, further covered by canopies. Different clusters are also interconnected through underground tunnels, linking different communities.

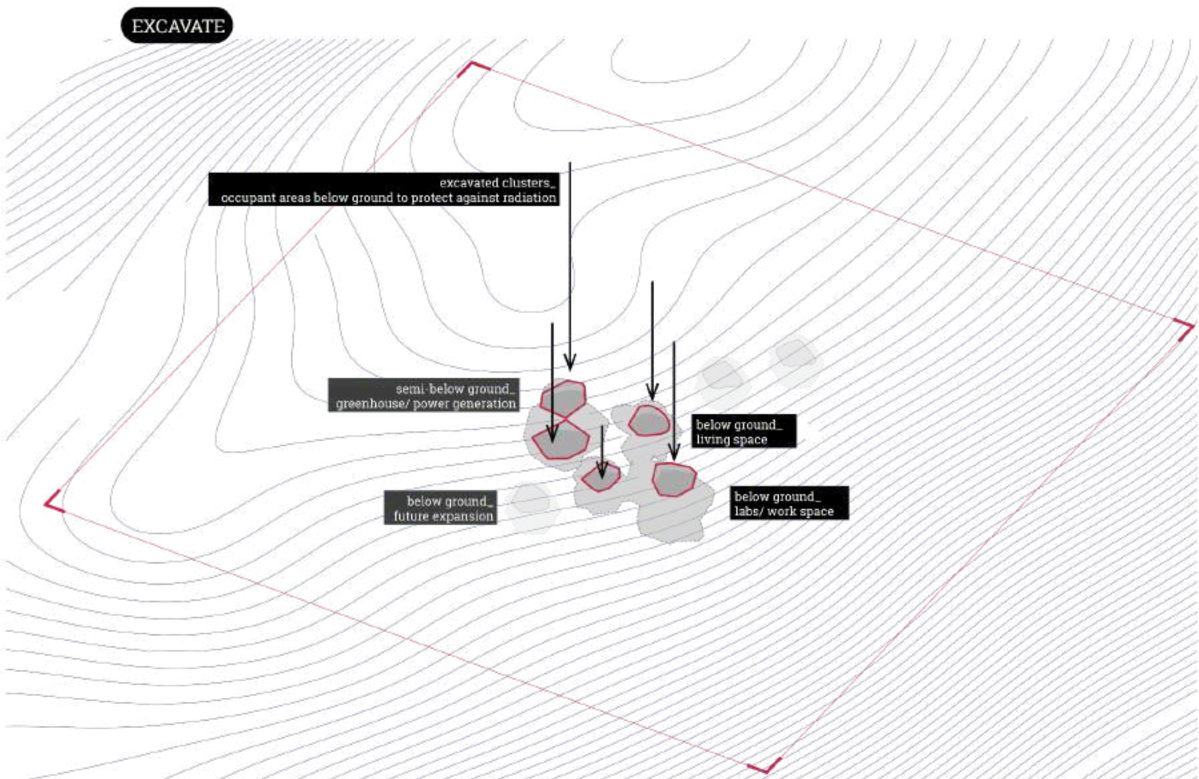
House unit design

The communal habitat design starts with the house unit design. A spatial diagram is first considered to arrange the cell spaces according to the safety, flow of electricity, food production, privacy, light gain, and robotic 3D printing material and exploration.

Firstly, the overall floorplan of each module/ habitat for 3-6 people has four inflated module bubbles connecting them via structures similar to airlock modules, arranged in a star shape with airlock walkways that allow accessibility to each room. It is also important to consider the possible expansion of a Lunar base as having separate building modules for different purposes. As it can be seen from the evaluation, it is



considerably safer to arrange the building modules and airlocks in a scattered chess-like fashion as it utilizes the available space efficiently, allows fast movements between the modules, and, most importantly, issues the safe escape if one of the modules fails.

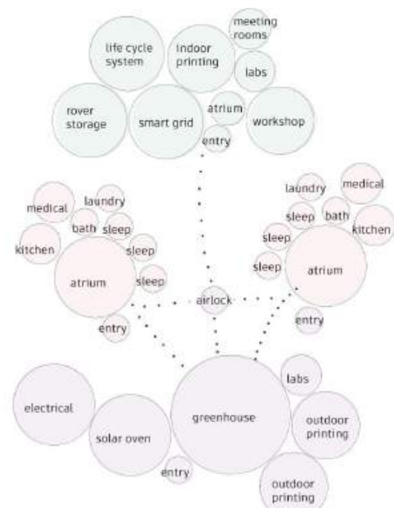


As mentioned earlier, one functioning habitat is designed for 3-6 people and has 4 module bubbles, following the sloping terrain built underground:

- The top bubble is the Life Support cluster, which includes functioning spaces like greenhouse/ lifecycle systems, rover storage/ workshop, labs/ workshops.

- The middle bubble includes 2 Living clusters, including sleeping quarters, a kitchen, a medical, and a toilet.

- The bottom cluster is designed for a working/ lab cluster; it includes a solar oven, outdoor



printing, and an electrical mechanical lab. The outdoor lab is located at the bottom cluster because the robots could be sent out for exploration or for collecting regolith, water, and material for more 3D printing.

Each bubble and cluster includes an atrium with protection film and mechanical closing and opening to avoid too much radiation. The atrium and skylight openings depend on the function of the cluster; the communal areas will have larger openings compared to sleeping quarters, located in the innermost part and underground, to protect the inhabitants from radiation.

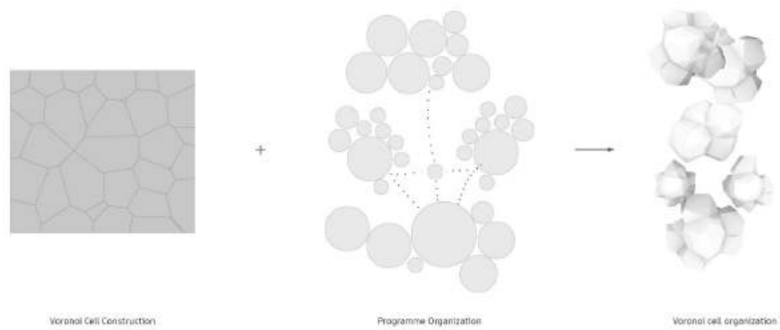


Fig. Voronoi Housing to community

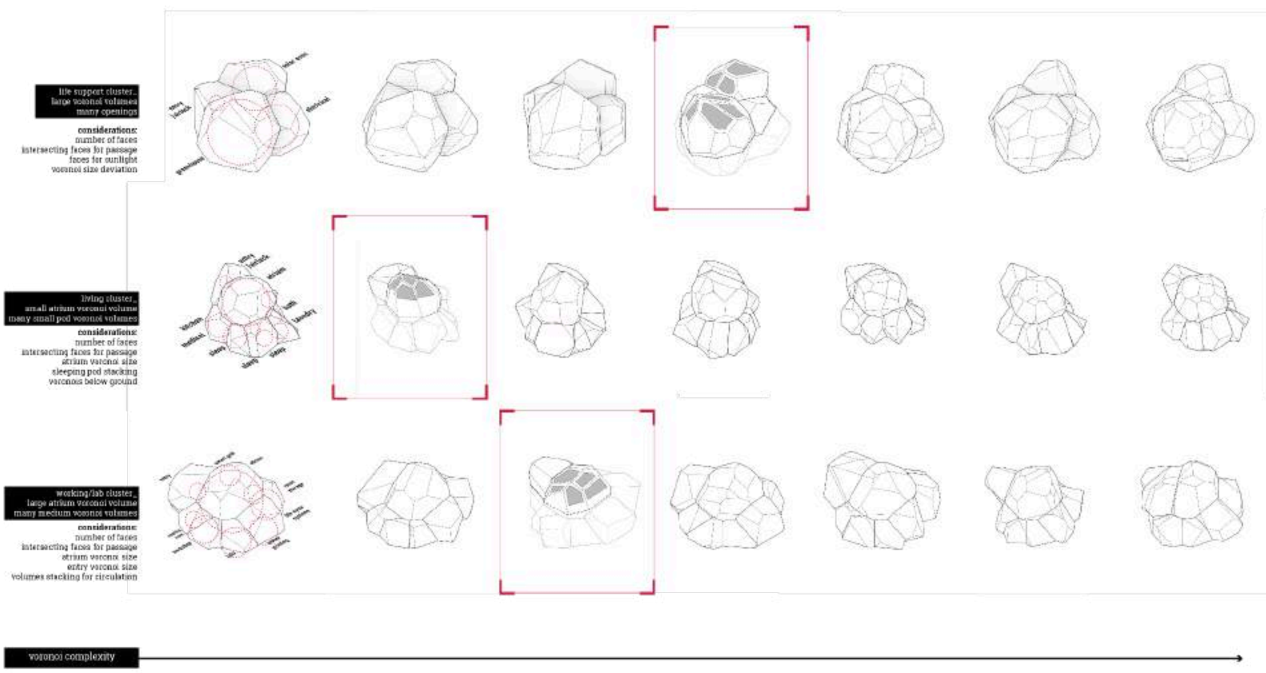


Fig__. Form Finding: Voronoi Development

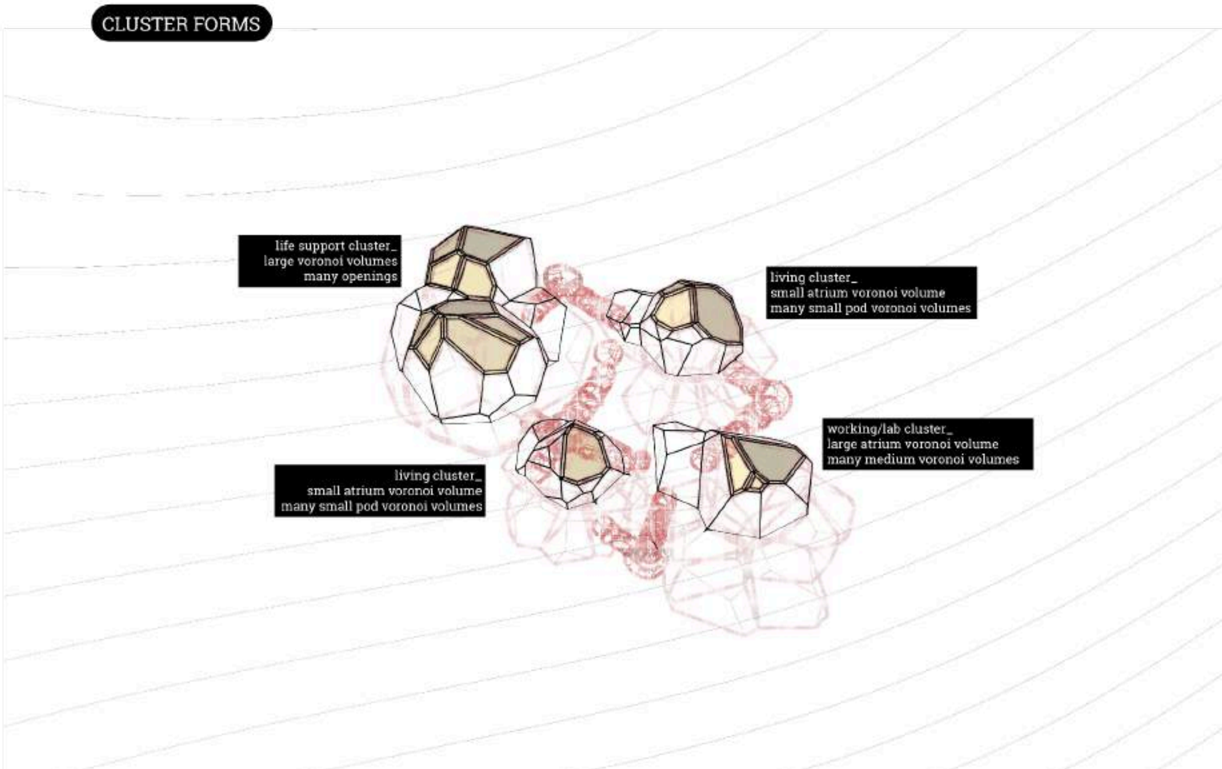
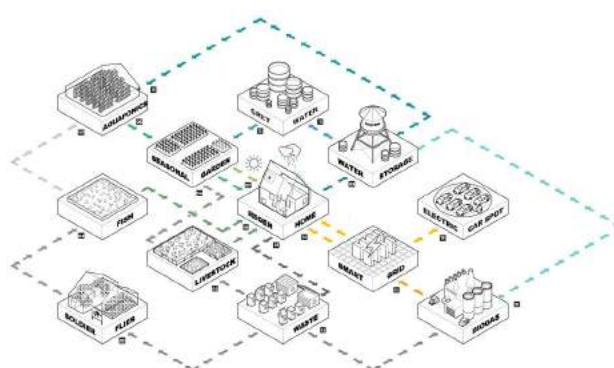


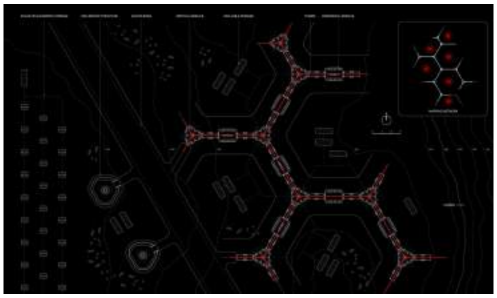
Fig__. Final Cluster Form

Each space, represented by points in the digital model, is used as input for the grasshopper sketch. With the controlled input, the script generates similar options of units, in which the option with the best spatial condition and larger surface area is chosen for the design.

Lunar Energy and Health and Life Support

For Lunar Energy and Health, we have looked into 4 points: Food production, Energy system, Water recycling system, and Air revitalization, within each energy generation cluster. One example is Aquaponic and Algae plants, as NASA(2020) suggested, which are grown in the greenhouse using waste from the inhabitants to improve the psychological environment and provide the oxygen needed for daily living in Martian habitats.





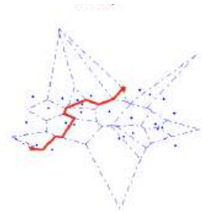


Figure 5: Shortest Path Found by 100 Ant Agents (length: 239.8, time: 1.172s)

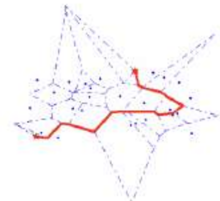
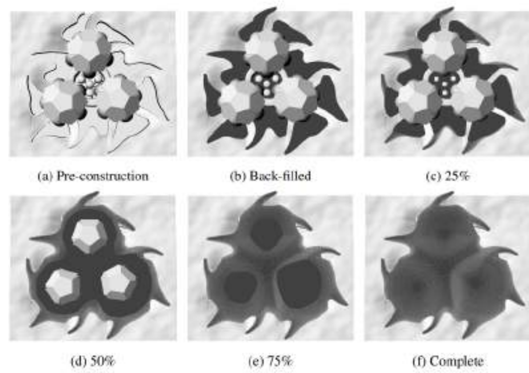


Figure 4: Shortest Path Found by 10 Ant Agents (length: 341.5, time: 0.172s)

Robotic Construction System

Another criterion for the Moonshot 2050 competition is the Lunar Robot. The wireless robots, powered by power beaming, are crucial for many roles, such as collecting material (regolith and water), exploring sites, managing energy, and communicating. However, the most important specialty is the robot's construction process.



(a) Pre-construction (b) Back-filled (c) 25% (d) 50% (e) 75% (f) Complete

Figure 2: Plan view of progressive regolith construction

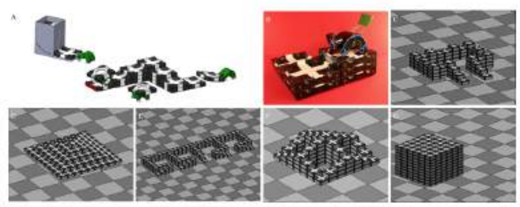


Fig. 1. (A) Overview of proposed system. Robots collect blocks from a cache (at left) and use them to build a desired structure starting from a marker block (with red face). (B) Hardware implementation. (C–G) Examples of structures buildable by the system, demonstrating single-path additive structures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

Our design aims to develop systems in which large numbers of autonomous robots build large-scale structures according to desired specifications. We present algorithms for TERMS, a multi-robot construction system inspired by the building activities of termites. The system takes in input a high-level representation of a desired structure. It provides rules for an arbitrary number of simple climbing robots to build that structure, using in-situ Topological Interlocking steroids (in Voronoi form language) blocks under gravity conditions. These rules are decentralized, rely on local information, and guarantee correct competition with the target structure. Robots build staircases of blocks (potentially removed as temporary scaffolds) that they can climb to build structures much larger than themselves.

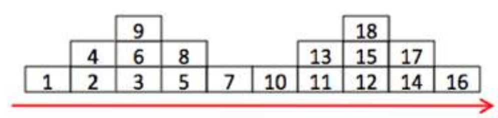


Fig. 4. Side view of a linear structure in which blocks will be added in the order shown as robots enter from the left and leave to the right.

Part IV. Design-to-Robotic-Production(D2RP)

The housing unit uses a mixture of Voronoi cell structure and a new form of research of Topological Interlocking Assembly form named Scutoid (derived from the Delaunay Loft theory and Abeille Tiles. This 6-5-6 shape cell behaves and interlocks its hyperbolic shape with the neighbors on all sides in their basal and apical surfaces. As a result, it forms an epithelial cell and adopts a novel shape named “scutoid”. Each cell space's dimensions and interrelationships can be flexibly manipulated using the grasshopper script while maintaining the integrated cell structure. (The Scutoid shape will be further explored in the later stage of fragment assembly consideration).

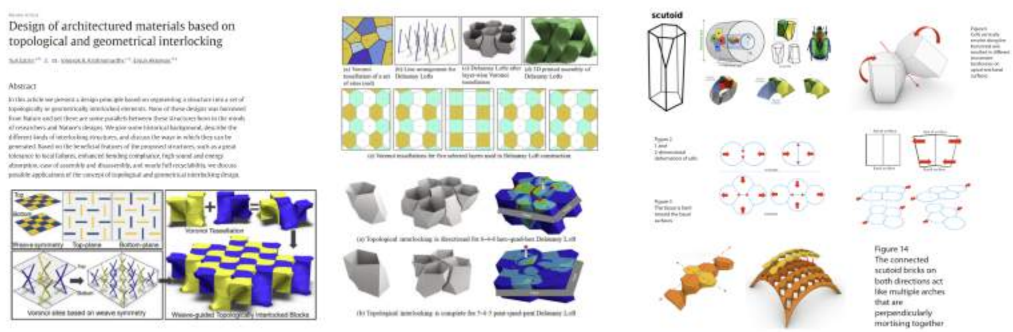


Fig__.Scuptoid Research Literature Review

The production step starts by tesselating the habitat and the canopy into smaller scutoid (i, Voronoi language) cells to identify and prototype smaller components. These cells are then grouped together in 3s to fit a form factor. The milling step determines this form factor. The bounding box of the initial form that gets milled is the form factor to which the combined cells are limited. Once the components are identified, the milling pre-processing can begin.

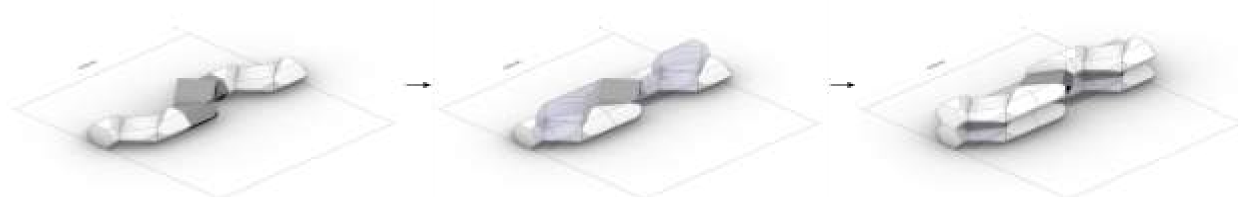


Fig__. Scutoid in Voronoi Language

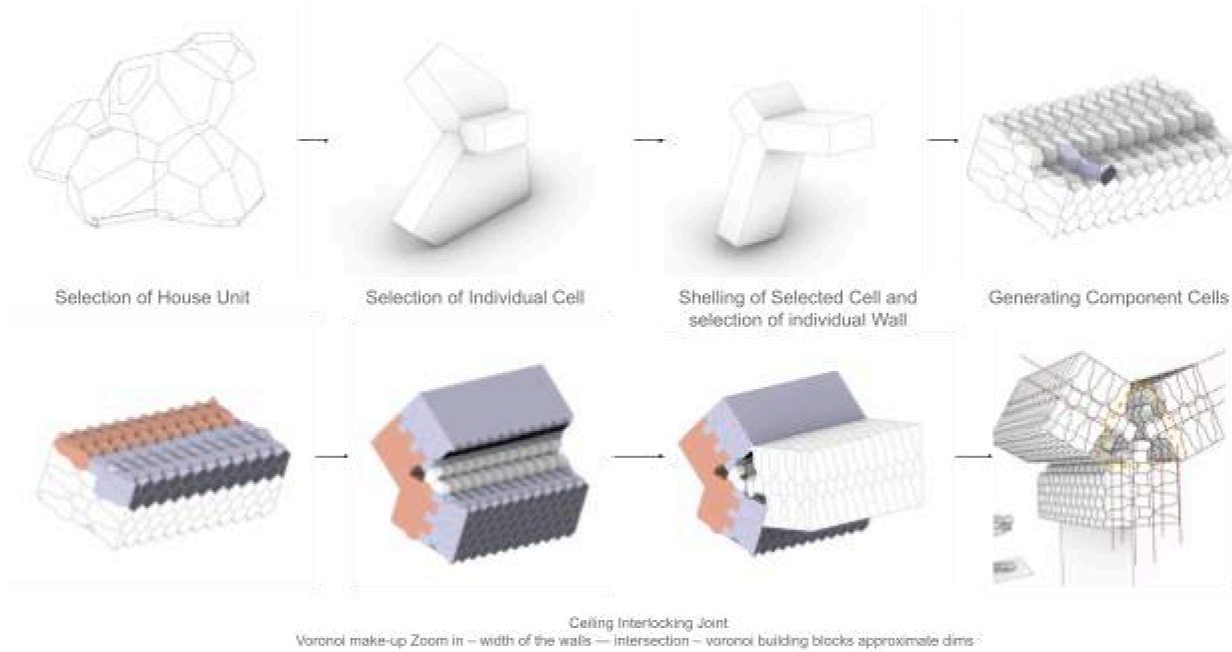


Fig__. Step to generate cell components from the house unit. (Ceiling Fragment detail)