The Cyber-Physical Space for Martian Underground Habitats

Multi-Scale Voronoi Integrated Lighting, Furniture, and Plants

AR0122 1:1 Interactive Architecture Prototypes Workshop

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Focus and restrictions – This paper focuses on the integration of furniture, lighting, and plants in a Voronoi based envelope in an underground off-earth habitat on Mars.

Related articles – 1) Bier, H. and Mostafavi, S. Structural Optimization for Materially Informed Design to Robotic Production Processes, AJEAS, 2015
2) Bier, H. and Knight, T., Data Driven Design to Production and Operation, Footprint Issue 10, Stichting Footprint, 2014

Abstract – Building in an off-earth environment comes with a lot of challenges. This paper focuses on building a habitable environment for astronauts on Mars. Because of the Martian climate the building will be placed underground. For the underground building, the Voronoi principle is being used to divide the spaces, optimize the structure and integrate different functions. For the materials, Biolith, PLA, Silica Dioxide, Martian concrete, and Earth concrete will be discussed. The conclusion of this, together with a structural analysis, is used to develop a wall fragment which follows the Voronoi principle. In the wall fragment, different functions such as furniture, plants, utilities, and lighting will be integrated. This integration is based on the different sizes of the Voronoi cells. Artificial intelligence is used to personalize the lighting inside the underground living and working environment.

Key words – Voronoi, Martial Habitat, Off-Earth Habitat, Adaptive Architecture, Design-to-Robotic-Production and Operation, Artificial Lighting

1 Introduction

This report is written for the elective 1:1 Interactive Architecture Prototypes. The aim of this elective is to create a habitable living environment for astronauts on Mars. Because of radiation, extreme weather, and temperature hazards, the Martian living environment will be primarily underground.

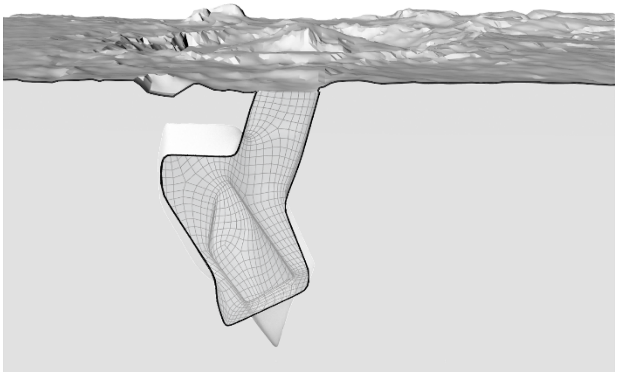

Figure 1 *Underground habitat concept*

The structure is based on a voronoi principle - where a point cloud is generated to create three dimensional polygons around it. Every point within a given polygon is closer to its generating point than to any other. This results in a more efficient use of material.

2 Context

2.1 Landscape and climate

The average temperature on Mars is minus 150 degrees Celsius (NASA, 2021). Its surface is rocky, contains volcanoes, craters, and canyons. The surface is mostly covered with red dust, which can be blown into a dust storm. These storms have the size of a tornado, and every decade a global monstrous sandstorm is formed, veiling the whole planet in dust. These storms can be a mortal threat to exploration: The global storm in 2018 killed off NASA's Opportunity rover by coating its solar panels in dust (NASA, 2021).

2.2 Radiation

Besides cold and sandstorms, there is a third, more dangerous threat: radiation. In table 1, the equivalent radiation dose per year is shown, with the corresponding shielding depth. The maximum acceptable amount of radiation for humans is 10 mSv/year (WNA, Reuters, 2020). According to table 1, the minimal required shielding depth should be at least at 300 centimetres.

Table 1 *Required shielding depth (Röstel et al., 2020)*

Equivalent dose per year	Required subsurface shielding depth (cm)					
(mSv)	AR	SS	SC	AT	W10	W50
400	79 ± 1	105 ± 1	89 ± 3	None	None	None
300	100 ± 1	131 ± 1	137 ± 2	14 ± 3	None	None
200	126 ± 1	164 ± 1	184 ± 1	39 ± 1	34 ± 1	16 ± 1
100	167 ± 1	215 ± 2	248 ± 2	84 ± 2	87 ± 1	87 ± 1
50	205 ± 1	265 ± 3	305 ± 3	133 ± 2	137 ± 2	164 ± 3
10	295 ± 3	377 ± 6	432 ± 6	240 ± 3	243 ± 3	334 ± 6

Note. AR = andesite rock; SS = sandstone; SC = sulfur concrete; AT = Arabia Terra; W10 = 10% water in the andesite rock; W50 = 50% water mixture with andesite rock .

To avoid sandstorm damage, and to reduce radiation, astronauts should find shelter in an underground habitat.

2.3 Daylight

When living in an underground habitat on Mars, another problem is receiving enough daylight. Since Mars is one-and-a-half times farther from the sun than Earth is, the sun appears correspondingly smaller in the planet's dusty sky (NASA, 2021). As a result the Mars solar constant is 590 W/m^2, while the Earth's solar constant is 1350 W/m^2.

2.4 Importance of daylight

A circadian rhythm is a natural, internal process that regulates the sleep–wake cycle and repeats roughly every 24 hours. It can refer to any process that originates within an organism (is endogenous) and responds to the environment.

3 Materials

3.1 Comparative analysis

Regarding the material used for the voronoi structure, factors like thickness and strength, source of materials, possibility to print better surface details and sharper features, and recyclability are considered. Also literature on what materials have been tested and can be produced on Mars has been studied, these were aggregates and binding agents which could be combined to get a concrete like mixture.

3.2 Selected materials

For selecting the materials, various factors such as the origin of material, visibility (opaque or transparent), printing thickness, strength, the precision of printing, performance in Martian temperatures, reaction to human skin, and recyclability of the material were considered.

Materials such as Martian concrete, biolith, and Earth concrete are studied for structural purposes as well as a finishing layer on the interiors. PLA and Silica Dioxide are studied for transparent surfaces and Silica Aerogel for insulation purposes. The materials were studied based on predetermined criteria and thereafter we assessed the materials based on their performance.

As the design progressed, we arrived at the conclusion that we would not require an additional insulating material, as the air between the voronoi shapes would act as an insulator. Based on the above elementary assessment, Silicon Dioxide would be ideal for making transparent surfaces as it will be easier to produce on Mars than other transparent materials.

For the main structure, we decided to use a combination of both Martian concrete as well as biolith. Martian concrete has a high strength compared to the other materials which is perfect for the structural layer, while biolith has a higher precision and can be in contact with humans, without causing harm or discomfort, which is more suitable for the inner layer (see figure 2).

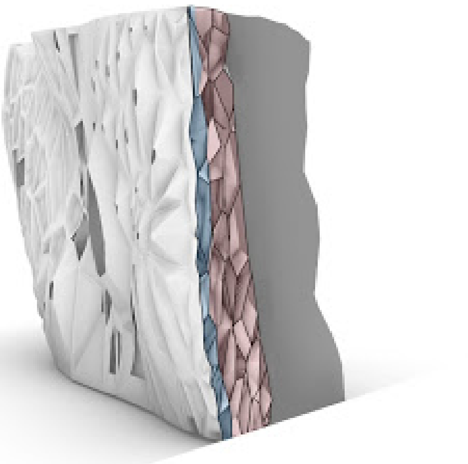

Figure 2 *Material layers (biolith in blue, Martian concrete in red)*

4 Fragment

4.1 Development

To develop the fragment, first the structural analysis was done. Based on this we were able to generate a point cloud with the required thickness and offset. Based on these thicknesses and the structural requirements another point cloud was generated. Together with vectors we were able to transform this point cloud into the voronoi structure. The voronoi is more open at the places where the structural requirements are low, and more closed where the requirements are high. Finally, the sub-surface has been optimized to integrate the planned functions by creating bigger sized voronoi at places that structurally allow it.

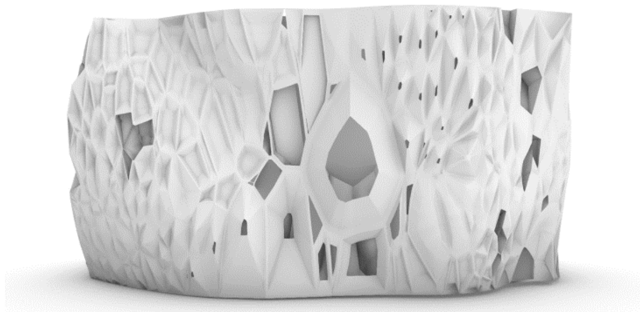

Figure 3 *Material layers*

Architecturally, in the voronoi design, three scales of Voronoi have been used (see figure 3). These voronoi patterns can be open or closed and allow deep optical variety within the envelope.

5 Functions

5.1 Function integration

The finishing layer has many functions integrated within the voronoi shapes, such as integrated plants, lighting, utilities and furniture. The integration happens through all scales, the bigger voronoi shapes can form shelter for astronauts, while the smaller shapes can house lighting elements.

5.2 Furniture and plants

The biggest size is used to integrate furniture where the astronauts can withdraw themself inside the envelope to find a embracing place to relax. The middle size voronoi will be used for the integration of plants and storage.

5.3 Lighting

The smallest sized voronoi will be used to integrate an artificial intelligent lighting system. This intelligent lighting system is able to vary with the different moods we want to create in different rooms or areas, based on the time of the day, the activity of the inhabitant, and the corresponding preferred mood.

Here, we distinguish between the colours and uniformity of light - for example, the work areas should be bright and uniformly distributed with cooler colour tones to optimize focus and productivity. On the other hand, areas to relax can be dim and non-uniform with warmer colour tones, possibly creating patterns and colour variations.

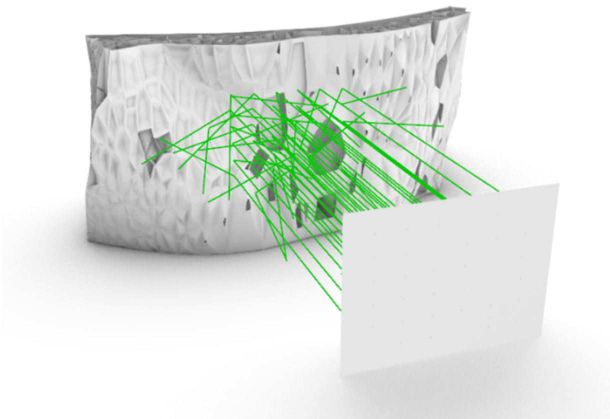

Figure 4 *Diffuse scattering light analysis*

As mentioned before, a three scale open and closed voronoi pattern is used, and one of the reasons to do so is to create a diffuse reflection of the light. Figure 4 illustrates a proof of concept to show how the light scatters in a diffuse reflection after it hits the voronoi envelope. This creates a positive impact on the quality of the plants, because the top leaves will create less shadow for the leaves that are behind them. It also creates a more soft environment to improve the occupants comfort (Hansen et al., 2021).

6 Integrated Artificial Intelligence

Light has a huge influence on the way we experience space. This influence is based on the colour, temperature, and intensity of the lighting. However, every individual responds differently to certain light characteristics. This knowledge in combination with the difficulties in lighting distribution in space habitats, allows the integration of an artificial intelligent lighting system. This system will be able to learn and respond to the different preferences and bodily states of the cyber-space inhabitants.

6.1 Deep learning preferences

The data collection of individual preferences for task related types of lighting can already be done on earth. This will be done by executing light changing experiments in combination with a survey. The bigger the data set, the more precise the algorithm will be able to learn the individual preferences, which gives a personalized lighting environment as output.

6.2 Measuring bodily states

The lighting preferences will be combined with the current bodily state of the inhabitant. In this paper we distinguish between three different states: focus, relaxation, and sleep. The measuring of these different states can be done by providing the inhabitants with wearables of choice, ranging from a smartwatch with integrated heart rate sensor to a brainwave device collecting raw EEG data. The choice of wearable can be made based on usability versus data precision. The data from the wearables can be transformed to standardized lighting colour, pattern, and intensity outputs, creating an personal optimized living/working environment.

7 Conclusion and discussion

The Design-to-Robotic-Production (D2RP) process presented in this paper is unique in the way it integrated functions in the different voronoi scales. This process involved the design and the optimization of material distribution to achieve completeness in the integration of functionalities. Considering the integration of lighting inside the envelope, further research should be done on the psychological and physiological effects of permanent dim light on humans. Moreover, the ability of an artificial lighting system in compensating the lack of sufficient daylight for very long stays.

Additionally, more research should be done about the integration of more individual datasets using the same space.

Considering the integration of furniture and plants, further research will be needed to investigate the optimization of comfort in the integrated furniture. This can be done by modelling and testing large scale prototypes. On the other hand, more research should be done about the integration of a hydroponic system to care for the integrated plants in the envelope.

8 References

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