The Martian Wall

Optimizing a Wall Fragment for 3D Print Construction on Mars

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Focus and restrictions- This report focuses on computational optimization for structural efficiency, life support integration and 3d printing production of a wall fragment

Abstract – Computational tools allow to test and optimize structures for load bearing efficiency, less material usage and multi-functionality. In this report a strategy for designing and constructing a wall fragment through additive technology is being presented. The context of design is the Martian habitat developed by TUD for the Open Space Innovation Campaign ‘Off-Earth Manufacturing and Construction’. The process focuses on Design to Robotic Production and Operation (D2RP&O) which integrates Algorithmic design, Simulation of Robotic 3d Printing.

Key words– Parametric Design, Computational Design, 3d Printing, Robotics, Design to Robotic Production, Design to Operation

1. Introduction

The aim of this course is to propose a concept idea for housing on Mars. Where the astronauts are safe from the harsh conditions on the Martian surface. It has been proposed to make a housing that is underground, as it is speculated that 1-2.5 meters of marching ground would be sufficient to limit a large part of the radiation present, also temperatures in the ground will be more stable than at the surface.
We aim for a Voronoi structure, mainly to save material and to strengthen weaker spots by compacting the Voronoi structure.

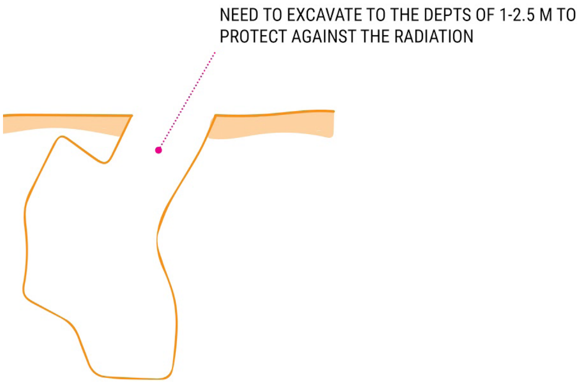

Figure 1. Underground housing concept

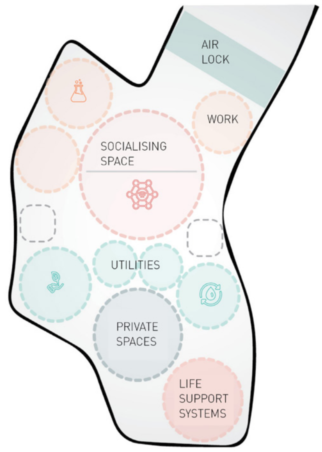

Figure 2. Spatial Planning

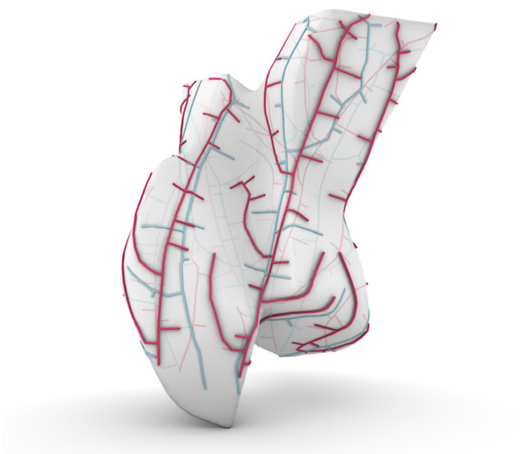

Figure 3. Life Support Canals : Concept

2. Design Context

For spatial planning, a vertical hierarchy of spaces was proposed (Figure 2). The active spaces were located near the entrance of the habitat and the passive spaces were located deeper. A large central space was provided for the social and recreational activities of the astronauts. For the transportation of life support throughout the habitat, a canal system was proposed (Figure 3). The canals act as the blood vessels of the habitat, making it a place suitable for life. The canals were designed integrated within the structure. The Voronoi around the canals were densely populated to improve the insulation. This method is further explained in section 4.

3. Material Choice

For 3d printing on Mars new materials were considered such as Martian biolith (Shiwei et al., 2020) and regolith (Readers, n.d.). The first design approach included a two layered wall of two materials, Martian Biolith, as an insulating layer and concrete for structural support. However, it was concluded that this approach was problematic in terms of 3d printing and failure due to the different thermal expansion coefficients. Consequently, concrete is being chosen as a single for 3d printing a wall, due to its high strength. The wall will be optimized for thermal insulation by creating Voronoi cavities.

Regarding the concrete choice for 3d printing a filler such as Martian regolith can be used. As for binder Ordinary Portland Cement is being chosen due to its high strength and the possible availability of Calcium Carbonate on Mars (Reches, 2019).

4. Designing the Wall Fragment

For the design of the wall, the utilization map was first rendered on the habitat unit, to visualize the stresses, later used for optimization. A wall fragment of 1.5 x 1.5 meters was isolated and was studied in detail. This part was extruded between a range of 50 and 80cm according to the utilization map. Points inside the extruded solid were then generated and their population responded to the structural analysis, as well.

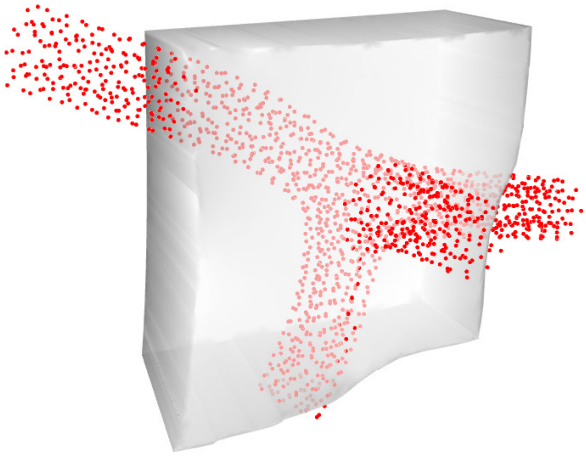

Figure 5. *Points that are used to Generate the canal Voronoi's*

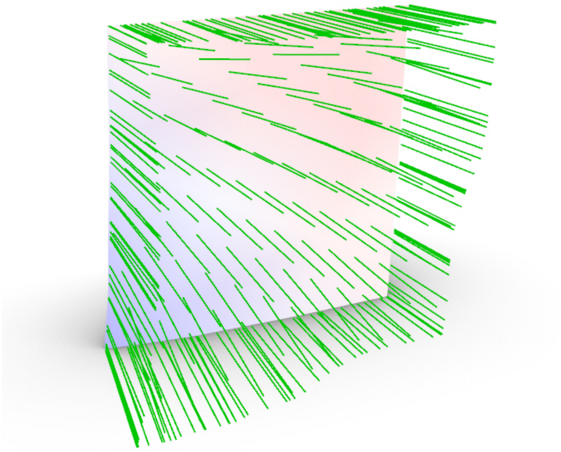

Figure 4. *Structural Optimization*

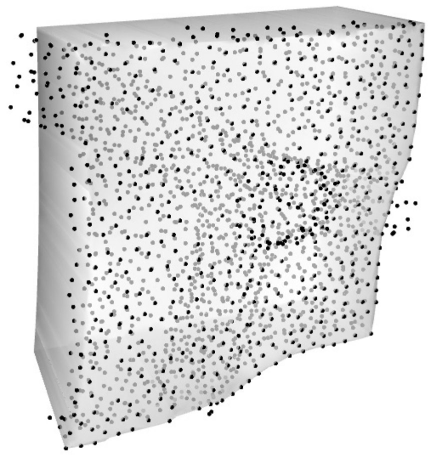

Figure 6. *All the points that are being used for the Voronoi rendering*

For creating an insulating layer on the wall, more points were populated in the inner side of the extrusion, while keeping a minimum proximity distance of 6cm, which is the minimum size for the 3d printed Voronoi's. Integrating the life support system, canal cavities were needed. To create them the Voronoi generation method is used. We started by assuming a needed canal and then points, 6 cm apart, were generated in the axis of our canal. Two offset-ed auxiliary mesh pipes were we also populated with points and through simulating collision it was ensured that they kept a minimum distance of 6cm. Then all the points were combined to generate the Voronoi meshes.

Faces can be printed when the angle with the print bed is more than 45 degrees. Meshes that are less than 45 degrees were culled. Also, the ones that were overlapping with the canal's axis were deleted. A skin on the inner side was finally created with an access point for sensors and actuators. The gradient density of the points previously generated also results in a gradient effect of the Voronoi cavities which we assume will improve the insulating properties of our wall.

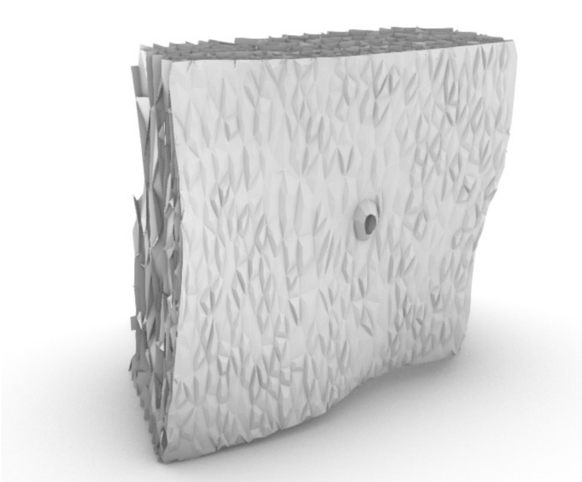

Figure 7. Final Wall

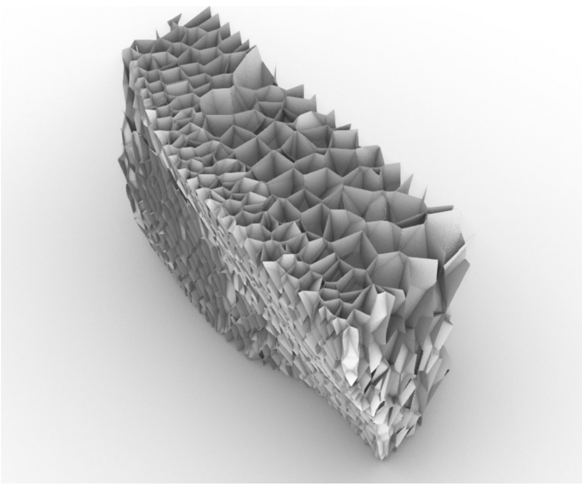

Figure 8. Voronoi Gradient

5. Operations

The habitat must have an environment similar to Earth. To achieve that, it must have the following aspects: 1. An atmosphere similar to Earth. 2. Removal of Carbon dioxide. 3. Removing contaminating or trace gases. .4. Normal humid environment (Craig Feudenrich, 2014). For the course, the Atmosphere Control and supply aspect was looked into, more specifically Oxygen Control Systems. The sensor network onboard the International Space Station (ISS), the WiSe-Net (Wireless Sensor Network), was studied for a general overview (Stenzel, 2016 Aug 15). The wireless communication onboard the ISS is established by different technologies. After a detailed comparison between the available technologies (Stenzel, 2016 Aug 15) the RF communication (Ultra-Wideband Radio Frequency Communication) was considered the best option. This system can be operated without batteries but by using microelectromechanical devices (MEMS) in combination with low-power communications (Stenzel, 2016 Aug 15). A general study of the sensor-actuator network shows a closed-loop system. The sensor reading is used as an input for the control system which controls the setting of the respective actuator that modifies the probe accordingly (Stenzel, 2016 Aug 15). The oxygen control system consists of two major components: 1. a Potentiometric (pO2) sensor. 2. An oxygen titration pump (Stenzel, 2016 Aug 15).

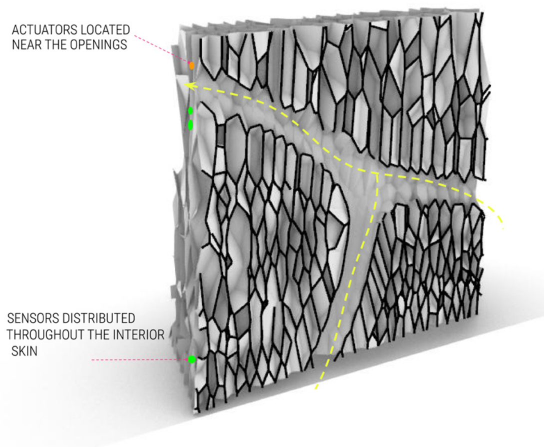

Figure 9. Location of Sensors/Actuators: Concept

For the habitat, the sensors are distributed throughout the interior space with a considered range of 50x60 m. The actuators are located at the access points of the canals for faster response time and control (Figure 9). The acoustic performance of the fragment was also tested. The interior skin without any surface treatment was checked for its acoustic properties. The presence of convergence zones of sound waves was observed. To also improve the acoustic performance of the wall the Voronoi on the skin were extruded by varied values to create undulations. After testing the sound transmission for the optimized version a better distribution and scattering of sound waves were observed.

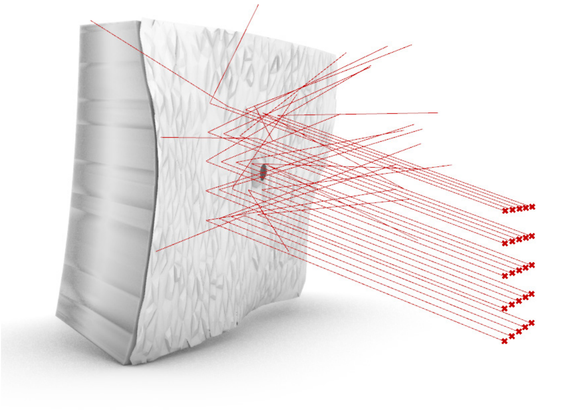

Figure 10. Acoustic Stimulation

6. 3D Printing Production

We propose a New structure for printing the housing, we do this by making use of the research of civil engineering. They excavate a downwards spiral down around the housing volume to create a strong hull (Dr. Henriette Bier & TU Delft team, 2019). Based on this idea, we want to start excavating from the bottom up in a spiraling movement, while the voronoi structure is gradually printed.
In simpler words, when the tunnel is excavated in an upwards spiral the voronoi is then printed directly after the excavation. A "hole" in the previous structure will have to be left for the robots to supply and remove materials. Once at the top, the regolith that still remains within the proposed housing volume can then be excavated and the holes in the voronoi can be filled again in a downward spiral. This technique will ensure that there is no possibility for the cave to collapse. But most importantly, less material will be needed due to the lack of supports. When first excavating and then 3D printing from below, support for the more horizontal parts will be necessary. This construction proposal saves material and guarantees construction security.
Printing is done by means of layers, which can be pre-calculated in a computer program. Or by a robot directly in situ. With this, the computer divides the part to be printed in layers, which then can be changed to a continuous tool-path as the printing process can't be interrupted. the continuous tool-path can then be made by the printer into a voronoi shaped construction.

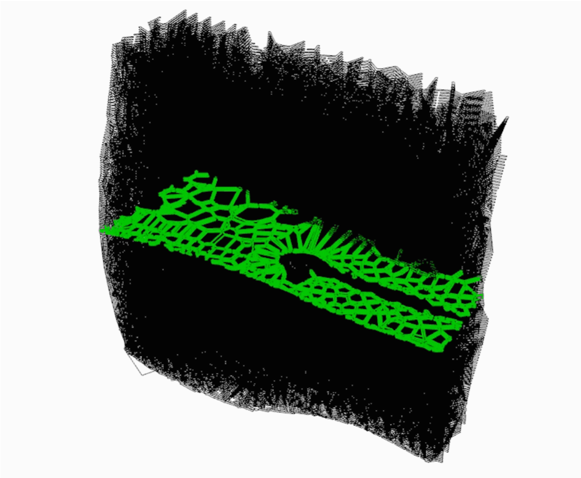

Figure 11. Continuous tool-path

7. Conclusion

Geometry optimization through computational methods is an effective method to achieve the optimum structural performance using less material. In addition to this, these methods allow to ingrate further qualities to the final structure such as acoustic and thermal insulation. This layer however must also be tested in real conditions.

For extra-terrestrial colonization the possibility of using a single material, locally available, to build multi-functional structures is a method that could ease construction in the early stages of extra-terrestrial colonization

8. Reflection

Reflecting on our project we see some things that require further research. The insulating improvement by creating a gradient Voronoi's must be verified experimentally. Also, we acknowledge the fact that this design choice causes an increase of the wall's self-weight and the production time.

For the operations, there is a need for further in-depth research; regarding the necessary sensors and actuators and their specific requirements. The airtightness of the canals needs to be verified experimentally and optimized according to the life support requirements.

Regarding the material choice, a considerable improvement would be integrating fibers in the concrete mixture. This could also contribute to the generation of a more effective material in terms of structural performance.

After the prototype it could be suggestive that the angle at which the voronois are deleted in the script is too low. Light bridging is still occurring, suggesting that printing is taking place around some spots in the air, and bridging is not possible at this moment with a fluid filament for the continuous tool-path. Further research and prototyping is hereby necessary.

Figure 12. Prototype of PLA 1 : 0,07 (FDM)

9. References

- Craig Feudenrich, P. (2014, November 19). How Space Shuttles Work. Retrieved from How Stuff Works: https://science.howstuffworks.com/space-shuttle4.htm#:~:text=The%20cabin%20pressurization%20system%20combines,of%20fans%20circulate%20the%20atmosphere.

- Dr. Henriette Bier, MSc. Arwin Hidding, MSc. Arise Wan, MSc-cand. Edwin Vermeer, MSc MSc-cand. Krishna Jani, MSc-cand. Emma Chris Avramiea, and MSc-cand. Siddharth Popatlal Jain. (2019). Rhizome: Development of an Autarkic Design-to-Robotic-Production and -Operation System for Building Off-Earth Rhizomatic Habitats. Retrieved from: http://cs.roboticbuilding.eu/index.php/Shared:2019Final

- Readers, G. (2020). Literature Study Survey. 7–8. http://cs.roboticbuilding.eu/images/7/7d/Regolith_as_future_habitat_construction_material_-_Willem_Hoekman.pdf

- Reches, Y. (2019). Concrete on Mars: Options, challenges, and solutions for binder-based construction on the Red Planet. Cement and Concrete Composites, 104(December 2018), 103349. https://doi.org/10.1016/j.cemconcomp.2019.103349

- Shiwei, N., Dritsas, S., & Fernandez, J. G. (2020). Martian biolith: A bioinspired regolith composite for closed-loop extraterrestrial manufacturing. PLoS ONE, 15(9 September), 1–11. https://doi.org/10.1371/journal.pone.0238606

- Stenzel, C. (2016 Aug 15). Deployment of precise and robust sensors on board ISS-for scientific experiments and for operation of the station. Anal Bioanal Chem. 2016 Sep;408(24):6517-36. doi: 10.1007/s00216-016-9789-0. Epub. PMID: 27526089; PMCID: PMC5012259.