OUTFITTING A MARS HABITAT

Project by team:
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1 High level project summary

The team is developing further a project of outfitting Mars habitat. Team participated at NASA's Space Apps Hackathon, where it tackled a challenge of designing tools, furniture, and other items to assist astronauts on a one-year long mission on Mars. The approach was successful, and the team won Best Use of Technology award.

The objectives of the initial challenge were to design tools, furniture and other items for a one year long mission on Mars and find means to repair equipment when needed, e.g., rover wheel. Assumptions were made that habitat is equipped with materials extraction equipment, that can extract local resources such as metal, polymers and also use regolith which amounts are vast on Mars. Also the habitat on Mars is assumed to be equipped with the three printers, which have build volumes (length x width x height) and their resolutions as follows:

- Metal: 150mm x 100mm x 100mm, 0.1mm resolution
- Plastic: 310mm x 130mm x 140mm, 0.1mm resolution
- Concrete: The concrete printer can make giant objects, but it's outside the habitat. Anything you make to go inside your habitat must fit in the 2m x 2m x 2m airlock and decontamination area. 25mm resolution

After a rough landing on Mars there is an overwhelming number of choices what to tackle first to survive a yearlong mission. Although the procedures are rehearsed on Earth multiple times, in such circumstances it is wise to have a structural approach. Our team did just that. We have developed a structure of interchangeable parts – the building blocks for the assemblies and systems that may be needed on Mars. Considering the most important habitability areas such as waste removal system, crew morale, as well as including tooling lost during landing and a rover replacement wheel, we show how the same parts can be combined in many different assemblies. Thus, saving the scarce materials.

Thanks to Xibei Chen from DoraHacks reaching out to us and providing with the opportunity to apply for DoraHacks Space Resources and Exploration Grant. The grant opens up an opportunity to develop project further. And although some of the aspects of the initial project might seem surrealistic just now, they are definitely the initial steps towards the interplanetary future. In addition some of the technologies that were developed during the initial project can be applied on Earth already today. The team would be interested in deepening the knowledge of topology optimisation and additive manufacturing techniques. Thus the Grant would allow to continue work on topology optimization algorithms using Rhino Grasshopper and search for additive manufacturing techniques which can be used on Earth and other planets or natural satellites such as Moon.

2 Detailed project description

Although NASA's research on Deep Space Habitability identifies hardwired workstation, waste removal and recycling system, viewing window and private crew quarters as capabilities essential or significantly enhancing the missions, the rough landing complicates this challenge. Thus, tooling and replacement parts such as rover wheel become equally essential for the yearlong mission.

Our approach provides the database type structure of the building blocks that can be used for multiple purposes. By combining a limited number of parts many different assemblies can be created. To illustrate the approach, we have developed models of some tools. For example, by having an interchangeable handle and a screwdriver holder, tools such as screw drivers, knives, hand cranked drills can be assembled. Illustrations of these hierarchies are presented in the slides. Chart illustrating one branch of the tools is given in Figure 1.

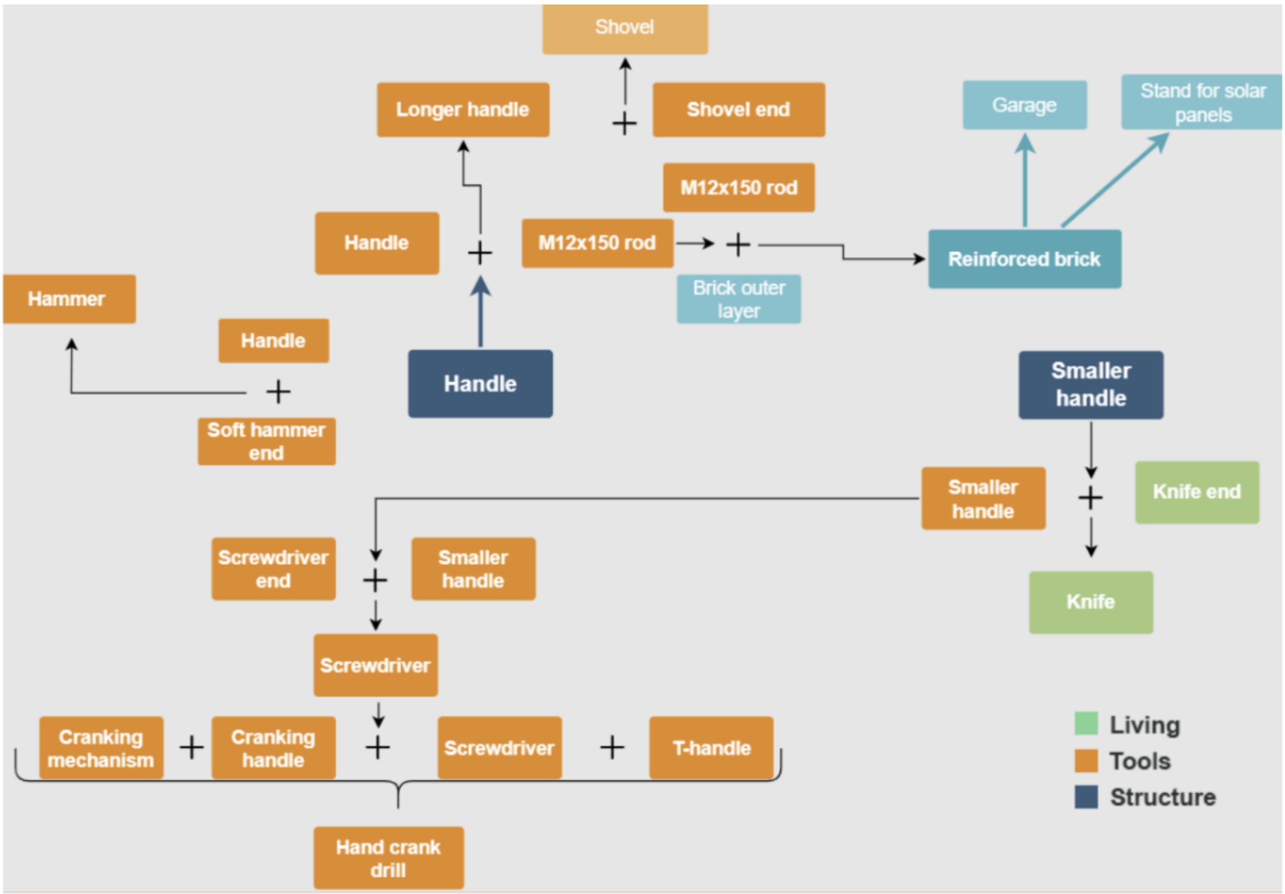

Figure 1. Structure of building blocks

2.1 Tools for printing

This section describes a few tools that were considered for printing. It was assumed that for metal printing powder bed fusion (SLS) is used while plastic parts are printed using material extrusion (FDM). This assumption eliminates the need for supports while printing metal parts. Although most of the metal parts were designed keeping in mind that overhangs shall be avoided.

Most of the assemblies such as knife, screwdriver, hand crank drill etc., utilize interconnecting parts. In our initial design these connections are modelled as threads, but given more time would be changed into quick snap connections where possible.

Figure 2. Screwdriver end and small handle mating

Cylindrical parts would ideally be printed upright (where dimensions allow) to have concentric print layers and less overhangs (even though overhangs are less of a problem with SLS technology)

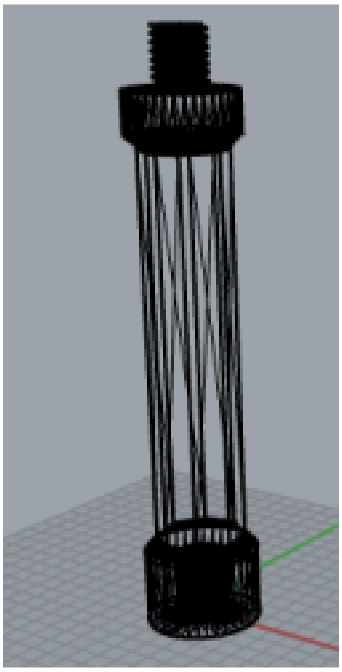

Figure 3. Handle positioning for printing

2.1.1 Hand cranked drill body

The hand cranked drill body has most of its features designed on the one side while the other side is kept flat. The similar design approach is also applied to other parts.

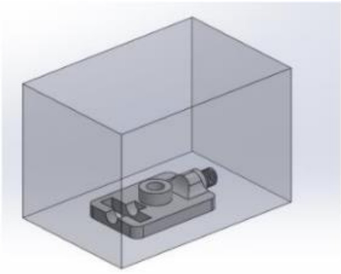

Figure 4. Hand cranked drill body in the metal printed bed volume

2.1.2 Print in Place Universal Socket

The print in place universal socket utilises both the metal and the plastic printer. The concept of this type of universal socket uses springs, however since springs of such small dimensions cannot be printed while maintaining their mechanical properties, a soft layer of printed TPU plastic is used to provide the necessary spring back action.

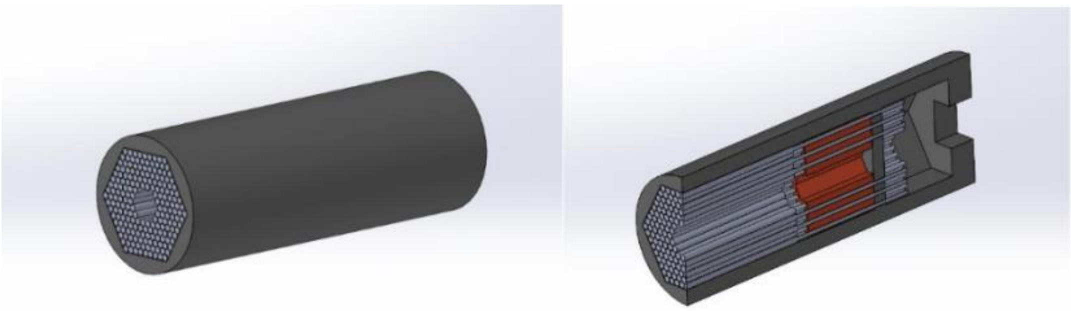

Figure 5. Universal socket model

The print requires to be paused when it reaches the dedicated point where the separately printed soft layer is placed onto the assembly and the print is resumed to complete the part. [link](#) to patent of original concept utilizing springs.

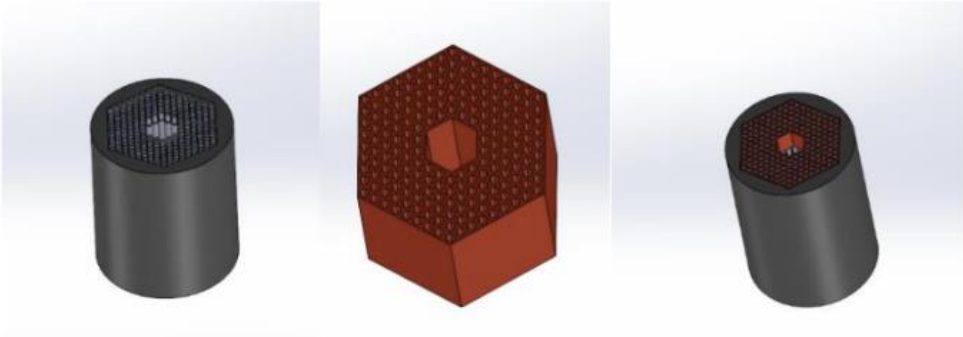

Figure 6. Metal and plastic parts of the universal socket

2.2 Model optimization

The models can be further developed, and topology optimized. We approached this using Rhino Grasshopper software, which allows to do parametric modelling and design. We have decided to create a proof-of-concept tool, that would allow to divide any given solid body into cells and apply multipipe at the boundaries.

This tool would allow to have quick and easy mass or geometry optimization. Most of the parts would be easily printable without the supports. With additional optimization, this can be done as a default tool feature. This is especially helpful while saving mass with general elements like bricks, handle and various other elements that would require higher volume, but does not require especially and relatively high stiffness.

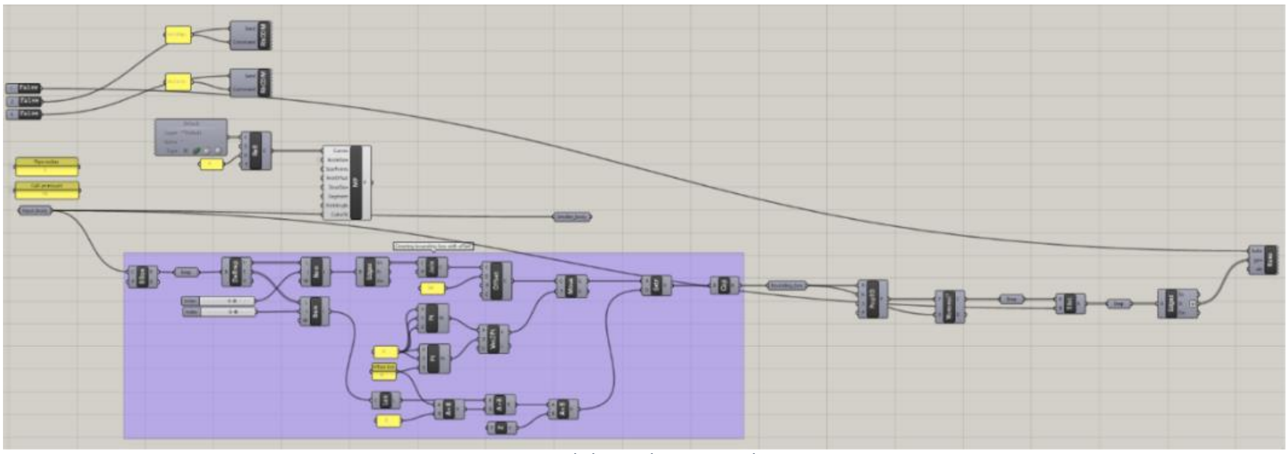

Figure 7. Script module in Rhino Grasshopper

Currently there are 3 main inputs:

- Solid body geometry
- Pipe radius
- Amount of cells / density of part

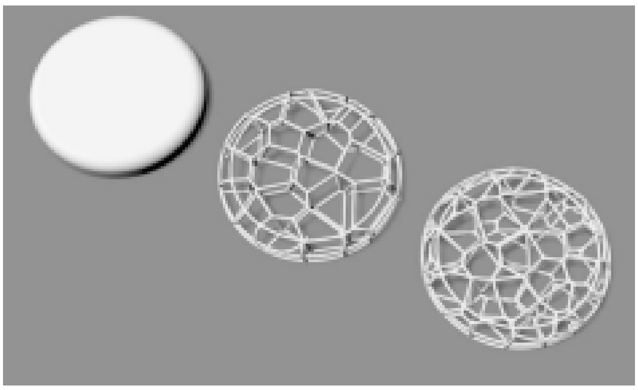

Figure 8. Example of solid body being reduced to cells in two different densities.

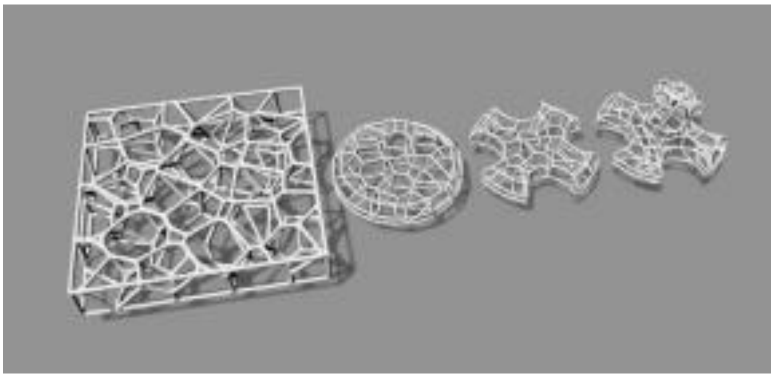

Figure 9. Example of different shapes being reduced to cells.

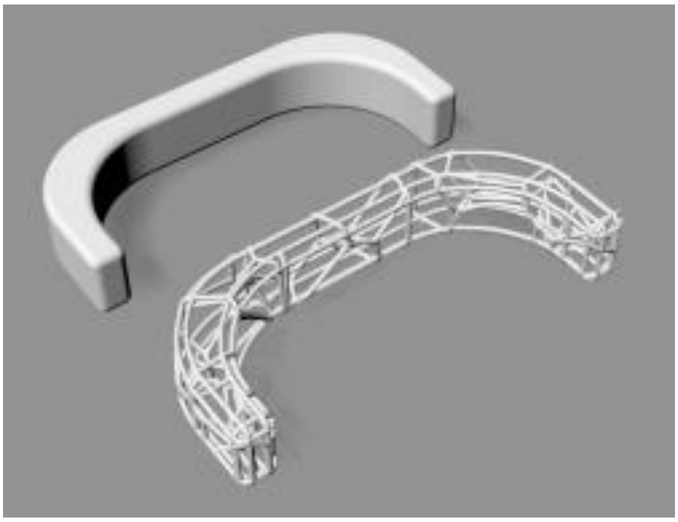

Figure 10. Part, we designed, has been optimized to reduce material volume needed to print.

Changing part from full volume print to optimized boundaries takes only a few minutes, while doing it in 3D design software manually, would require way more effort and it has to be done all over again with a new part.

2.3 Rover wheel

In addition, we have developed a printable rover wheel. The full-scale rover wheel was considered - 20.7” in diameter. To fit on a printer bed, we are making the wheel of the several parts and printing on both printers, metal and plastic. That also helps to save precious metal. The wheel consists of four metal hub parts that are assembles with printed screws made for the purpose. The outer wheel or the “tire” is also made of four metal rings segmented into 12 segments to fit on a printer bed. While the middle of the wheel is made of plastic honeycomb pattern sections, that interlock together. To check the feasibility of using plastic for the rover wheel in our design, we ran a quick static simulation, that gave us a safety factor of 1.3 for Earth conditions taking the conservative plastic yield strength of 13.5MPa. While on Mars we are getting the safety factor of 3.75 due to the lower gravitation.

The mars rover wheel is designed with the idea of a 3D printable wheel which is build out of segments. The design approach was to make something that would be interchangeable, easily replaceable and would still overcome the loads from the rover. You can say that the wheel is made out three “Pizzas“ and one „Wheel pizza“ is made of 12 Pizza slice formed segments and the middle shaft hub. The Pizza sliced segments are made from two parts, which are made from two materials, utilizing the metal printer for its strength and plastic for its lightness and bigger printer zones. The pizza slices will inter-connect with each other through the honeycomb structure pattern as shown in Figure 11. They would fit into each other and hold together due to the Mars rover weight loads. This is better illustrated in the supporting challenge documentation.

Figure 11. Honeycomb pattern interconnection

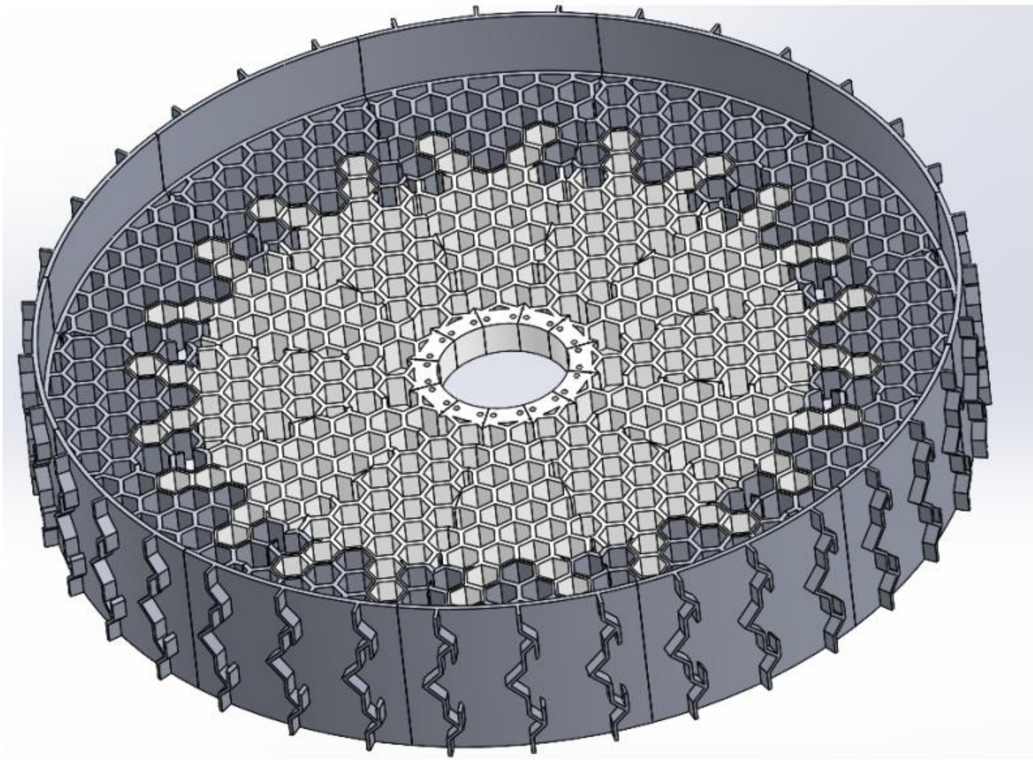

Figure 12. 1/3rd segment of the rover wheel

3 Space agency data

The most important Space Agency resource that we have used in our project was NASA's report on Deep Space Habitability Design Guidelines Based on the NASA NextSTEP Phase 2 Ground Test Program. That report has provided the clear guidelines on what are the essential capabilities in a deep space habitat and helped us to better understand how to tackle the chosen challenge. This let us define area for which interchangeable printable parts would be necessary. In addition, we have reviewed the NASA 3D models database to see what tools are already available. Moreover, we have reviewed NASA's Analog Missions to get a picture how missions are simulated here on Earth.

4 Summary and further steps

To summarize, in the initial project the database type structure of the building blocks has been established, and some examples of 3D models were presented. The models were designed taking in consideration scares materials on Mars. The minimum viable product of the topology optimisation algorithm was developed to further reduce material needs. Also, rover wheel replacement was developed, which can be produced and assembled on Mars thus giving the opportunity to repair damaged equipment.

The team tAMing particles is now seeking to further develop the project shifting focus towards additive manufacturing techniques which would be viable on other planets and natural satellites such as Mars and Moon. In addition, the team would like to develop topology optimisation algorithms in Rhino Grasshopper further.

5 References

1. All 3D models were created by the team.
2. NASA/TP-2020-220505 - Deep Space Habitability Design Guidelines Based on the NASA NextSTEP Phase 2 Ground Test Program [November 2019] was used as a reference to define important habitat capabilities.
3. https://www.nasa.gov/analogs
4. https://patents.google.com/patent/US5644959A/en was used as a reference and inspiration designing universal socket head.
5. https://www.nasa.gov/chapea