

# Red Oasis: A Voronoi habitat for Martian terraforming

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## Abstract

The course engages in an investigation for a human habitat on Mars, designed through voronoi based computations, 3D printed with robotics and assembled through human-robot collaboration. Red Oasis, the final design of the project, is a Martian habitat that houses two researchers working on the initial stages of terraforming Mars through farming.

## 1 Introduction

Information regarding the climate and topography of Mars will be investigated to inform the conceptual design of the habitat. The design shall take into account spatial arrangements and functional programs that facilitate life in outer space.

### Storyline:

Two researchers have been selected to set up the first Earthling colony on Mars. Their mission is to collect soil and environmental data as the first step to one day colonize Mars! If this mission is successful, humankind will have their first agricultural farm in outer-space.

## 2 Background Research

Climate, landscape, and agricultural possibilities of Mars will be investigated to provide site context, while requirements of space habitats will be investigated to supplement key design dimensions for designing in outer space.

### 2.1 Climate on Mars

Climate of Mars is essentially that of a cold desert, it has the average temperature of -80F, with much of the surface of the planet covered in volcanoes, canyons, and impact basins, the landscape is essentially carved by wind and dust (Figure 2). Although dust storms are common on Mars, the atmosphere on Mars is a hundred times thinner than on Earth. Therefore, force from windstorms are not sufficient to damage buildings. The atmosphere on Mars also contains more than 95% carbon dioxide and less

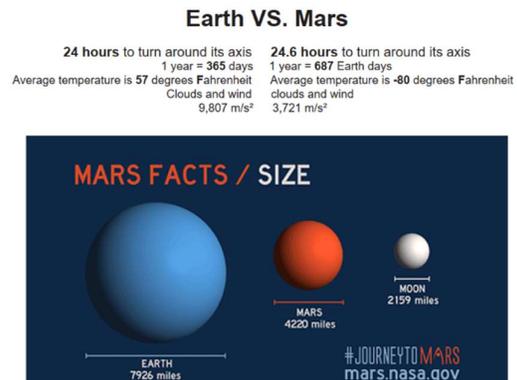


Figure 1: Earth and Mars comparison

than 1% oxygen. Radiation harmful to humans is also present on Mars. Therefore, astronauts will not be able to move freely on Mars without protective suit that supplies oxygen.

Oxygen can be created by a device brought by the Perseverance rover (Figure 3), which landed on Mars on Feb. 18, 2021. It functions similar to a tree, taking in large amounts of carbon dioxide and exhale oxygen (NASA, 2021).

Water on Mars is found mostly in form of ice caps at the Martian South Pole. However, studies have found intermittent flow of water on present day Mars creating hydrated salt streaks along slopes in the landscape (Figure 4)(NASA, 2015).



Figure 2: Mars landscape

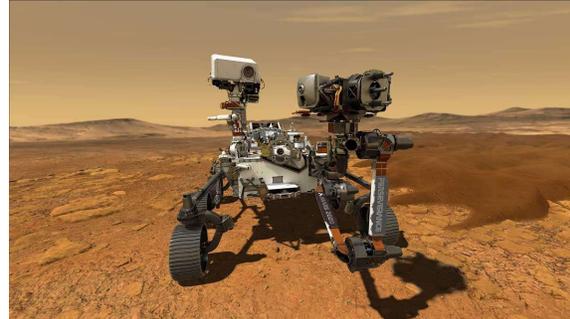


Figure 3: Salt streaks on Mars proving intermittent flow of water (Source: NASA)

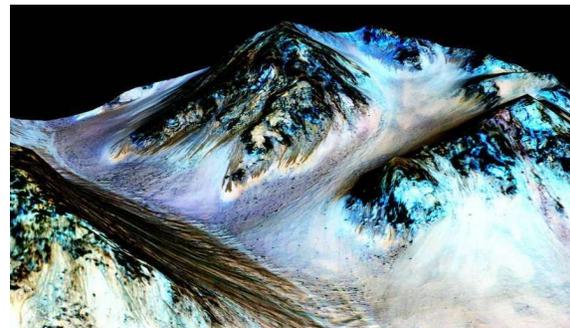


Figure 4: Salt streaks on Mars proving intermittent flow of water (Source: NASA/JPL/University of Arizona)

## 2.2 Planting on Mars

Soil on Mars is similar to iron rich volcanic soil on Earth, making it difficult for plants to grow. Since, planting is a big part of our design concept, we have investigated the potentials of both in-situ soil planting and aquaponics.

In-situ soil planting:

Research shows that alfalfa plants can survive the tough volcanic soil that covers Mars and can be used as biofertilisers to enrich local soil for future planting of edible crops such as turnps, radishes and lettuce (universetoday, 2022). These crops grow well in simulated Martian soil



and are low maintenance with rapid growth rates.

**Figure 5: Alfafa plants (Source: Universetoday.com)**

Hydroponics with artificial light:

Hydroponics offer high yield in smaller areas, nutrients can be brought from Earth and added directly into the water, artificial lights can be added to aid growth. However, it is not possible to grow deep rooted plants such as pumpkins, potatoes, cabbage etc.



**Figure 6: Conceptual image of hydroponics on Mars (Source: Nasa )**

### **3 Concept & Design Process**

Our first step involves compiling a list of user's needs a comprehensive list of the required regions as dictated by the design specifications. We then proceed to allocate the appropriate sizes to each pod based on their intended functions, followed by a strategic placement of the pods for optimal functionality. The living pod and three greenhouse pods, each of varying dimensions, are positioned around the central laboratory pod. All the pods are interconnected with the use of safety doors which are designed to separate the pods in case of any potential leaks, thereby ensuring the safety of the entire habitat. Our design incorporates a Voronoi system for the interior wall, featuring varied sizes and densities based on the intended use of each pod. The Voronoi cells within the greenhouses are deliberately bumpy in nature, comprising small, elongated cells that are ideal for use as pots for plants. In contrast, the Voronoi cells within the living pod are larger and smoother in texture, providing an optimal storage environment for living essentials while also enhancing the comfort and livability of the habitat for its inhabitants.

### **4 Component**

We abstracted three components from the Voronoi-based concept and focused on those for the production process. We chose the components based on predetermined size requirements so that the robot could handle them. They had heights ranging from 550 cm to 450 cm, which created an intriguing and appealing aesthetic.

After the components were selected, we started preparing the grasshopper script for the milling process. From a single large foam block, the components would be milled out separately, so we made three different files based on the provided grasshopper script. The first script is being used for rough milling to get the foam block down to a general shape approaching the desired component. The second script is then used to control a smaller bit size for milling that is more detailed. Less material is milled away, as the focus is more on achieving the required smoothness and precision on the surface.

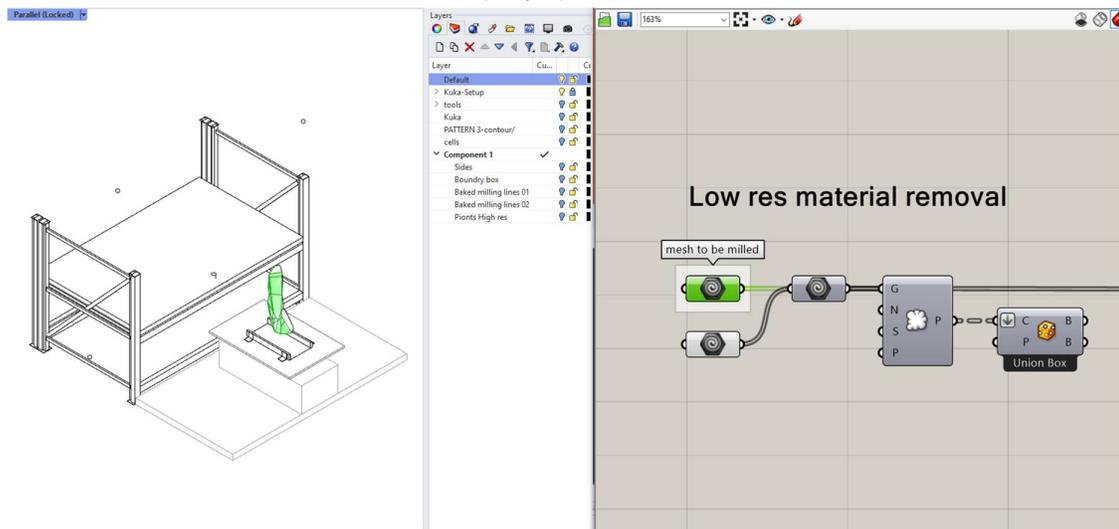
After the primary milling was finished, we used Grasshopper to decide where to drill holes so that the robot could grab the components and assemble them. With the original script, the intention was to randomly generate the location of the holes. To allow for human interaction, these areas had to be on

the same side and as far apart as possible from one another. Additionally, we wanted to give the holes in our design concept a second use since they could be used as plant pots inside the habitat and the greenhouses. In order to accomplish this, every hole had to face the interior of the constructed habitat. However, the random generation did not give us such a required solution even after going through 500 options. In the end, we altered the script to manually select the desired surfaces for milling the holes.

## 5 Production Process

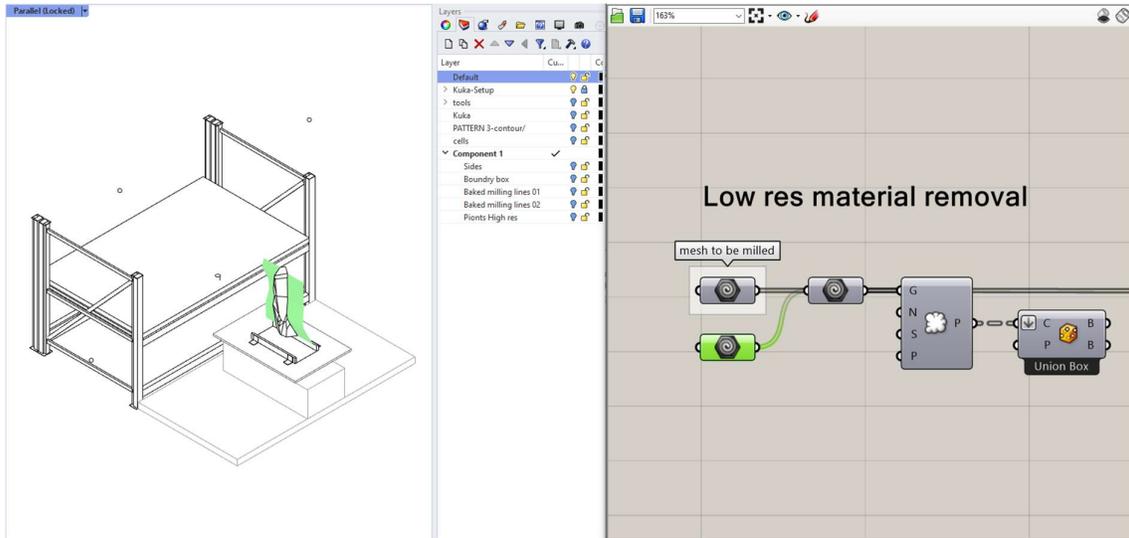
### *Part 1: milling components*

Each piece of the component was placed into the Rhino production file and then linked to the Grasshopper production file. In the first step, the meshes of the component were exploded and the faces on one side were selected and linked (Step 1).



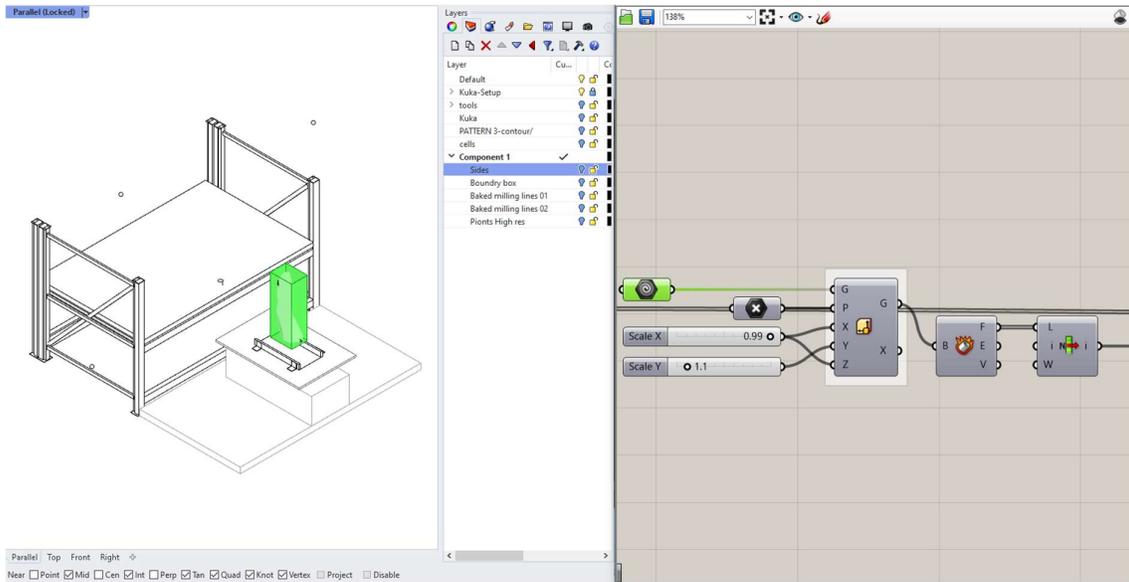
**Step 1: set multiple geometries, and meshes of the components**

After creating the side meshes, the robot arm can mill until this region. These sides are linked to the Grasshopper script (Step 2). Next is to populate points within the previously selected geometry. A bounding box is created based on this geometry.



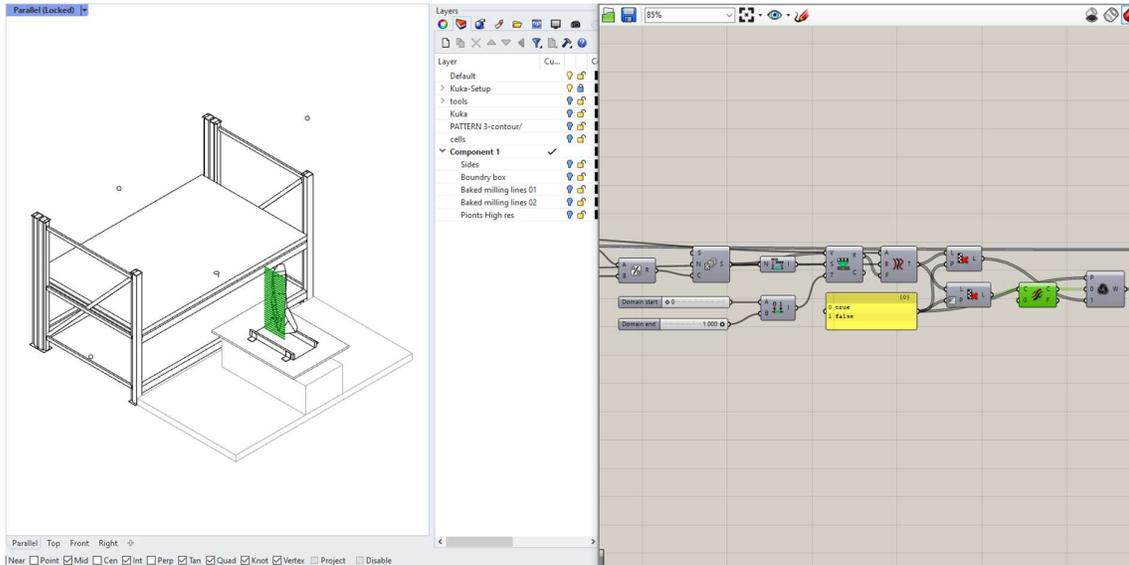
**Step 2: set multiple geometries, and side meshes of the component**

The next input is a bounding box drawn in Rhino and linked to the script (Step 3). Then the script creates a bounding box that is slightly bigger than the box from Rhino (Step 4).



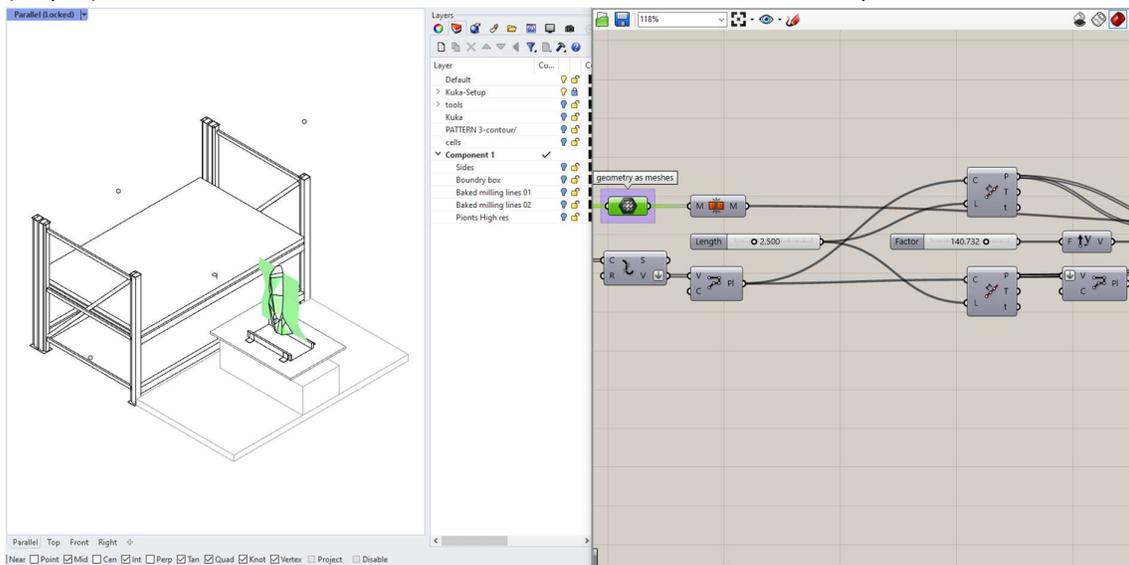
**Step 3: set one geometry, bounding box**





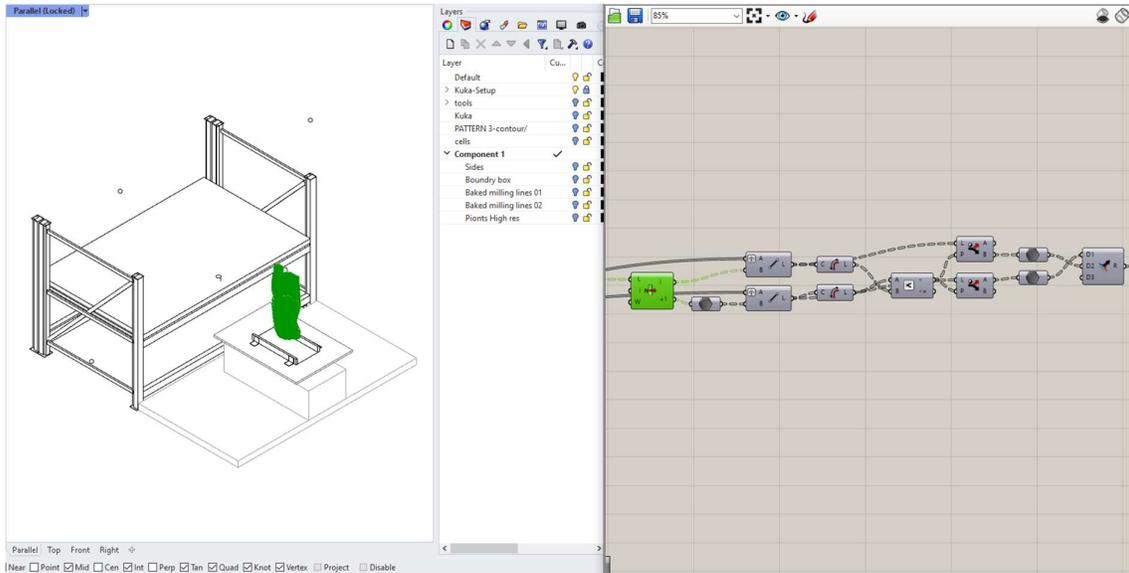
### Step 6: horizontal curves

The geometries of one side, which were imported from Step 1 and Step 2, will be turned into meshes (Step 7). The surface that the robotic arm has to mill out for the component to be revealed.



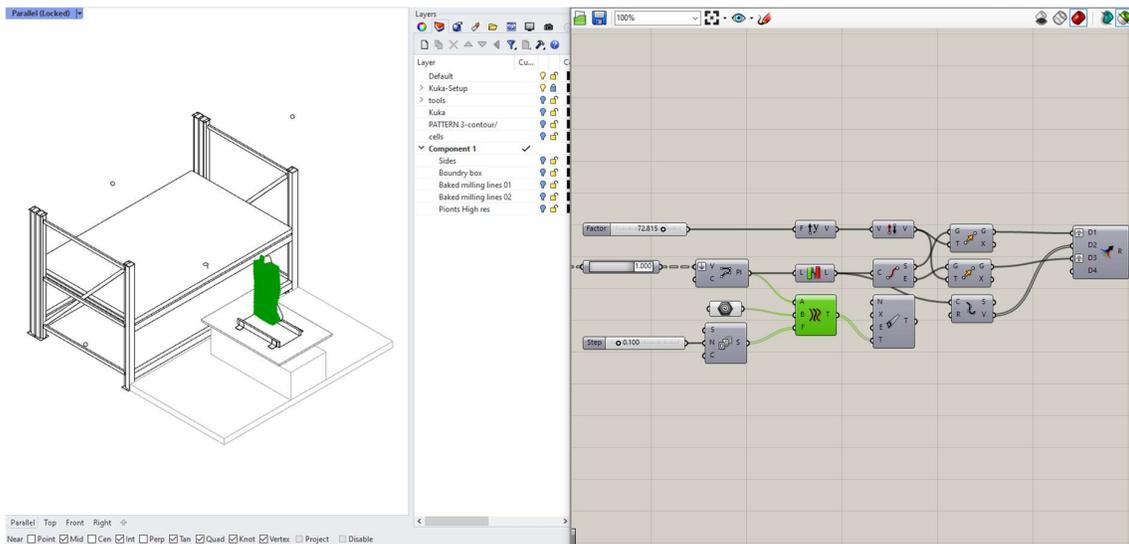
### Step 7: geometry turned into meshes

The next step is to have horizontal curves drawn on the face of the mesh (Step 8). This is a path for the robotic arm to follow while milling the component.



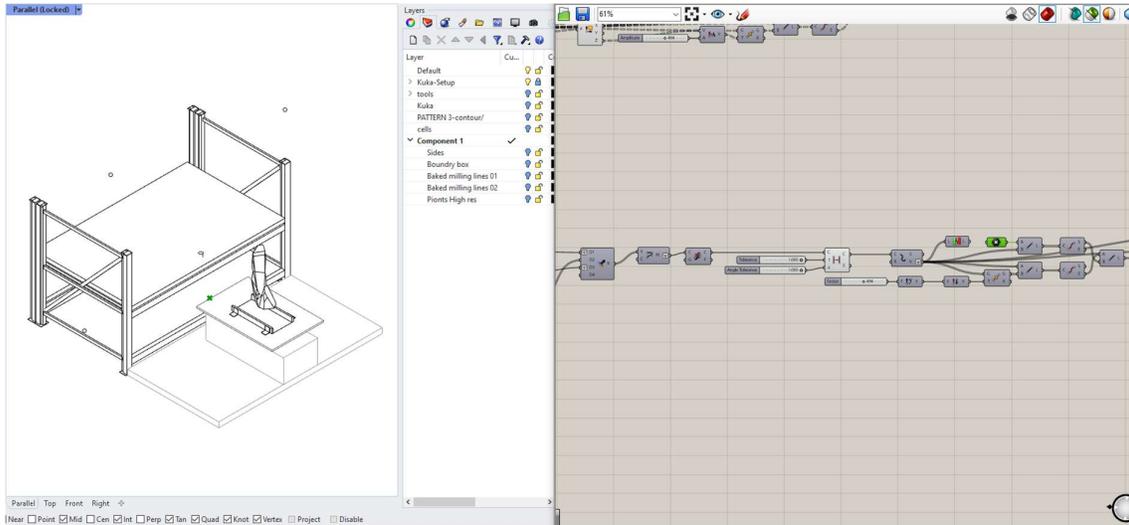
**Step 8: horizontal curved lines**

Next is a more redefined path for the robotic arm to follow ( Step 9). Here the slider indicates the distance between the curves, so this means in between the lines is 1cm in this case. For this step the curves continue as one line, so at the end of the left or right side, it goes down. It's like a zigzag motion.



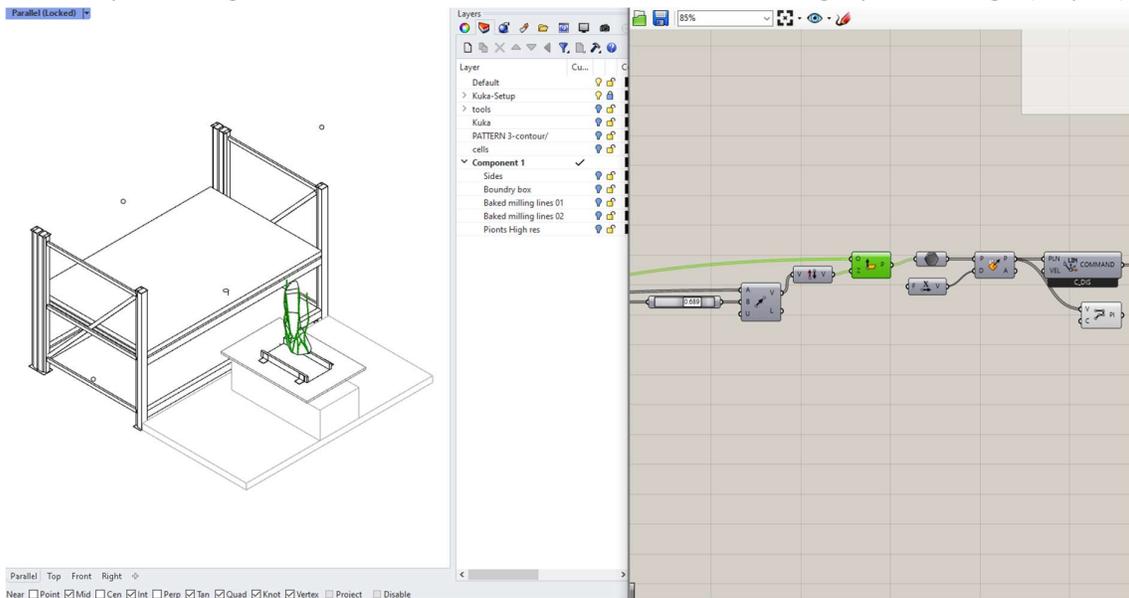
**Step 9: redefined milling path, created from horizontal curves.**

There is a point referenced as a placed/coordinated for the robotic arm to fall back on (Step 10). For example, the robotic arm can't make a specific motion due to the angle, it can first go back to this point and start again/continue milling.



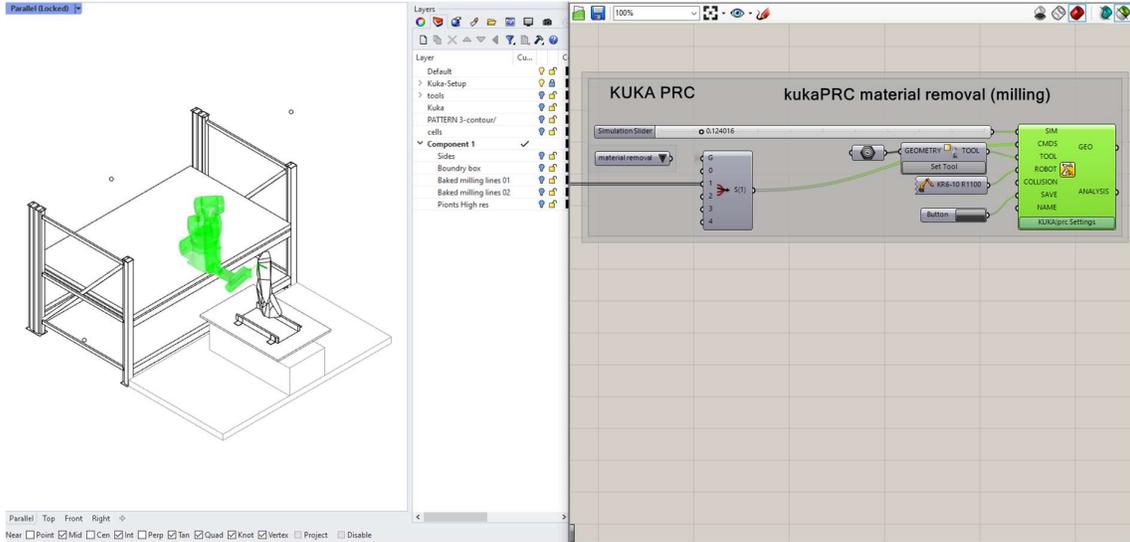
**Step 10: set one or multiple points**

Then the plane is aligned for the robotic arm so that it can mill from the right position/angle (Step 11).



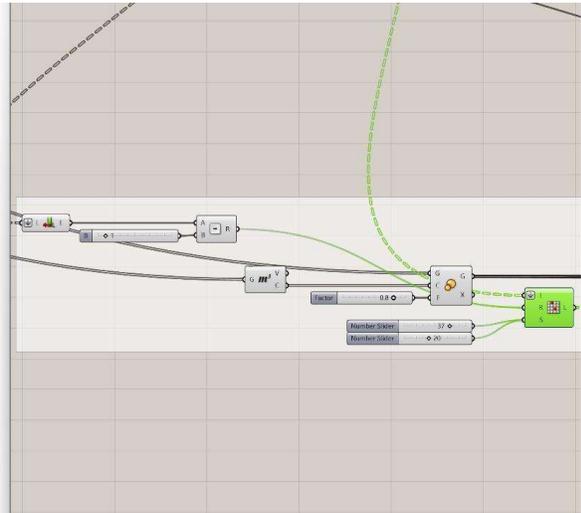
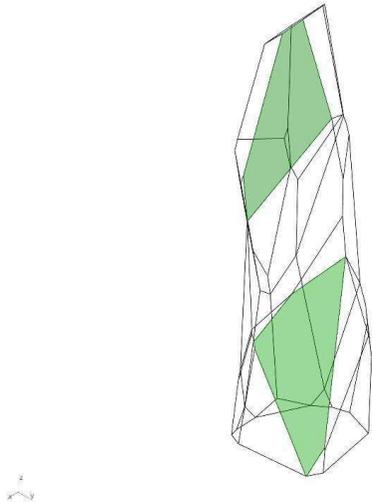
**Step 11: aligning the plane**

The last step is connecting the model to the KUKA PRC and simulating the milling process to check for any collapses/errors (Step 12). When there is an error, the whole process needs to be looked at where it could come from. It has to be identified where it went wrong if anything should be added or geometries or points that need to be moved. When everything works, the milling process begins.

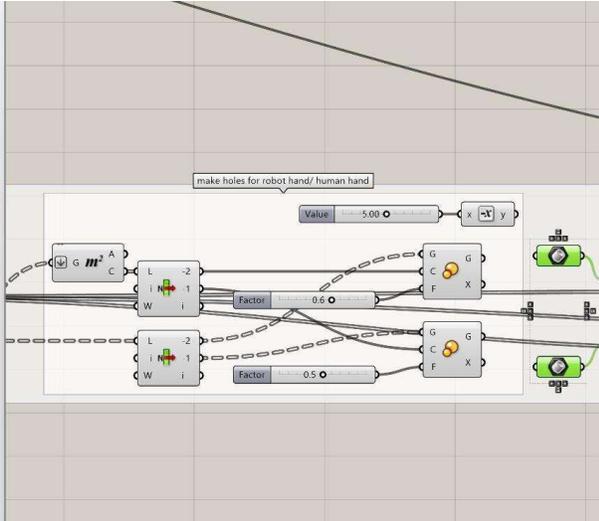
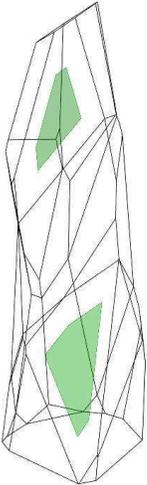


Step 12: connecting to the robotic arm and simulate the milling process

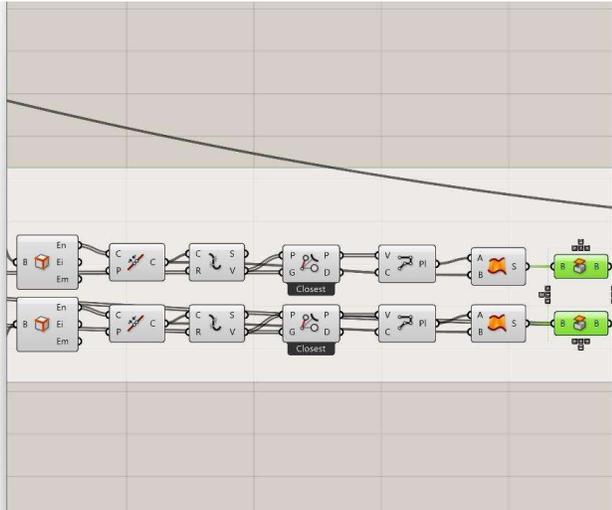
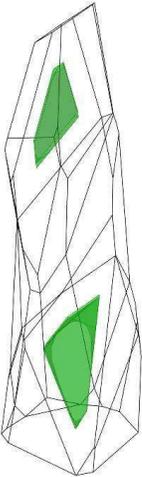
Part 2: Milling the holes



Step 1: Using separate number sliders to choose the right faces for the holes as the random generator did not give the right solution after 500 possibilities.



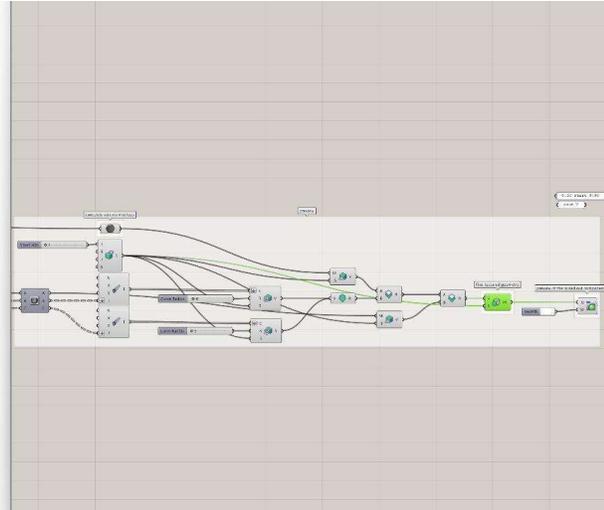
Step 2: Using scaling factors to determine the size of the holes.



Step 3: Create edges, pull to the inside of the geometry, and then create a surface between them to close off the edges. Then cap them to make it a hole with the right depth.



**Step 4: Collect all data and visualize it.**

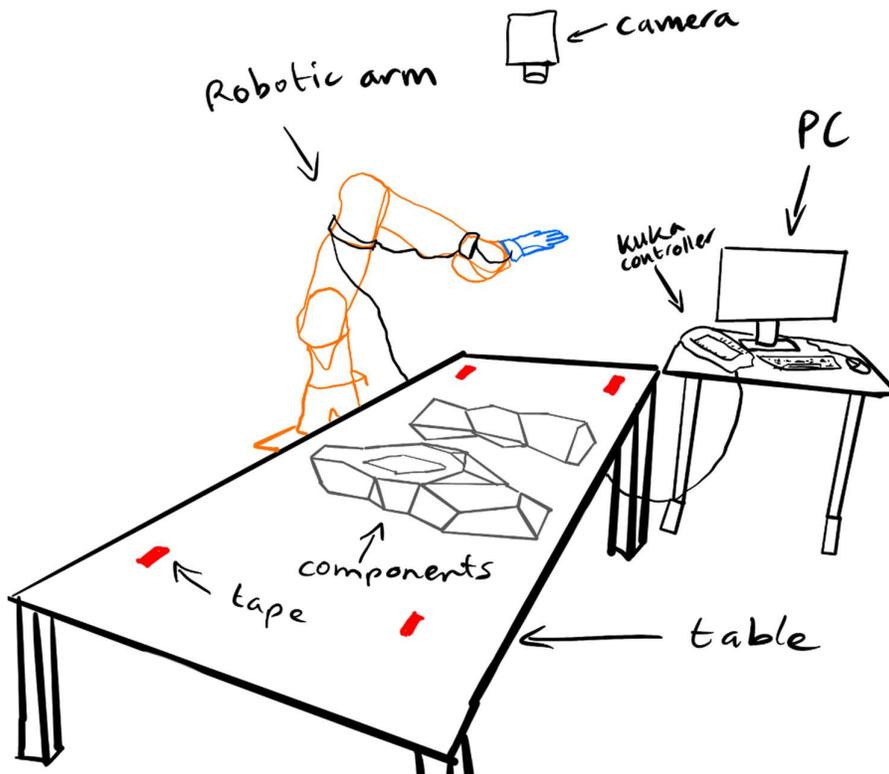


## 6 Google collab CV

- (1) To process our image, we utilized the IA-CV library, which we downloaded using Python requests. Since our coding platform was Google Colab, we imported an image from Google Drive.
- (2) Using the image, we detected both the edges and frame. For edge detection, we employed the `cv2.findContours()` function from the Open-CV library. We adjusted the edge range `ex; ey` until it only displayed the visible edges of the frame.
- (3) We created a list of the detected contours, which we then used for `cv2.minAreaRect( )` and `cv2.boxPoints`, together with `shapely.geometry.Polygon`, to draw a polygon with dots at the corners around the edge-detected frame from step2.
- (4) To rotate and scale the image, we used the perspective wrap, `iacv.wrap`. We then removed black pixels using `iacv.border2color` to make the frame invisible.
- (5) We used `iacv.picpermetric` to determine the number of pixels related to 1cm in the image. enabling us to measure objects with precision.
- (6) We repeated the edge detection, frame detection, and perspective wrap steps on the new image without the border, this time to detect the components. We also made the polygons again. However, we blurred the image since too many edges were detected. Then we repeated the entire process.
- (7) Using `image_wrap` and `image_thresh` from `numpy`, we limited detection to only select the gray area in the image. We then drew the polygons again.
- (8) We installed `rasterio` to create a raster of the geometries. We then utilized edge detection again, but first converted the image to grayscale.
- (9) We drew polygons around the holes and an orientation point for the robotic arm, enabling us to accurately manipulate the image for our desired purposes.

1.

## 7 Robotic assembly



**Human-robot assembly set-up**

### Things the robot might need to know to assist the human in the task

1. Camera: used as part of computer vision to identify where the components are in relation to the table.
2. Marker points: red tape is stuck onto four points on the table to be identified by the camera and translated to the computer as location points for the robotic arm.
3. Grip location: The robotic arm needs to be moved manually to a location where it can grip the component in a secure and balanced way.
4. Point of origin and end point: These points are selected by manually moving the robot hand and stiffening it, then saving it on the computer. These points are needed as data for the robotic arm to generate a path moving from the origin to the endpoint.
5. Size of component and distance from the table: To reduce crashing between the component and the table, the robot should have this information when generating the path between points.

### Reflection

The experience showed an interactive collaboration between humans and robot. We learned that the robot requires a lot of information to perform tasks that we take for granted with our natural cognitive abilities, such as picking up an object without knocking over another object in front of it, or accurately locating where to grip an object in order to pick it up.

To have an accurate read of the surface the robot is working on, extensive cameras at different angles or sensors along the robotic arm will be needed to create a 3D vision for the robot to perform accurately and create paths of motion without damaging other objects. Robotic arms also rely on software and programming to operate, and errors in this software or programming can cause failures or malfunctions. This can be caused by factors such as human error, bugs in the software, or issues with the programming language or environment.

We learned that a good balance between human and robot collaboration in construction can potentially improve precision, reduce excessive loads on the human body, and ultimately increase productivity. For example, the assembly of a large structure of many pieces can be done with the robot as the muscle and the human as a precision guide. For 3D printing where a high level of consistent precision is needed, robotic arms can be used to create intricate designs and shapes that would be difficult using traditional methods as it is tedious and requires extended hours of concentration by the human.

The session also raised some questions on the extent of human or robot participation that should be involved in regard to the ethics of a sustainable human workforce. The ultimate goal of human-robot collaboration should be about improving the quality of work while reducing strain on the human body, without reducing human value in the process, which will in turn lead to a replacement of the human workforce with a robotic one.

## **8 Conclusions**

To conclude, the skills picked up in this course have aided the design of our RED OASIS design project by expanding our understanding of computational tools, exploring the potentials and drawbacks of each, as well as the role they play in construction. The RED OASIS is designed for two botanical researchers to start life on Mars. The decision is based on the fact that this planet will be home to humanity's earliest inhabitants and therefore their scientific studies could serve as a starting point for its expansion. For the interior wall, our design uses a Voronoi system with varying dimensions and densities depending on the purpose of each pod. The Voronoi cells in the greenhouses have a purposefully rough appearance and are made up of tiny, elongated cells that are perfect for use as plant pots. The living pod's Voronoi cells, in comparison, are bigger and smoother in texture, offering an ideal setting for storing necessities for a living while also improving the comfort and livability of the habitat for its inhabitants. Three elements from the Voronoi-based approach were abstracted, and we concentrated on those for the manufacturing process. To ensure that the robot could handle them, we selected the components based on preset size specifications. We started preparing the grasshopper script for the milling operation after the components were chosen. The original script's goal was to create the holes' locations at random. In the end, we changed the script so that the appropriate surfaces could be manually chosen before the holes were milled. The course's computer vision Google Colab script was used, and its edge detection has been modified to improve the edge detection of our image. The interactive demonstration of the robot and human collaboration has taught us that the robot needs a lot of information to do the things that we naturally do with our natural cognitive abilities, such as picking up an object without tipping it over something else in front of it, or precisely determining where to hold it. For future interactions to perform effectively and

establish an efficient route of motion, it will be necessary to have many cameras at multiple angles or sensors on the robot arm in order to provide a real 3D view that does not conflict with anything else. This will make it possible for a robot to precisely measure the surface on which it is operating. This may be due to a person's mistake, software failure, or other problems.

## 2. References

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