MARS OASIS

Group 1
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Introduction

As space technology continues to evolve rapidly, the prospect of human presence on Mars is no longer just an ambitious vision but is transforming into a realistic scenario for the coming decades. Nicholas (2017) highlights the strategic intentions of NASA and SpaceX to send manned missions to Mars by 2030 and 2040, respectively. This growing international mobilization has led to a series of design and technological efforts focused on developing habitats that can ensure sustainable and safe living in an extraterrestrial environment.

Beyond being a technological challenge, Mars is of immense scientific interest due to its geological similarities with early Earth. During the Noachian period, Mars had liquid water on its surface, while its geological conditions may have been hospitable to the development of microbial life. The preservation of ancient soil layers due to the absence of plate tectonics, makes the planet an ideal "archive" for studying prebiotic chemistry and understanding the origins of life.

The arrival of the Mars Exploration Rovers (MERs), Spirit and Opportunity, in 2004 provided the opportunity to study ancient water environments on Mars and assess their potential to support life. Initial results confirmed what satellite data had long suggested—that a variety of water environments existed on the Martian surface billions of years ago. In addition to water, these ancient environments record elements of the chemical building blocks of life (carbon, hydrogen, nitrogen, oxygen, phosphorus, sulfur), as well as chemical and/or mineralogical traces that may be linked to the emergence of life.

In this context, the Martian Habitat project proposes the design of an autonomous, protected, and functional shelter for 3-4 scientists, aimed at conducting research on water, geology, and the possibility of life. The construction of the habitat is based on human-robot collaboration, utilizing local materials such as regolith, and integrating modern technologies such as Design-to-Robotic-Production-Assembly and Computer Vision. This project creates a functional model for sustainable living and scientific presence on Mars, with a long-term perspective of colonization.

Site - Location

Arcadia Planitia, located in Mars' northern mid-latitudes (35°–50°N, 150°–180°E), is one of the most viable locations for human settlement due to its abundant water ice, favorable environmental conditions, and accessible terrain.

Radar data from HiRISE orbiters program confirm that subsurface ice exists just 30–60 cm below the surface, with some areas containing up to 60% ice by volume. This resource is crucial for life support and fuel production, reducing reliance on Earth-based supplies. The region's relatively low elevation results in a slightly denser atmosphere, aiding spacecraft landings.

Arcadia Planitia also offers stable environmental conditions. It receives sufficient sunlight for solar power (500–600 W/m^2 in warmer months) and experiences fewer large dust storms than equatorial regions. Its periglacial features and volcanic history provide valuable opportunities for scientific research on Mars′ climate and geological evolution.

With its combination of water availability, safe landing conditions, and scientific potential, Arcadia Planitia stands out as one of the most practical sites for the first human settlement on Mars.

Design considerations

Case studies / precedents

To begin with, we selected three projects from previous years by fellow students, as a starting point. We analyzed them by four aspects, namely context, volumes, circulation and humanity. By context we studied the placement of each habitat and their connection with the surrounding environment. Next on the agenda were the volumes, where the analysis of the inclusion forms happened. At circulation, we studied how clear and accessible the floorplans are. In terms of humanity, human needs and well being were in focus with recreational and green spaces. After setting up the criteria, we analyzed the projects systematically. These analyses later helped us form our Mars Habitat design.

Lunascape is a habitat designed for the Moon in 2024. It is situated in a crater, which offers natural protection for the astronauts from the environmental hazards. The sloped terrain provides a safe and suitable foundation for construction, allowing the structure to be partially embedded underground for added stability and insulation. The architectural design is characterized by an intentional alteration of volumes, creating dynamic spatial experiences. Spatial centrality is emphasized by the connecting spaces - which are permeable, although some functions, mainly secondary spaces, could be reached through corridor-like volumes, reinforcing the sense of linearity. This design also benefits from the slope of the terrain, as the linearly connected spaces are aligned with the surface of the Moon. Sleeping quarters are centrally located, subtly exposed within the structure, providing both privacy and integration into the core living areas. To enhance comfort and well-being, interior spaces are shielded from direct sunlight, taking advantage of the crater’s natural shading and subterranean positioning. Meanwhile, common areas are placed above ground, allowing for social interaction and connection to the environment. Additionally, dedicated recreational spaces support the psychological and emotional needs of the inhabitants, promoting a sense of community and humanity in an otherwise harsh landscape.

The following case study is Communal Housing Typology on Mars from 2023. This project’s scale is slightly bigger than other examples, as the designers of this habitat imagined a scenario where multiple astronauts live on Mars. The research behind their idea is well-established and greatly applied. The habitat is located partially underground, enabling openings on the main volume, in order to let natural light into the common space. Individual areas are mainly hidden underground, providing sheltered space for the astronauts.The distinction between common and private spaces is defined not only by their context but also by their architectural formation. Individual living cells resemble standalone housing units, reflecting residential typologies familiar from Earth. Every unit is organised around a main courtyard, which contains several green areas for gardening and plant production. All these activities and the sight of green, help mental well-being.

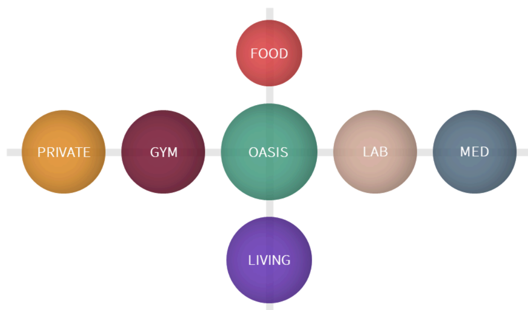
The last project that has been analysed was Red Oasis which was designed during the course in 2023. This is completely placed above ground exposing the habitat to the environment and to Martian winds. The designers used less volumes, which resulted in a more coherent and less fragmented shape. The placement of the volumes makes it hard to orient inside the habitat, as the connection between the spaces are not clear. Although a cave-like design approach has been used, it is controversial, as the whole habitat is on the surface, with a flat floor. However, they benefited from it, as plant pots have been integrated into the wall, creating a friendly environment with easily reachable plants. In vain to the many green oases, the lack of private and recreational spaces and functions weaken the concept. Another crucial element that we miss from this design, is the lack of openings that could create either visual or physical connection to the surrounding area.

Concept, Design development

After we concluded the benefits, potentials and disadvantages from the analysed projects, we started to develop ideas based on our established criteria, considering the four aspects. Firstly, we took site-related specifications, human needs and architectural features into consideration, whilst creating the program by collecting functions and defying the percentage of each space. As we wanted to include many functions in our design, we decided to combine some of them in order to make the shape less complex. Integrating storage areas and hygienic spaces with primary functions made it easier to generate the volumes.

FUNCTION	NUMBER OF ROOMS	CAPACITY	PERCENTAGE
BEDROOM - personal	4	1	10%
BATHROOM - hygienic	2	2	5%
GYM - recreational	1	4	10%
OASIS - shared	1	4	20%
KITCHEN - food production	1	4	10%
LIVING ROOM - shared	1	4	15%
WORKSPACE/LAB - shared	1	4	15%
MEDICAL SPACE - common	1	4	10%
STORAGE - common	2	4	5%

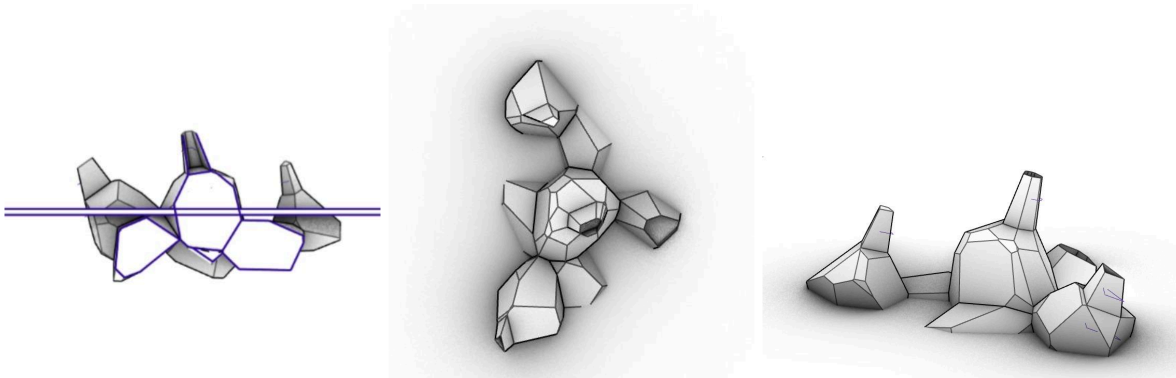
Table 1: functions needed in habitat



Images 1 & 2: bubble diagram of functions

After setting up the program, a form-finding process started, where we turned the program into a bubble diagram and started to play around with different volumes in Grasshopper while getting to know the program. Those volumes were the input for our Grasshopper script that created voronoi based shapes out of those volumes.
We generated the first initial forms, some of them were a dead end, others led to new ideas.

After discussing some alterations, we drew a more linear floor plan, which became the core of our design. We also came to the conclusion that all the shapes lacked height. We created horizontally extended, cylindrical volumes and manually added ‘chimneys’ that gradually narrow towards the top. This allows them to receive direct light, while also considering the need to filter radiation. These extended volumes give space to more common functions, such as the greenhouse, the gym and the laboratory, working area. Private quarters and secondary functions are protected from sunlight, and have lower headroom.



Images 3, 4 & 5: first volume design

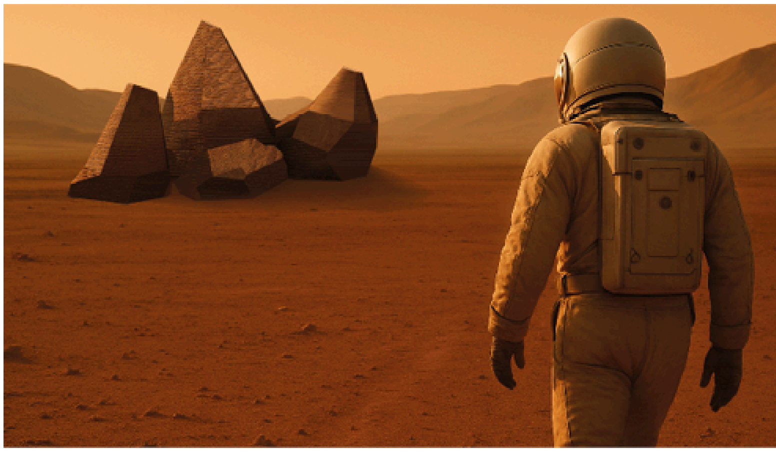
As a result of continuous consultations during the semester, changes have been made in our design to get a more coherent and working shape. The added cones have been connected to the base volumes more smoothly, resulting in a bulkier shape.

Images 6 & 7: Final volume with new cones

As we found the final shape, designing the interior spaces became primary. The central volume holds place for our oasis, which provides greenery for astronauts' well-being. Moreover, plant pots have been designed for the walls in the central volume - so called oasis, for plant production. These pots are voronoi-shaped, extracted from the wall thickness, in order to be able to accommodate the soil, seeds and vegetables.

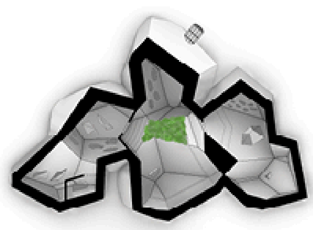
To form other inner spaces, we were inspired from medieval castles and fortresses structures, where storages and hidden staircases, even rooms have been carved into the thick walls. With the use of this approach, we included beds, personal and common storage spaces in the wall, in various shapes and in different heights on the wall. As the floor of our habitat is not flat, we added slopes and stair-like volumes in the space to facilitate the movement and daily life of astronauts.

Visualisations

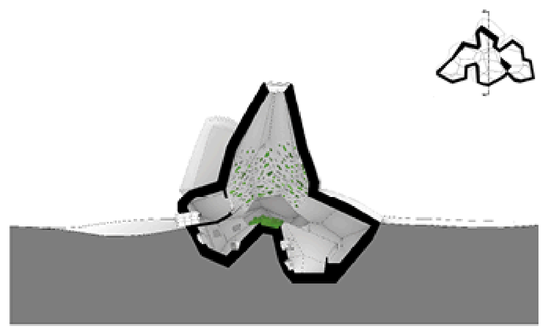


Render

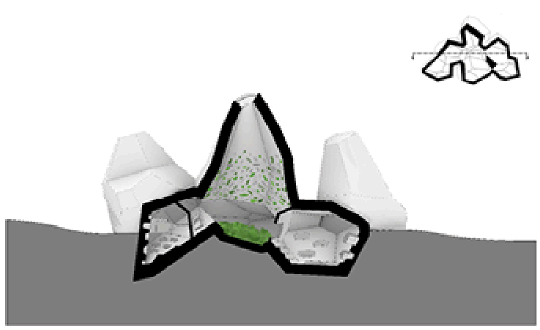
Site



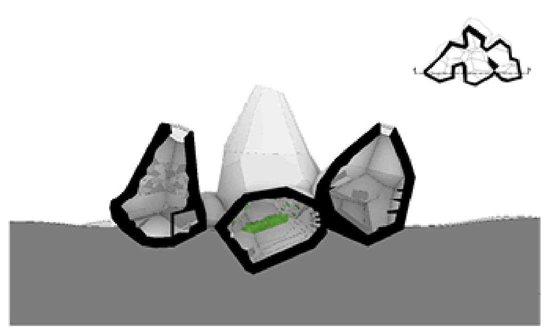
Floorplan



Section AA



Section BB



Section CC

Fragment construction and design

For our final design we had to work on a fragment of the habitat. This fragment should represent our design considerations and show how the habitat would be constructed. The first step we had to take was choosing which fragment we wanted to work out for production. The fragment we choose is located between the gym and the greenhouse. This fragment is representable for our design because we want to include the food supply and the greenery inside of the walls.

The second step in making the elements which will construct the habitat is doing an analysis on the stress in this fragment. We did this by using a Grasshopper script that used our fragment as input. We used the lines that were created by calculating the stress within this fragment later in the process.

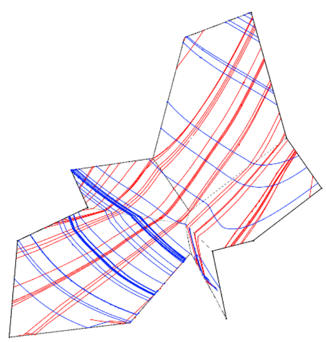
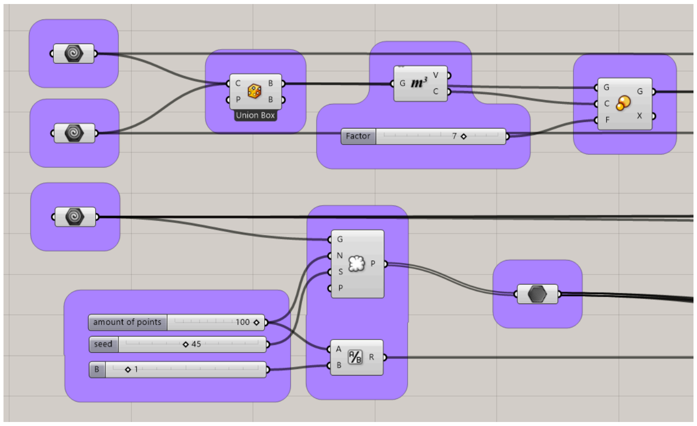


Image 8 Stresslines in fragment, needed to generate interlocking components optimaly

With this information we started on the third step, creating voronoi based building blocks. This process started with a simplification of the chosen fragment. We used Grasshopper in combination with Rhino to make the voronoi based elements in the fragment. The input for the Grasshopper script was the top- and bottom part of the simplified fragment and the surface that is in between those two parts. From this we could create a bounding box and points what makes the elements in the end.



Screenshot 1: Input and creating the points and building box (see *2. kinked-components_group1.gh*)

Before the elements can be created from those points we had to make the points into lines. For this we started with including the stress lines, what we created with the earlier script, and the direction of the top- and bottom elements. We make three sets of lines, lines in the topper element, in the bottom element and lines that kink where the input surface is.

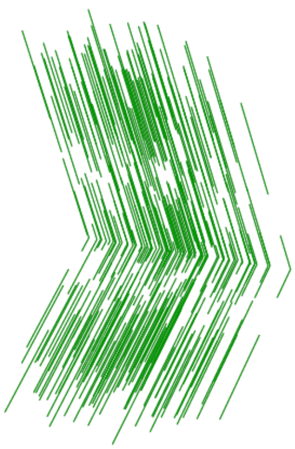
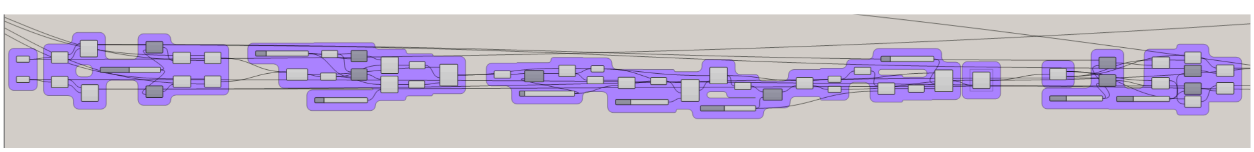


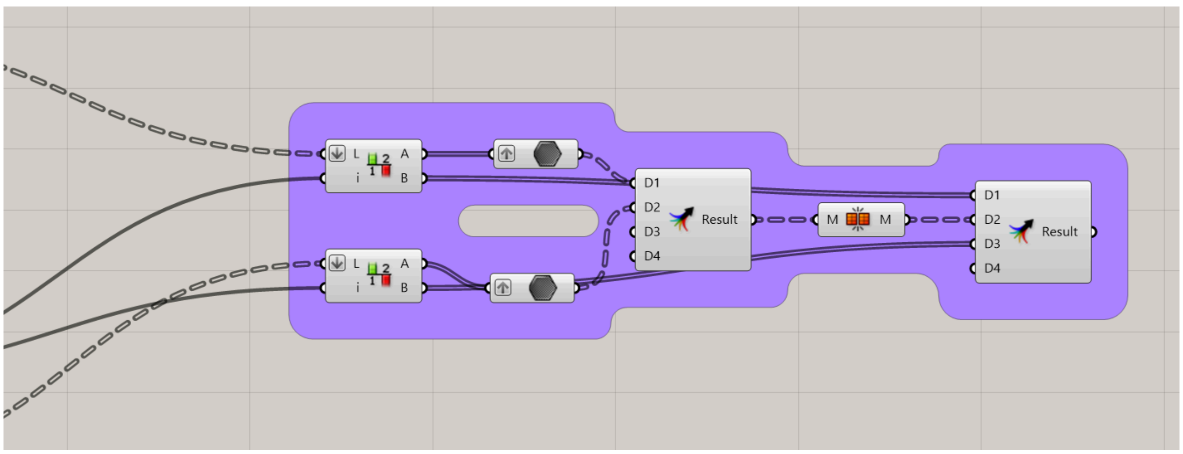
Image 9: The three sets of lines (see *2. kinked-components_group1.gh*)



Screenshot 2: Script for making three sets of lines (see *2. kinked-components_group1.gh*)

These lines are used later in the script to be the center lines of the building elements/components. To make the interlocking as good as possible we had to make the lines crinkle. This is done by creating a pipe around the straight line, creating points within those pipes and connecting the points to create this crinkled line.

Because we have three sets of input lines, we also have three sets of components. For the later design and production process we had to pick four components. Those components are within the kinked components set. As you can see in image 9,the components interlock with each other and can be stacked on top of each other perfectly.



Screenshot 3: The last steps in creating the components (see *2. kinked-components_group1.gh*)

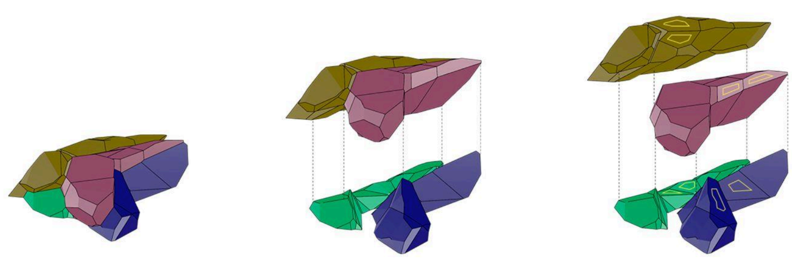


Image 10: Stacking of the components

What we mentioned earlier we chose this fragment because we could represent our habitat with it. The part that is positioned into our greenhouse we wanted to design in more detail. The idea is to include the food supply and the greenery into the wall/components. For this we looked at our simplified fragment and the building components.

The plants we selected to show in our design are plants that are able to grow in this situation, such as vegetables, cereals, nuts, herbs and fruits. So our fragment wall incorporates edible plants, as food and as decoration. These crops were selected for their relatively fast growth, nutritional value and their proven potential for cultivation in this environment.

The plants are grown in basaltic regolith simulant soil, which mimics the mineral composition of Martial soil. This choice not only provides food for the astronauts, but also contributes to air purification and psychological well-being in an isolated environment.

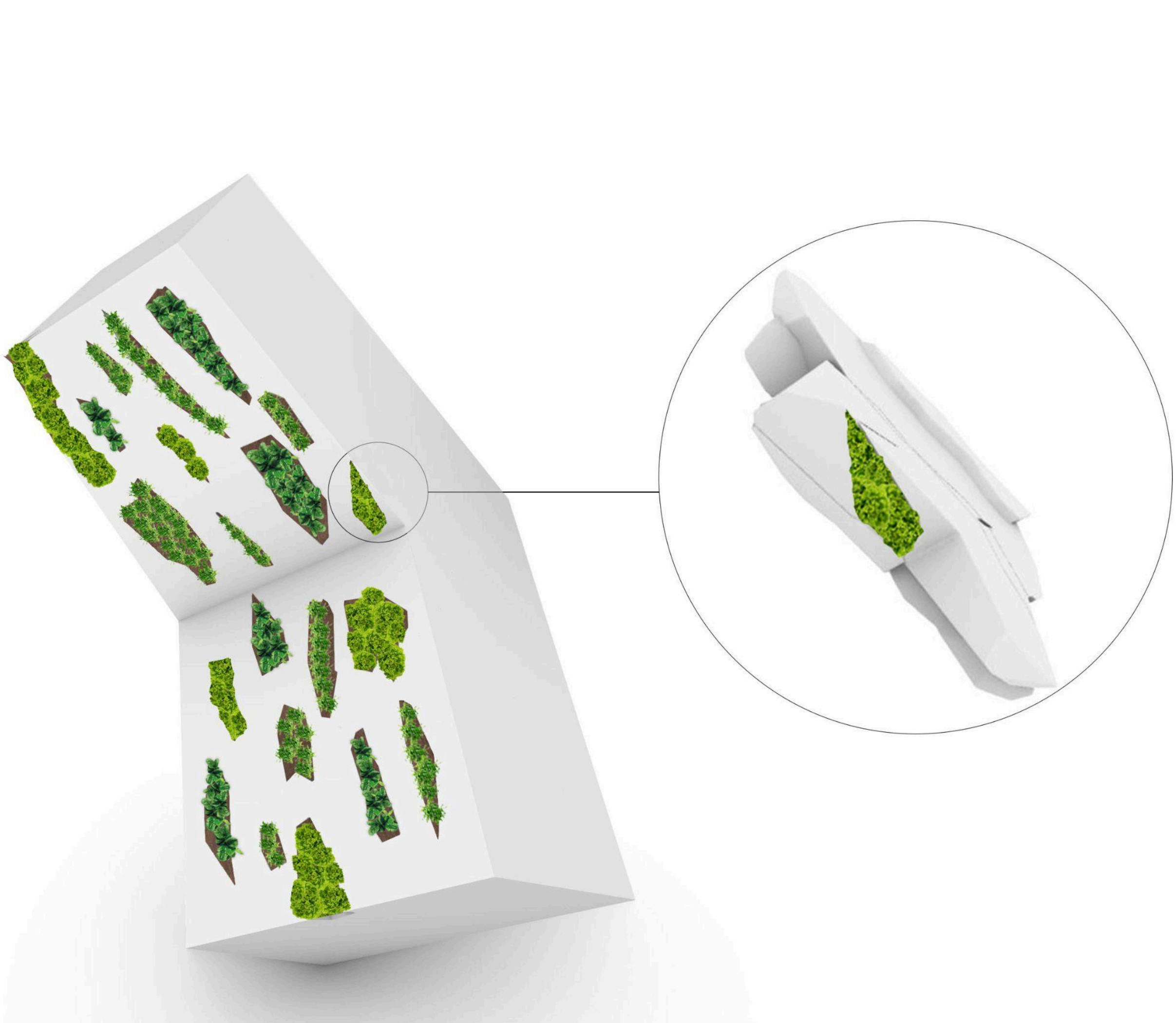


Image 11: Fragment design

To cultivate the plants, we integrated an automatic hydroponic system in the fragment. This means a system where plants live of water and nutrients, without soil. The fragments contain cavities for water to flow through the plants. The fragment surface has spaces in which the plant can sit, with a cavity underneath for the plant roots to reach the piping (image 11).

To make this system automatic, a number of sensors are included in some parts of the fragment. These include pH sensors, nutrient sensors, temperature, water flow. These are only needed in a few components to maintain quality. Furthermore, in the oasis a camera is needed to track growth, a temperature sensor and CO2 levels. Responding to this, the nutrient, water and acidity pumps can act on the sensor input to streamline the growth process.

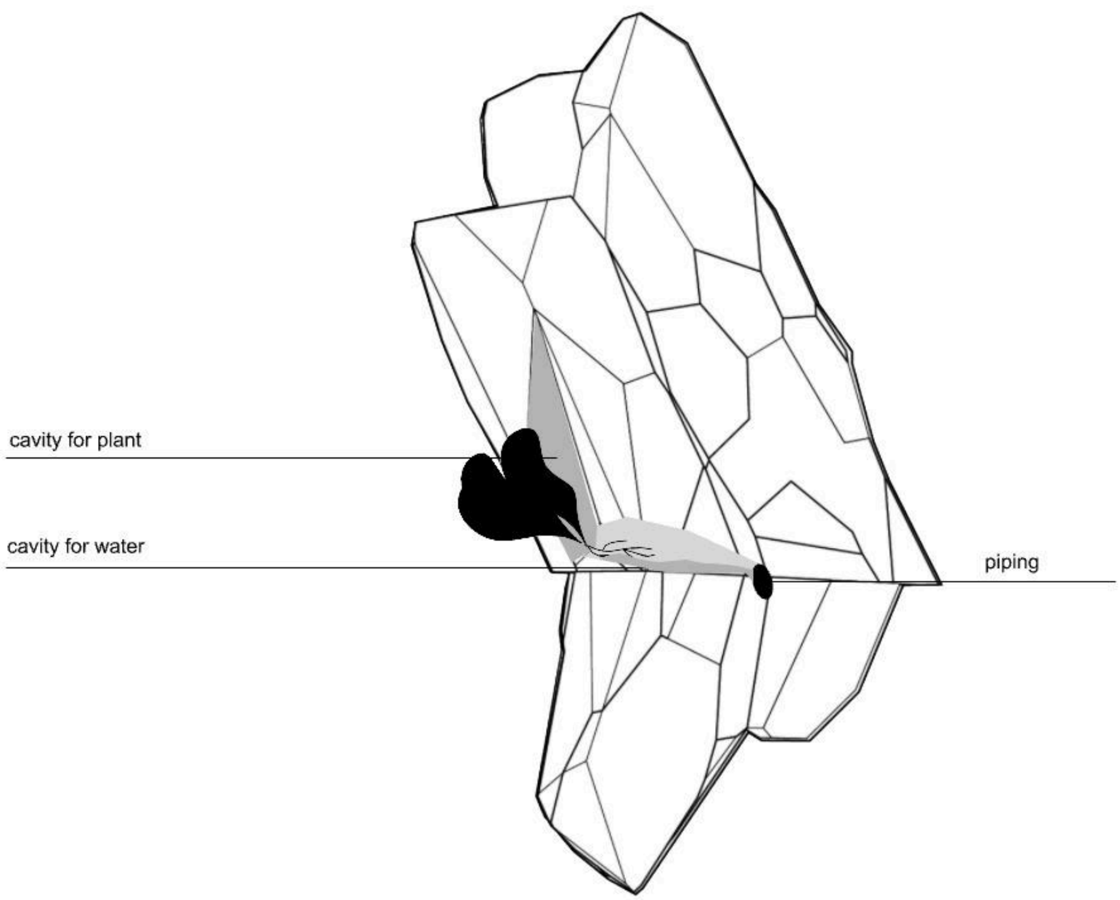
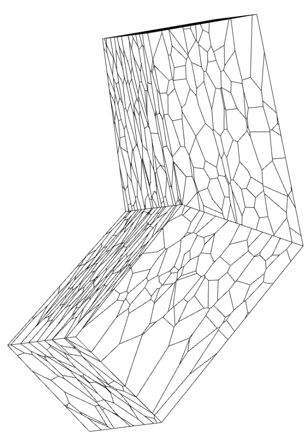
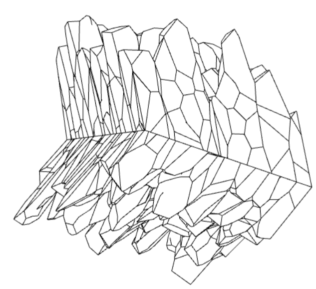


Image 12: Compnenent with a plant. Space for sensors in the cavity for water.

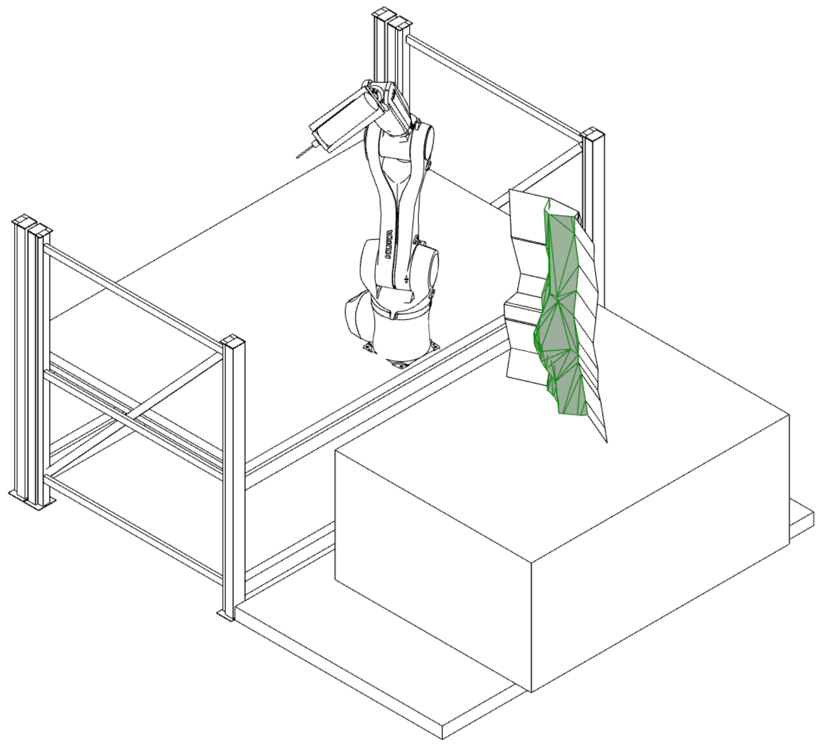
Design to Robotic Production and Assembly (D2RP&A)

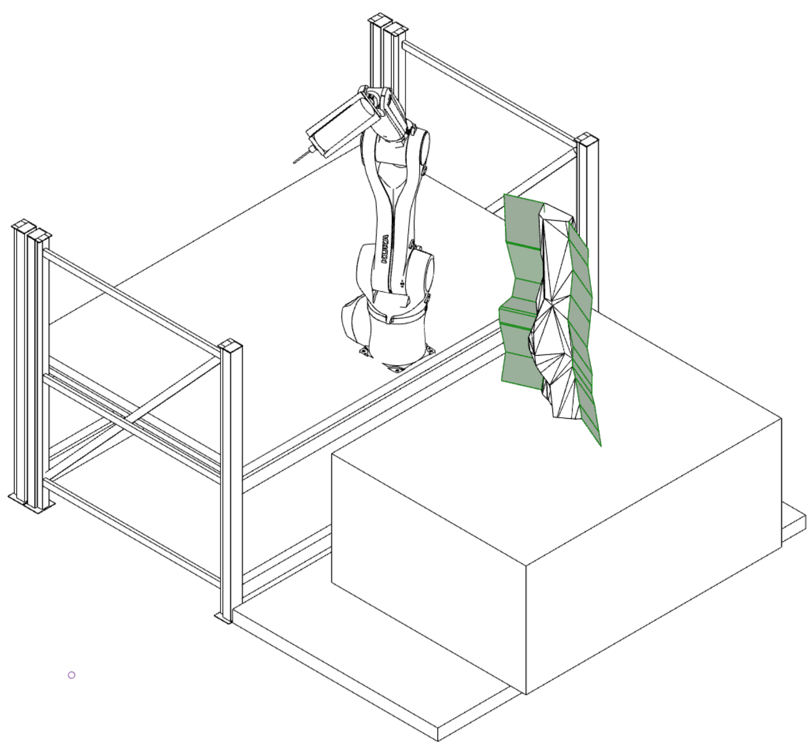
The process of manufacturing this design consists of splitting the geometry into fragments on two levels in order to break it down into a manageable scale for robotic production. On site, the robots would fabricate components individually using 3-D printing technology with Martian soil and then progressively assemble them to create the full habitat. For the purpose of this project, we selected a certain wall fragment to develop in further detail (see: fragment section above). Using a new Grasshopper script, this fragment is split into several individual kinked components which are also generated with Voronoi logic. Each component is required to fit within a general bounding box of 0.2 x 0.2 x 1.5 m, in order to optimize robotic production. Once the components are generated from the fragment, we choose one and the milling phase can begin. Tool paths generated in Grasshopper 3D guide the milling process by the robotic arm.





Images 13 & 14: Example of a fragment (left) with kinked components zoomed in (center), and individual components which will be milled from a block of XPS for demonstration purposes (right).

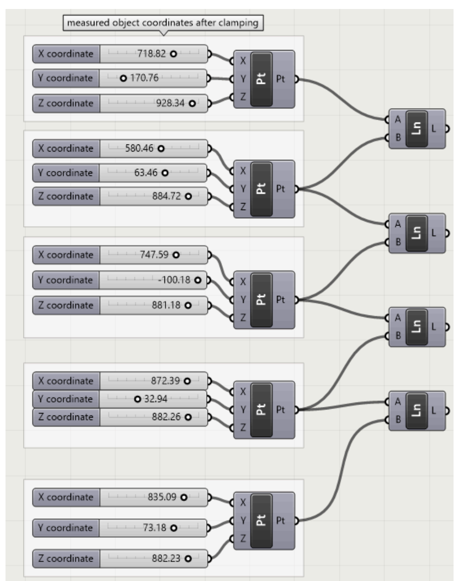




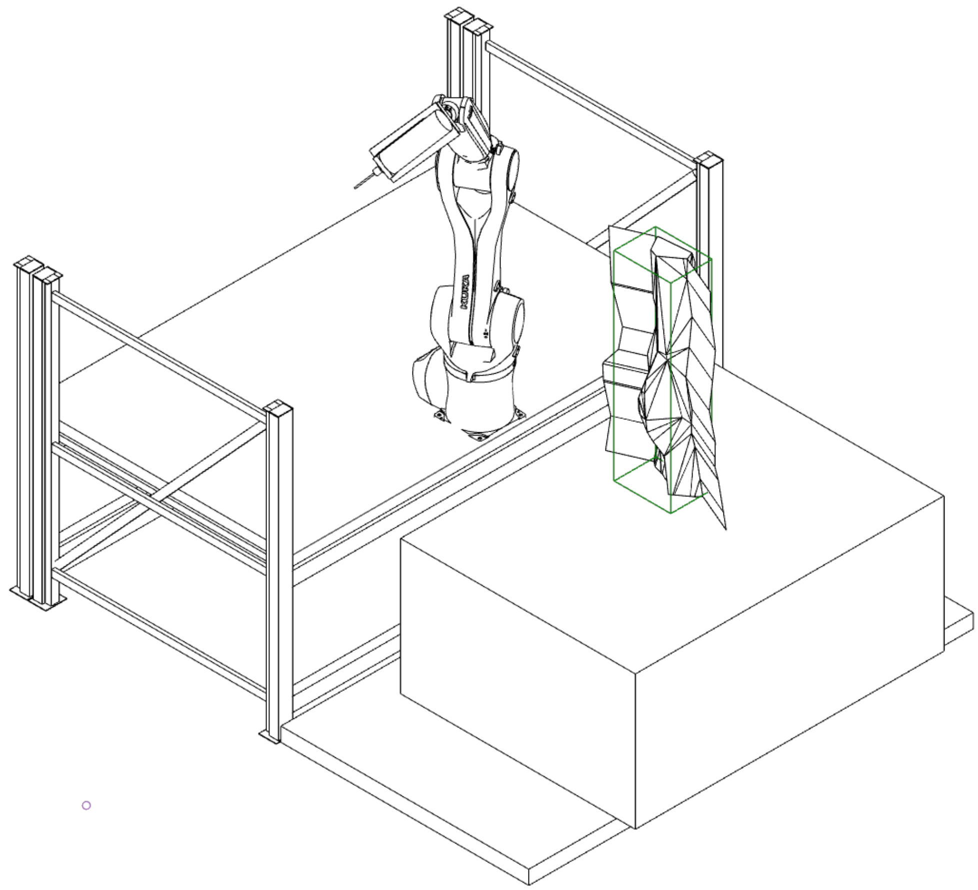
Screenshots 5 & 6: Initial set-up of the robotic arm with selected side and “side flaps” of the component

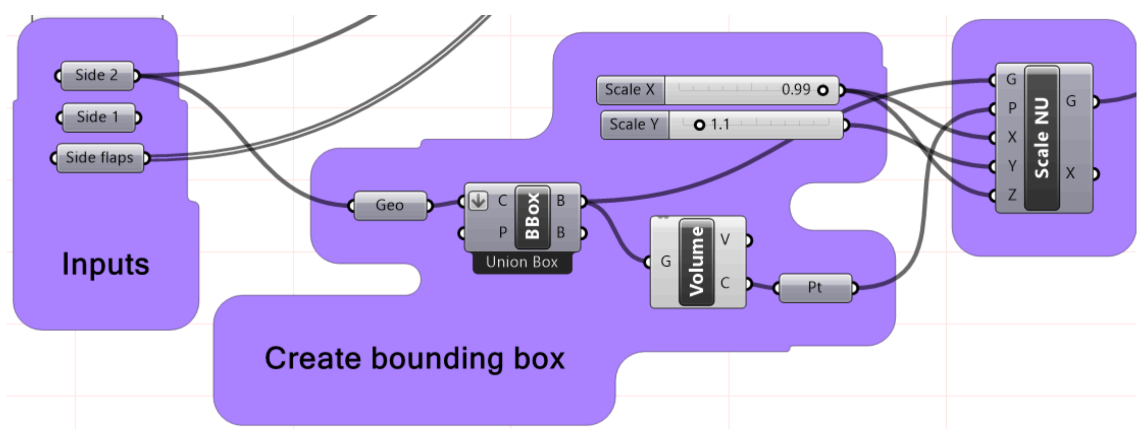
The robotic production (milling of EPS) is done by the KUKA 6-axis robot, which executes the milling without safety sensors. Instead, the workspace is cleared and modeled ahead of time; the tool paths are conceived in such a way as to avoid collisions and impossible positions of the robotic arm, to safeguard against damage to components, the environment, or the robot. The initial block of XPS is positioned to match the computer's bounding box (see figure below) and the robot's frame of reference, and fixed in place to avoid misalignment issues during the milling process.

The material removal begins from the exterior of the XPS mass and gradually moves inward - the amount of passes that the robot performs is specified in the Grasshopper script. To simplify the process, the component's geometry is separated by side and two "flaps" extend to delimit the boundary of each side. After the material is removed, the robotic arm performs a second pass for finer detailing. The process is also mirrored on the opposite side to produce the full component.

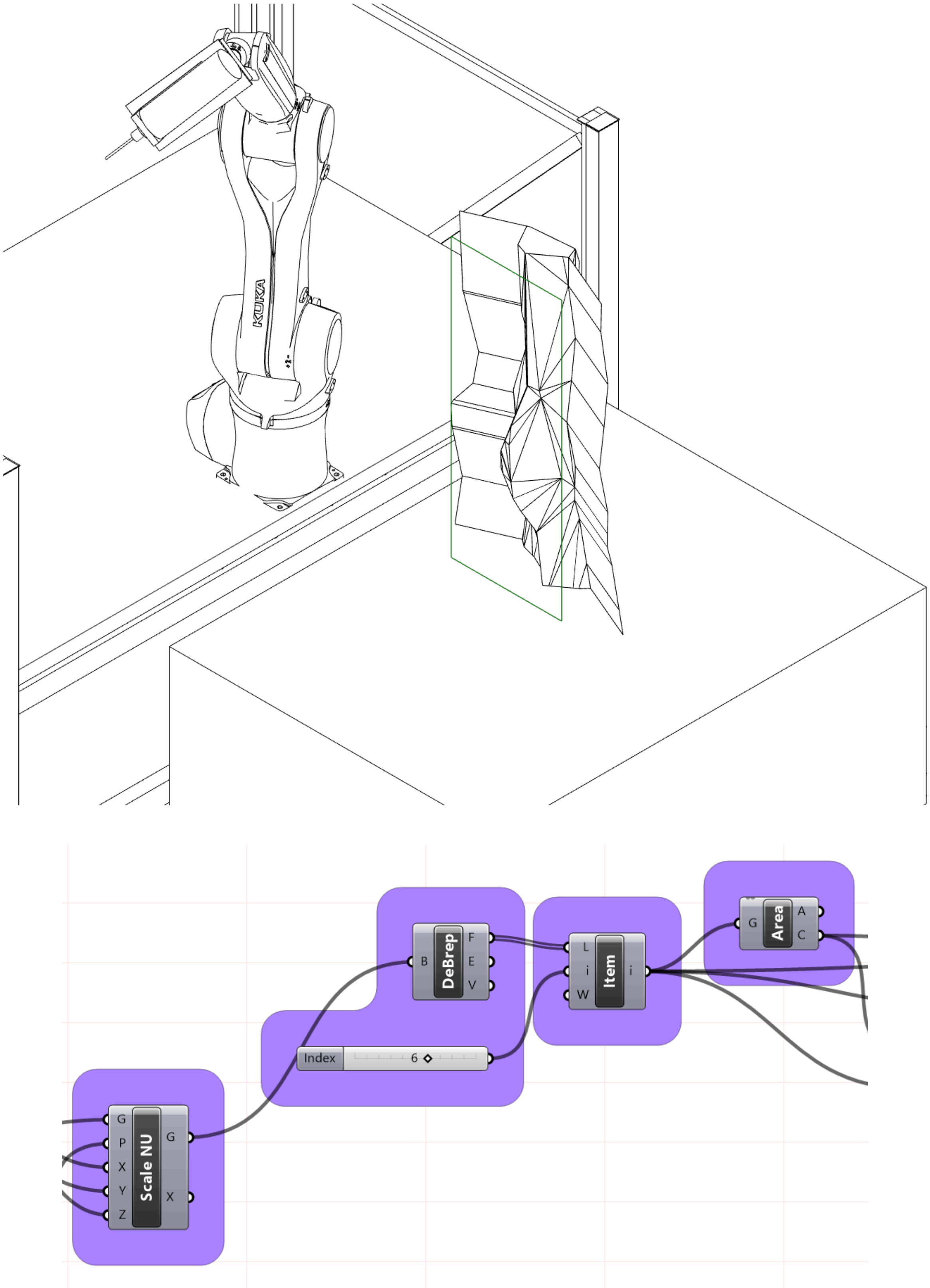


Screenshot 4: The XPS box is placed in these coordinates.

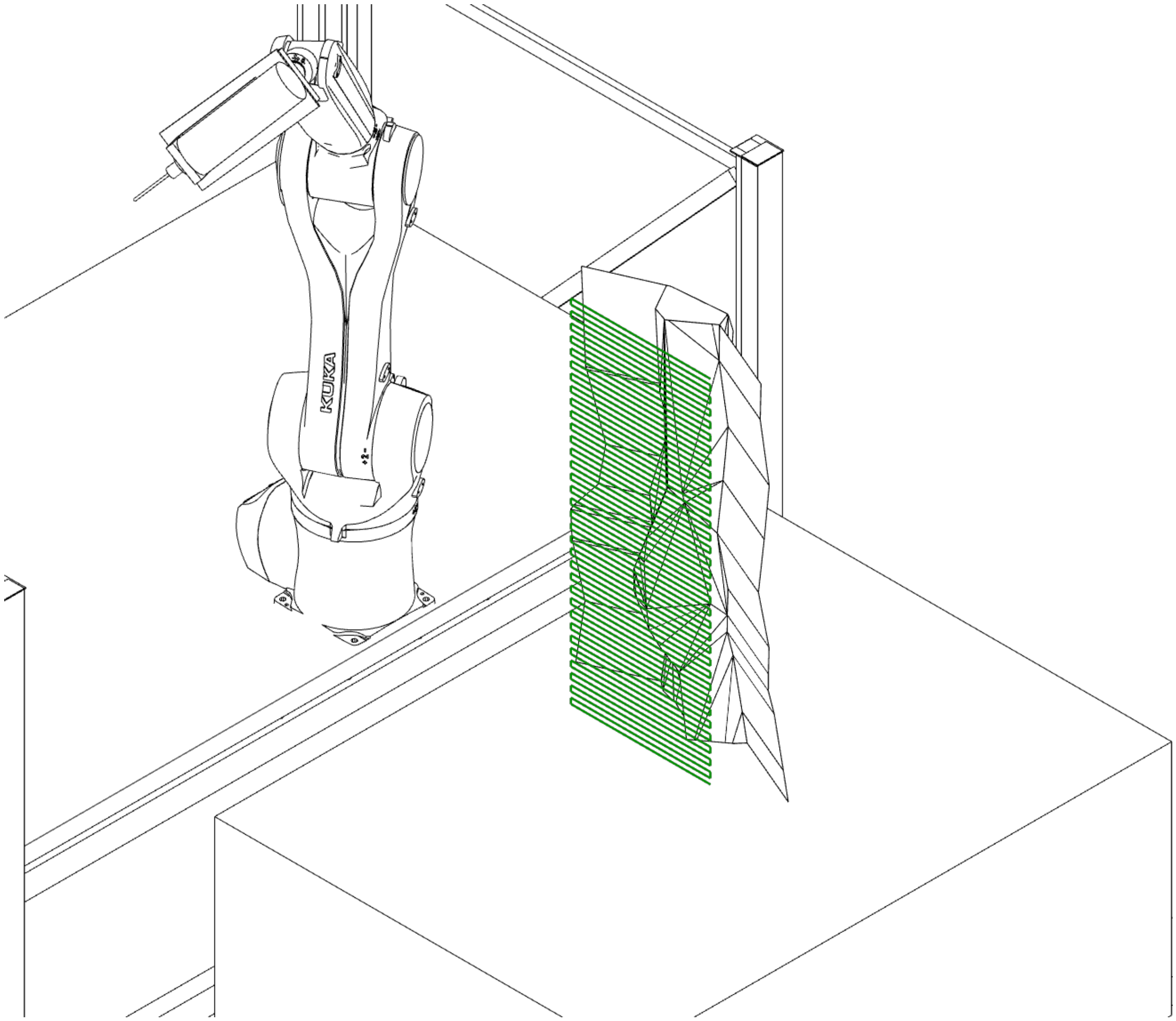


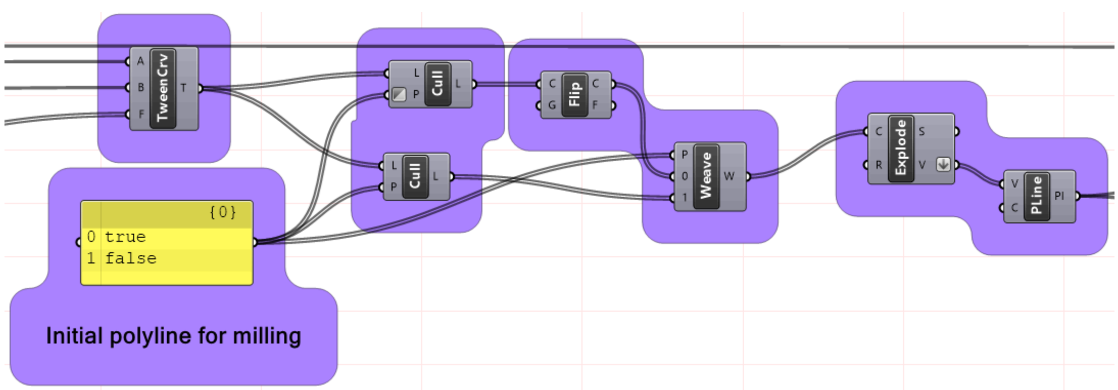


Screenshots 7 & 8: A bounding box is specified around the component to begin to trace the tool paths



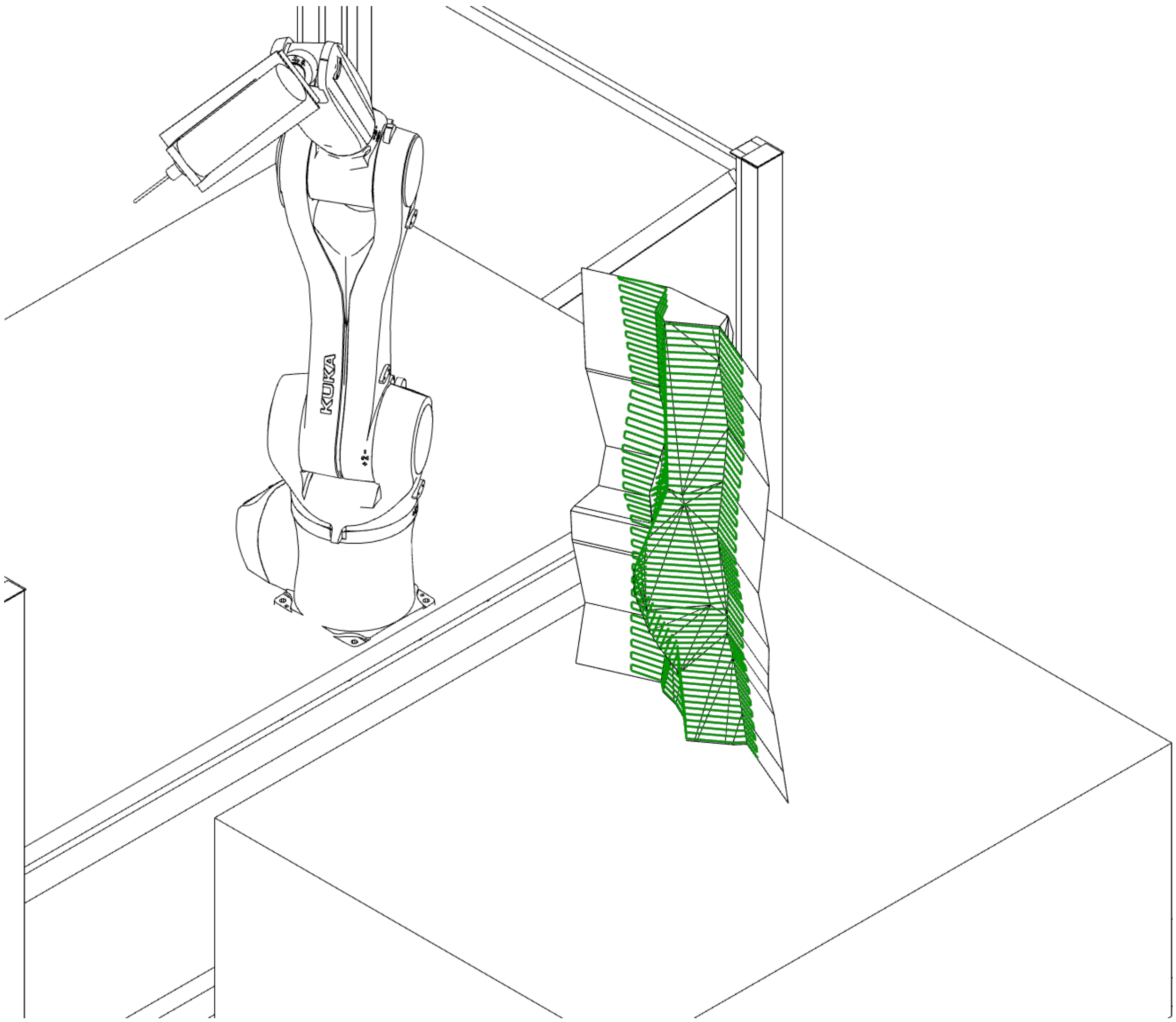
Screenshots 9 &10: The correct surface is chosen in order to create initial tool paths

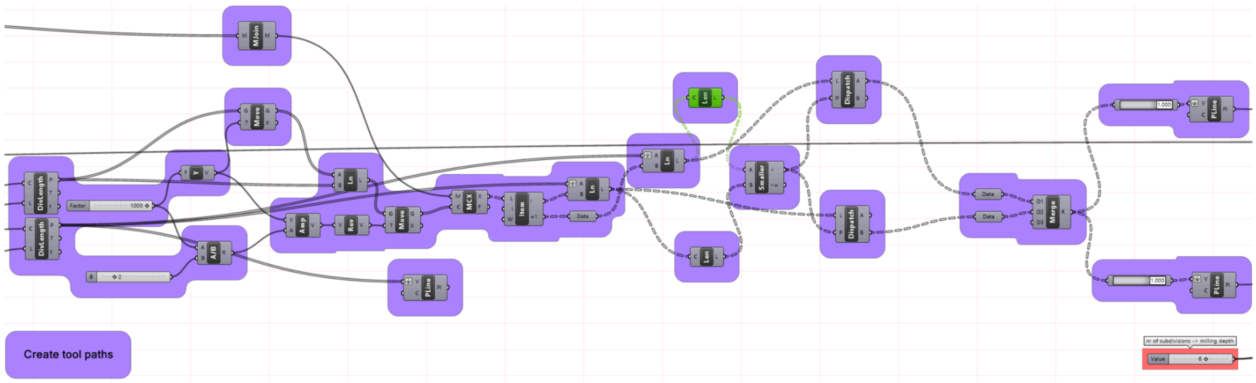




Screenshots 11 & 12: Creating the polyline

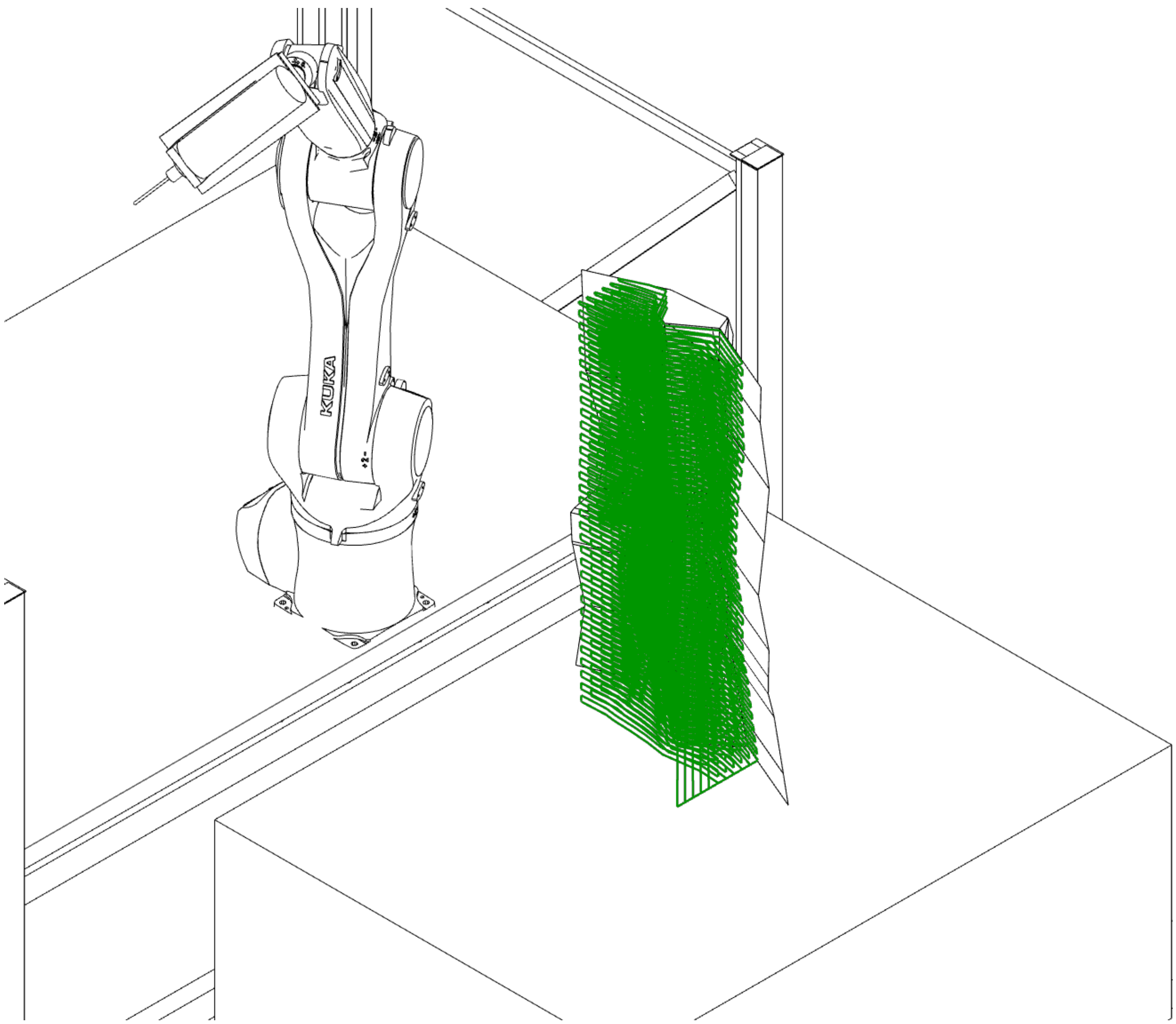
With a few commands, a polyline from horizontal curves is created on this surface, representing the general form of the tool paths. This polyline needs to have the starting and end points on the same side.

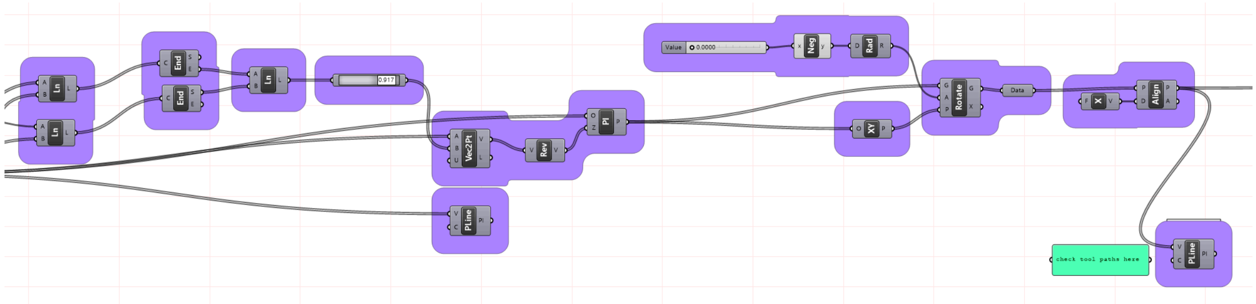




Screenshots 13 & 14: Projection of the polyline onto the surface

The initial creation of the horizontal tool paths consists in creating a projection of the previously created polyline onto the surface (end result of the side milling).





Screenshots 15 & 16: Final tool paths

Finally, the tool paths are created after running a series of commands depending on the angle of the robotic arm, the amount of passes necessary, and the alignment of the robot arm with respect to the component

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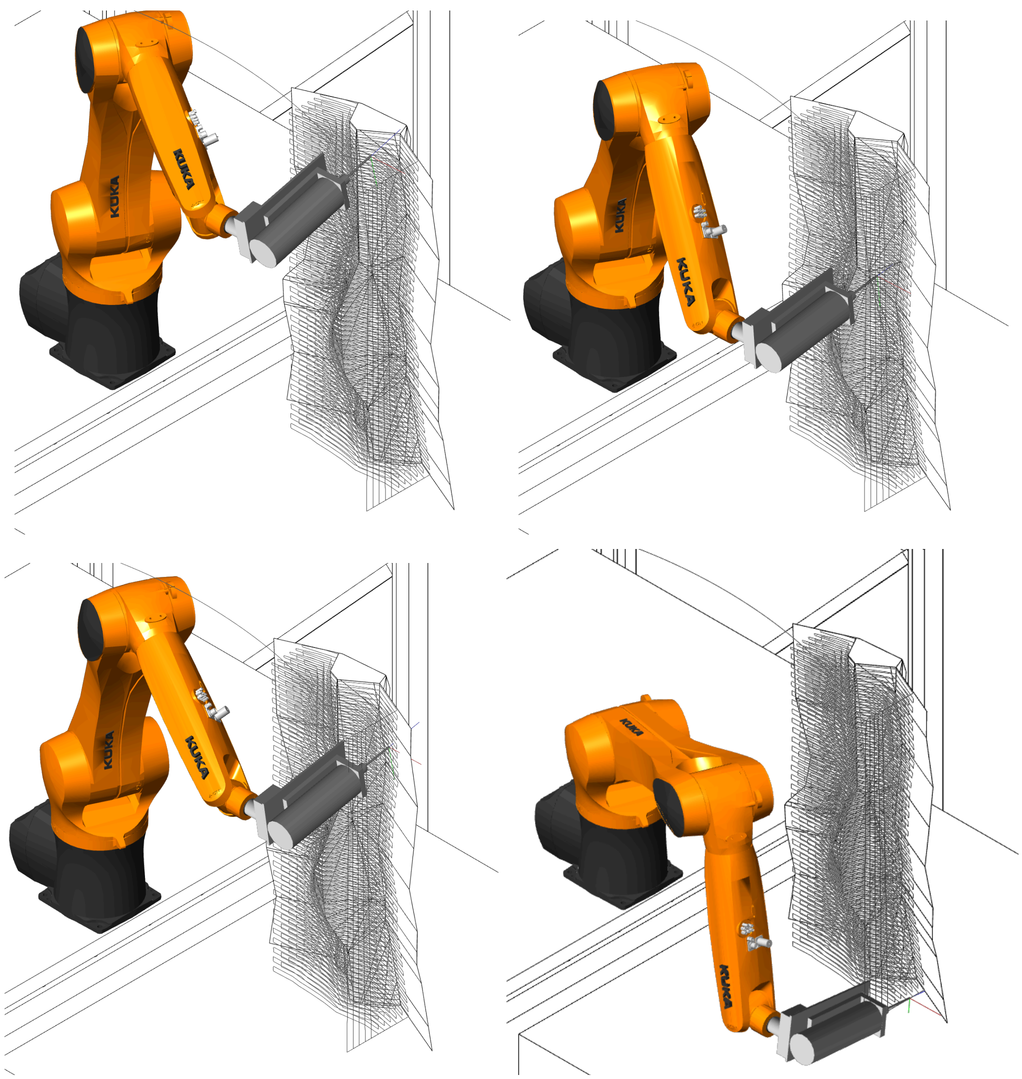
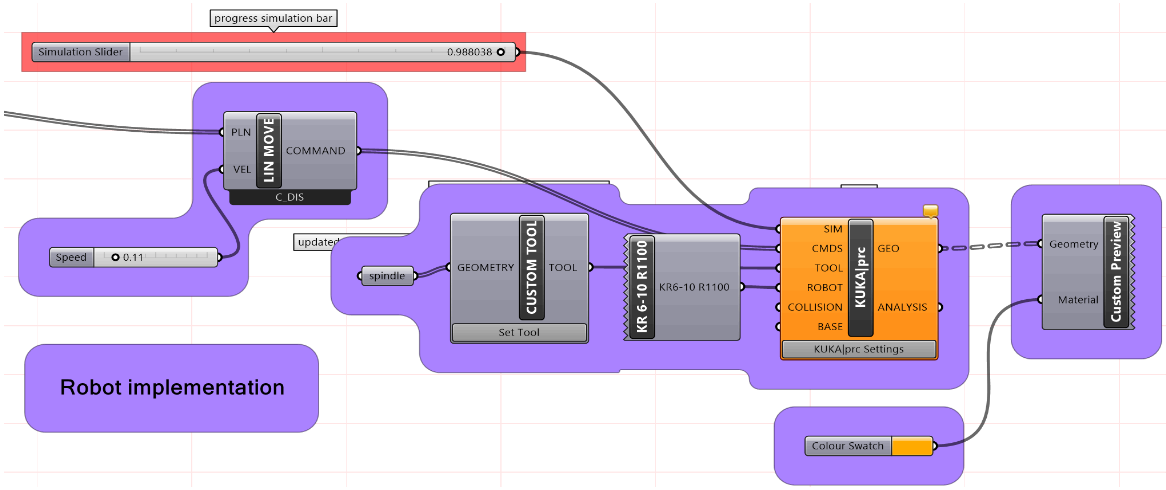
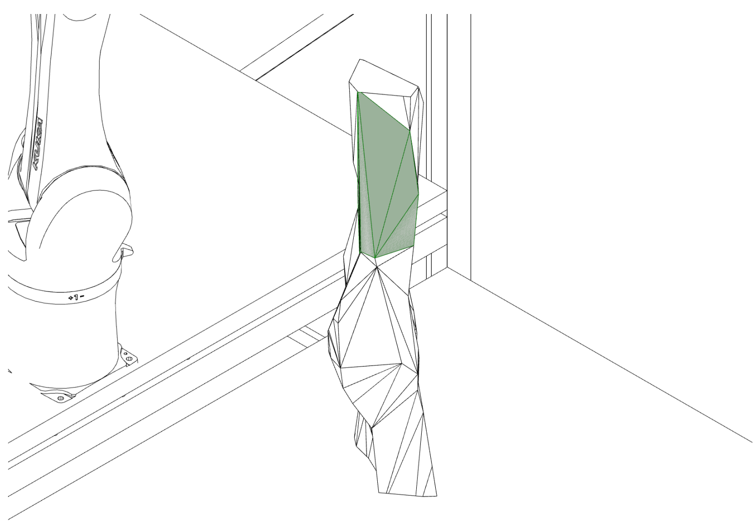


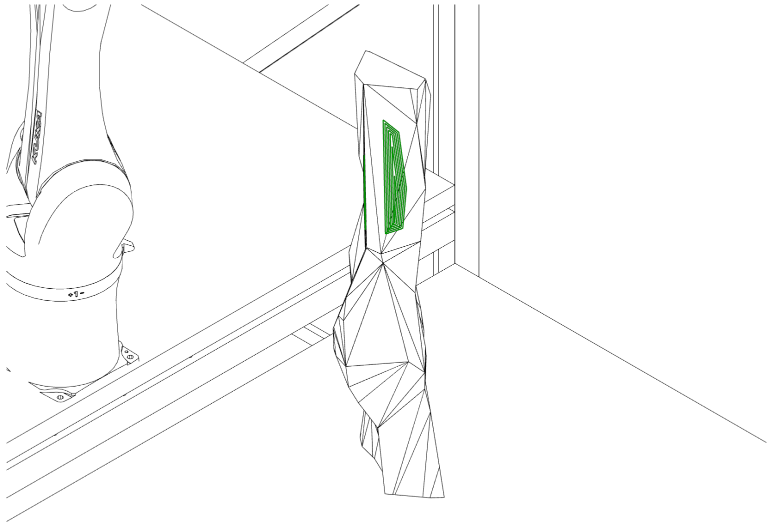


Screenshots 17, 18, 19, 20 & 21: Process of robotic milling, following the generated tool paths.

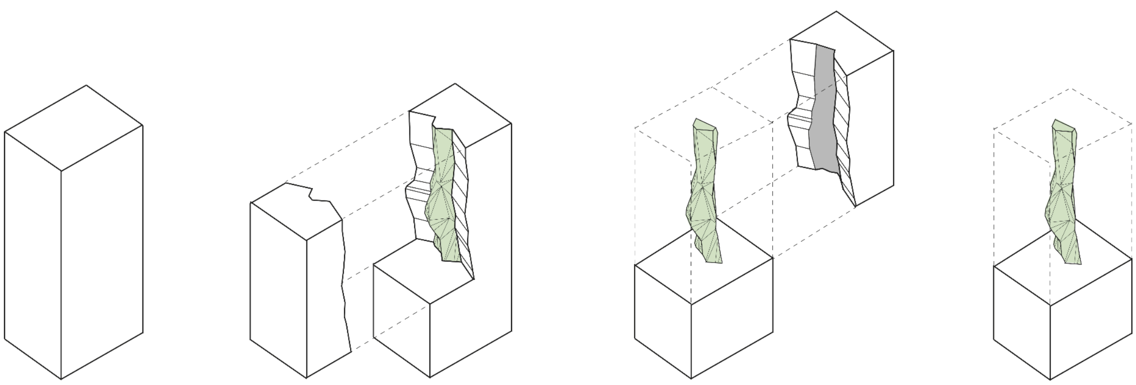
After the component has been milled, hand holes must be carved out in order for the robot to be able to pick up the fragment and assemble it with its neighbors. The process of creating these tool paths is very similar to the previous step. It consists of choosing two surfaces of the milled component (to have two holes), and for each determining the size and depth of the hole, in order for the robot to be able to grip it.



Screenshot 22: Input for the second step: creating tool paths for the hand-holes. This input consists of two surfaces.



Screenshot 23: Creation of milling toolpaths in order to dig out the hand holes.



Screenshot 24: final visualization of the milling process