

Settling between the cracks of Mars

MSc 3

AR0122 Interactive Architecture Prototypes Workshop 2023

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The Interactive Architecture Prototype (IAP) workshop aimed to investigate off-earth habitats designed computationally, 3D printed and which involves Human Robot coordination. The brief was to design a customisable and adaptive habitat for astronauts on the surface of Mars, using Design-to-Robotic-Production & Operation (D2RP&O). The report will highlight the design concept, the computation process and methods for its development and will embrace the findings.

Research on Mars environment & climatic conditions:

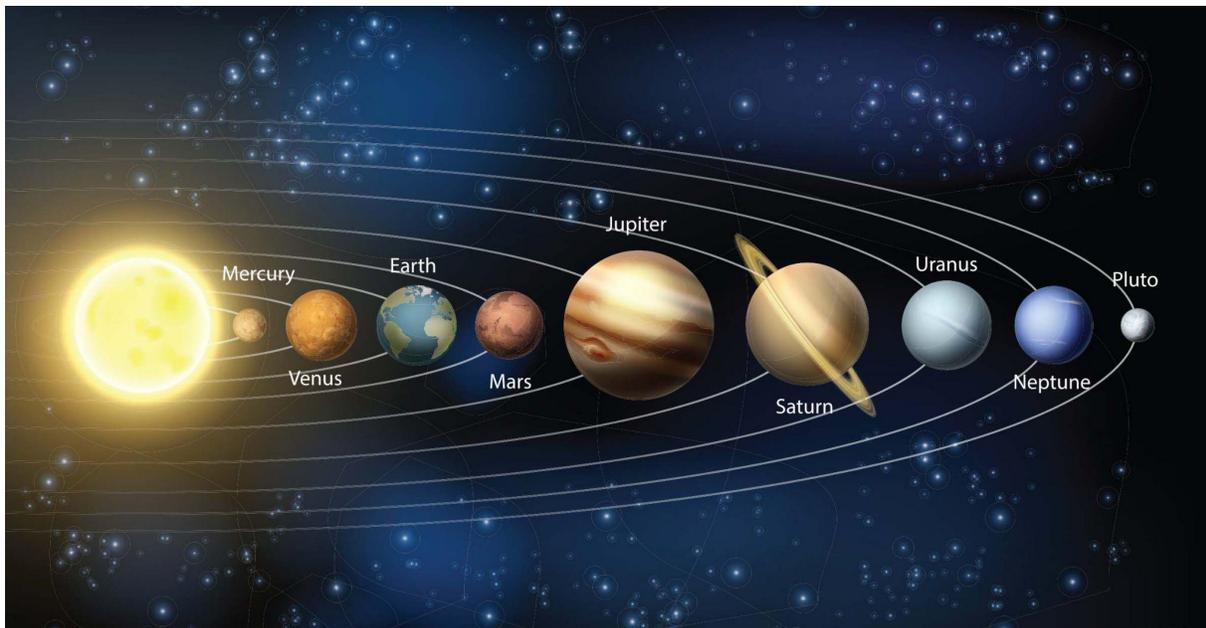


Figure 1: the solar system (SAFA 2016)

Mars is the fourth planet in the solar system and it is often called the red planet because of the high percentage of rusted iron minerals on its surface.

The planet Has two moons; Phobos and Deimos unlike the Earth which has only one and they have too little mass for gravity to make them spherical (NASA Solar system exploration 2021). Furthermore, the Martian surface gravity is only 37% of the Earth's, however, it is still suitable

for humans to walk on it because of its hard surface. (VAO n.d.) The main difference is that people will weigh approximately three times lighter.

Climate on Mars

On Mars, the Sun appears about half the size it does on Earth. This is because of the distance of more than 142 million miles from Mars to the Sun. At the closest point to the Sun, the Martian southern hemisphere leans towards the Sun, causing a short, intensely hot summer, while the northern hemisphere endures a brief, cold winter: at its farthest point from the Sun. (NASA Solar system exploration 2021)

The High temperature is around 20°C and the low temperature is around -153°C, which explains why this planet can be convenient for humans to live on. But seasons are twice as long as on the earth.

Also, Mars has the largest dust storms in the solar system. They can last for months and cover the entire planet. The seasons are extreme because its elliptical (oval-shaped) orbital path around the Sun is more elongated than most other planets in the solar system.

(NASA/JPL-Caltech 2022) This can be challenging for people and especially because humans are not used to this climate on Earth. That's why it should be considered in the design properly.

Atmosphere

Mars has low atmospheric pressure on its surface which is the reason why liquid water cannot exist on its surface for long. (Hoekman 2020) However, it has sufficient ice in its polar regions. If the ice on its south pole melts, the resulting water will be sufficient to cover the planet's entire surface to a depth of 11 meters. Mars, in addition to Earth, is the only other planet that has polar ice caps. Its Northern cap is called – Planum Boreum and the Southern cap is called – Planum Australe. (NASA Solar system exploration 2021)

Therefore Mars has a thin atmosphere and the composition Mars's atmosphere is 95.0% Carbon Dioxide, 3.0% of Nitrogen and 1.6% Argon. The absence of oxygen explains why humans cannot live on Mars. While the composition on Earth is 20.9% Oxygen and 78.1% Nitrogen. (Dobrijevic 2022)

Radiations

Natural Radiation on Mars is much higher compared with Earth. The thin atmosphere provides only a small shielding effect against cosmic radiation. (Marspedia 2022). It provides moderate protection against solar radiation. Mars also lacks the magnetosphere that protects Earth. The average natural radiation level on Mars is 24-30 rads or 240-300 mSv per year. This is about 40-50 times the average on Earth. (Hassler DM, 2014) (McKenna-Lawlor S, 2012)

Protection against radiations

Long-term habitats should be equipped with radiation shielding, thick enough to reduce the radiation to a level equal to Earth, that is, almost zero. Best protection may be achieved with houses built in natural caves or set into cliffs or hillsides. Any matter placed between a person (or radiation-sensitive equipment) and a radiation source reduces the amount of radiation they absorb. Mars One's solution is a thick layer of regolith on top of the settlement modules. (Marspedia 2022)

An effective shield will require at least several hundred grams of regolith per square centimetre, according to one study. (McKenna-Lawlor S, 2012) Using a regolith density estimate of 1.4 g/cm³, this means the regolith layer would need to be over 2 meters deep. For concrete with an average density of 2.4 g/cm³, the required thickness should be about 40% less. (NASA, Tony C, 2012)

Magnetosphere

Mars has no global magnetic field today, but areas of the Martian crust in the southern hemisphere are highly magnetized, indicating traces of a magnetic field from 4 billion years ago. (Langlais, Benoit, 2019)

According to prior research based on an underground rhizomatic structure with skylights, [Rhizome 1.0](#), it seems evident that building underground has many advantages including better temperature control against drastic shifts and protection from harmful radiation on Mars. "Dust storms, cosmic rays and solar winds ravage the Red Planet's surface. But belowground, some life might find refuge" says Nikk Ogasa in the article [Martian crust could sustain life through radiation](#) (Ogasa).

Site:

Based on the research about Mars' climatic and environmental conditions and evaluating the findings by previous workshop groups, we decided to build the habitat that is submerged in the ground to be protected from cosmic rays and solar winds. But the excavation of martian soil is a labor intensive task that could require heavy machinery and cost valuable time. Further research found out that fractured surfaces with polygon like shape are seen on the floors of Martian craters by NASA's Mars Reconnaissance Orbiter. Scientists estimate that on the surface of Mars, there are more than 43,000 impact craters with diameters greater than 5 kilometers (*see figure 1*). "The Martian crater polygons show cracks on both large and small size scales. The larger cracks are more than 100 meters long and up to 10 meters wide" (["Cracks on Mars hint at dried-up lakes"](#)). This pattern resembles the pattern of dried-up mud pools on earth, but are significantly larger in size. Places on Mars that show polygonal ground may indicate where future colonists may find water ice. So we decided to leverage the existing cracks in the Martian surface to build underground spaces for the habitat, thus eliminating the need to dig the planet's surface.

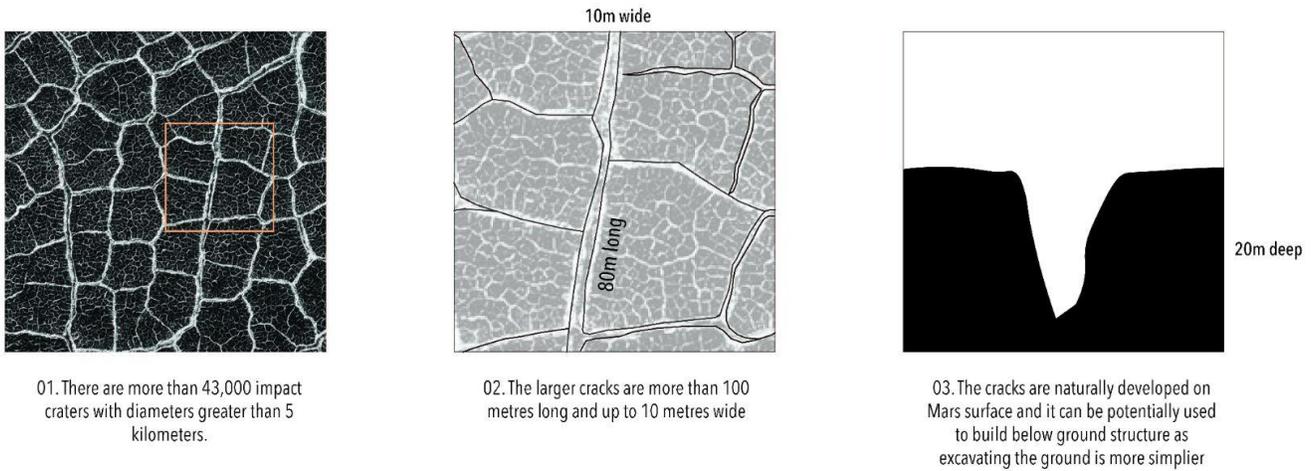


Figure 2: Cracks on Mars' surface

Form:

The cracks taper as they go deep about 20 meters, so we imagined a habitat that is linear in form and can be placed in the cracks. The form also allows for vertical arrangement of spaces, with the most public spaces near the ground surface and most private spaces below ground (see figure 2).

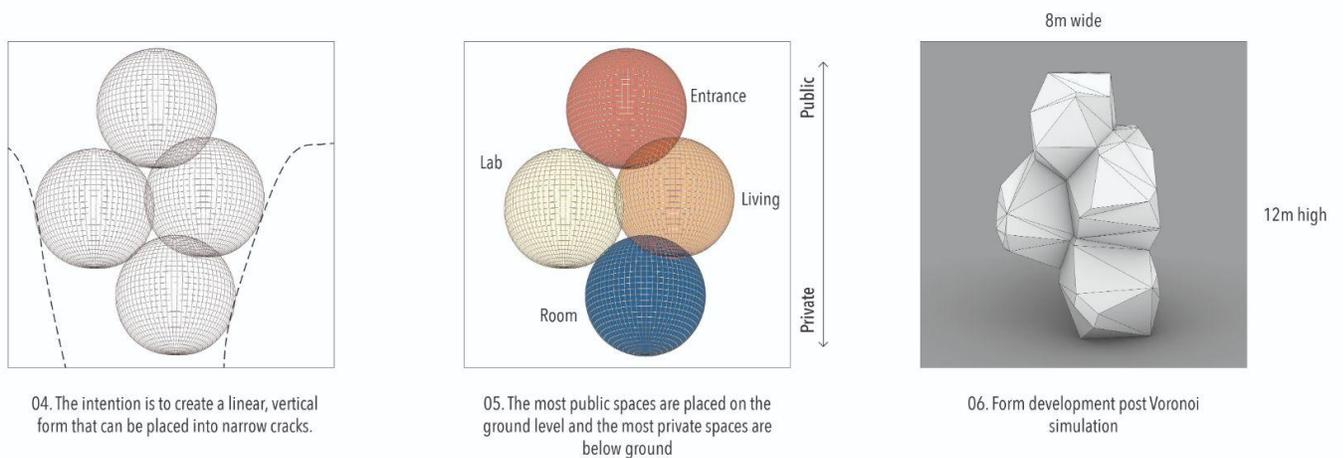


Figure 3: Design Approach

As a part of the workshop, we used Voronoi simulation to create a form that best suits our concept. The initial step was to start with a volume and convert it into small cells. In this case we started with a cube with a cylindrical cut out at the center. A grasshopper script was used to

convert the cubes into cells. The 'Populate 3D' command helped in generating points inside the cube that would eventually form the cells. We tweaked the number of points to have a better control on the division of volume. Interestingly, the Voronoi script ignores the cylindrical cutout and populates the entire cube. A different command called 'Populate geometry' was an option to restrain the points with the given form. Use of command 'Scale Nu' allowed us to control the scale of the cells into Y & Z direction.

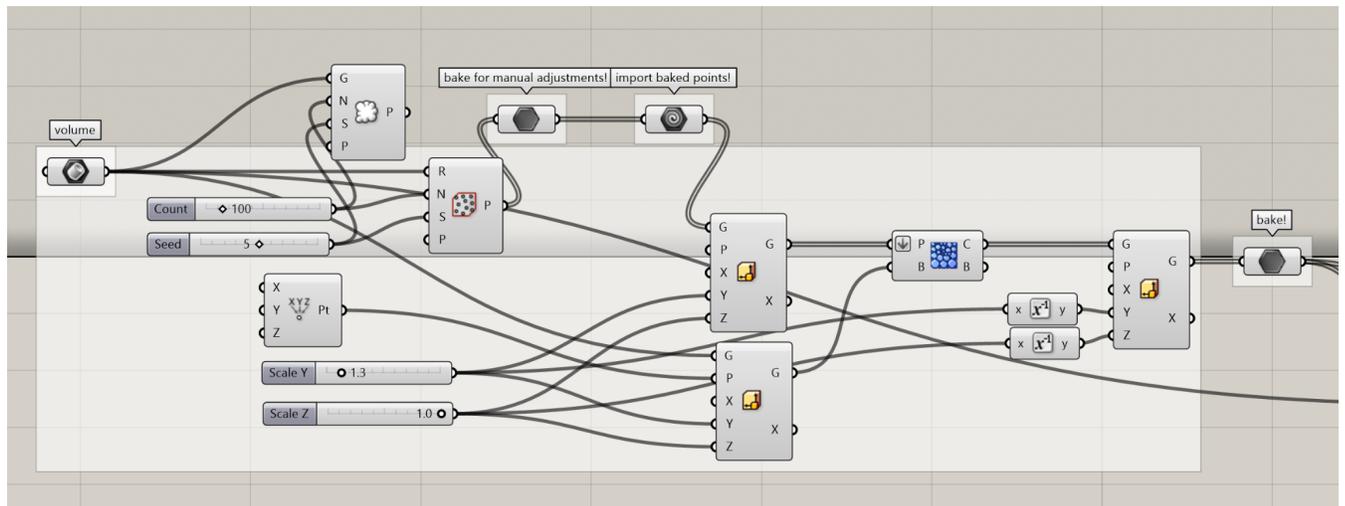
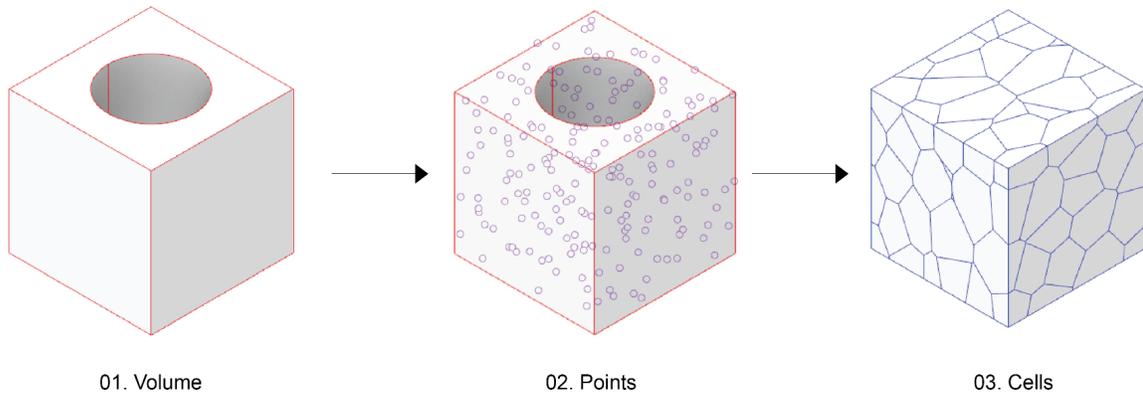


Figure 4: Volume to Cell method

The cells were then baked and a desired form was extracted out of the volume. The selected form was based on the justification of linear and vertical habitat. The identified cells were put back into the next grasshopper script to deconstruct into curves (see figure 4), which allowed for

customisation and modification of the cell shape. As voronoi has its own limitations, the step to manual modification of steps was crucial to obtain necessary width for curating internal spaces for habitat.

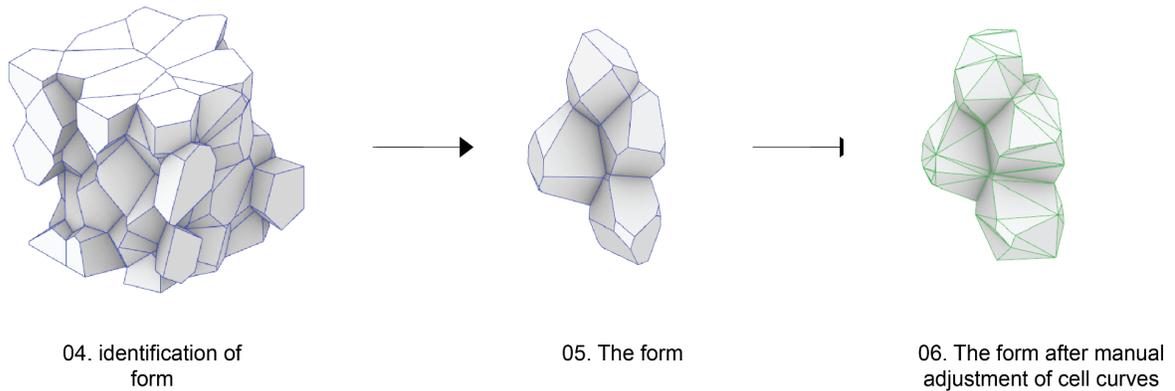


Figure 5: Development of form

Design realization:

The final outcome is a group of 4 Voronoi cells arranged in linear form. Each cell has a defined function as seen in figure 2. The cracks are filled with regolith or sand to create a below ground base and the structure is then placed in the crack. Eventually, the dust storms will fill the remaining cracks, creating a natural landscape. (see figure 5).

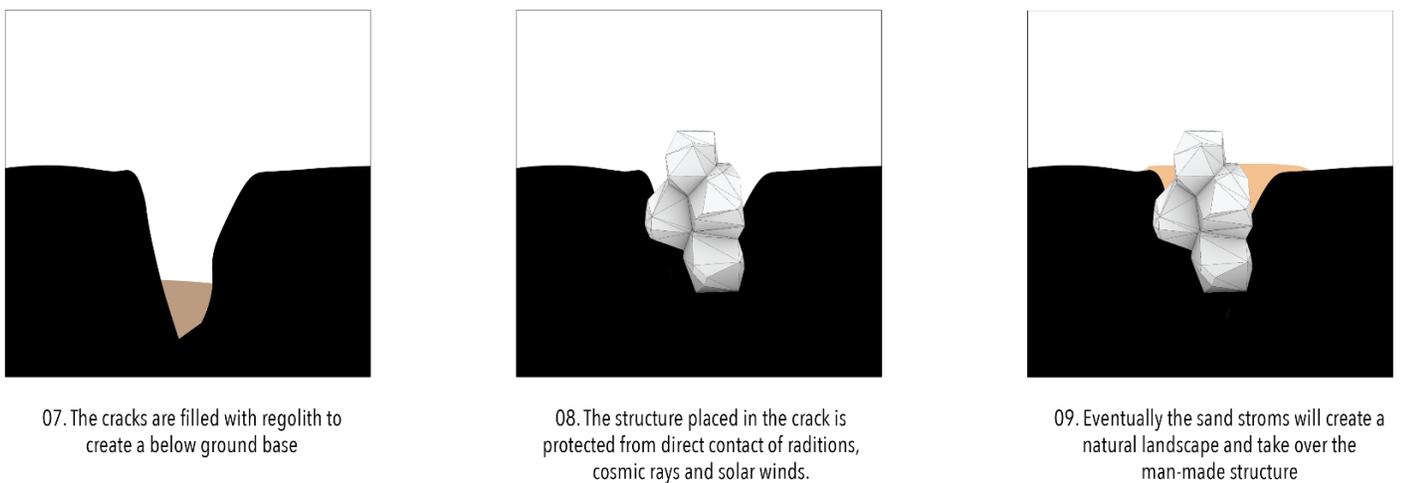


Figure 6: Regolith as base reinforcement

D2RPA&O process:

The robotic production and assembly process involve the creation of the small exterior wall components of the habitat using Voronoi cells, which are between 30-70 cm in size. To achieve this, a grasshopper script has been developed to set up the KUKA robot for the milling process. The production process involves placing the elements on a table and using different waypoints to specify the robot's frames and toolpath for milling. The robot then follows the path and removes material from the EPS box to produce the desired components.

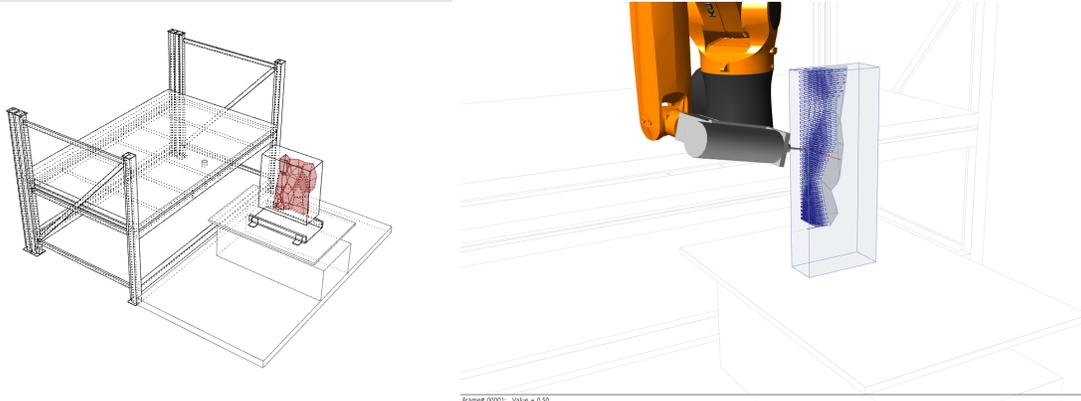


Figure 7: The Milling process.

Computer Vision

We explored CV techniques to generate communication for the robot to identify the larger hole of a component. We used structural reasoning from images; such as contour finding algorithms, perspective warping, and geometric object handling to achieve the desired outcome. To read the python script developed for the task, please use this [link](#).

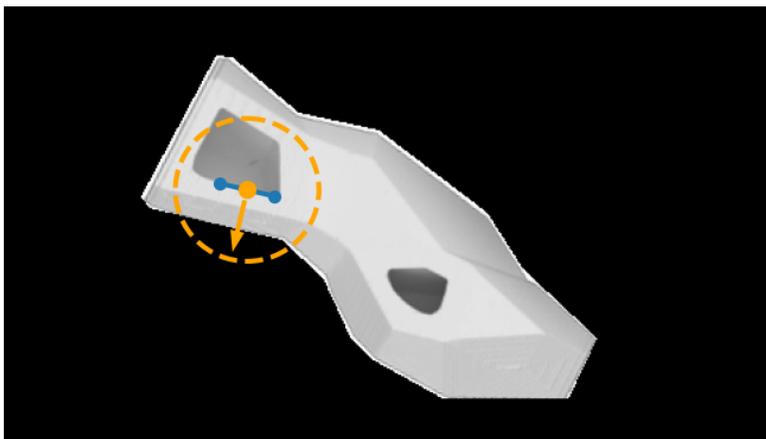


Figure 8: The position and orientation of picking edge. This end result will be used in HRI assembly.

HRI

The Robotic Lab's Human-Robot Interaction workshop demonstrated the potential for robot assistance in heavy labor activities. In our case, assembling the design requires lifting and placing large wall components next to each other. This task can be performed more efficiently with human-robot interaction. A computer provides generic inputs based on a Cartesian plane to help the robot identify the component, lift it, and place it at the desired location with human assistance.

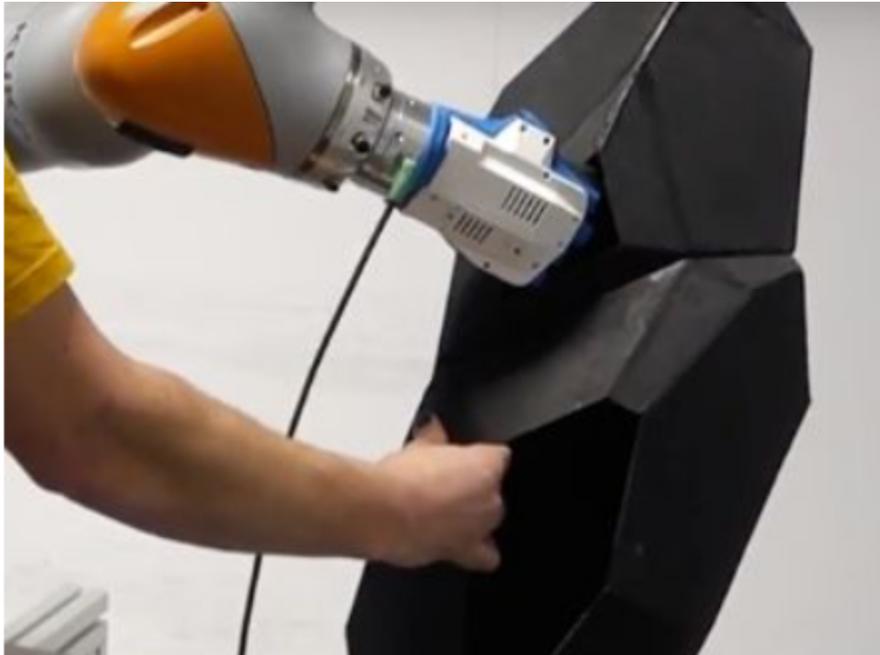


Figure 9: Human-Robot Collaboration. Source: Robotic Building - Rhizome2

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