BIO HAVEN

RECLAIMING AND RECONDITIONINGURBAN BIOTOPES

REPORT

1:1 Interactive Architecture Prototypes Workshop
(AR0122) (2021/22 Q3)

Faculty of Architecture and the Built Enviroment
TU Delft

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Introduction

The following project, BioHaven, has been a product of development for the workshop "1:1 Interactive Architecture Prototypes" (AR0122) held by the Complex Project Chair during the third quarter (Q3) of the academic year 2021/22.

The objective of the course was to deliver a piece of outdoor furniture to be placed on the TU Delft Campus that could work as an example of a structure that utilises modern Design-to-Fabrication techniques and Human-Robot-Interaction with a holistic approach to structure, function, environment, and assembly.

The course brief has challenged us to use a multi-faced design approach utilizing innovative Design-to-Robotic-Production-Assembly and -Operation (D2RPA&O) techniques as well as Computational Design (CD) process and a Human-Robot-Interaction (HRI).

Research

The starting point and focus were to identify the users on campus and the needs and activities of them. In our research it became clear to us that we needed to create a structure that acts as a part of the landscape, and we started researching the options. As inspiration we found three projects that guided us in the initial stage of design: "Distortion", the UK Pavilion exhibited at 2015 Expo in Milan and the 'Swoosh Pavilion" built in 2008.

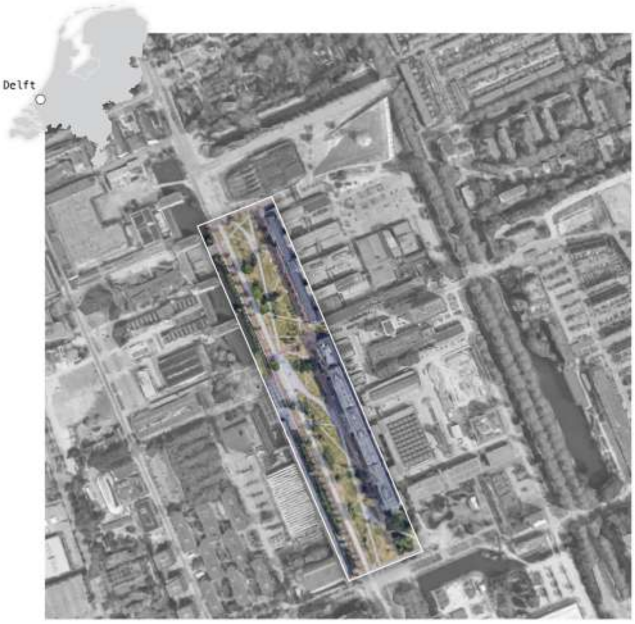
"Distortion" 2015

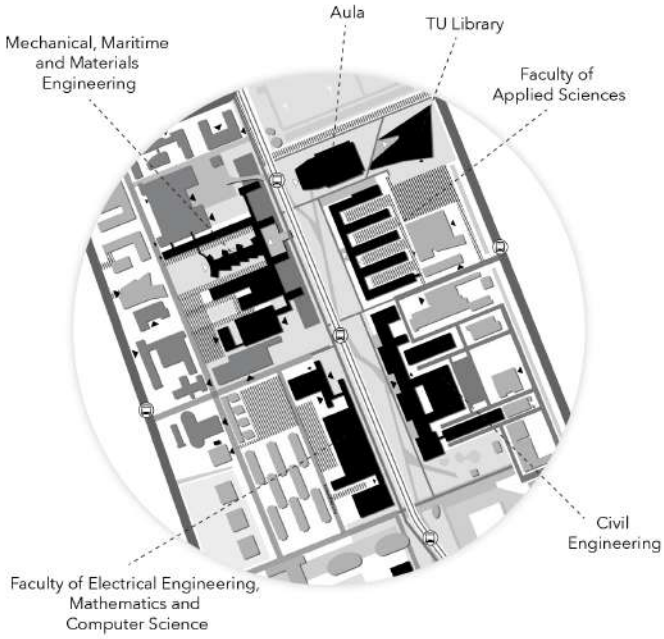
UK Pavillion, 2015

Swoosh Pavillion, 2008

From our initial investigation the possibility of conceiving a modular and interactive structure that would create an immersive experience and interact with the nature on campus while preserving the natural biodiversity evolved, resulting in our final design concept.

Site maps





The context of the Tu Delft Campus has been screened in order to find where this piece of furniture could be hosted. The Mekelpark, in the end, has been chosen to host the project due its easy reachability for student, professors, and visitors. The analysis started with comparing the different situations of the project at the time of its opening and its current situation.

Mecanoo's photos - 2013

https://www.mecanoo.nl/Projects/project/44/Mekel-Park-Campus-Delft-University-of-Technology

Nowadays - 2022

The surroundings of Mekelpark were analysed and the location of the main access points for users, and the main activities of the site were identified. This informed the design, which aimed at complementing the existing situation. Giving space for animals and plants, but also offering the existing users additional possibilities for congregation. By placing furniture at strategic locations, the park can be activated and turned from a green corridor into a green living room.

Current situation

Users

Students
Professors
University Employees
Visitors

It is mostly a human-used space that does not provide place for little animals and insects that populate the park

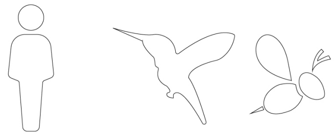
Activities

Walking
Biking

It's rarely used as a stationary place where people can meet and gather together due the lack of presence of appropriate urban furniture

Objectives

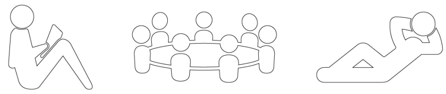
Users



Having a place that can gather all the users of the park habitat, protecting the biodiversity and creating a new quiet and natural seating spot

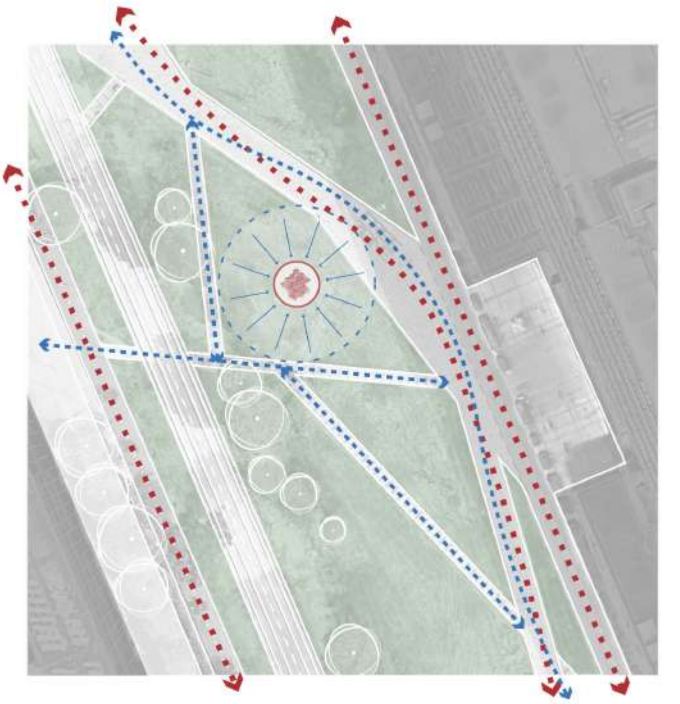
Activities

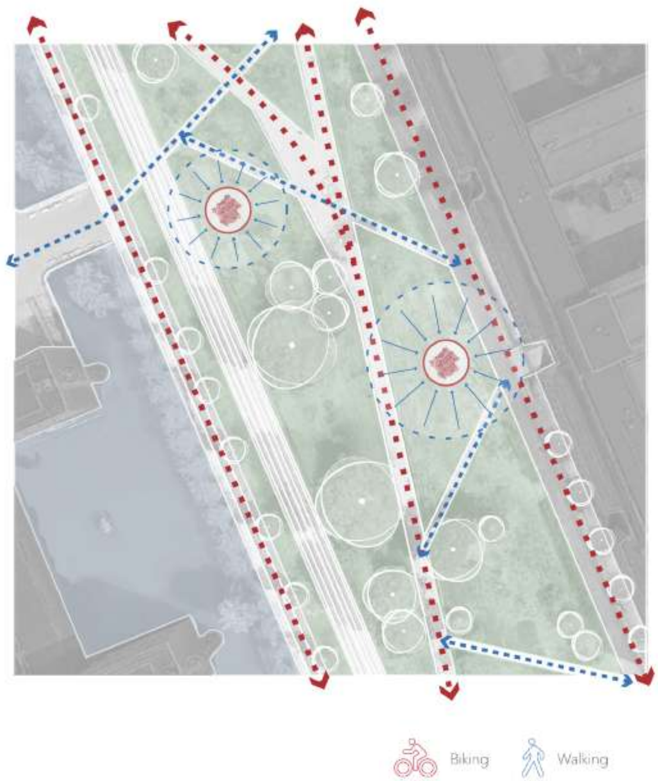
Using the park as a gathering spot



Reading / Meeting / Sitting / Relaxing

In the new situation the park gains new users. By introducing the new furniture biodiversity is increased as the furniture acts as miniature nature reserves and buffer zones for the local bee, plant, and bird habitats. Great care is placed on the placement and spacing of the furniture. By placing them at intervals they create links for the flora and fauna, but simultaneously enable for definition in the park for social interaction and activities. The new structures enable for playful use of the park, and offers both different protected subspaces for smaller groups, but also potential for people to meet in bigger groups. It offers a new potential for students, staff, and local residents to use the park not just for walking but for sitting, reading, meeting, eating and more.



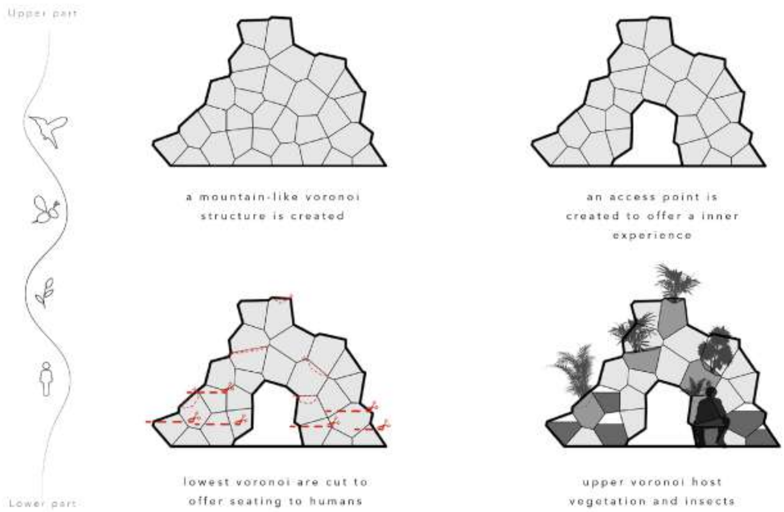


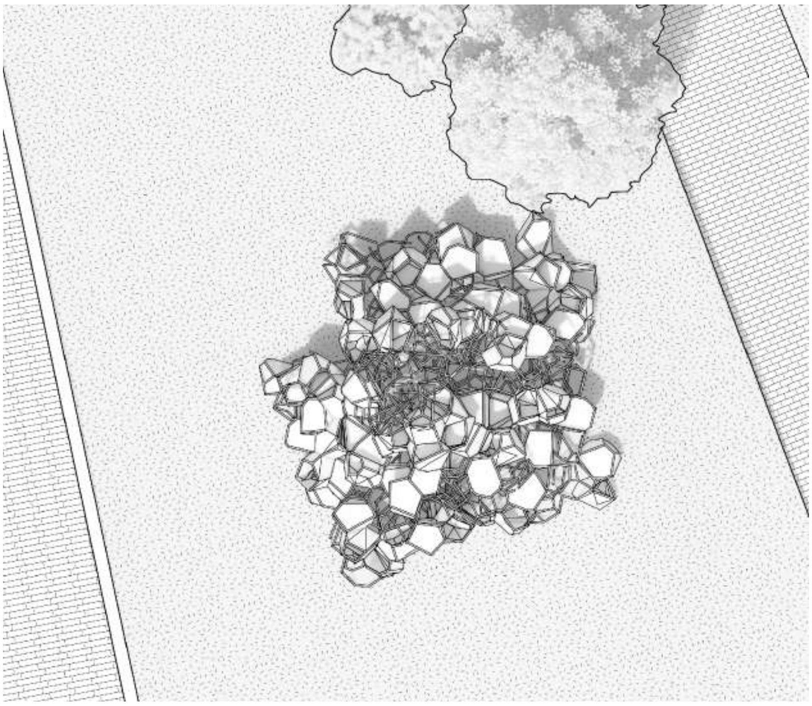
Analysis of slow and fast tracks and accessibility in the chosen sites

Design

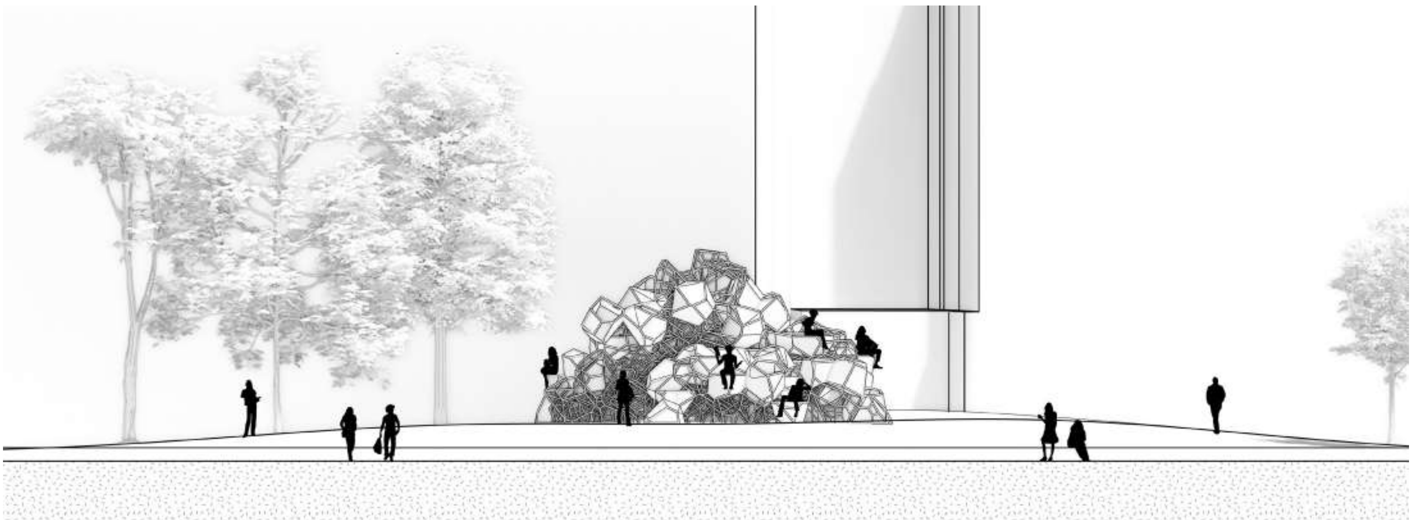
The design takes footing in an attempt to use digital design and fabrication methods to create furniture that can achieve the stated objective. However, the aim of the design was also to achieve this in the form of a design that mimics elements found in nature and that can enable for a organic looking structure. In essence, the design treats the furniture as landscape to give variety, diversity and definition to the monotonous grassy fields of the park today.

The design ususes parametric tools and a Voronoi structure to create this organic looking structure. In this structure the cells are divided into groups based on their placement to be used for different functions. Some are modified to be used as seating, some to be used for plants, and some are left open to allow for a higher porosity of the local flora and fauna within the structure. By doing this only a portion of the structure is actually usable by humans, the rest are reserved for the other users of the structure.





Plan

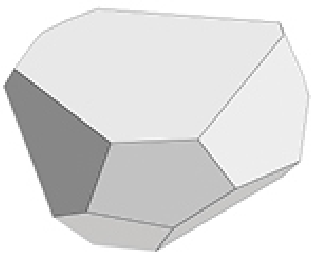


Elevation

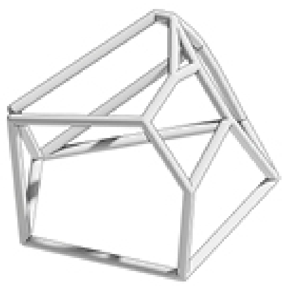
Micro scale

Voronoi

The plant cells are made up by 28mm thick plywood



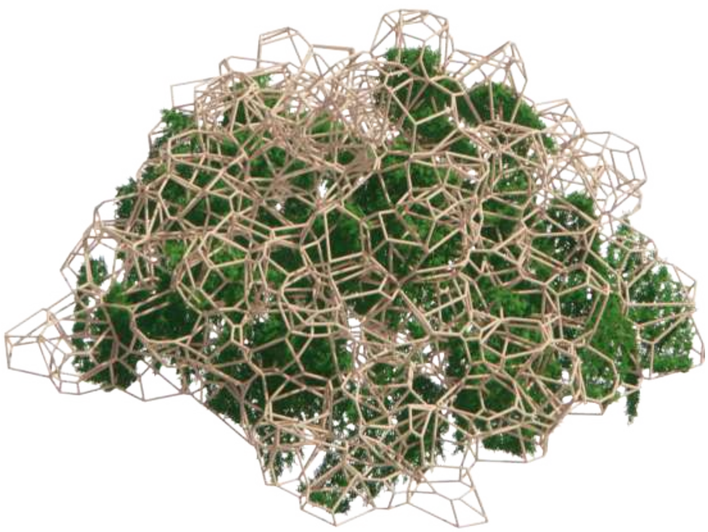
The seating cells are closed with a flat top to enable sitting and climbing to other seats



The node structure is constructed from wooden beams that connect through series of 3D printed nodes

Meso scale

Structure



Context

Axonometries

North-West

North-East

South-West

South-East

Materiality

The main body of the structure consists of timber rods, cross-laminated timber (CLT) panels, and 3D-printed Polycarbonate nodes.

The wood finish of the structure gives it a warm and natural expression and adds to the sustainable aspect of the project. By adding plants to the structure, the project gets woven into the surrounding nature in a natural way and adds to the biodiversity on site. Simultaneously it adds certain shading meanwhile introducing a sense of softness and harmony to the experience of the structure on site.

TImber Rods

CLT Boards

Polycarbonate

Plants

Parametric Design

For the design part, we chose to work with a Voronoi shape due to its structural stability and organic looking pattern. The BioHaven is a collection of voronoi cells that are stacked on top of each other. The design includes an inside and outside area which blend together through a partial cladding. The final furniture is a place where you can sit and eat your lunch, enjoy the vegetation and maybe even spot local animals.

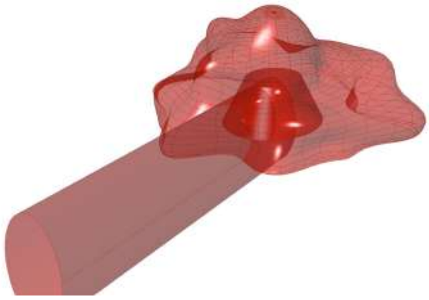
Completed using Grasshopper, the parametric design considers several different inputs and calculations that create solutions for different needs of the design.

Step 1: Voronoi box

First we start with creating a box. Then we start by populating the box with points and create voronoi cells out of them.

Step 2: Cutting Shapes

Simultaneously we make shapes that will be used to exclude certain Voronoi cells. The flattened cone and cylinder decide the boundaries of the inside area, while the irregular shape decides the outside shape of the structure. All shapes can be altered parametrically to generate different structures for different locations.

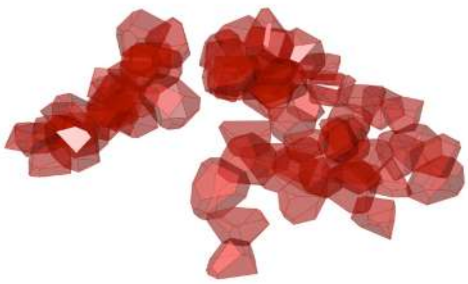


Step 3: Dispatching Cells

Both inputs from steps 1 and 2 are taken to dispatch the cells that are inside or outside of the cutting shapes. After this, the script sorts the voronoi on the outside of the pile from the inside ones, leaving us with two

Step 4: Seating and Vegetation

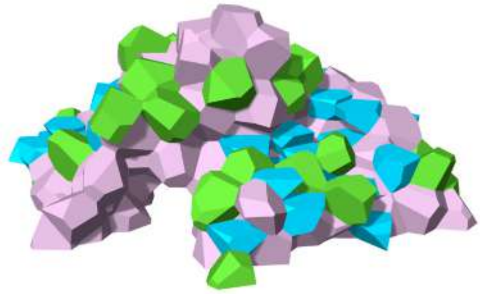
The cells on the outside are taken apart. We sort the higher and lower layers in different lists. Then we take a different number of cells per layer apart via random reduce. The cells that are reduced will be put back to the normal pile of cells. We then split quasi-randomly the list of cells in two. One list for seating voronoi and one for plants. "Quasi" because a script is added to locate more seating cells at the bottom of the structure.



Step 5: Sorted Cells

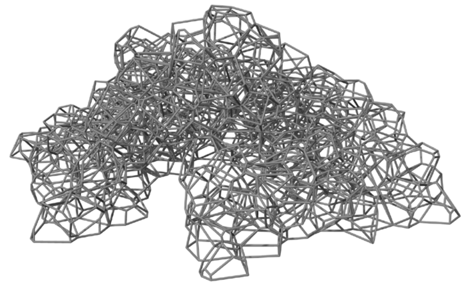
We end up with three different lists containing different kinds of voronoi cells in our model:

- Structural cells (purple)
- Seating cells (blue)
- Plant cells (green)



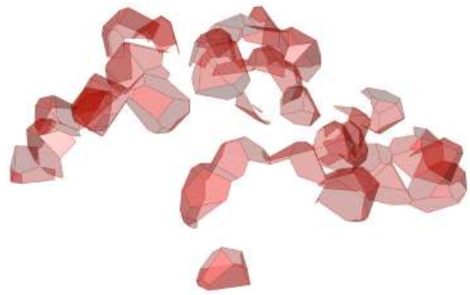
Step 6: Piping

All the cells are baked and checked for problems in Rhino. Some undesirable cells are removed at this stage, after which the geometry is imported back in Grasshopper for structural analysis in Karamba3D and piping.



Step 7: Dispatching Inside Faces

This step locates the faces of the plant cells that are bordering other cells in the model and which ones are naked. This step became a struggle for us as it required a complex flattening and grafting process of lists. Via the unflatten node, the tree structure of the cells was kept intact, so that the following script could function per separate cell.

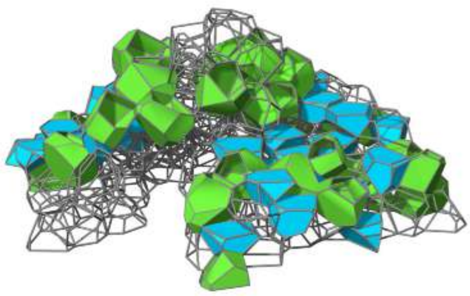


Step 8: Creating Plant Hole

In this last step we take all the outside faces of the plant cells apart and run a script on them. First, we sort the highest three faces of each cell. Then we calculate which one of them is the biggest and remove that face from the complete cell. This way we can ensure that we always have a big enough opening on the outside and top of the cell.

Step 9: Finished

We take all desired outputs and bake them.



Node Solution

In the node generation session, we use mainly two plugins: Karamba and tOpos.

We use Karamba for the structural analysis, which is able to simulate the forces in the structure according to the given loads and visualize it. It also optimizes the beam profile based on the forces. The beams are then brought into tOpos together with the force s vectors, and the form of the node is then generated that is structurally sound in the given situation. The node file is then finalized for the 3D printing process.

1. Structural Analysis

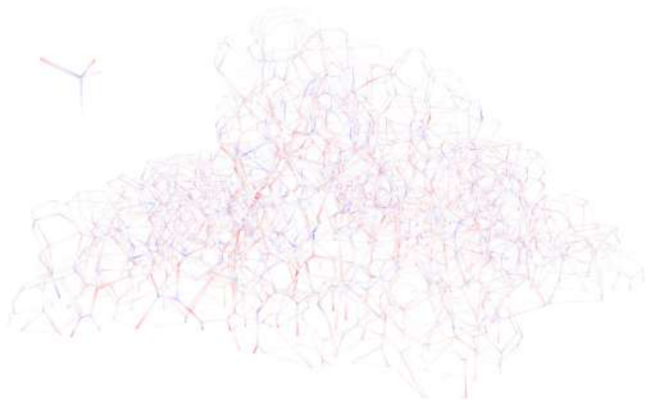
Step 1:

The first step is to assemble the model by inputting three basic elements:
- Beams
- Foundation Points
- Loads

Step 2:

After assembling the model, Karamba will simulate the forces of the structure. So that, the forces on the beam can be visualised.

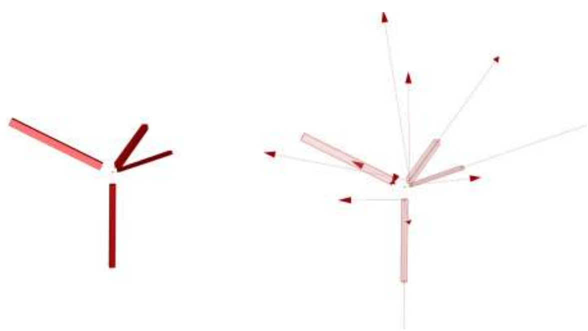
The extract value of the forces on the selected beams will then be used to generate the real beam, and later also for node optimisation.



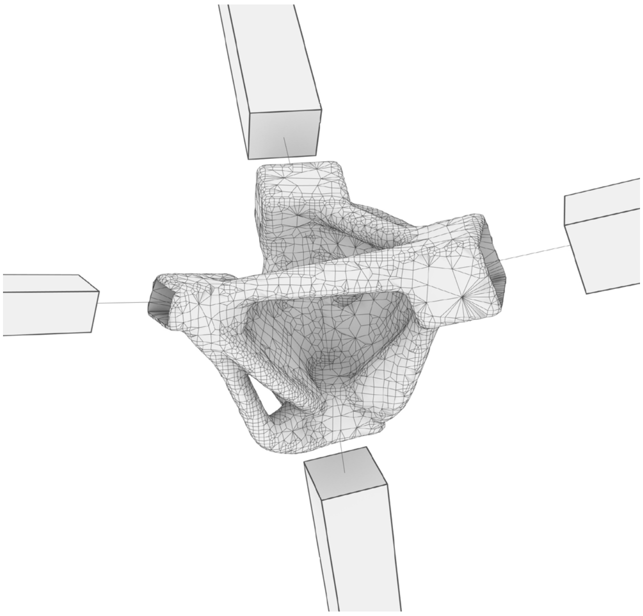
Step 3:

The vectors of the three forces are calculated, and further used in the node optimisation.

The distance between the centre point and the beam can manually be adjusted.



2. Node Generation



Final Node

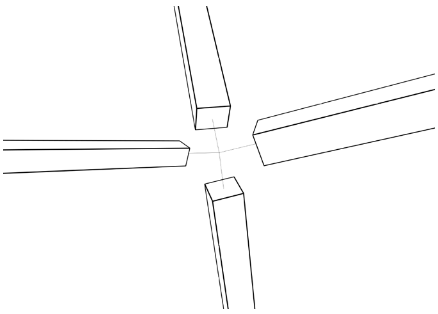
Now the beams are generated by Karamba, we optimised the node by setting **three different load cases** that will generate three shapes made by from three different vectors. As the final step, a Boolean union is made over the three different shapes to get the final node.

The main crucial aspect in the optimization process, is deciding the amount and orientation of the load vectors acting on the node through the beams. To get an accurate result, the simulation must be split into different load cases. In our optimization we used three load cases oriented in polar directions. Thus, for each load case, the vector must be rotated 120° in the same plane, perpendicular to the beam. Using four load cases would mean steps of 90° instead.

The amount of load cases decides the accuracy of the optimization of the final node in comparison to an ideal node.

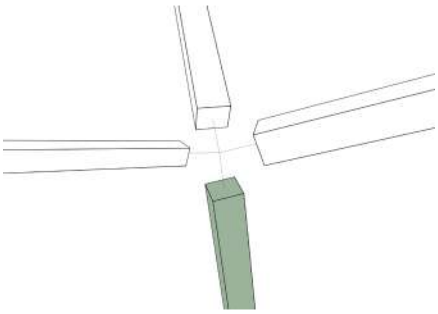
Step 1: Beams by Karamba

The size of beams depends on material, loads and the structure load itself.



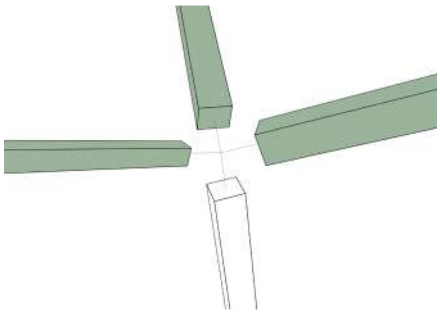
Step 2: Set supporting beam

Choosing the one below



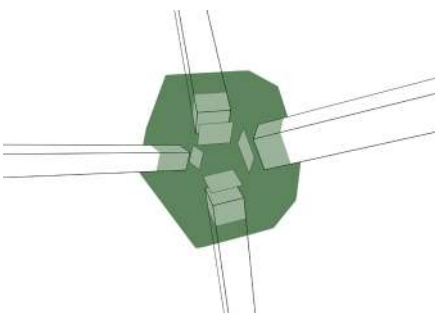
Step 3: Set loading beams

Choosing the three remaining ones



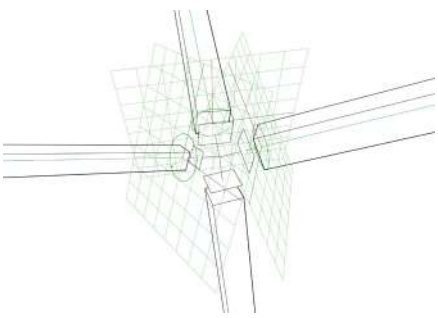
Step 4: Set node frame

Generating a polyhedron by extending the capsurfaces of beams in order for Topos to limit the node inside this frame



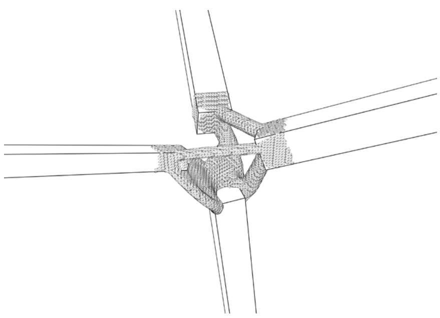
Step 5: Set forces as vectors

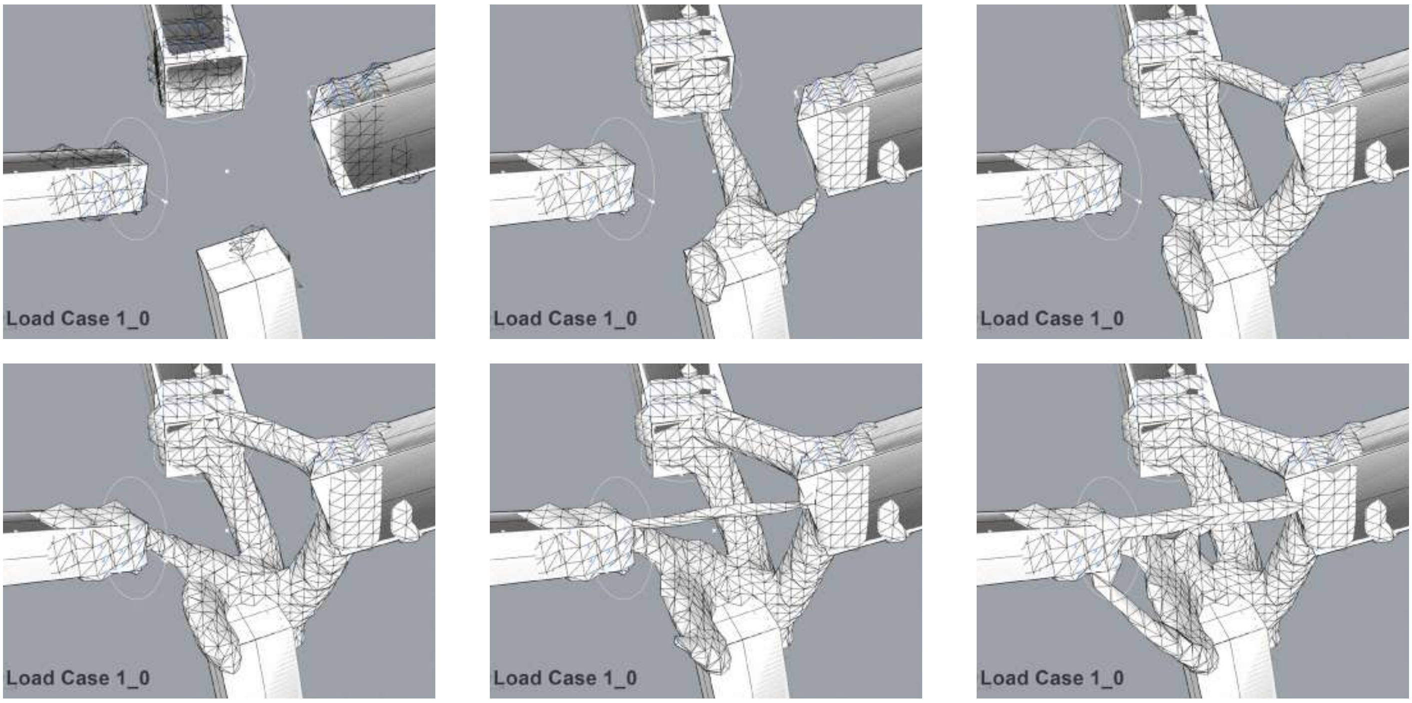
Set a vector on capsurface and also perpendicular to the centerline of a beam. Vector rotation 120° and 240° degree for the next two beams.



Step 6: Generate result by Topos

Connect all elements to the Topos script to get one result for a load case.

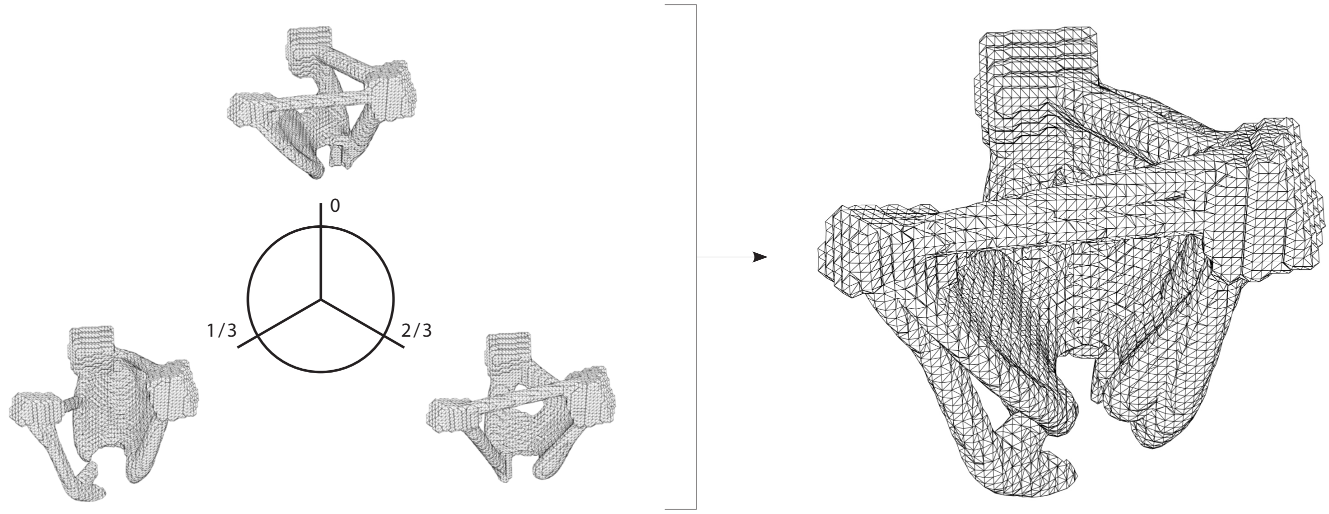




Example of the process made for LOAD 1

Step 7: Repeat the process with the other two load cases

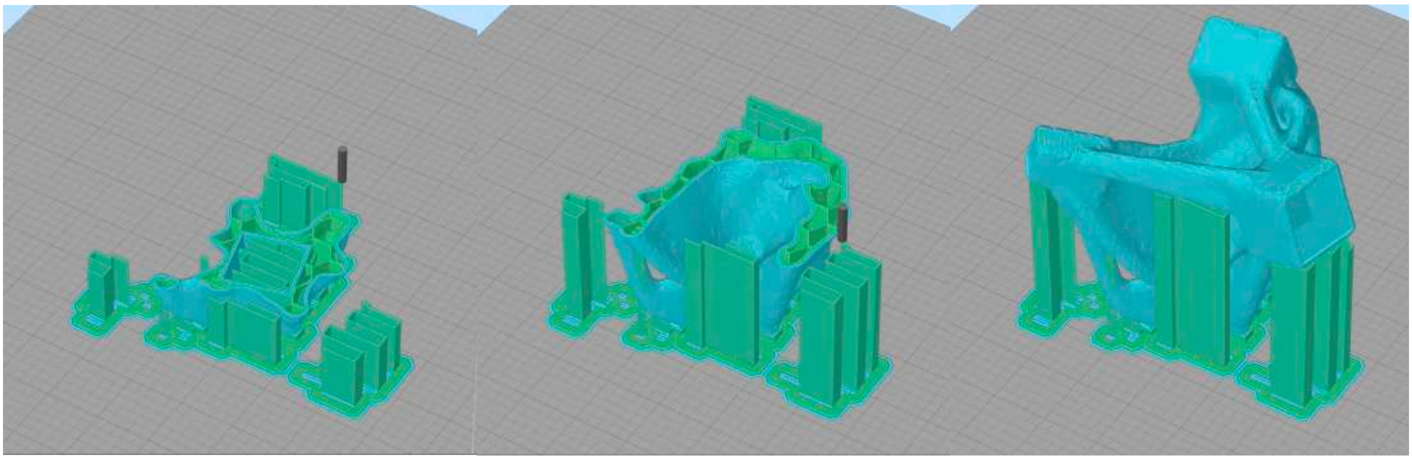
Step 8: Join three shape results and form a unified shape



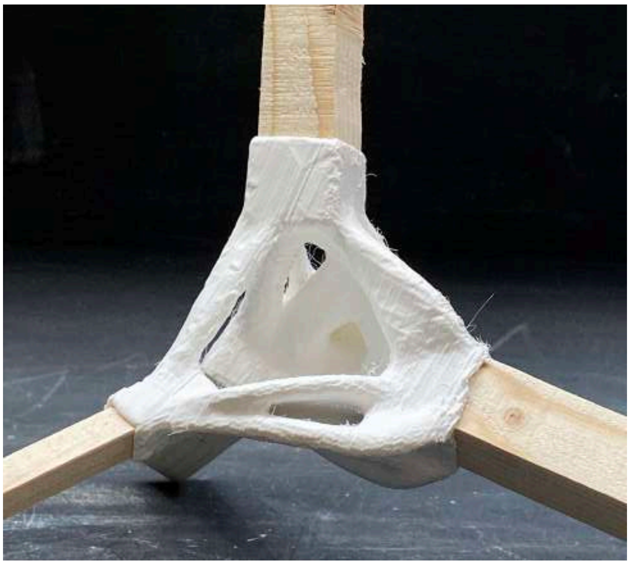
Step 9: Smooth the node's surface and split it with the beams

Node Fabrication

1. 3D Printing Process



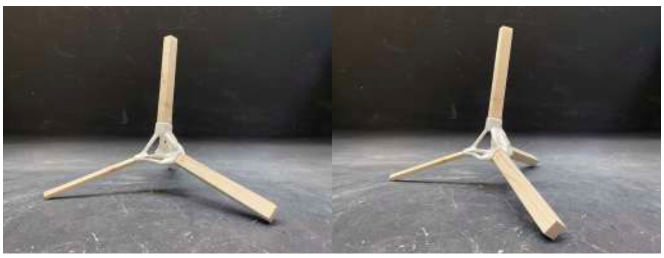
For the fabrication process of the node, we used the 3D printers at the Robotic Lab.



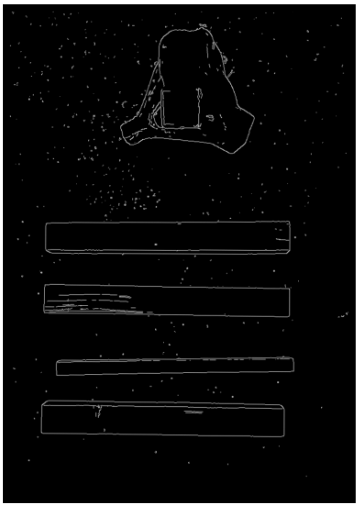
Even if the model has been parametrically generated, some problems with the smoothness of the outer surface and the sizing of the node created delays in the printing.

Firstly, we exported the node from Rhino as a STL file and set the settings of the ANYCUBIC CHIRON printer using 1.2mm nozzle. We opted for high-quality settings, such as EPS and layer height set as 0.2mm.

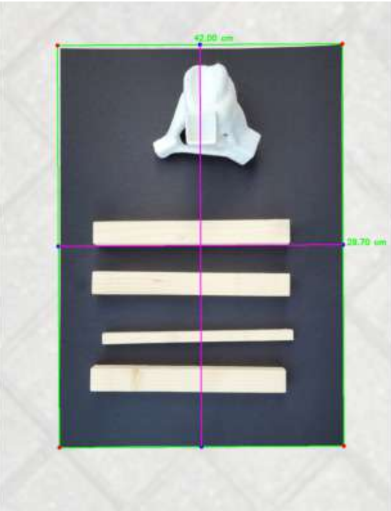
The trial-and-error process of printing made us realise some of the problems of manufacturing and forced us to find solutions to these problems. We had to go back to refine our node generating process. We tried to make the node smaller and thickening the outer layer of the joint part to perfect it. The result of 3D printing was satisfactory and together with the wooden beams, we got an 1:1 prototype node.

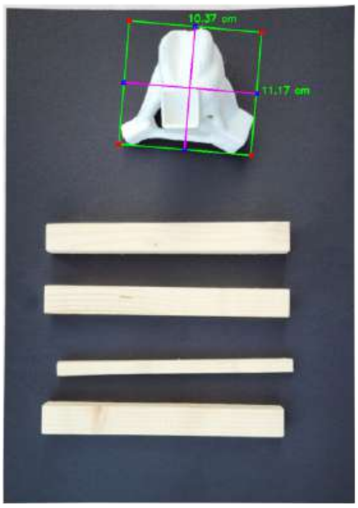


Computer Vision

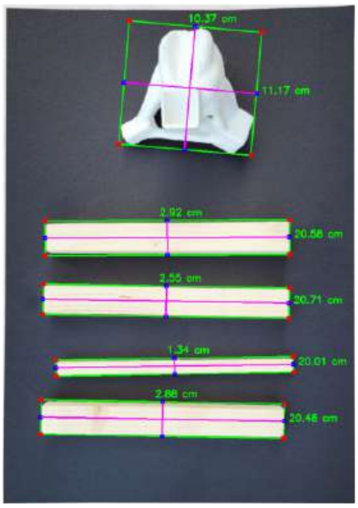


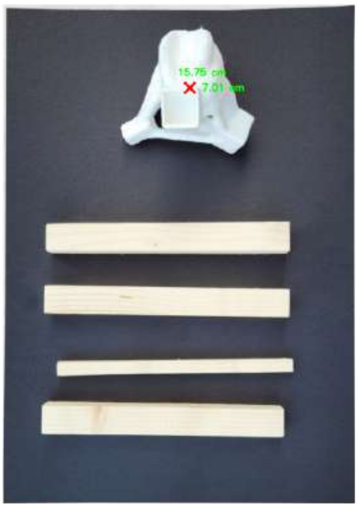
In the Computer Vision session, we explored image processing using python and the Google Collab Service. By using different Python libraries, different image processing actions can be applied to the image. In order to understand the process, we also had to better understand how the computer reads an image, an approach that is very different from an intuitive human approach.





The Python script developed in the CV session was to be used to create the visual link between the node and beams and the robotic arm, which would be crucial for the later Human-Robotic Assembly part. The goal was to create a script that would enable the robotic arm, to visualise, locate and grab the elements and bring them to the assembly point. The photo of the node and beams (placed without overlaps) would be taken as an input. After manipulating the image with processes like eroding and dilating to wipe out unnecessary noise on the original image, the script is able to detect the boundary of the background table and the boundaries of each element.





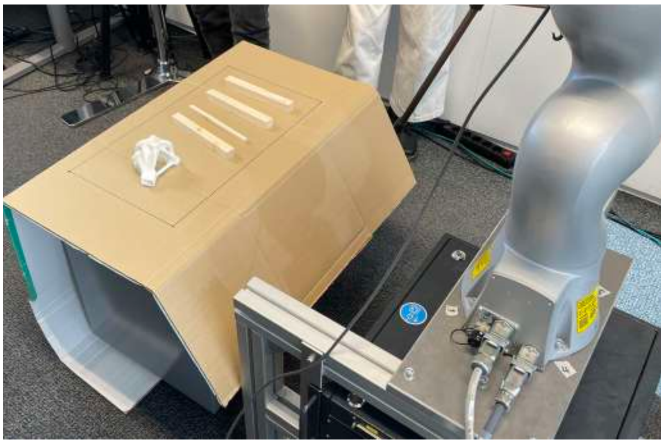
With the measurement of the actual black piece of paper as an input, the pixel per metric transformation tells the computer the relative size of each element. The target element could then be selected based on its size or based on the coordinate of the centric point of each member.

By locating the centre point of the element, the computer can tell the robot arm not only where the object is located but also where to grab it. It can then pick up the element and place it in the right position.

Collaborative Human-Robot Assembly

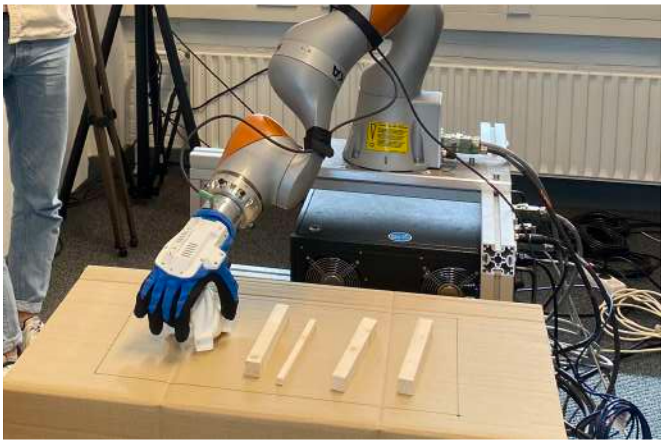
The KUKA robotic arm is a particular arm, equipped with a human-shaped hand and its seven joints make it possible to be maneuverer with large flexibility.

The robotic arm grabs the wooden beams placed on a small table in front of the robotic arm, and place the beams to the designated location, where the collaborative assembly will take place. Humans in this process will manoeuvre the robotic arm when necessary to enhance efficiency. The collaborative system takes the advanced abilities of both: the robotic can lift heavy stuff while human has a rationale when it comes to solving quick problems.



Step 1: Synchronize

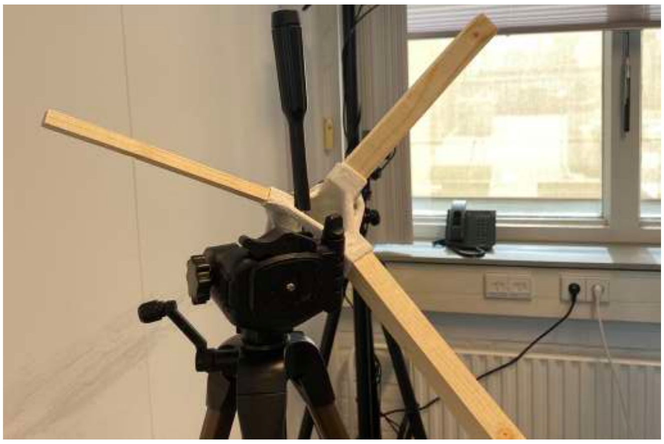
We guided KUKA to the node rack, by inputting this as position A in its controlling programme. The relative position of the small table to the robotic arm is another input, which is a prerequisite for enabling the robotic arm to later locate the members on the table.



Step 2: Computer Vision

We import a photo of the four beams and the node, placed on the small table. This way, the CV script bonds the robotic arm to the real world. KUKA can move to whichever point you click on the imported photo.

The improvement of this system can be achieved by placing a camera on top of the table that takes multiple frames as constant inputs. By doing so, the robotic can make real time updates of the changing setup of the table.



Step 3: Grab and Assemble

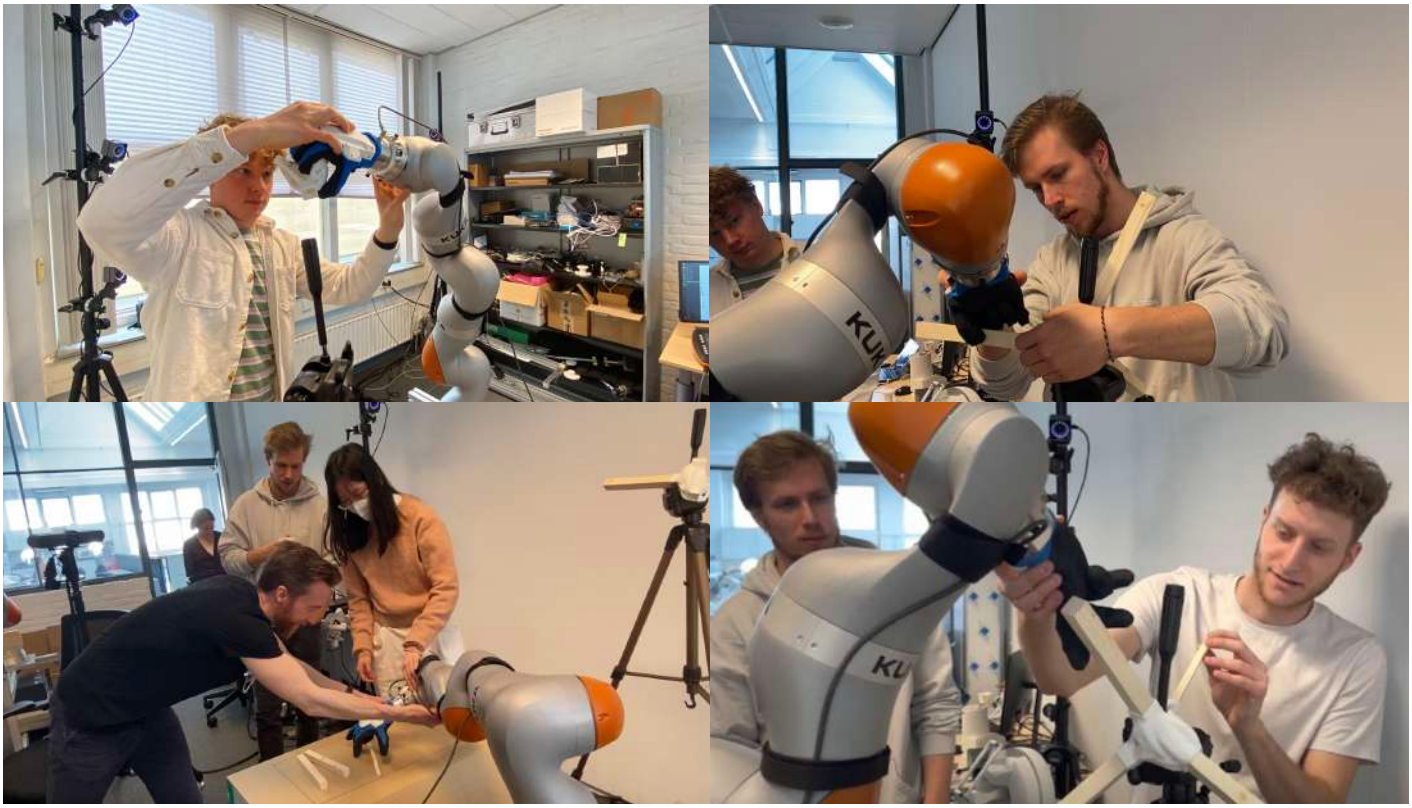
When KUKA has moved to the specified place, the human can guide it to a more precise location, where the robotic hand can grab the target item. After successfully grabbing the item, the arm can send the item to the prescribed position A.

The assembling of the beam to the node requires more accuracy, thus this is done by a human after KUKA has transported the beam from the small table to the node position.

HRI Reflections

During the Human-Robot Interaction, we discovered some of the possibilities of a collaborative assembly. The interaction aims to take the advantages of the robot and use them to compensate the weaknesses of humans: strenght, stability, precision and durability are some of the resources that a robotic arm can provide during the assembly. On the other hand, the robotic arm misses the rational sense that humans have and provide during the process.

Although the experience we had was not using each user at its maximum potential, the assembly was a way of showing how this process can be executed. Some of the problems we faced, such as difficulties in grabbing smaller pieces and problems with the robotic torsion that would get stuck, are being studied in order to find feasable solutions. In the construction industry, the opportunities given by the the use of robotic arms will lead into a more efficient and more precised workflow. The process can be improved with the use of a continuos flow of images that are scanned and analysed through a computer vision script that would facilitate the data collection and the machine learning process.



Photos of the process

Final Conclusions

The BioHaven project tries to show how contemporary design tools and fabrication methods can be integrated into the architecture / furniture design process. The design has been generated through the use of parametric tools. The use of Grasshopper and the possibility of changing parameters of the Voronoi shape, enabled the design to meet different needs, functions and activities. Thanks to the use of the Voronoi logic that is applied on different scales (macro, meso and micro), the BioHaven furniture is able to face the needs of the Mekelpark while symbiotically host humans, vegetation and local plants.

As described in this report, the design went through several phases such as Parametric Design, Node Solution and Fabrication, Computer Vision and Collaborative Human-Robot Assembly. The combination of these different processes enables us to envision new possibilities and new logics for design and manufacture. It has the potential to increase efficiency and widen the scope of what's possible in an architectural practice.

Using this method, questions about for instance structure are brought into the design at an early phase. This is apparent in for example the form of the node that is developed primarily based on its structural performance simulated using parametric design tools. By parameterizing the design a flexibility is introduced that used to be unattainable within design just years prior. Instead of redoing the design and modeling out the results we can test a lot of different possibilities just by dragging a slider. This opens up a world of possibilities if applied in the right instances.

As for the realization of the design, the 3D printing technology makes it possible to materialize relatively complex, organic forms, which would otherwise be difficult to produce through conventional manufacturing processes. It is easy to see the potential of this synergy of parametric design and 3D printing, as a way to fabricate complex geometry where precision in key, such as is the case with the node within the structure of this project.

During the computer Vision module, we tackled how image processing can be utilized for data collection and machine learning in sight of a future collaborative assembly approach. By introducing computer science into the design process we can enable smarter solutions within design to fabrication transitions. It is clear that when the assembly becomes very complex or the elements become very heavy that assistance from a robotic arm interacting with the design through computer vision can enable for a faster, cheaper and safer fabrication process. If thought about in an early stage, as done within this project, the scope of what's possible within an architectural practice increases.

In this course we got an introduction to a way of thinking about design, and an approach which if applied in the right instance has the possibility of changing the limitation we set on our design and enable for new structures resulting from innovative design-to-manufacturing processes.