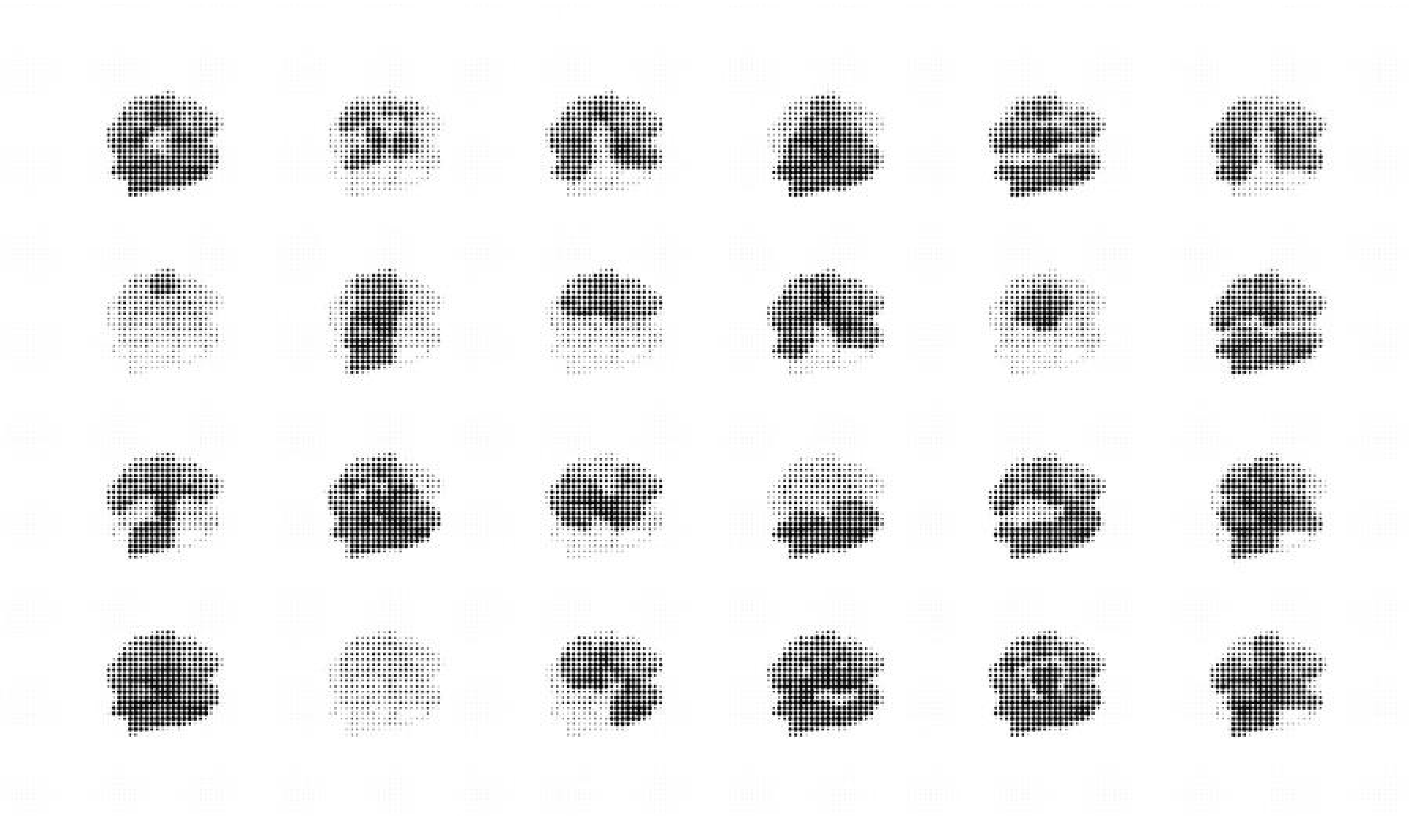
AR0122

1:1 Interactive Architecture Prototypes Workshop



Technische Universiteit Delft
2021/22 - Quartile III

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I - Introduction

The course focused on development of interactive furniture concepts with parametric design tools. Within the parametric development process we used grasshopper and rhino to develop the final form. Later, the structure was optimised with the Karamba and topos tools and prepared for robotic production and assembled node construction. We've prototyped the node using a 3D printer and hand crafted wooden elements that were later assembled by a robotic arm - KUKA. The design process integrates functional, structural, material and sensor-actuators into the interactive furniture production. The class focused on 2 main aspects of design - computational design & optimization and robotic production & assembly.

In the first part of the report we describe the idea behind the furniture and the process of computational design, where we explain the process of generating the structure from a point network and the form finding process. Later we introduce the functions and final form of the design. In this paper the final process of karamba and topos structural optimization is explained, that differs depending on locations as the furniture was created as an adjustable and flexible form, a system that can be used in different places. Furthermore, we show the 3d printing process and optimization of the node for print using the Simplify3D program.

Later, we dive deeper into design to robotic production assembly and use of computer vision, where we explain the process of preparation for assembly and recognition of the objects that were to be assembled by robotic arm. In this part we share our reflections and questions raised in the studio. Finally, in a conclusion section we share the reflections on a course, our limitations and what we learned during this process of interactive learning.

Our vision for the interactive design was a development of outdoor and indoor furniture. The design combined within itself 5 most important features - interactivity, so the users can create their own form form modules; biodiversity - cells that would work with environment and purify the air; education - a space to work, explore, play and socialise and safety - so the furniture would be good to use for younger and older users. Following the thought of "playground for students" we developed the concept of the wall, that can be assembled in different ways and create new forms for social interactions. During the design process we wanted to include mentioned values, therefore different types of cells were created with the usage of different types of material - from rubber, to PLY and wood.

II - Computational design

Generating a 3D Point Network

We started the process of computational design with the generation of a point cloud, from which a 3D voronoi pattern could be generated. Initially, we wanted to challenge ourselves and see if we could generate a point network based on an alternative method. We explored methods of connection points in a point cloud in a 2D environment first - to get a grip on the concepts that could later be translated to 3D. Alternatives we experimented with are the Delauney tessellation method and the barycentric dual mesh. From the Delauney tessellation, the midpoints of the triangles are taken and connected, forming a cell structure that is reminiscent of a voronoi tessellation. This kind of mesh generation, however, is based on two operations instead of one, hence the name barycentric *dual* mesh. See image below.

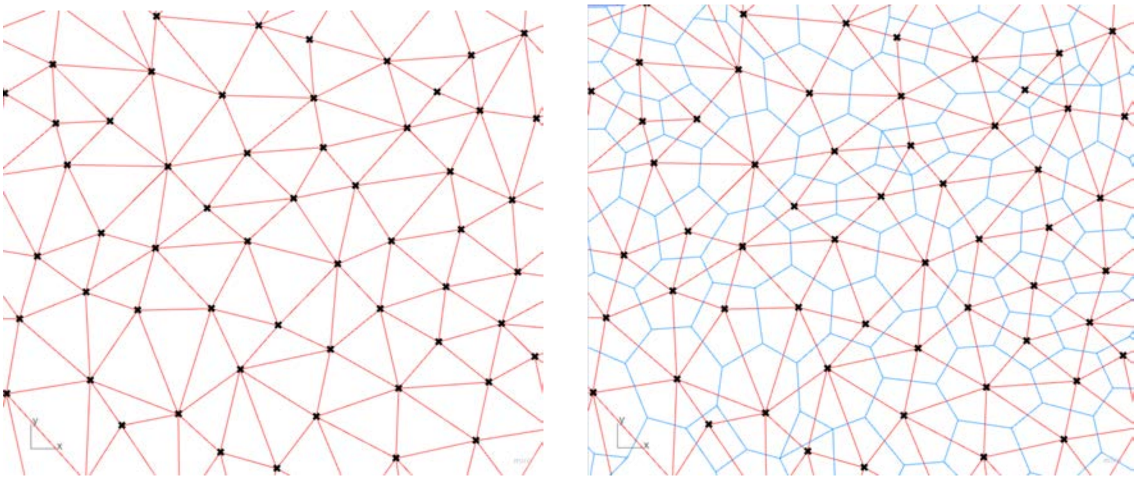


Figure 1, Delauney tessellation (l) and the barycentric dual mesh (r).

We also experimented with applying a gradient to the cell structure. In creating a randomised coordinate jitter, based on a point's distance to an attractor, we gradually transformed a hex pattern into a voronoi pattern. See image below. This proved to be an important feature of the final topology, which we will address later in this report.

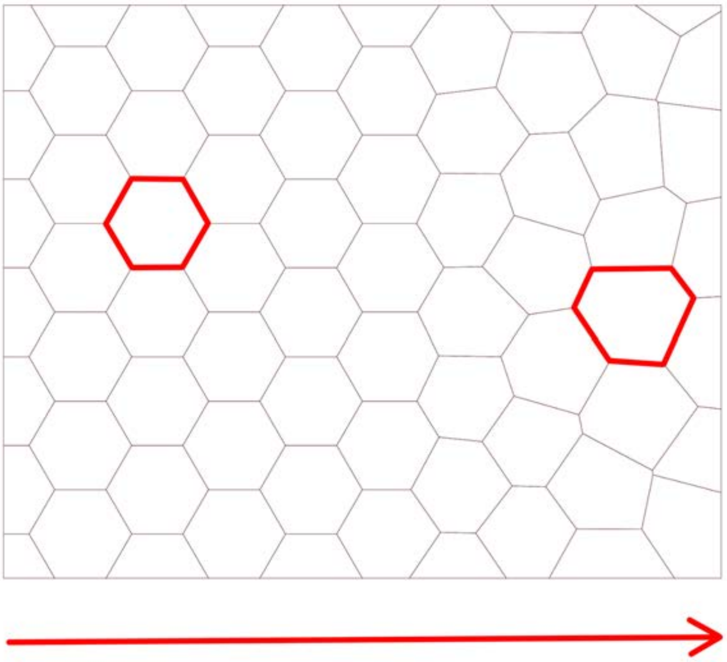


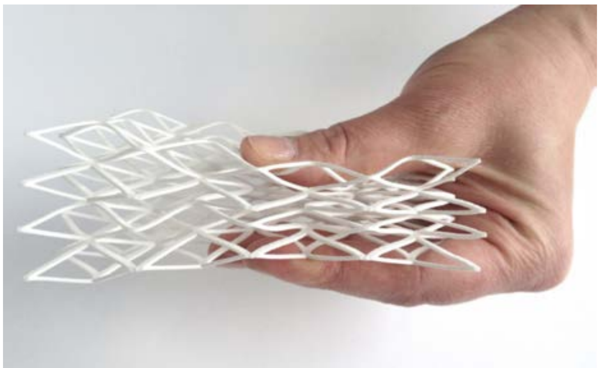
Figure 2, Gradual randomisation of point coordinates to create a hex-to-voronoi gradient.

When translating our findings into 3D, the generation of this alternative dual mesh proved to be very challenging, and since the exact properties of the 3D point network were not necessarily relevant to the assignment, we decided against this alternative method and agreed to use the conventional voronoi tessellation method.

Form-Finding

Material

The load bearing, fixed structure is composed of wooden beams. The elements that infill it are the 3D printed cells that can be freely disassembled to create versatile, adjustable furniture. The material can adjust to the user, therefore, it is designed to be printed with a rubber-like material (Fig.x). During the research, we found out that even better would suit the foam-like material, because of its lower density - even two times lower. The approximate size of one cell is similar to a chair or bench - from 70-100cm in width and 50-90cm in height. With the assumption that the cell is 90% porous, the cell would weigh up to 15 kilos printed from the rubber-like material (Fig.x). Therefore, we concluded that it should be prototyped and tested in reality to meet the design goals of flexibility. To make it comfortable for users to carry around and compose the cells for themselves, one should weigh a maximum of 5 kilos.

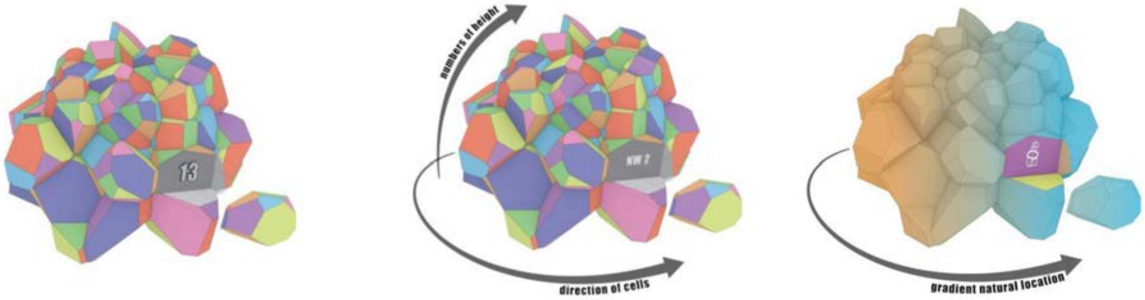


← Figure 3, Biomimicry 3D printed soft seat material, source: https://www.lilianvandaal.com/, access: 30.03.2022
→ Figure 4, Designed structure for the furniture cell.

Cell Design

Thanks to their porosity, they can suit different functions: as a solar unit, greenery, luminous, storage, seat, working place, water filtering or a battery charger. Additionally, the units will have the colour-coding system so the users could easily assemble and disassemble the cells, following their needs and the site requirements. The adjustability is therefore not only connected to the activities but also to the pre-conditions - the structure can be used in versatile surroundings - in the park, as an urban furniture, on the public square, as an interior furniture. The design potential is almost infinite.

Figure 5, Cell library for versatile functions.



Multicolor Shell, Cell Organization: Number & Color Based

Multicolor Shell, Cell Organization: Number & Color & Direction Based

Gradient Shell, Cell Organization: Natural Approach, Color/Map Based

Figure 6, Different colour-coding connection systems.

Structural Optimization - Karamba and Topos

During the structural optimization in Grasshopper, we used the Karamba plug-in. The analysed structure (Fig. x) consisted of beams creating cells. To test different options, we firstly implemented only specific section families for the structural beams - QRO(EN10210-2) and QRO(EN10219-2). Subsequently, we chose all the accessible families for the final optimization that showed the best results for the structural efficiency. We applied The programme calculated the most optimised section for all the beams with variable size from 10x10cm to 20x20cm (Fig. 7).

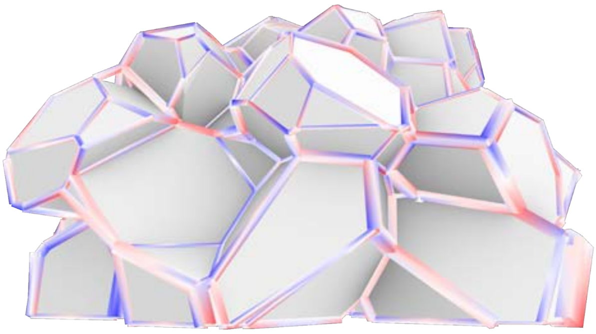


Figure 7, Final structure with Karamba optimization

Next, we chose two nodes for further investigation. The first that had one support beam and three loads and the second that had two support and two load beams (Fig. 8). Furthermore, we also added the gravity loads and activity-related forces (3 kN/m2), and summed them up. Moreover, we also included the loads from foam-like cells - the 3D printed infill of the structure. With the porosity of 90% and the material density of 0,5-0,6 g/cm3 the total force was FZ=1,5KN per one node. For the Topos optimization calculations we did not include the external forces such as the precipitation or wind, therefore, it should be further investigated in the construction project phase.

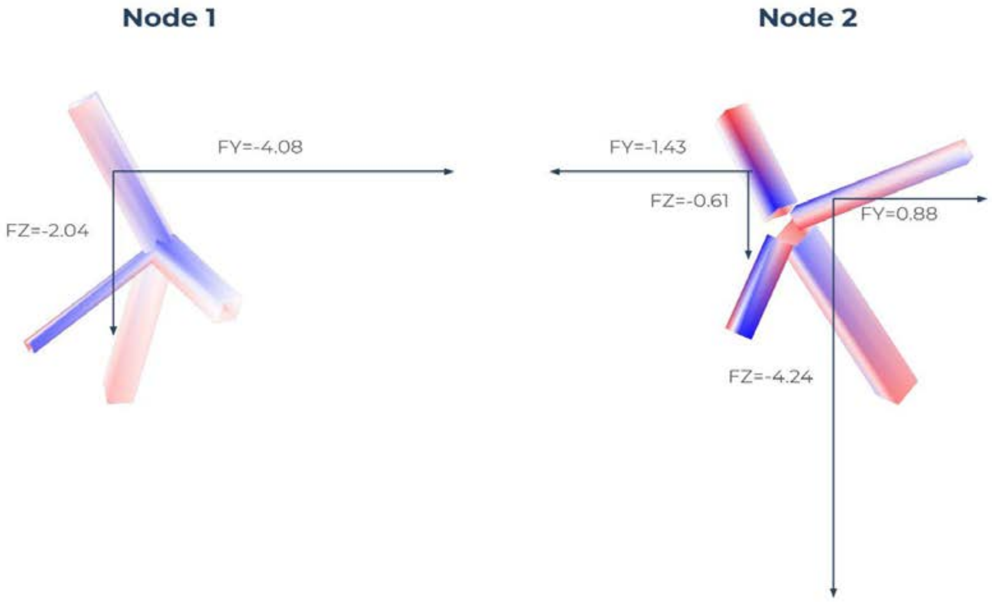


Figure 8, Two chosen nodes with structural forces after Karamba optimization

The "Node 2" was chosen for the final node optimization with the resolution diameter set to 60 and 40 iterations. Next, we worked on the post-processing with 3D modelling in Rhinoceros to achieve a material efficient and aesthetically satisfactory form of the node as a closed polysurfaces. We added the beam ports and optimised the model for 3D printing. We decreased the material fill from 40% to 20%, and finally to 15%. We set the amount of supports as small as possible with the infill of 10%. We reduced the printing time from 32 hours (1:1 scale) to 17 hours (1:2 scale). Furthermore, we changed the percentage of the infill and reduced the time further to 5 hours and finally to 2,5 hours with no infill by changing the nozzle from 0.8 to 1.2. The first node prototype was printed in 1,5 hours with a poor result on the top layers which caused the collapse. The final 1:2 scale model was printed with 0,8 nozzle and in 7 hours.

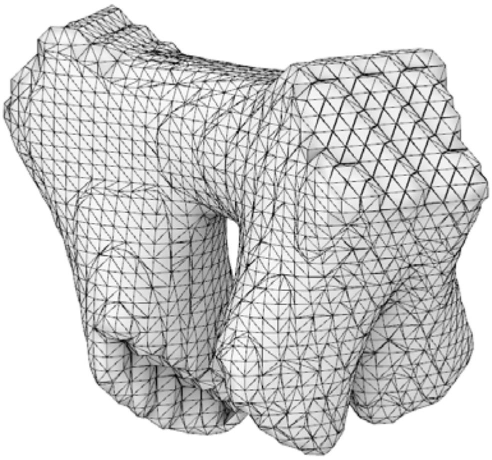


Figure 9, node before the post-processing.

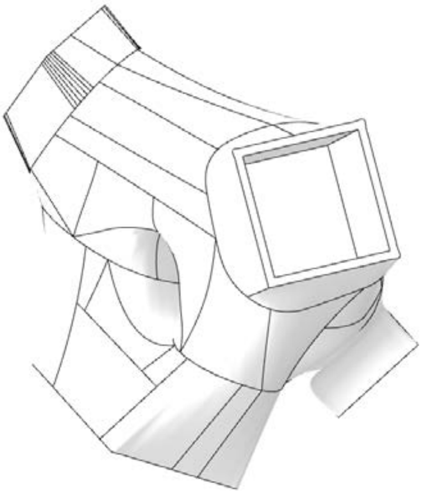


Figure 10, node after the post-processing.

III - Computer vision

The Computer Vision segment of this research focused on the usage of the right virtual measurement techniques of the dissected node on a 2D planar surface, in order to create an accurate digital visual for the robotic arm to process and take action. The image processing techniques applied, are conducted via Google Collab, and programmed with the Python language, using different Python libraries.

This script focused on the construction of a system that uses a 2D visual and analyses its elements, measures their dimensions and detects their centre points. The trials were done for two different sample images, and then for our node. But before that, the scripting has been studied under the subjects of digital image processing/reading, manipulation, library importing, measuring and locating.

Our Trials

The first case, took in use the image of a disconnected node module on a carpet base. In this example, the “erosion” and “dilation” tools were useful to diminish the noise of the carpet, and clear out the image to be clean enough to detect the objects. Despite the attempts of a clarification, the erosion and dilation functions were insufficient for the clarification process.

This led us to the second case where the same visual’s background was substituted with a plain base. This case had helped the script to advance and obtain the results for the object dimensions and centre points.

The final script was with our node pieces, and started with the image of the elements of our node separated, on the floor. After adjusting and having the script process the image, the erosion and dilation tools were used where necessary to eliminate the noise caused by the object’s texture. Afterwards the computer was able to detect the bounding box successfully, with the accurate sizing and crop down to it.

Figure 11, Computer Vision

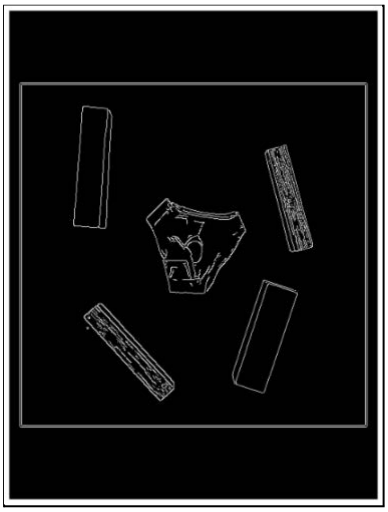


Figure 12, Computer Vision

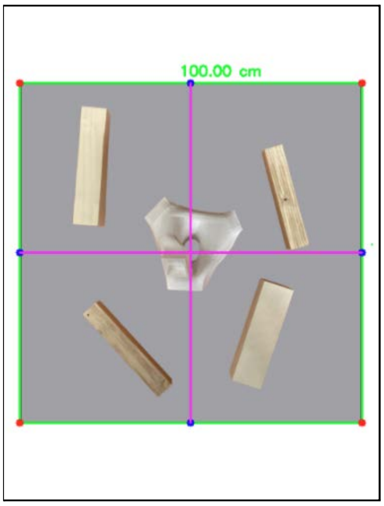
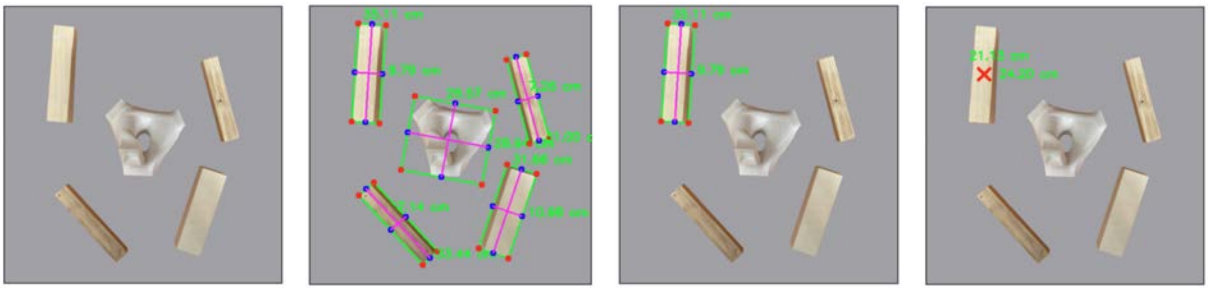


Figure 13, Computer Vision

After the image framed by the bounding box has been warped, the pixel per metric transformation has been executed. This allowed the script to determine successfully the dimensioning of each object, as well as locating their centre points with coordinates. This is beneficial for the robotic arm to further determine where each object should be picked from.



Figures 14, 15, 16, 17, Computer Vision

The Robotic Input

After having had the script running successfully, these commands were put in use with the robotic arm. The input is crucial and pivotal for the arm to be also assisted properly. The location of the objects, their dimensioning and centre point detection codes were inputted for the robotic arm to execute the "pick and build" actions into the designated area. After that came the assistance of the human aid, in the "Human-robot Interaction", for the assembly.

IV - Human-Robot Interface

Assembly

The robotic arm is a human aided system that has 8 hinges and is bolted at a fixed position. The end of this arm is a human hand shaped "grabber". This structure allows it to move in a lot of angles with ease and freedom. The previous section that discussed the computer's visual provisions played a crucial role here, and allowed the robotic arm to detect the pieces of our node in the bounding box, based on a visual. The human intervention came in to maximise efficiency; by using the robot's power and human's minimal adjustments and maneouvering.

The first step was introducing the robot to the location of the bounding box. By guiding it to the origin and around the box helped it associate the planar surface as the work base.

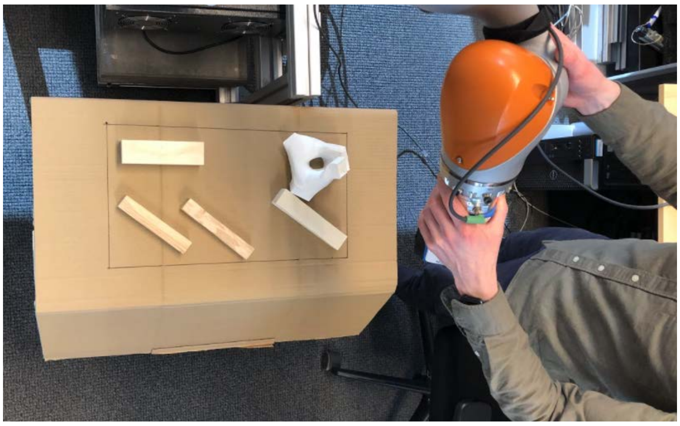


Figure 18, HRI

The second step was inputting the image of the bounding box into the system, with the node pieces laying on it independently. The previous computer vision script merges with the robot at this stage. This allowed the robot to distinguish, locate, and measure the objects to identify a workframe and its elements.

Figure 19, HRI

Figure 20, HRI

The last step was the robot grabbing the objects and with the human assistance, delivering them to the designated spot for assembly.

Figure 21, HRI

The Building Sequence

Figures 22, 23, 24, HRI

Our Experience

We started this project with the ambition of creating a prototype as an urban furniture to be located on the TU Delft campus. Our initial experiences over the collection of data, references, design, creation, and automation have been evaluated repeatedly to form the final vision. Through all these stages our aim has been towards creating an artefact that contains a modular structure that offers different amenities in spite of its non-repetitive structure. In the workshop, by taking a node and focusing on how the bigger goal could be achieved has been an insightful experience on the balance between robotic & human based construction. Our encounter with the stages through the process of designing for an automated construction were put in practical use in the last week. And made us take the first practical leap of these ideas becoming physical.

The robotic workshop acted as a harvesting of what we have been seeking for the past weeks of the course. It has shown us that if the stage before the construction is executed in the best way possible, it makes the actual production take less effort and human aid. The coding being one of the phases that takes place before the construction, it is crucial to have a smoothly running script to get the best return of implementation on site; and the extra smoothening would make the human intervention become less of a labour while keeping its cruciality. We've experienced the computational design bridge over to robotic manufacturing first hand, and seeing the possibilities of it becoming a tool of the contemporary built environment has been a subject we're just introduced to and is yet to reach its full potential.

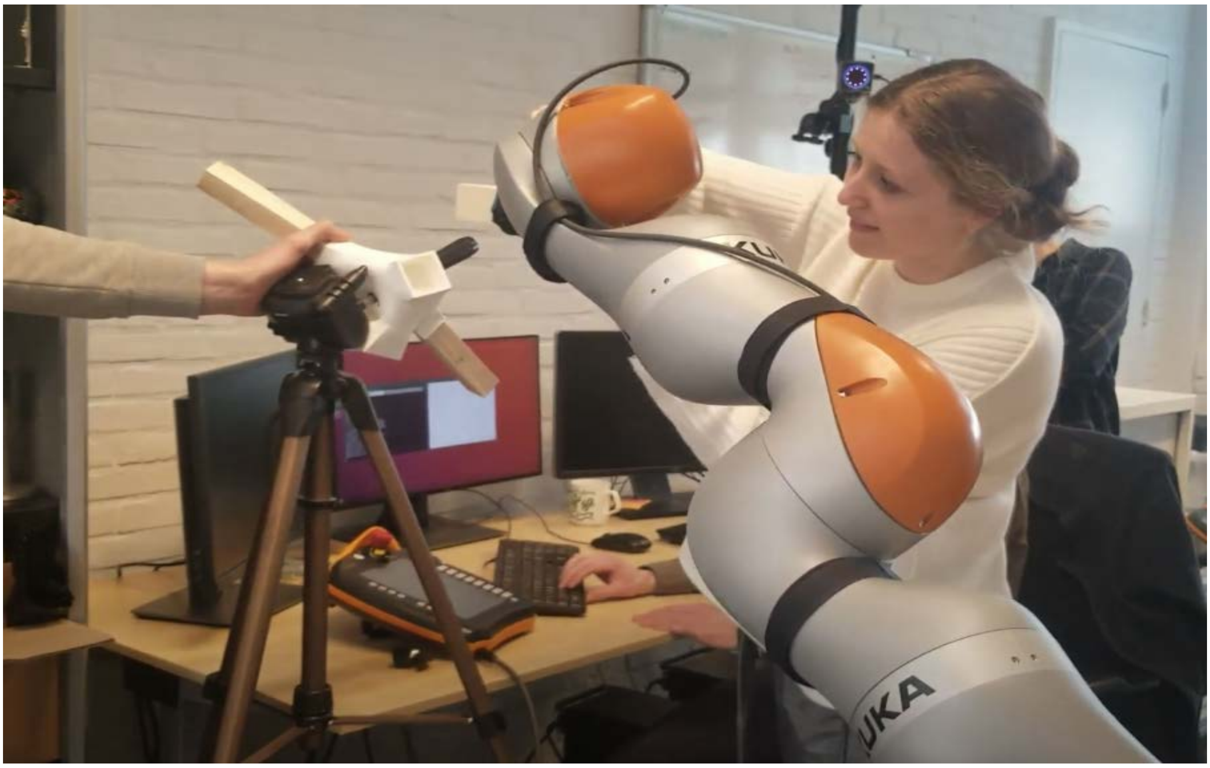


Figure 25, HRI

Questions it Raises

The robotic industry is progressing rapidly, affecting different aspects of modern working life. Collaborative and interactive robots support human workers in ranging work environments, where they help staff extend the professional services they provide, create new opportunities, entail resource efficiency, and increase productivity. The rate at which these developments occur is faster than ever before, which raises questions about the implementation of human-robot interactions in various fields, specifically architecture. Robots incorporating artificial intelligence can be applied to assist with certain tasks under human supervisory control. As experienced in the workshop, the use of a robotic arm with the help of humans was applied to assemble the various components of our node. The time it took to accomplish the task with the human and the robot working together, took longer than if a human had performed the task themselves. However, as discussed during the training, if the scale or complexity of the task was increased, the use of the robotic arm would prove itself to be more effective, efficient, and safe. Due to this observation, it raises the questions of how do we evaluate the efficiency of HRI on more complex projects? As well as, for a given task, what is the threshold that it must reach or surpass for it to be worth the use of robot interaction?

Understanding the behavioural dynamics that underlie human-robot interactions in groups remains one core challenge in robotics research. The constant movement of people, both in physical and interpersonal terms, does not offer a routine that is easy to compose and script in advance, and presents a level of unpredictability, inherent to social interaction, that is hard to factor in with today's technology. Throughout the workshop, moments of unpredicted movements and paths of the robotic arm were witnessed. The arm calculates the best trajectory for it to complete the required task, not always evident to a human, which can cause unforeseen interactions or incidents. Such experiences evoke the questions of to what extent is the behaviour of robots unpredictable? How do we design robots that can adapt and adjust to their surroundings, and be flexible to unforeseen factors possibly influencing or affecting their line of work? Such interactions also evoke questions on a more personal level, with respect to how much are we willing to subject ourselves to digital technology in order to enable natural interaction with robots?

Figure 26, Human-Robot Interaction workshop at TU Delft

Design for manufacturing

After the workshop, Micah and us started discussing the implementations of robotic manufacturing for architects. When we posed the question of how us architects can efficiently and robustly design with the process of robotic manufacturing in mind, Micah returned the question to us. The integration of (semi-)autonomous manufacturing with a design process that is becoming increasingly dependent on computational design, is of course one of the large challenges of contemporary architects and therefore of great interest for us to investigate, as aspiring architects. How then, could we refine our design process to take into consideration robotic manufacturing?

One lesson we learned is that robotic manufacturing can greatly decrease the labour that a construction worker has to do, while at the same time, the robot is not at all dexterous. A human is - for now anyways - always needed for aiding the robotic arm. The process of aiding the robot towards a building element should therefore be tailored to the human, as they have to do the intelligent decision-making of finding the element and aiding the robot towards it. The labelling of the elements can be tailored to the robot, however. By using, for example, QR codes, a computer using computer vision can easily and accurately pick very similar elements of which the difference would otherwise be near-impossible to discern, if it were a human task. An example of nearly identical objects, of which the final location in the construction is of vital importance, is the Buga wood pavilion (see image). Here, the cells are all unique and should be assembled in the right orientation, location and order.

The pursuit of efficient workflows that combine design and manufacturing, is one that we only scratched the surface of. We have been handed the first handholds to try to tackle this problem in our own design careers, but a lot of lessons can still be learned in this relatively new field of design.

Figure 27, Buga wood pavilion, source: archdaily.com, access: 25.03.2022

Figure 28, The robotic arm being guided by Micah during the workshop at TU Delft.

V - Conclusion

We joined this course in order to follow a curriculum in which we could explore and learn about the possibilities that come with 3-D parametric designing and printing as a whole. Even though these segments are separately being studied around the world with various disciplines, the conduction of the whole design process starting from the initial sketches and ending up with an actual 3-D prototype provides the have not the most advanced, but the most complete grip that is the fundamental foundation of this course.

Over the duration of this course we were lucky enough to work with experienced people to guide us and answer our questions. Even though we might've been familiar with some parts of the process, seeing all of the different pieces come together and create a bigger, fundamental workflow was a unique experience in this manner. We've learned many new things about the human-robot interactions and how they are taking power from the computer vision. Running full scripts on Google Collab, understanding what is behind the scenes of a human aided computer run a task, and especially being able to implement these to our own creation and node were new and memorable learnings.

There are many things that could be improved. To address these improvements in the right manner, it is important to mention that as new learners of this workflow, we were given a set of information that we needed to practice. This included different segments of a parametric design process, computer vision, and human robot interaction. Since we were practising some of the subjects for the very first time this defined a framework for us to operate within. This could be considered as a limitation on the freedom of design, rightfully so, nevertheless it is the first steppingstone to go limitless. Eventually after this project, we could say that the completion of that framework earned us the learning curve. Now, only after getting the hang of the process in simpler terms, we now have the possibility of expanding our knowledge and capabilities in this field without limits. The initial thing to begin the list of improvements would be going in more depth in details in the design process, possibly experimenting with more materials and working on different scales.

As a team, we are satisfied with the result and how the final project turned out. From the beginning of the project we were able to keep up with both the official and our own deadlines so we never really had big setbacks from our schedules. In the first weeks this allowed us to be more flexible in design and allowed us to be able to go back and change one or two small things instead of rushing full steam ahead. We also found the feedback from the tutors very valuable and helpful in regards to whatever it was we were struggling with throughout the different segments of the project.

Figure 29, Final result of the interactive Playscape design.