Experiments in Robotic Thatching

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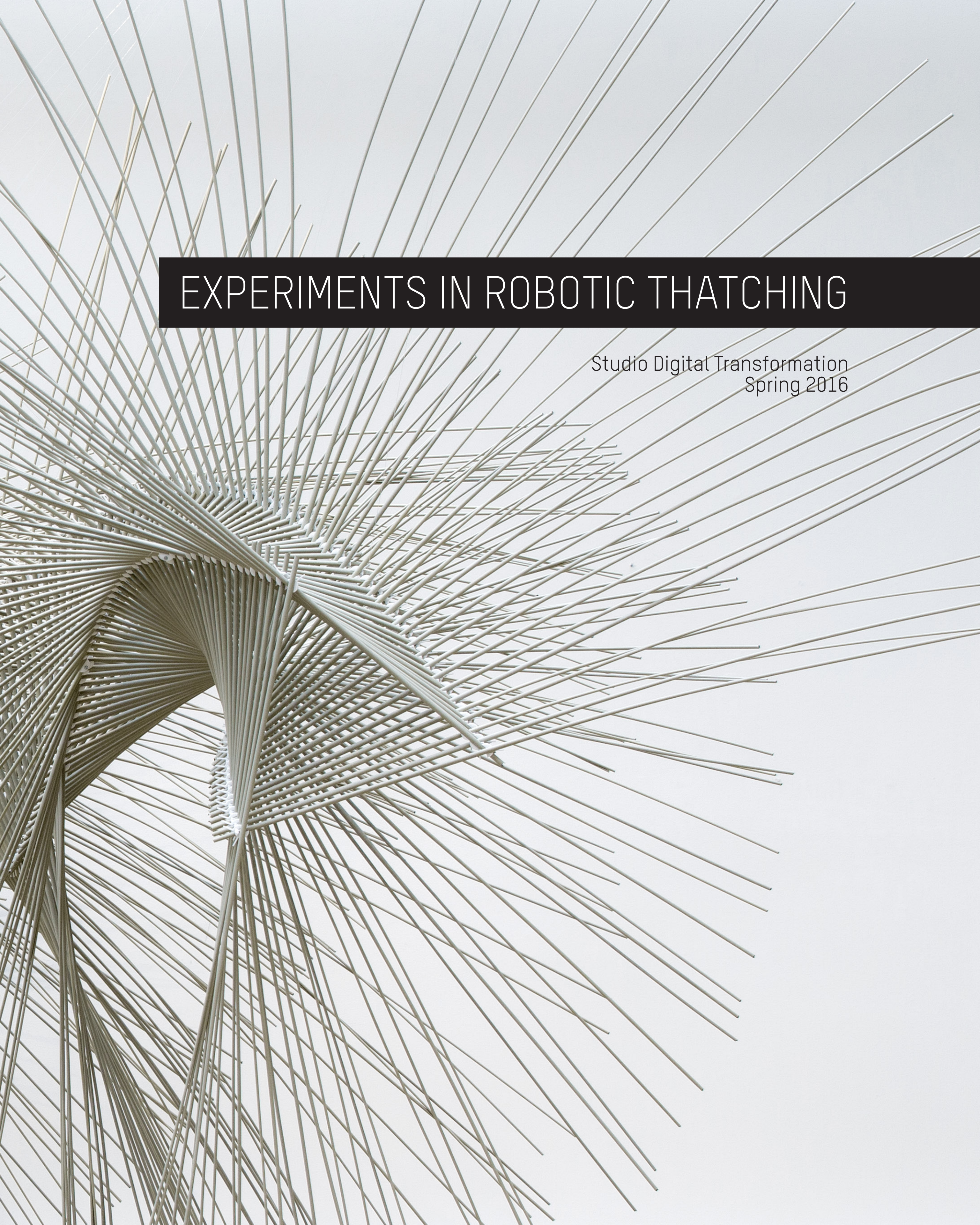
EXPERIMENTS IN ROBOTIC THATCHING

Studio Digital Transformation
Spring 2016



EXPERIMENTS IN ROBOTIC THATCHING

Studio Digital Transformation
Spring 2016

Master's degree programme
Aarhus School of Architecture

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CONTENTS

PREFACE

This booklet is developed in tandem with the production of an installation for the Milaaano 2016 Salone del Moderna exhibition. As such, it should be read as a documentation of the development, discussions, and production of the final product.

The theme of this year's exhibition is "History as Catalyst." The intent of this project log is to show the process of design and fabrication of an installation for the exhibition. The project experiments with translating the traditional craft of thatching into a computer aided process using digital fabrication methods on the six-axis robot. Our goal was to develop and fabricate a spatial structure in 1:1 which will be exhibited inside the schools exhibition gallery at Ventura Lambrate during Milan's Design Week 2016.

"Consciously and unconsciously we have inherited traditions acquired from our family and friends. Traditions, resulting in customs and habits, are passed on from generation to generation. And so traditions have found their origin within cultures, families, friendships and personalities. Traditions are everywhere, and form an important source of inspiration for today's designers."
- Thinking Tradition, Overall theme at The Ventura Lambrate 2016, Dezeen.

ASSIGNMENT

"Our goal is to develop methods and tools to transform the traditional craft of thatching into a computer based fabrication process. We aim to explore the potential of the historic building techniques of thatching, which has been existing in many different cultures and which primarily has been passed from generation to generation. It is our intention to transfer those techniques into a computer driven environment with the special focus on digitally fabricating a roof or wall structure. This new structure will be illustrating and discussing the potentials of using history as a catalyst to develop architecture of a performative and engaging character."

- Assignment paper for Studio Digital Transformation F16 by Jan Buthke

THATCHING

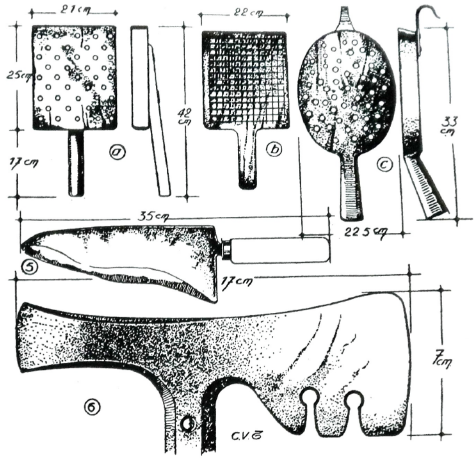
Introduction

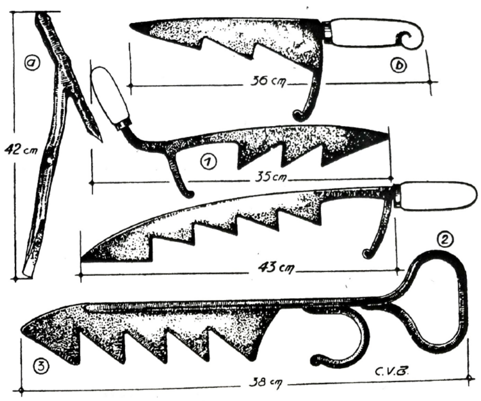
Thatching is the craft of building a roof with dry vegetation such as reed. The material is layered to allow water to shed off the roof while providing insulation. Because of the abundance of reed material and simplicity of construction, thatching is one of the oldest types of roof construction and can be found all over the world.

The method of thatching is deeply seeded in tradition, with each culture and region having their own processes, materials and tools. Methods have been passed down from generation to generation, affecting the use and knowledge of the craft today. Only a small amount of craftsmen know the traditional method of thatching, and while there are some modern advancements, it remains largely unchanged. So while the technology and a lot of other building methods changed and improved, the craft of thatching today looks very similar to a century ago. This has affected the popularity of thatched roofs.

A lot of people see thatching as an old and obsolete method, which has more disadvantages than advantages. But it can't be denied that most appreciate the aesthetic of a thatched roof. However, one of the biggest advantages is its sustainability. The roofing material, such as reed, can be found all over the world and is ready for use almost directly after harvest. To keep thatching relevant, it is imperative to protect our wetlands and the reed that they contain.

"Local building materials always form a harmonious feature in the landscape surrounding their place of origin." (John Betjeman)





Thatched roofs can last decades, and once they are renewed, most of the material can be composted and returned to the ground. The reed also provides good thermal insulation and can withstand strong wind and rain. So the reed has a lot of advantages but is often seen as an underestimated material which could be social based.

In the past, thatched houses were harder to insure due to the risk of fire. The development of underlaying fire retardant materials has made it possible to insure homes in almost the same manner as tiles and other hard materials.

During industrialization, thatching became more expensive than, for example, tiles and therefore people chose the tiles instead of thatch also because of the natural development of technology which of course had influence on social aspects. As the popularity of the material waned, fewer thatchers were educated and the craft became less important. Today, the high cost of thatched roofs is in large part because of the cost of labor. But with the increasing interest and attention towards sustainability, thatching is again becoming an accepted building system. But the lack of technological advancement, knowledge and methods has not made thatching socially accepted—yet.

Is it possible to clarify and highlight the benefits of thatching by translating traditional methods into new technology?

"Ecological architecture also implies a view of building more as a process than a product. And it suggests a new awareness in terms of recycling and responsibility exceeding the scope of life. It also seems that the architects role between the polarities of craft and art has been redefined. The priority of representation will be replaced by the priority of performance. After decades of affluence and abundance, architecture is likely to return to the aesthetics of necessity in which elements of metaphorical expression and practical craft fuse into each other again; utility and beauty again united." (Juhani Pallasmaa)

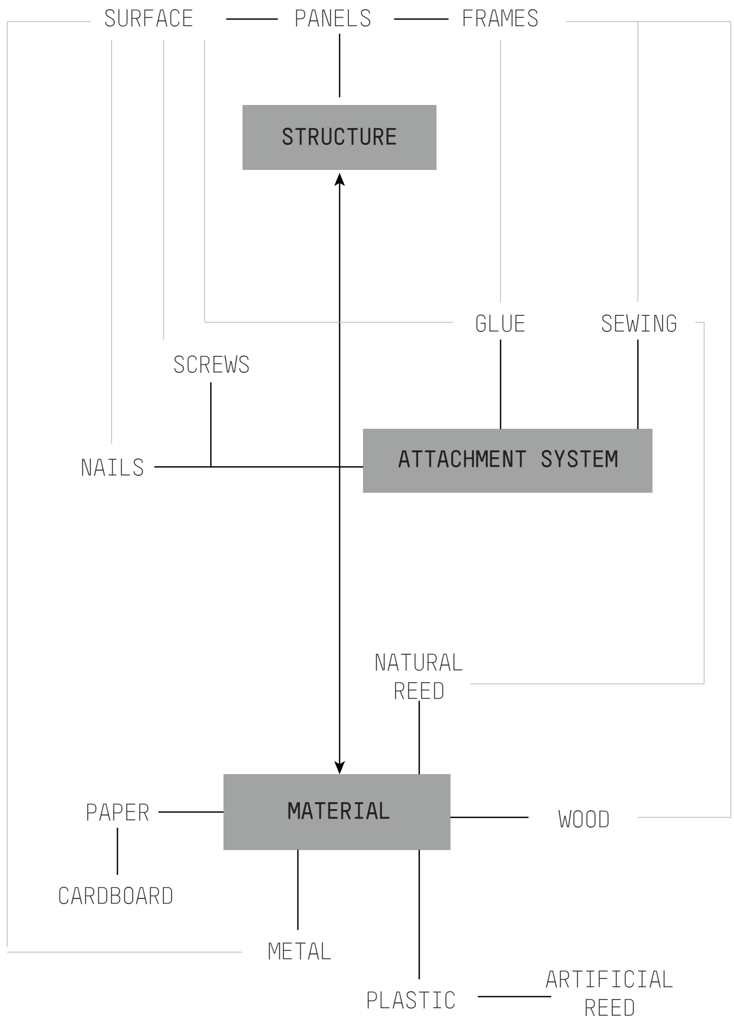
EXAMPLE OF A TRADITIONAL THATCHED ROOF

DIFFERENT TYPES OF REED

THATCHING WORKSHOP

It was important to better understand the traditional process of thatching, and to use our experiences to influence the design process that would follow. This meant getting our hands on the materials and tools themselves.

Over the course of two days, Studio Digital Transformation took part in a workshop that taught traditional thatching. The tutors, Bjarne and Ruud introduced to not only traditional thatching methods, but new applications. Wall assemblies and complex forms were shown and discussed during the tutorial.

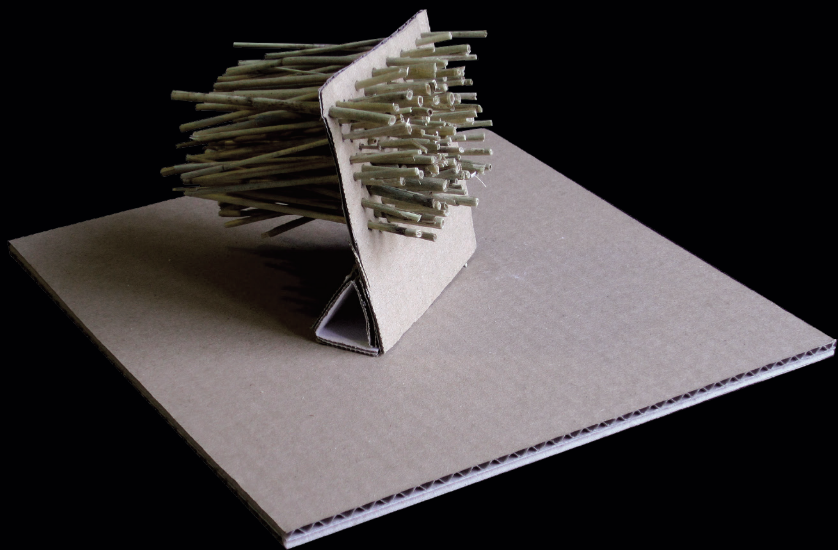

SURFACE
PANELS
FRAMES
STRUCTURE
GLUE
SEWING
SCREWS
NAILS
ATTACHMENT SYSTEM
NATURAL REED
PAPER
MATERIAL
WOOD
CARDBOARD
METAL
PLASTIC
ARTIFICIAL REED

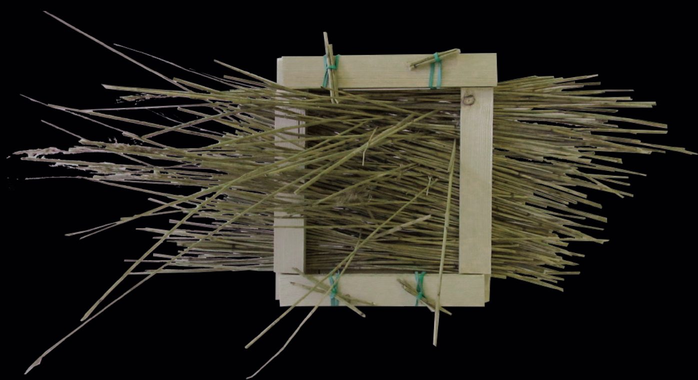
DISCUSSION 04.02.16

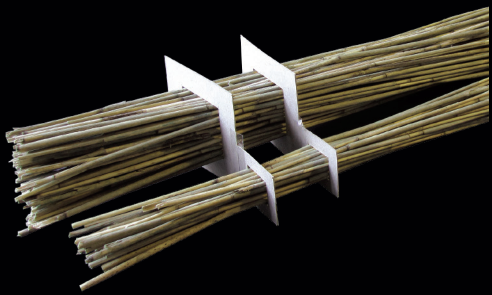
We need to investigate the material and the methods of thatching. What are we aiming for? Since our assignment is about thatching, that already sets up some parameters that we have to take into account. There is the material, the method of attachment and the structure. And these three parameters dictate and rely on each other, and we can't let one of them be absent. Having that in mind we also have to rethink the material, but be true to the tectonics. Which starts a whole new discussion - to what extent should we be true to the old and historical method? Maybe we set the new rules of digtial tectonics of thatching? So our task is to find the qualities of the material itself and define the properties of the material. We have to investigate the possibilities to be able to translate them into a new set of rules. And another important thing to have in mind was that this project is about experimenting, investigating and researching, not about thatching a nice roof. This project should show some new potentials of thatching and indeed also of the robot.

ANALOG INVESTIGATIONS

The initial assignment was to clarify the properties of the material and test different variations of expression that the reed could create. It is important for us that the material properties of the reed is functioning as a foundation for the project. The project will be developed upon the testing, experimentation and analysis of the material and the models produced.



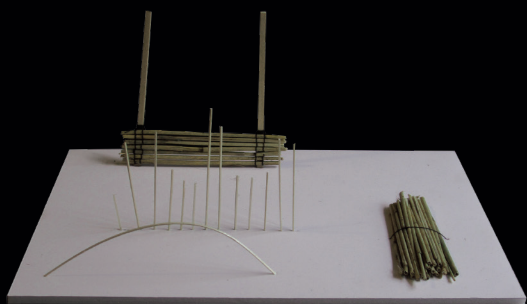


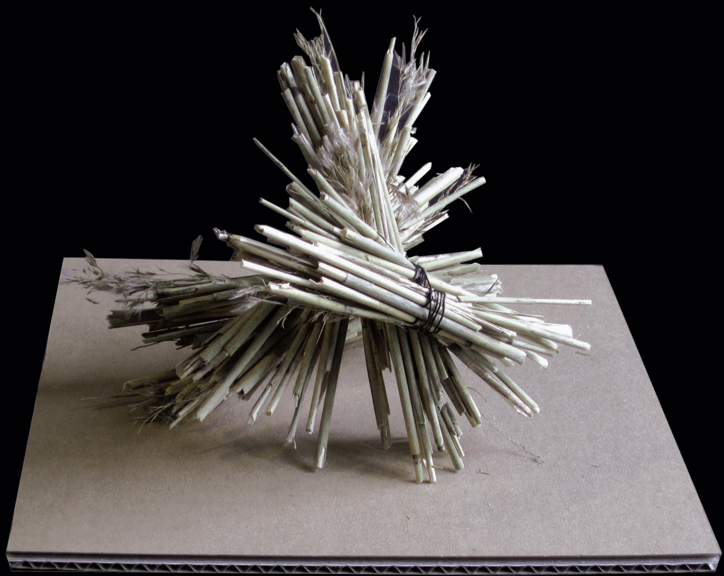


Our first models show the potential of the reed as a natural material. How can the reed be attachted to a surface? Can the reed attach itself? How much does it bend and when does it break? Which expressions does the reed create? What if the reed penetrates a surface or frame expressing a structured side and a more wild side - showing two inherent qualities of the reed that lies mostly hidden by the thatchers?

We were drawn to the natural reed because our goal was to use the traditional material in a new context but it also opens up the discussion of the clash between a new technology and a traditional material.

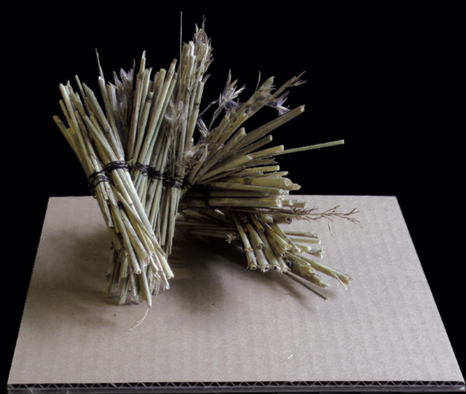
Can this be done in another way that still shows the potential but is not obvious? The straightforward design would create a simple form or structure and thatch the natural reed nicely onto it. But do we want this project to be "straightforward" or can we let the project lead us in a new direction through experimentation and thinking of new ways to consider "thatching"?

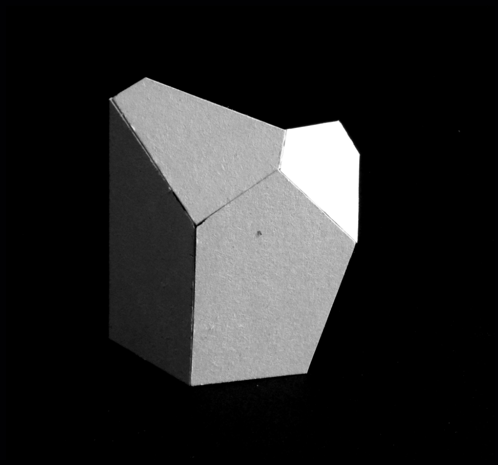


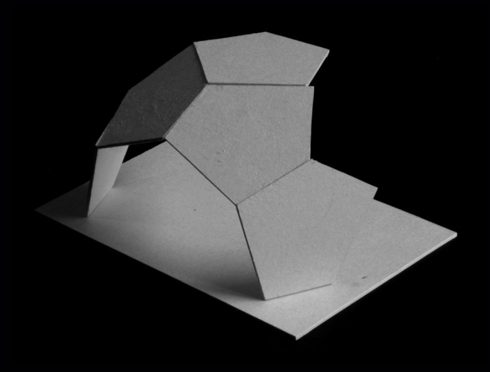


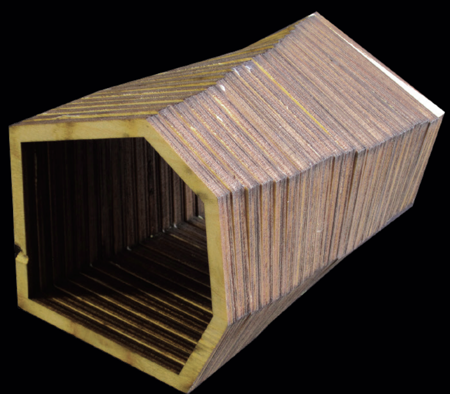
DISCUSSION 05.02.16

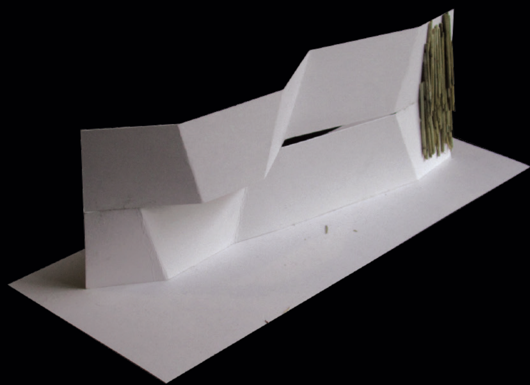
At this discussion we sat around the table with Robert Trempe discussing our first models and the outcome of the models. We all had small models using smaller pieces of reed, which made the models really difficult to discuss, because the properties of the material was not what it would be like in the right scale. So Robert tried to change our mindset of building these models. Maybe it wasn't about downscaling a potential project, maybe it was about testing the robots job. In that sense actually reversing the order of the process. How can the robot help us? Are there any tasks that the robot would do better or faster than us? Can the robot place the reed? Can it attach the reed - and how?







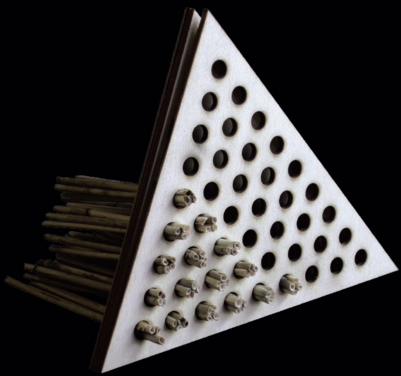


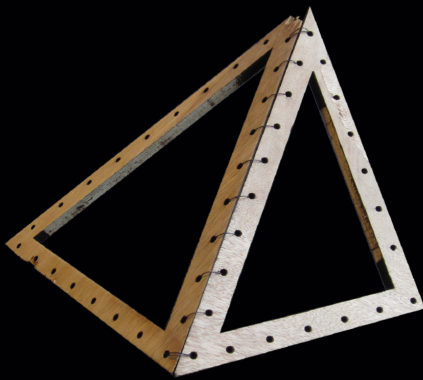


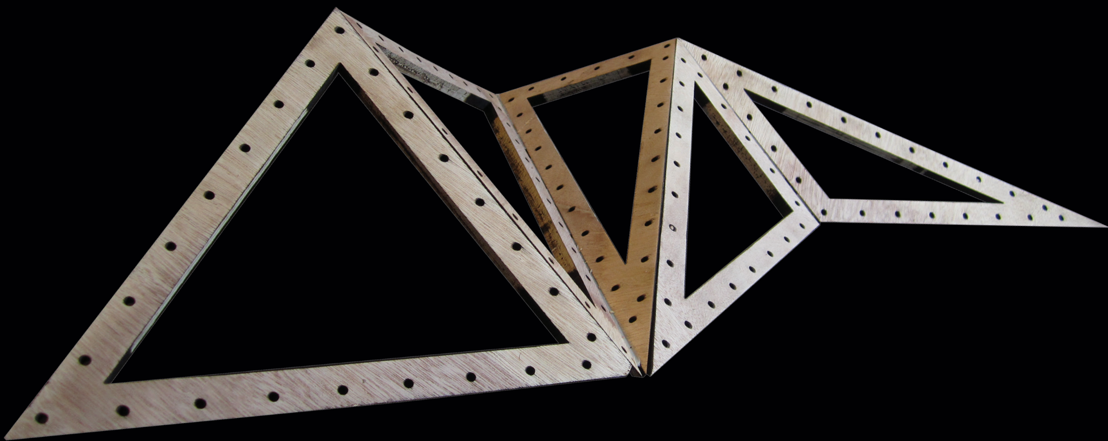
Through the iterations of model exercises, two typologies emerged:

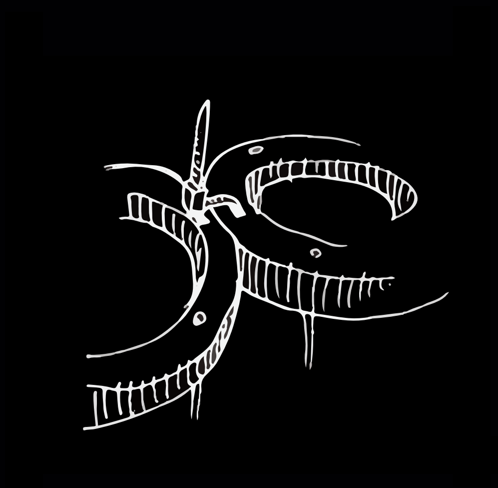
One was “messy” and the models worked with the reed itself as a structure connected in different ways. Can the reed stand by itself? Can we make something intuitive but still structural? Can we make architecture with the material as our key part?
The other one was “massy” and the models was developed with some kind of underlaying structure of panels or frames.

The idea was to penetrate the panels and show both ends of the reed, one end could be fixed and straight like thatchers pad the roofs and the other end could be wild and organic and show the natural qualities of the reed.
These directions were very different but interesting in their own ways. We divided into two groups - a messy and a massy for further development and experimentation with the two directions.





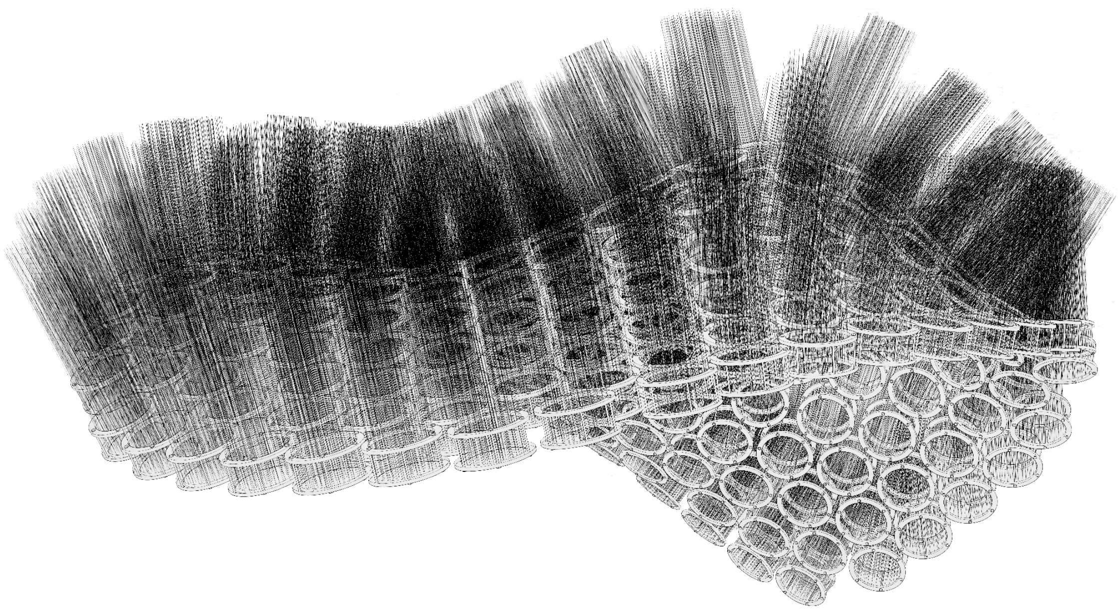


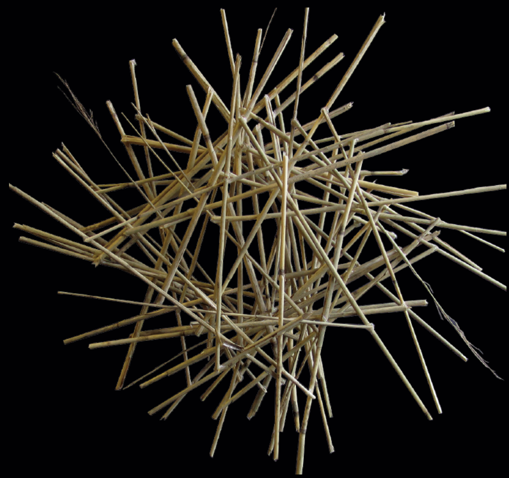


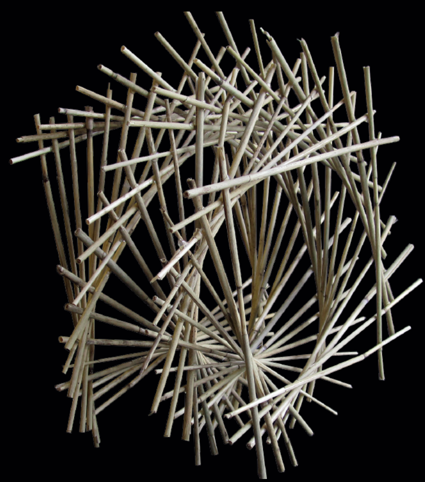
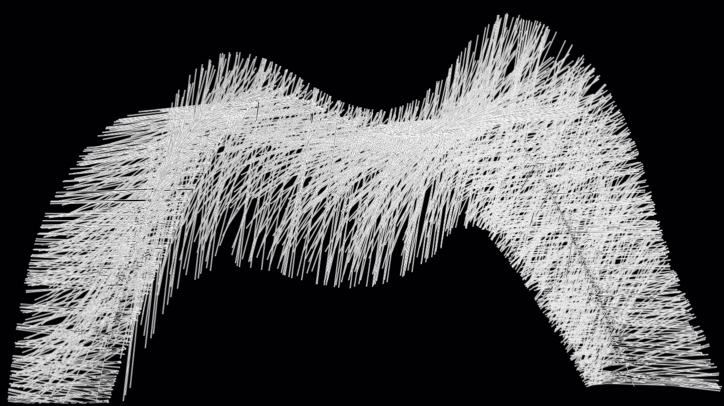
MASSY

Panels Penetrated By Reed

The "Massy" idea came from the concept of handling the reeds as piles and attaching them to a generic main structure. The structure could be either timber frames or panels, or even piles of reed fastened together to form a structure itself. This system should then keep the reeds in place, either locking it completely or still allowing it to be processed by the robot, for example by tapping, as done in the traditional thatching methods.
The strength of this idea rested in that we could keep the reeds in piles, forming a mass or volume that we could subsequently shape. This way of working with the materials would allow us to stay very true the to traditional way of thatching. The main issue with this approch was how to make the robot handle the reed; the benefits of robotic assembly would be its ability of repetition and highly accurate movements. However, this is difficult to apply to the reeds as a volume, because of the non genereic nature of the material. Since the robot does not have the ability to sense the material, our inputs, when programming it, would need to be extremely precise regarding the handling of the materials. And since every pile of reed would deviate, at least slightly, in size and form, the precision of the robot will not be exploited.
However, if the precision of the initial position of the reeds does not affect the final expression, the job of the robot could be to adjust; cut, move or bend the reeds. As long as the input would be a somewhat generic surface or shape, the robot could, with the right tools, process it to a certain expression, with any pre-programmed shape or pattern.



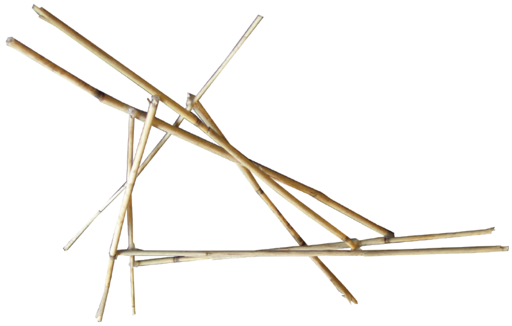



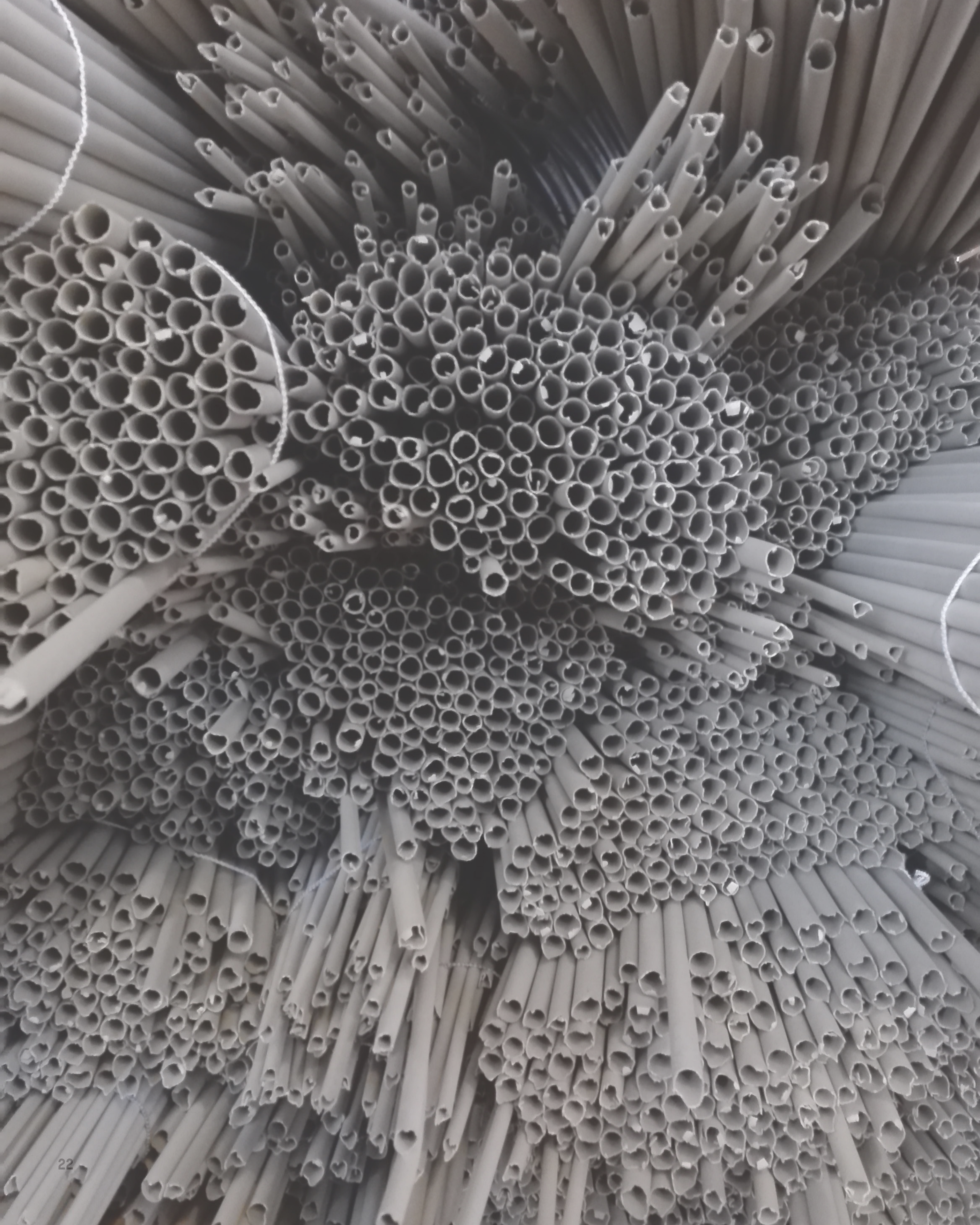



MESSY

One Reed Placement

The overall idea of the messy typology is to develop a structure with the reed itself. This could show the inherent qualities and possibilities of the reed that normally aren't showed in thatching. By working with both the reed as bundles and the reed as one individual object, we experimented and tested different methods and expressions that the reed could create. Letting the reed itself define and develop different structures, thinking the robot as a tool for precise placement of the reed. We were fascinated by the idea of placing one reed at a time, which both created structure, patterns, surfaces and different spaces in between. One model was built with one attachment point in the middle of the structure, creating some kind of spine that the reed relied on. We also experimented with triangles, squares, pentagons, hexagons, trying to develop a method and system for the object. The triangle created an asymmetric shape, which was the most simple structure, that could create the most interesting shape in terms of surfaces and spaces in between and in that way still challenge the complexity, the material and the expression without looking too messy. The two models inspired us to experiment further and combine the simple idea of placing one reed at a time in a triangle, creating a spine swirling around. With the structure and logic of the model beginning to take shape, questions came along: Can the reed be both the material and the structure? Can we utilize the properties and qualities of the reed in more than one way? Can we make a structure which increases the curiosity and makes you want to explore it? Can we challenge and experiment with the relationship between simple and complex? How do we keep the idea of thatching in the project? How does it relate to thatching? Is it just because of the material or are we showing other and new possibilities for the craft?





ARTIFICIAL REED

At the thatching workshop, Ruud and Bjarne introduced us to an array of different kinds of materials: The natural reed that almost all thatchers use, a reed-like material looking like spagetthi with 80% recycled natural reed and 20% plastic, and a synthetic reed made from 100% plastic.

The two thatchers were very proud of their craft, and weren't so exited about the 100% artificial reed. Because of this, we received only a brief introduction to the material, which to them was quite foreign.

After testing and experimenting with the natural reed, we experienced a great deal of differentiation between each reed. As our utilizes robotic assembly, we need to think about how to make the robot's job easier, and with the natural reed it would be difficult to precisely programme the robot if the reed is different each time.

The artificial reed itself would also make sense in the context of digital fabrication. The natural reed and the robots would be pointing in two different directions.

We contacted the company that designed the 100% plastic synthetic reed, "Novariet" from Holland.

In mid-February, Leon Eikens from Novariet visited us at the Aarhus School of Architecture to present their products. He was very interested in the project, as it is rare that he is contacted by people that want to experiment with the potentials of his product rather than just thatching a nice roof. Because of the traditions in thatching it has been difficult for the company to built up a solid business, and therefore he wanted to hear our thoughts on the project in order to be assured it wouldn't work against their reputation. He made it clear that it was important for the company to be in contact with architects because it would be easier for us to see the possibilities of the material than the traditional thatchers. This was similar to our experience at the thatching workshop.

He offered to supply us with the reed necessary for the project. We could order the reed in any specific length and diameter, which would allow for accurate programming of the robot with the exact properties of the reed.

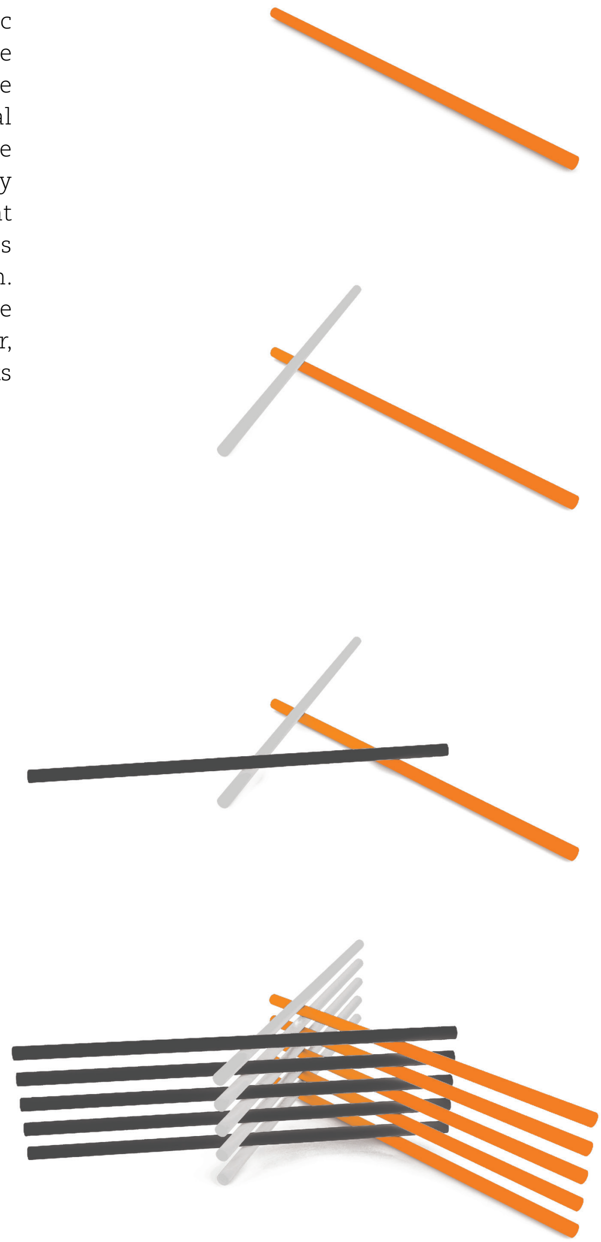
DISCUSSION 18.02.16

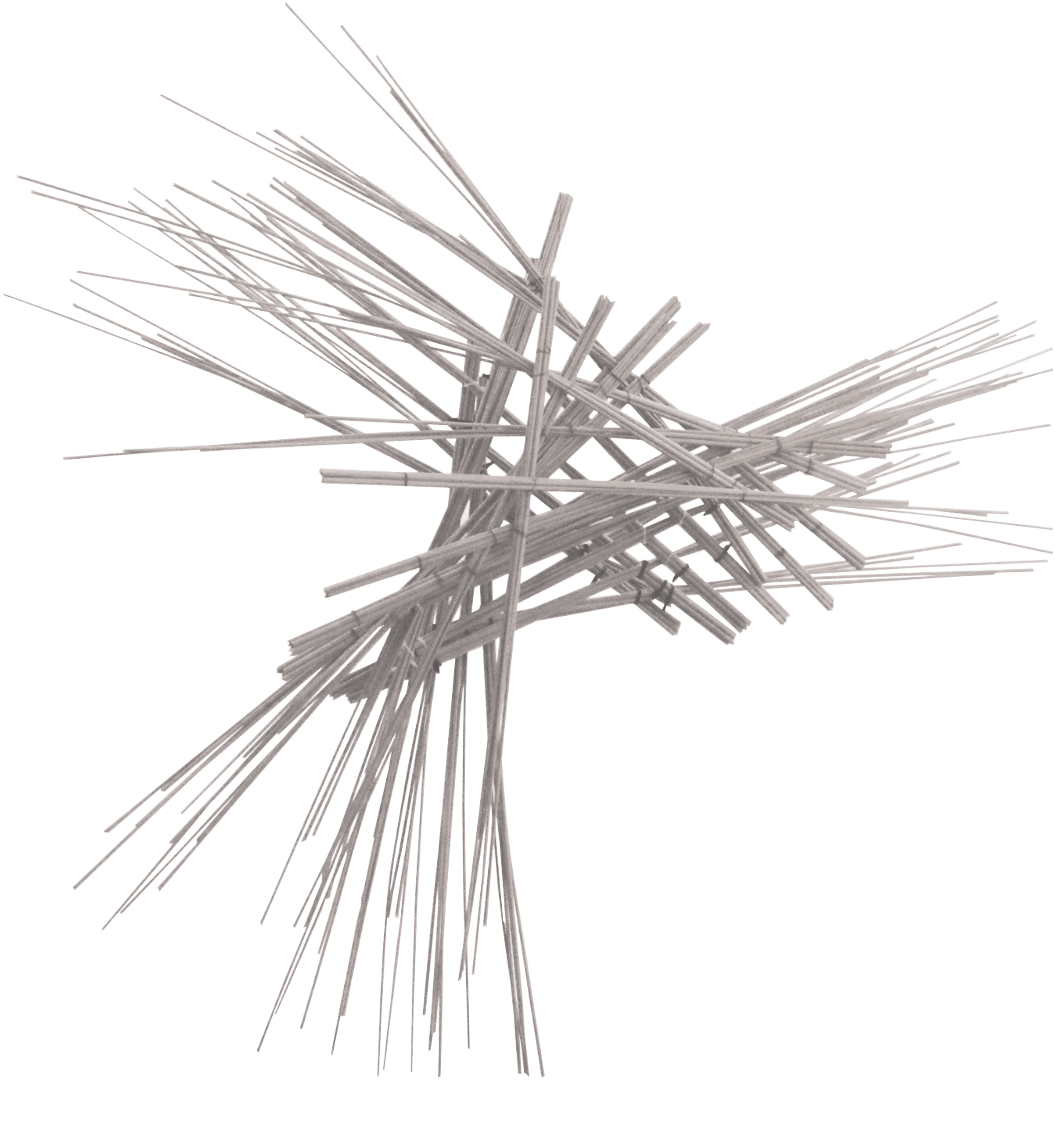
First, we discussed which of the design options were most suited to our goals: Messy or massy? It was clear that the surface-based model (massy) would have an inside an outside and, because of the panels or surfaces, it would be easier to compare it with a wall or roof structure. Maybe it is easier to relate it to thatching? But is that what the assignmest is about? The one reed model (messy) would create a structure that would be experimenting with and questioning the traditional methods and expressions of thatching. But will the idea of thatching be visible? Which direction would be the most interesting? Our discussion ended by choosing the messy model because our goal for the overall assignment is to experiment. The messy idea will give us more opportunities for experimenting and researching in abstract ways, which should invite people into the structure and upturn their idea of the process of thatching.

The idea of the one reed model is to create some kind of spine by building up the structure one reed at a time. One end of the reed would be the fixed and structual part of the spine and the rest would be hanging organically from the model showing the flexibility and inherent properties of the material. The one reed model would create a great deal of differentiation between sides and spaces, thereby becoming more spatial and responsive. This could also challenge the model. Can we make it more environmental or site-specific? Something specifically made for this room, instead of just designing an object that could be placed anywhere. Can we make the project more spatial and architectural, and give something back to the context? Maybe it is a structure that can branch out and shape the space by having different anchor points in the space? Rigid and precise, while also being organic and intuitive.

"...digital and analogue design techniques co-facilitate approaches to designs and interventions that make sense only in direct and dynamic exchange with their respective contexts and the way in which these interventions contribute to yield cultural and social arrangements. " (Michael Hensel, 2004)

The logic of the design is simple and clear, with geometry that can be translated to the robotic fabrication with relative ease. The challenge lies in keeping the shape and structure of the installation simple while reserving spatial complexity. In this case, the robot's job would be placing the reeds in a specific and precise way that could not be done by hand. The attachment system is still not specified, but many options are being considered. It depends on expression. Do we want to show the assembly or try to hide it? The reed could be sewn/stitched together, glued, or custom-designed 3d-printed joints could be utilized.

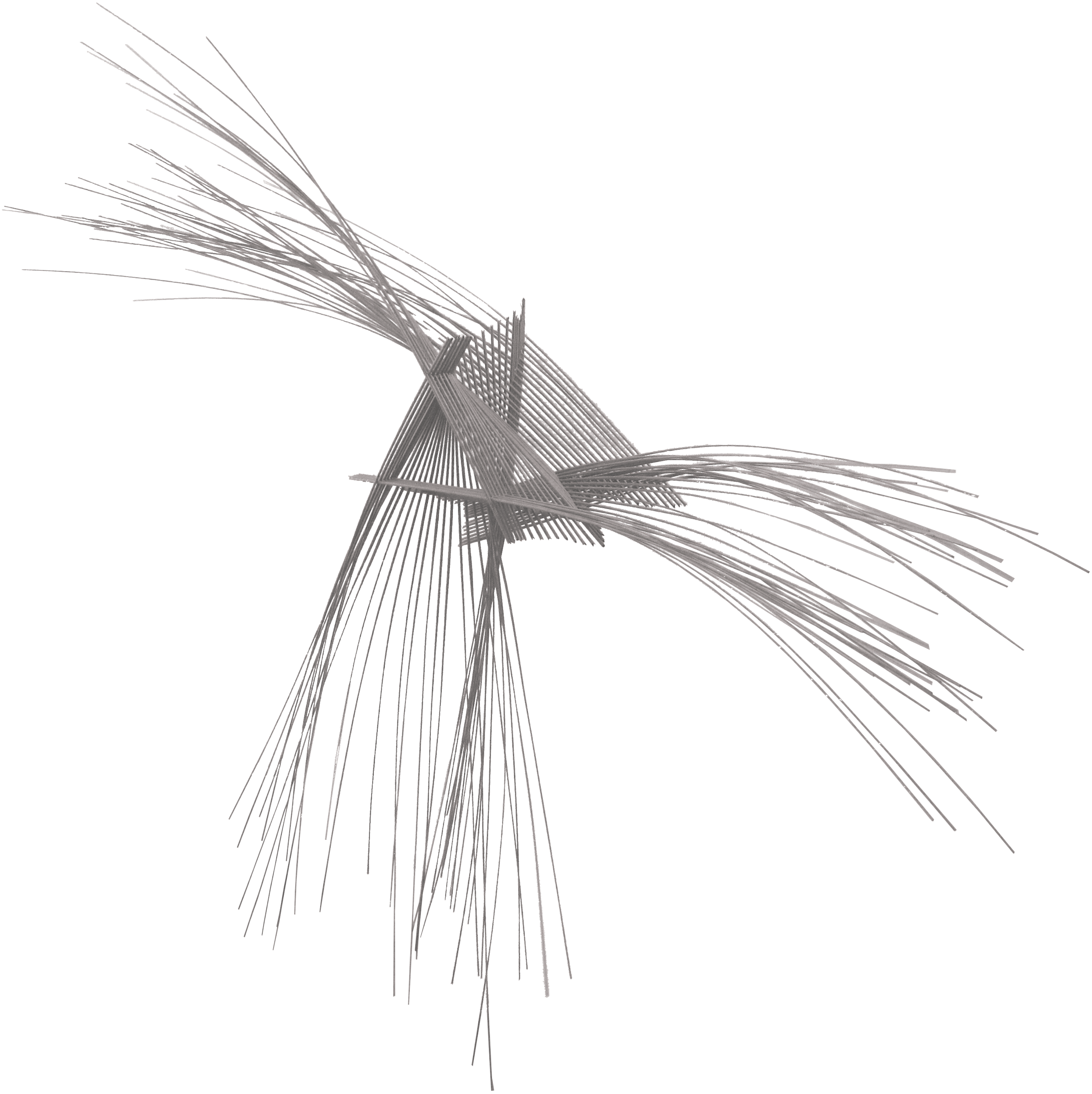




MODEL 1 - BUNDLE

By translating the logics of the models in natural reed this model was made with artificial reed. In our previous models it was difficult to read the real potentials of the material and structure because of the downscaling, so it was neccesary for us to make it in the right scale.
This model is trying to mimic the first models, and therefore we used bundles. At the same time it also shows the structural and organic qualities of the reed. It creates spaces and surfaces in between that makes you curious.

The form invites you to explore and ask questions to understand it. Can we enhance this curiosity?
The project should represent and translate a natural and organic material which behaves in a very beautiful and subtle way, but at this point it is very heavy and stiff and the sensibility of the material and the structure disappears.



MODEL 2 - SINGLE

This model embodied the second iteration, attempting to balance the sensibility and simplicity of the reed in the project. By building with one reed at a time a triangulated model was built in 1:1 showing a fixed spine and the organic part of the reed bending in response to gravity. By connecting sections, a long and spatial structure like a spine would arise in the context of the exhibition.

"The purely relational model used for the design of the structural system challenges the tradition of the architectural design in that its representation is non-formal. Instead, form arises as a result of the assembly of the structure." (Martin Tamke)

“What we can design and produce also needs to make some sense beyond artistic or aesthetic value. Focus can be placed not entirely on methodological efforts, although these can uncover unanticipated and interesting potentials yet to be conceptualized. Focus also needs to placed on embedding these efforts in theoretical frameworks that serve to refine research enquiries and that can sharpen the perception of new potentials arising from the work. In this regard, looking back is only half-useful if its purpose is to merely trace a historical development. Instead such an effort can serve to reintroduce interests, concepts and methods into an integrative approach.”(Michael Hensel, 2012)

OUR GOAL

In our Experimentation with the reed, the structure should question thatching. The connection to thatching would for the most part lie in the material, but by using the robot and digital fabrication methods this should enlighten the possibilities of new technology, and maybe create new ideas for the development of crafts into the digital environments. In that sense the idea of thatching would be inherent in the project as a reflection and interpretation of the structure and methods rather than as a physical element.

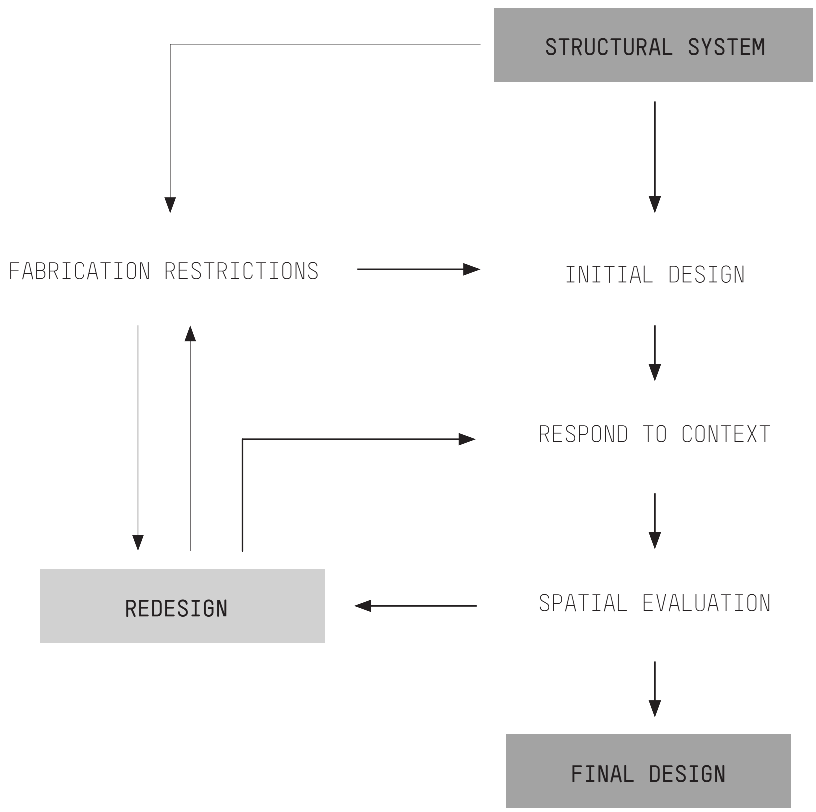
ANALOG INVESTIGATIONS INTO A COMPUTATIONAL ENVIRONMENT

After discovering the main concept and logic of the structure we divided into three groups to translate our analog invesigations into the computational environment. The project is still a joint project but the students in the teams have different responsibilities:

Robotic Fabrication:
Responsible for developing the coding for the robots. They are also responsible for making the tools for the robots so they can help us build the structure. During the production they will also facilitate the robots with help from the other students at the studio.

Joinery:
Responsible for developing and making the joints or assembling system for the structure.

Digital Tectonics:
Responsible for the overall design of the structure. This also means making the final Grasshopper definition for the other two groups to work with. Digital tectonics is also responsible for documenting the process of the project in order to make a booklet.



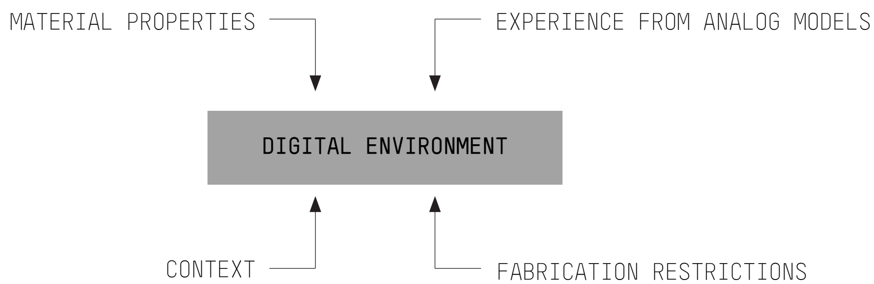
DESIGN DEVELOPMENT FLOW

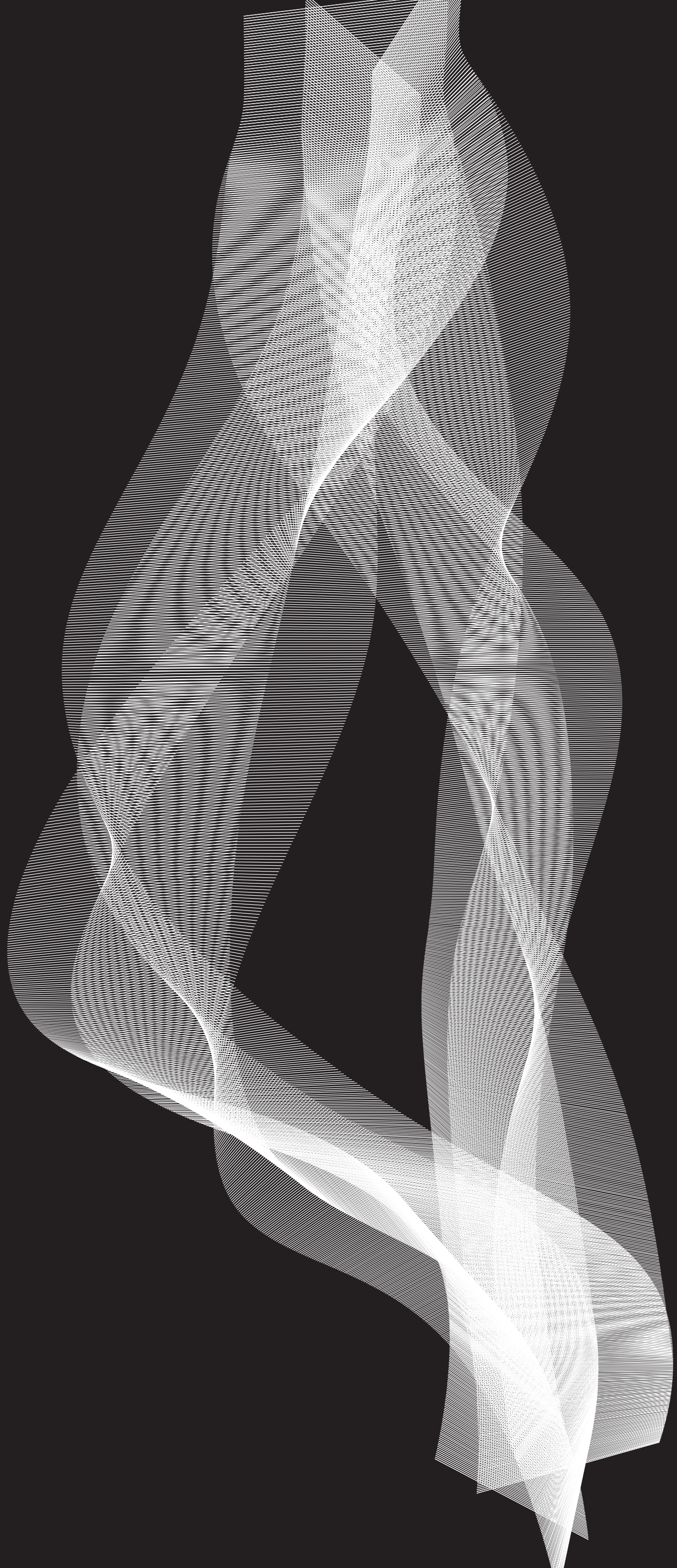
DIGITAL TECTONICS:

Design Process

With the general logic of the structure in place, the design group began to parameterize the the inputs and restrictions. Restrictions both regarding robotic fabrication, joinery methods, physical laws and spatial limitations. Most of these parameters kept changing throughout most of the process.
It was most important to constantly stay updated with what was happening in the Robotic fabrication and Joinery groups, since the new demands for the design kept appearing. Also the context, the exibition room in Milan, kept changing as the structure was constantly negotiating territory with the surrounding installations of AAA. This meant that the design process was feedback looping; for each loop the design would change to either comply with new requests or restrictions, or to improve the spatial experience of the final structure.

The design process was much about the balance between mass and lightness, since we wished the structure to make a statement in the room, to define space surrounding it, while at the same time not being a heavy object taking up a lot of space.



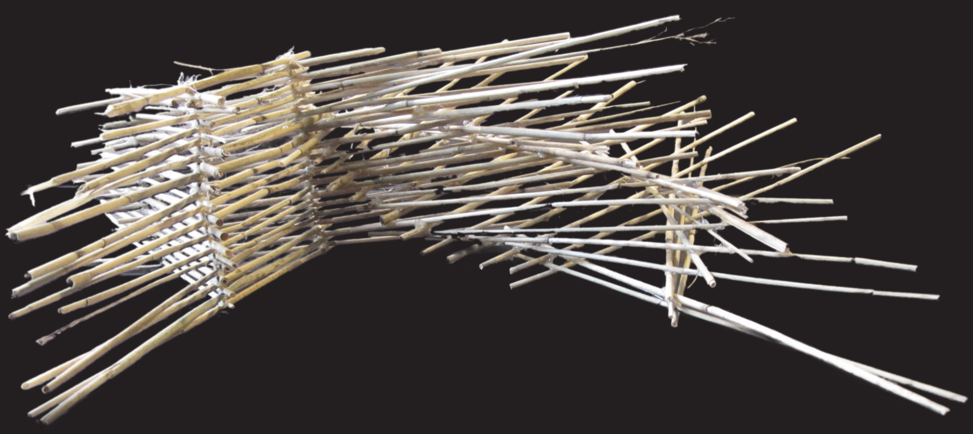


DIGITAL TESTING OF EARLY STAGE BIFURCATED STRUCTURE

Our first thoughts of the design was based on the idea of making the structure more space defining. Without adding a lot of volume, we thought of letting the structure split into two, to make it bifurcate, move around and reconverge.

Our idea was that one spine would be linear and having two spines would be spatial.

We spent a lot of time trying to make the bifurcation work. The main task was to get the stacking logic to work with two piles weaving together. This turned out to be quite complicated, and require both analog and digital testing.



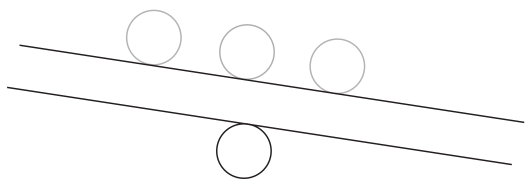
BIFURCATION

The existing system:
First reed lying flat
Second reed resting on top of that, with one end on same plane as the one below.
Third reed resting on the two first reeds.

In this way the first and second reed will be parallel to each other and the initial plane.
This will be the same no matter the amount of layers.

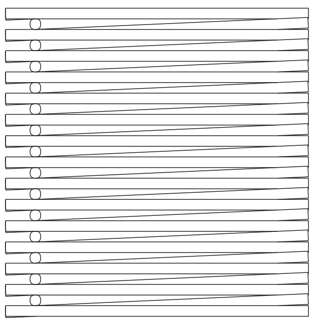
Since, though, every third reed is lying in a different angle than the direction of the piling, the height of the intersection will depend on the rotation of the structure.

This, however, is not an actual problem, since the offset is so small and the difference in thickness of each reeds varies. But this helps to explain the problem in bifurcating the structure.
We were able to do bifurcations in our analog models; because of the shifting material thicknesses and small scale this problem did not occur in a visually obvious level.
However in a bigger scale, and more precisely produced structure, this problem might not only be theoretical, but practical?



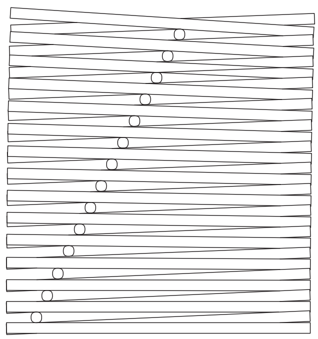
ROTAING LEFT; LOWER. ROTATING RIGHT; TALLER.

Because one reed isn’t lying perpendicular to the stacking direction it is not possible to brake the structure into two; as soon as the two paralelle reeds does not share meeting points with the angled reeds, they will change vertical angle and shift height in the following layers causing the general direction of the structure to incresingly tilt.



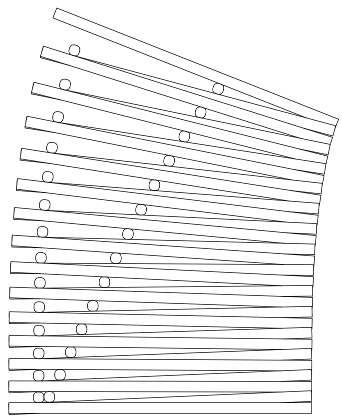
Reeds stacked in equally sized triangles.

The horizontal angle of reeds in all tree sides does not change during the piling.



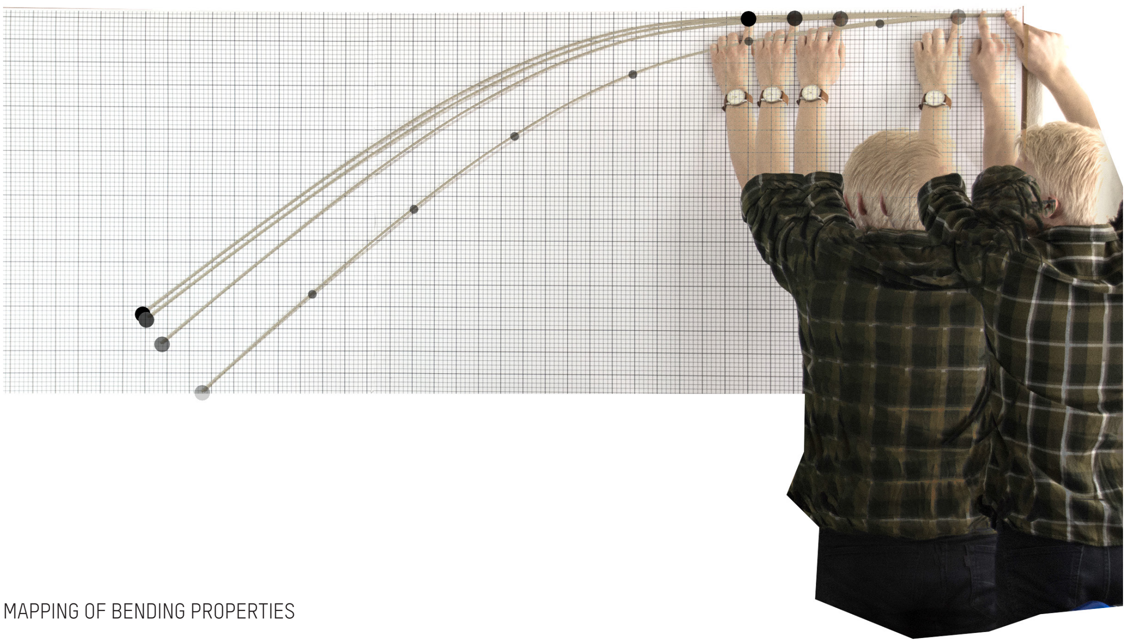
Reeds stacked in triangles consisting of sides of various length.

The length of the angled reed will determine the angle of the reed on top of it, wich will again affect the one above it, causing it to compensate; allowing the structure to grow in a liniar direction.



Two triangles of reeds are intersecting each other.

If a horizontally angled side is offset from another, the angles of the reeds above it will be different, causing them eather to collide in one side, or not meet in the other.



MAPPING OF BENDING PROPERTIES

MATERIAL PROPERTIES

To get an idea of the the structure and how it would appear in the exhibition space, we continually tested the design inerations by generating both perspective and plan drawings. As we wanted the spatial properties of the structure to be in a human scale, we had to be very precise about these tests.

Since the material we were working with was not completely rigid, we applied a simulation of gravity to get a more realistic idea of the physical shape after manufacturing. To do this it was necessary to make an input to the computer simulation, defining the bending abilities of our reeds. We therefore mapped the bending behavior of the reed at different angles and lengths through a series of photographs, that was later used to adjust the parameters of the digital bending.

Because of the feedback looping design flow, we had to decide on the materials rather early in the process; all three groups needed the specific properties of the material, to start developing.
Expecting to later in the process being able to have the robot adjust the length of the reeds, we ordered them in the length of 2000mm, wich we calculated to be our maximum length considering the ceiling height. The thickness depended, because of the extrution technic of the reeds, on the length.


RoboticThatch06
MILANO 2016

ROBOTIC FABRICATION

Moving forward against an actual design realization required a translation from a grasshopper environment into robotic movement. For this we used HAL.

The HAL plugin is a robot library that allow us to simulate and program simple and multi-robot cells. With its special programming packages, HAL facilitates the creation of advanced application structures including I/O management, error handling and multi-tasking. For the job we choose to use smaller ABB robots which is primarily optimized for packing applications due to their size, but if we were to divide the task into smaller pieces we could use different robots for each task.
Two sets of code where developed using grasshopper and HAL and represents two robotic workstations. The first workstation would be the cutting station. This station allows us to cut down reeds into shorter lengths and create a more spatial design. The second workstation would be the placement and stacking station. Here the job of the robot would be to pick up each of the already cut pieces and start to build up the design. However working with robots is not exactly an easy task and the lack of experience within the team made the risk of failure even higher.

Writing code and testing in 1:1 made us realize different parameters and limitations. In order to make a pile of reed, the design team had to provide curves with an offset to one another with the exact diameter of the reed. The curve must furthermore consist of four control points, one in each end and one at each intersection with the next reed. With this information we were able to stack reeds.

Tool requirements

- Grabbing a 2 meter flexible straw has need for mutiple pick-points in order to keep the direction of the reed.

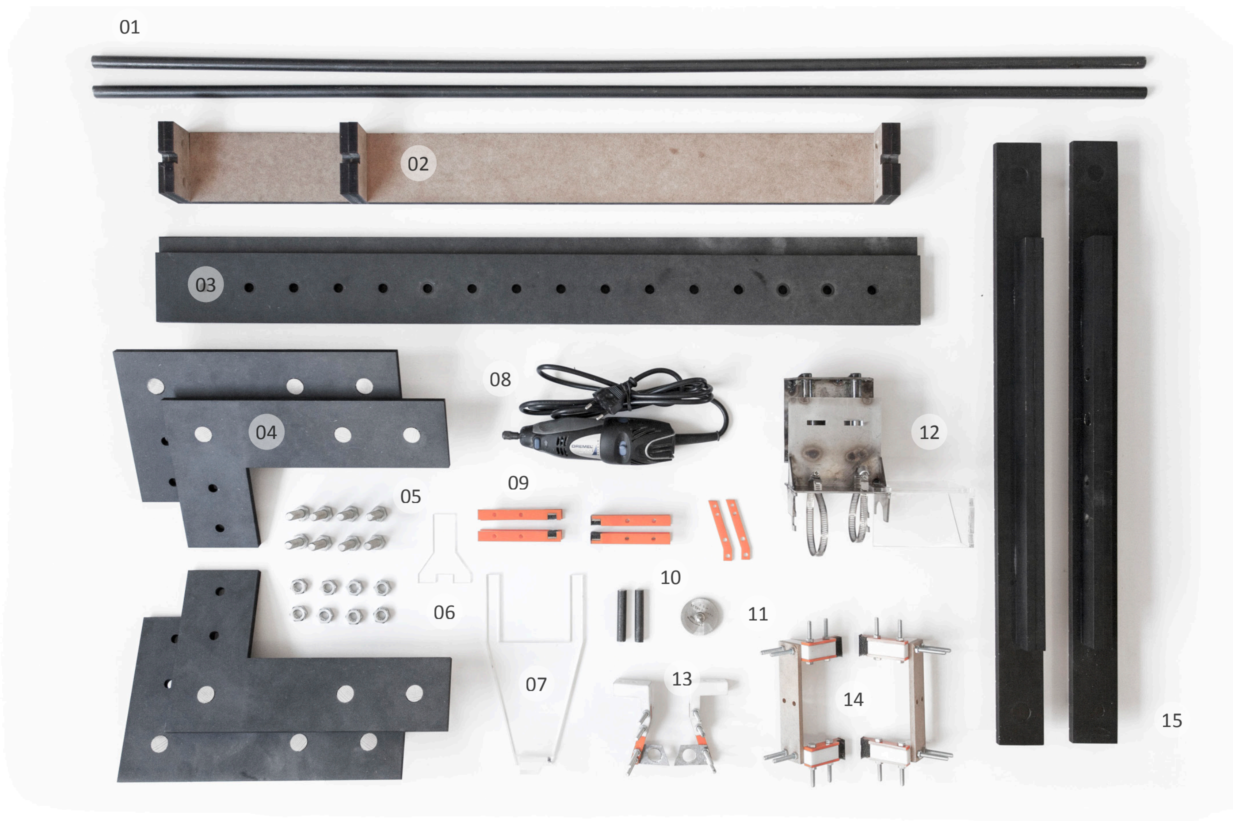
- Each of the reeds varies in thickness and an soft, malleable material is needed to account for this.

- The artificial reed is made of plastic and is rather hard to cut compared to natural reed.

With this in mind we designed a number of tools that allowed two robots with the same input to work together.

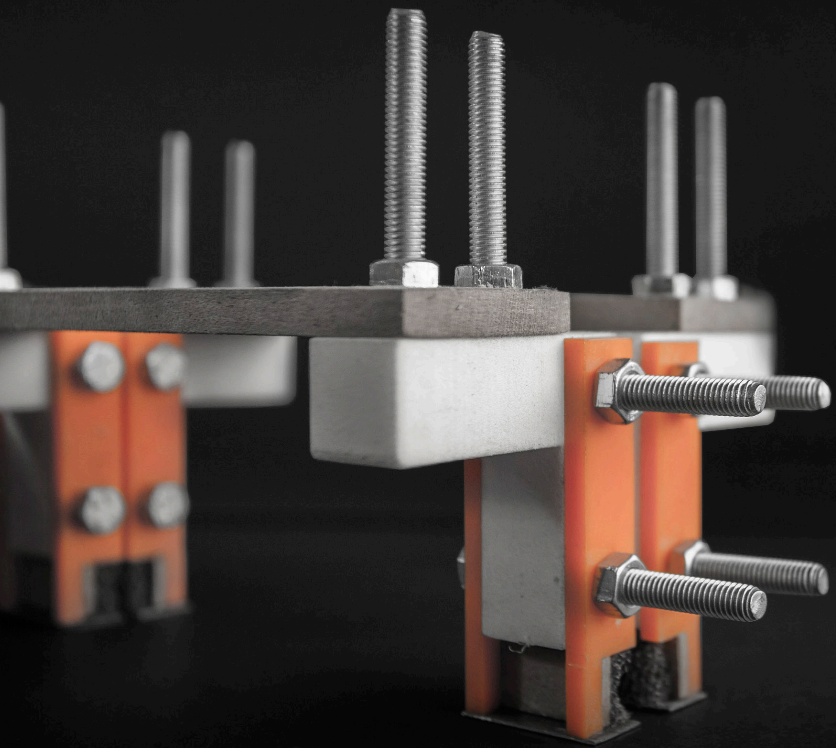
"Computational design strategies offer new ways of thinking of the recursive interchange through the inherent temporality of their medium. In contrast to the traditions of architectual drawing, computation is set in time. As one process calls the next, time unfolds across the cranching of its conditional statement and the counting of internal loops." (Martin Tamke, 2012)

ROBOTIC TOOLS



01 Rods for rail system
02 Reed dispenser
03 Table spacers
04 Table connectors
05 8 x bolts and threads
06 Attactment to cutter
07 Range finder
08 Dremel 300

09 Grabber prototypes
10 Space bars
11 Blade
12 Cutting train
13 Reed scissor
14 Grabber
15 Rail system



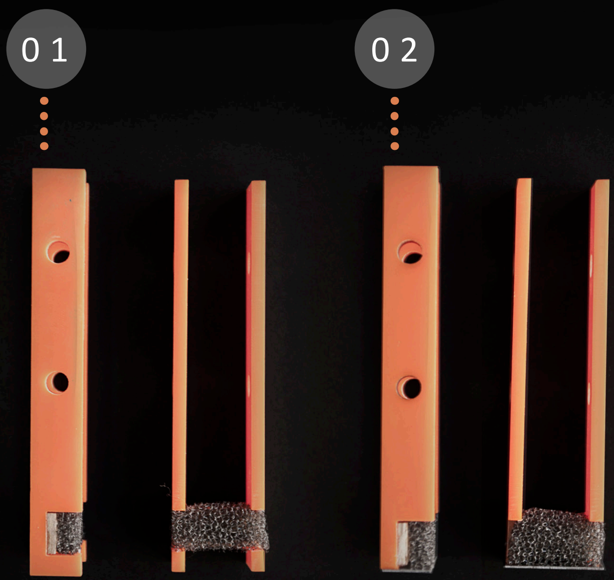
TOOLS

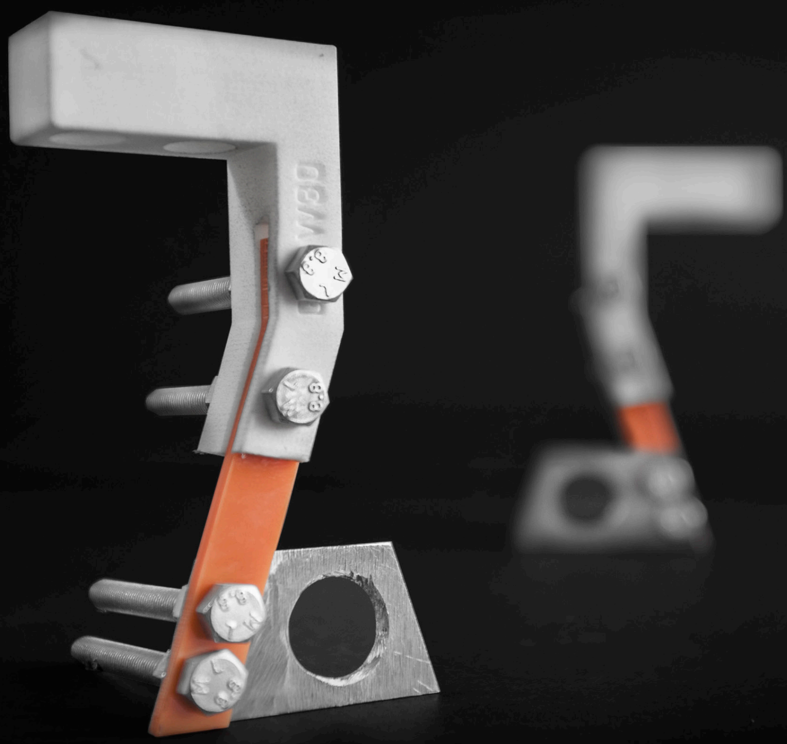
Reed Grabber

To pick up and place each individual reed, an extended grapper needed to work in unison to allow full control of the orientation. Air pressure made it possible to open and close the grabber and was all incorporated in the rapid code. At the pick-point an absorbent material was attached to account for the various dimensions of the reeds.

Different Generations

Developing various kinds of tools also required a certain amount of changes. The grabber was assembled in pieces and most of the changes were made in the acrylic part connected to the 3d print. The first generation (shown on the right) was able to grab and place the reed, but due to the difference in thickness, the buttom part was often touching the lower reed, and a second generation was needed where a thin metal plate replaced some of the acryllic allowing to move closer to the reed that had already been placed. Later, the grabber was also shortened to allow for more mobility.





Reed Scissor

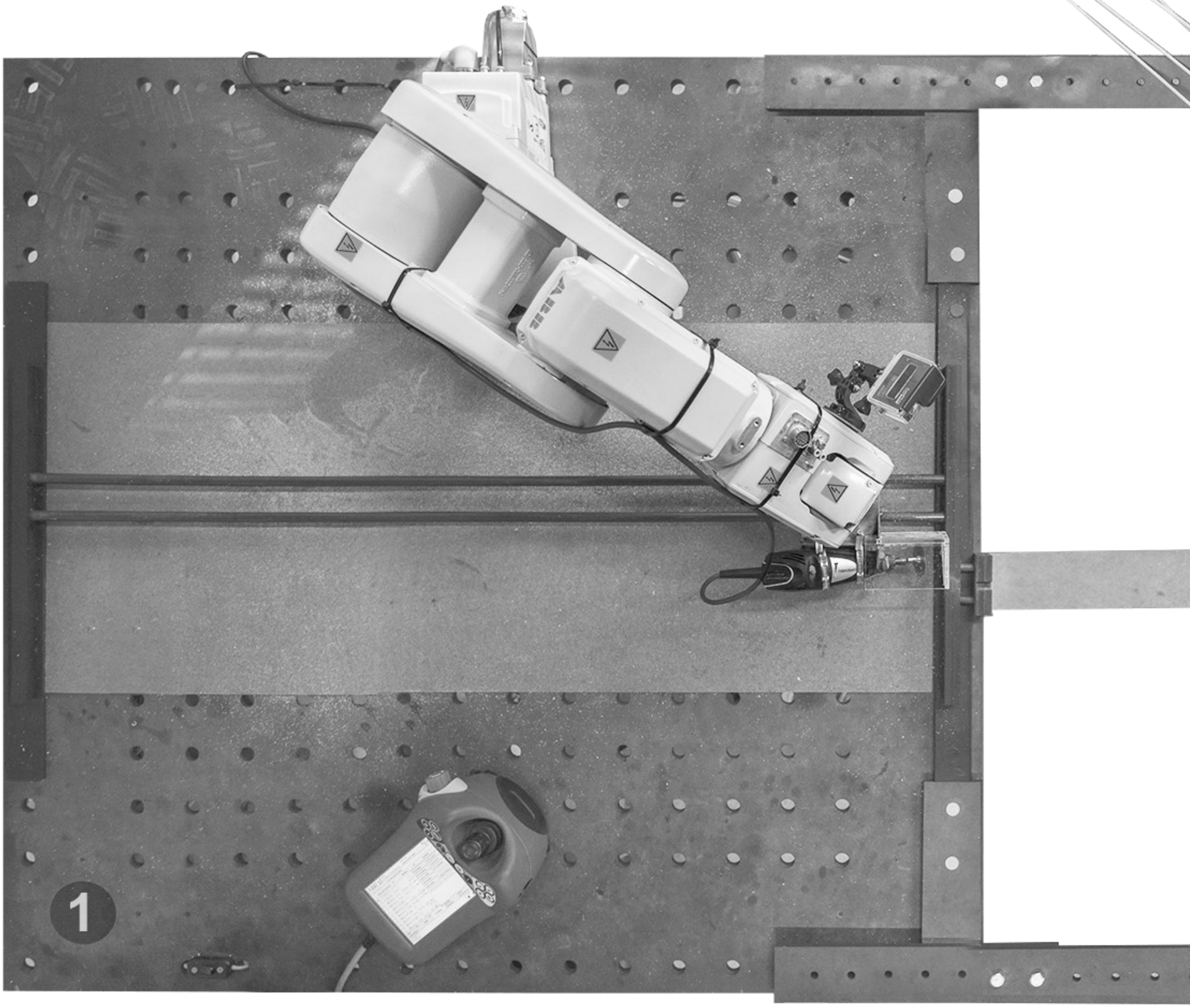
In order to cut the reeds different kinds of tools were developted and tested. The scissor besically works like a reversed cigar cutter, and when mounted to a Schunk gripper air pressure allowed the tool to move apart from one another. However the maximum pressure of 4 bar was simply not strong enough to cut the artificial reeds.

Cutting Train

The method of choice was a custom made rail system with a Dremel 300 mounted to a small train. The robot was able to move the train in two axis allowing us first to meassure the length and after cutting the reeds in two.

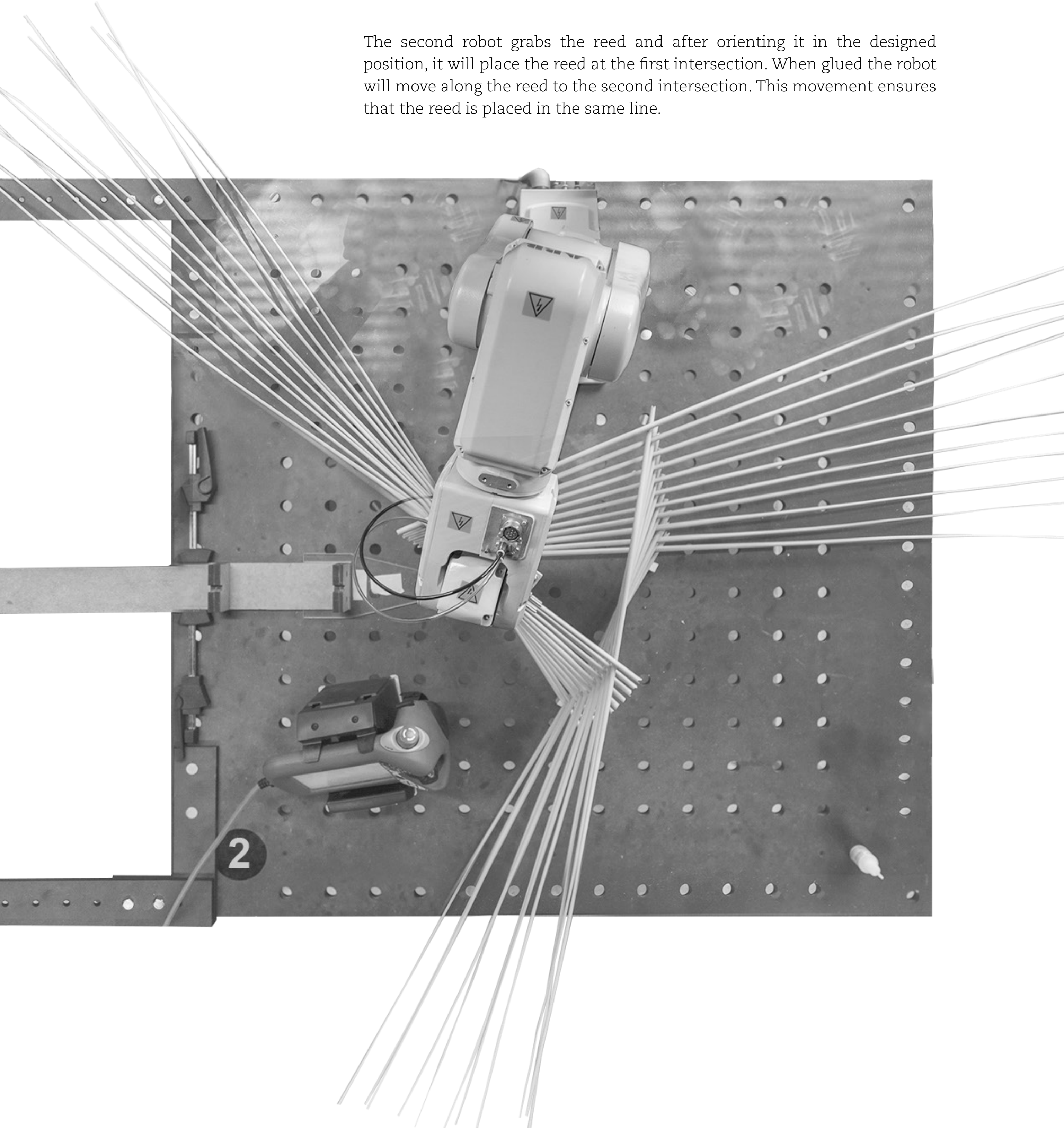
PRODUCTION PIPELINE

Grabbing | Cutting | Placing | Stacking

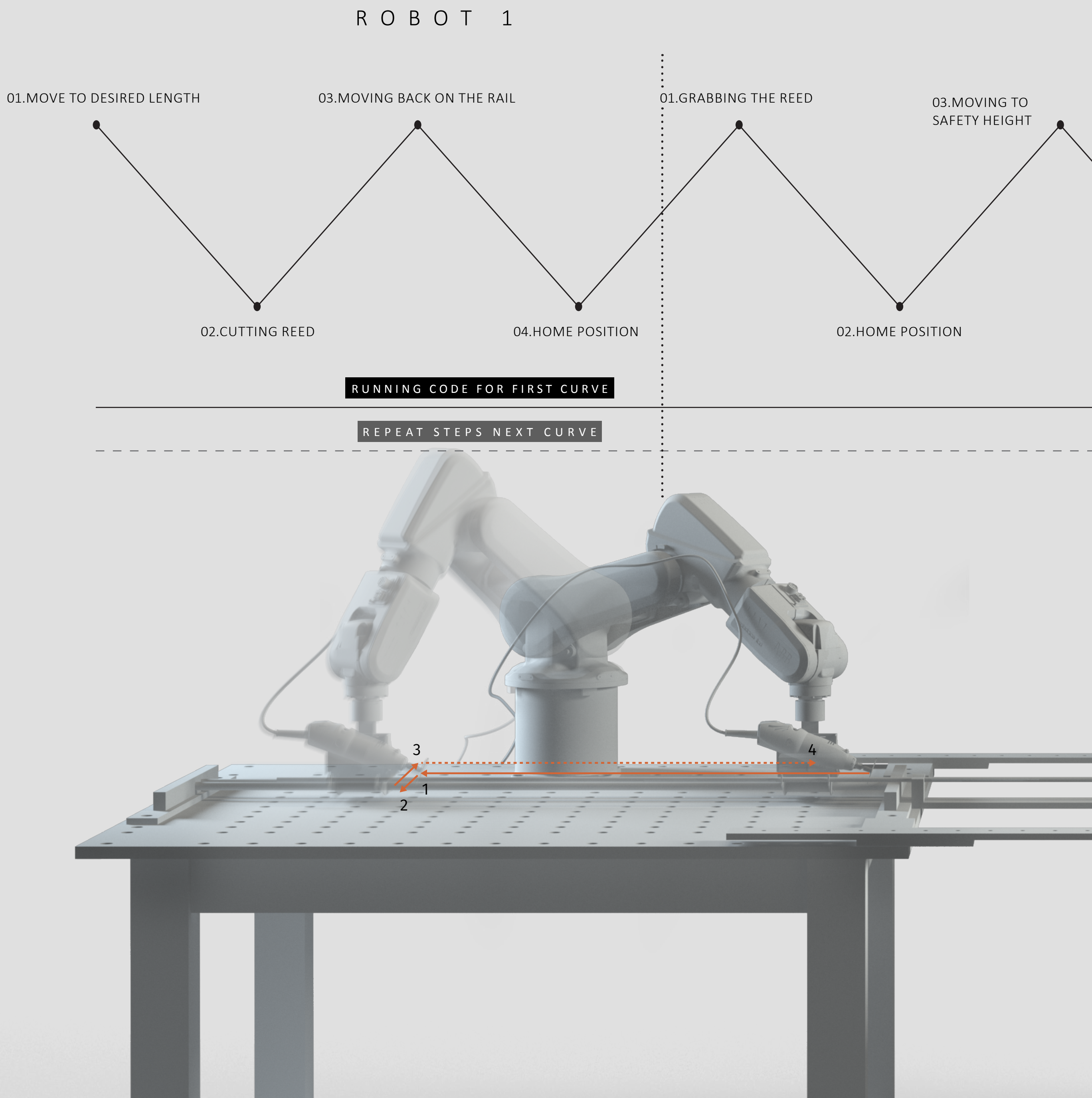


The first station measures the lenght of the reeds in order and translates this into movement on the trail. When the movement is completed a switch allows to turn on the blade, and the robot will cut the reed.

The second robot grabs the reed and after orienting it in the designed position, it will place the reed at the first intersection. When glued the robot will move along the reed to the second intersection. This movement ensures that the reed is placed in the same line.

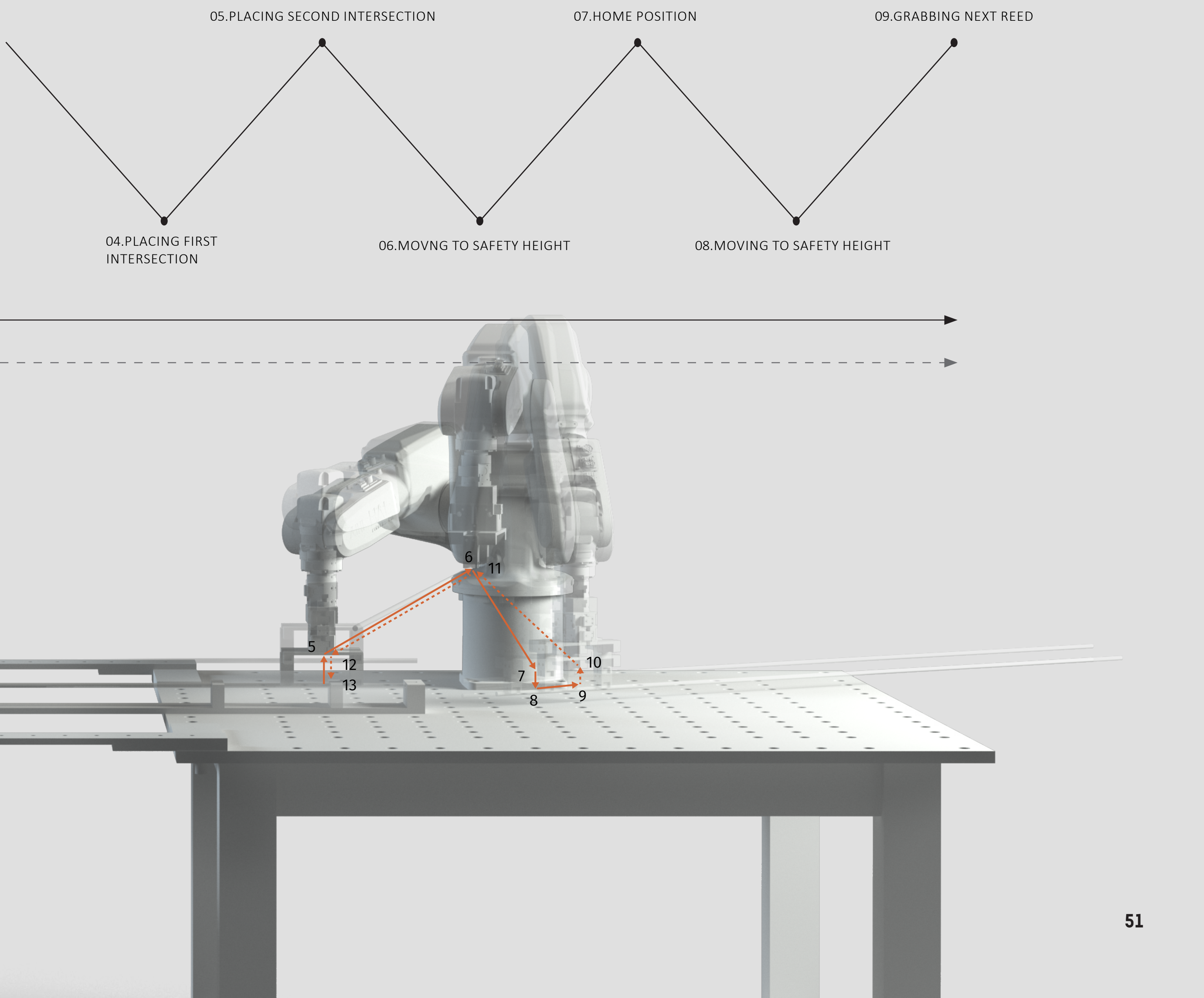


ROBOTIC PRODUCTION



The robots are both feed the same information. However, set up to interpret and utilize the information different. As shown in the diagram below. Robot 1 alters the length of the reed and robot places it. these 13 steps are is repeated for every curve in the structure.

ROBOT 2

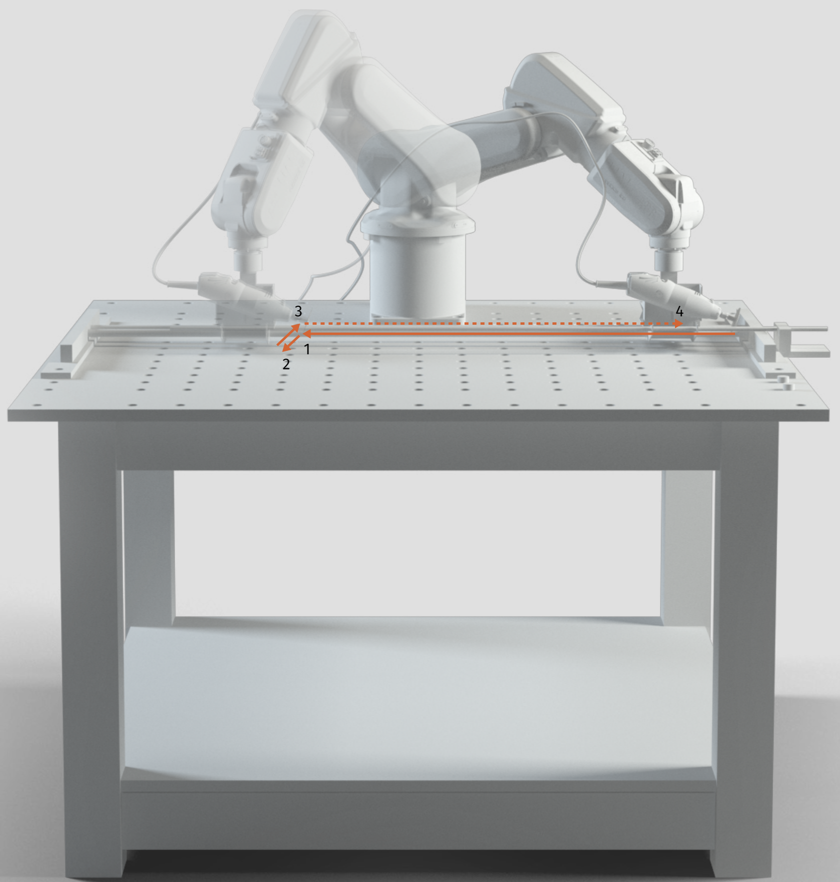


1 MOVING TO DESIRED LENGTH

2 CUTTING REED

3 MOVING BACK ON RAIL

4 HOME POSITION



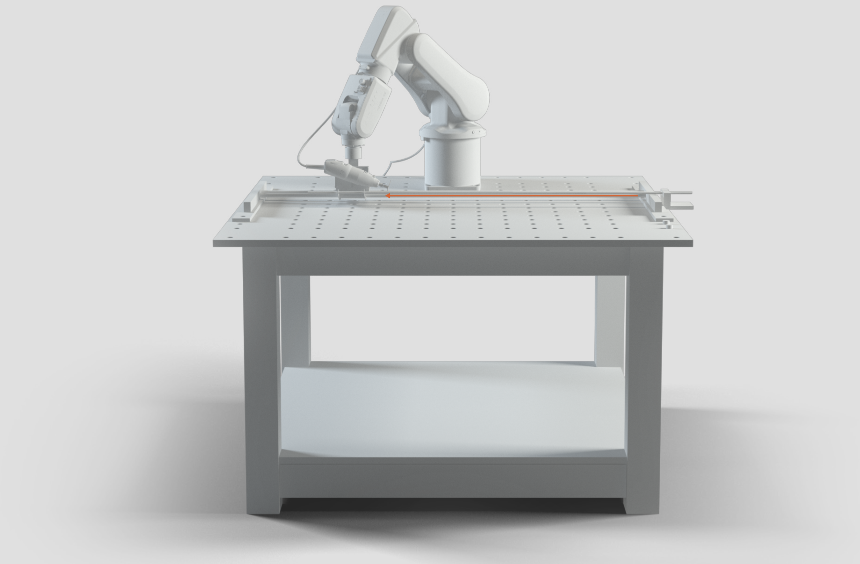
MEASURING AND CUTTING

Code generated for the robot

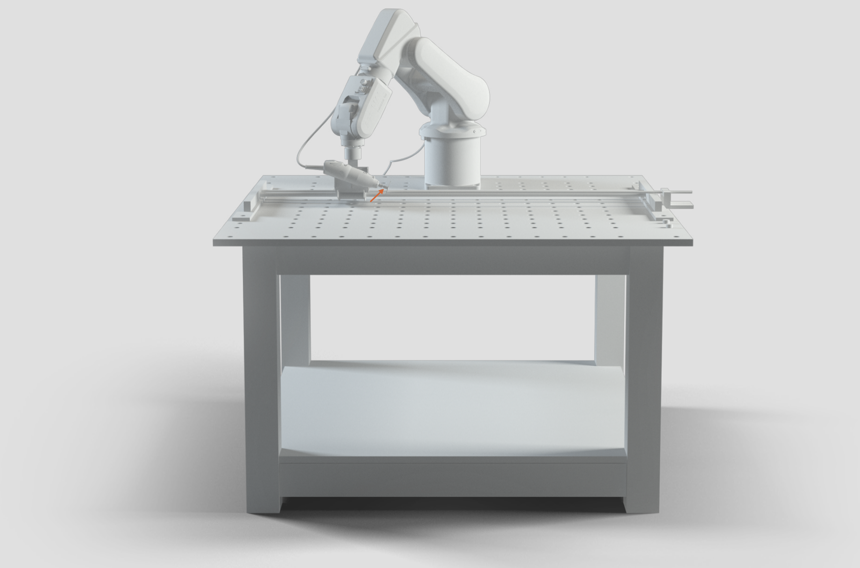
```
CONST robtarget Cut_Path_A0:=[[305.2,447.78,81.19],[0,0.7071,0.7071,0],[0,0,1,0],[0,9E9,9E9,9E9,9E9,9E9]];
CONST robtarget Cut_Path_A1:=[[305.2,-227.23,81.19],[0,0.7071,0.7071,0],[-1,0,0,0],[0,9E9,9E9,9E9,9E9,9E9]];
CONST robtarget Cut_Path_A2:=[[335.2,-227.23,81.19],[0,0.7071,0.7071,0],[-1,0,0,0],[0,9E9,9E9,9E9,9E9,9E9]];
CONST robtarget Cut_Path_A3:=[[305.2,-227.23,81.19],[0,0.7071,0.7071,0],[-1,0,0,0],[0,9E9,9E9,9E9,9E9,9E9]];
CONST robtarget Cut_Path_A4:=[[305.2,447.78,81.19],[0,0.7071,0.7071,0],[0,0,1,0],[0,9E9,9E9,9E9,9E9,9E9]];

 MoveL Cut_Path_A0,Medium,z1,Cutter\WObj:=WObj0;
 MoveL Cut_Path_A1,Medium,z1,Cutter\WObj:=WObj0;
 WaitTime 3;
 MoveL Cut_Path_A2,Medium,z1,Cutter\WObj:=WObj0;
 MoveL Cut_Path_A3,Medium,z1,Cutter\WObj:=WObj0;
 WaitTime 3;
 MoveL Cut_Path_A4,Medium,z1,Cutter\WObj:=WObj0;
 WaitTime 3;
```

MEASURING AND CUTTING

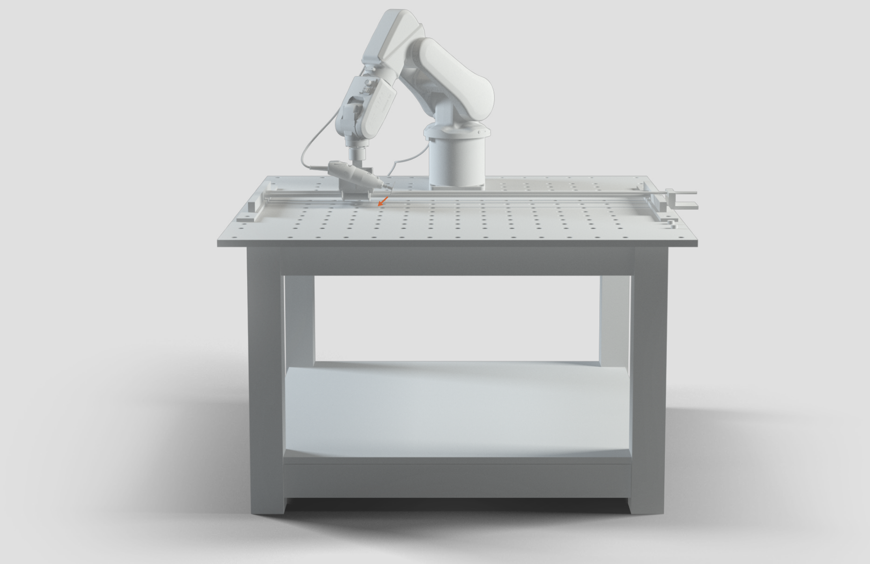
every step of the code displayed as robotic movement.



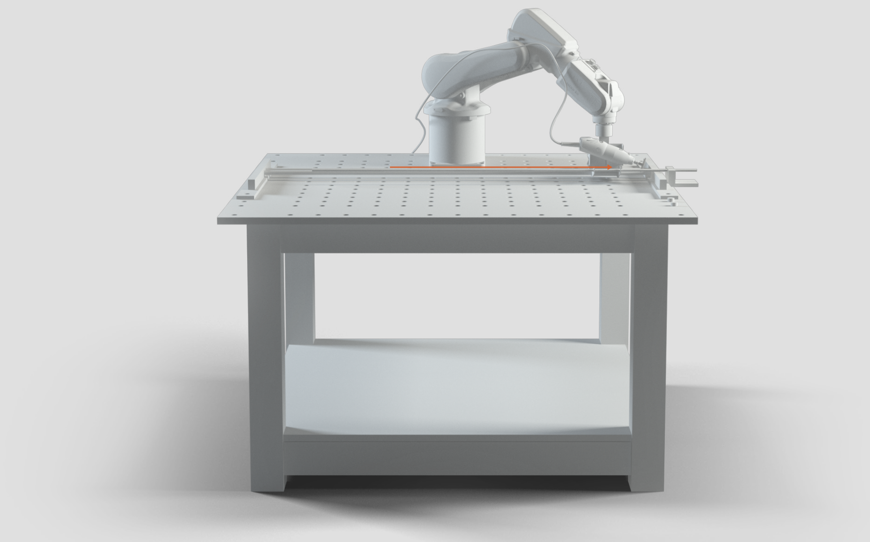
1 MOVING TO DESIRED LENGTH



2 CUTTING REED

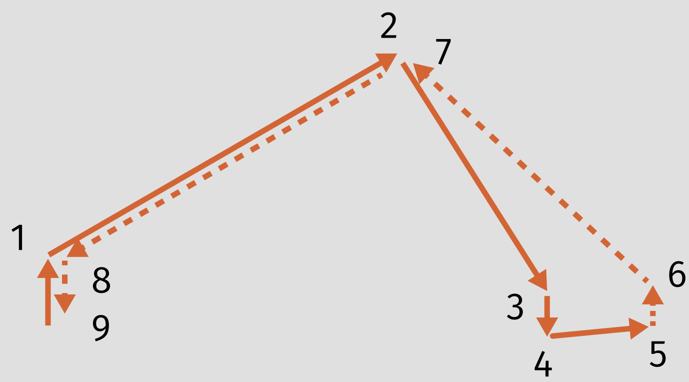


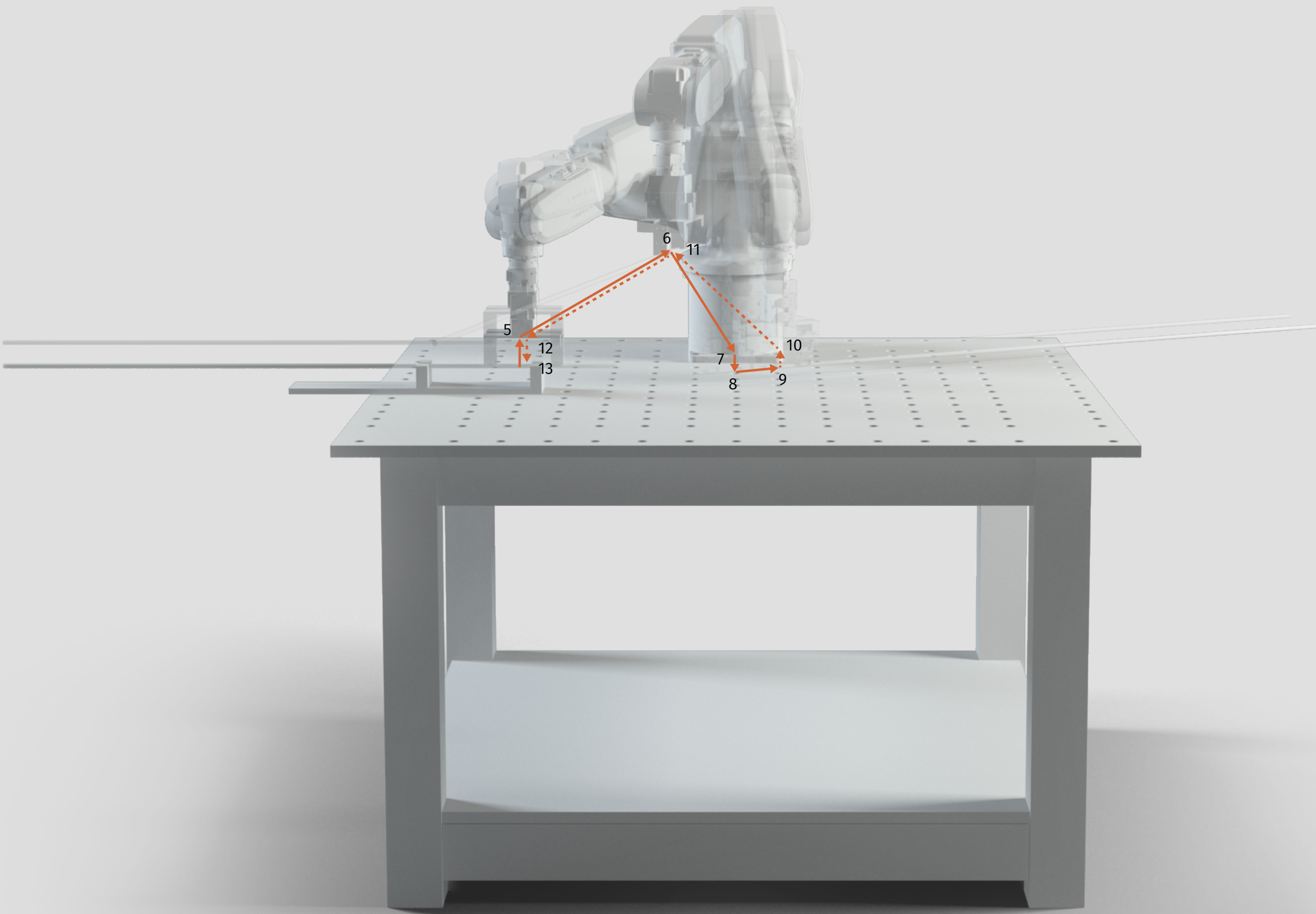
3 MOVING BACK ON RAIL



4 HOME POSITION

1 GRABBING THE REED
2 HOME POSITION
3 MOVING TO SAFETY HEIGHT
4 PLACING FIRST INTERSECTION
5 PLACING SECOND INTERSECTION
6 MOVING TO SAFETY HEIGHT
7 HOME POSITION
8 MOVING TO SAFETY HEIGHT
9 GRABBING NEXT REED





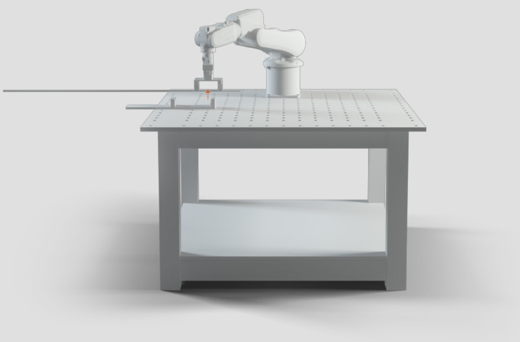
MEASURING AND CUTTING

Code generated for the robot

```
CONST robtarget GrippingPath_A0:=[[438.27,-373.42,86.85],[0,-0.7071,0.7071,0],[-1,0,2,0],[0,9E9,9E9,9E9,9E9,9E9]];
CONST robtarget GrippingPath_A1:=[[438.27,-373.42,44.85],[0,-0.7071,0.7071,0],[-1,0,2,0],[0,9E9,9E9,9E9,9E9,9E9]];
CONST robtarget GrippingPath_A2:=[[438.27,-373.42,86.85],[0,-0.7071,0.7071,0],[-1,0,2,0],[0,9E9,9E9,9E9,9E9,9E9]];
CONST robtarget Place0:=[[456.91,-249.7,239.37],[0,0.9476,-0.3195,0],[-1,0,1,0],[0,9E9,9E9,9E9,9E9,9E9]];
CONST robtarget Place1:=[[450.7,175.68,25],[0,0.9476,-0.3195,0],[0,0,2,0],[0,9E9,9E9,9E9,9E9,9E9]];
CONST robtarget Place2:=[[450.7,175.68,0],[0,0.9476,-0.3195,0],[0,0,2,0],[0,9E9,9E9,9E9,9E9,9E9]];
CONST robtarget Place3:=[[566.32,87.71,0],[0,0.9476,-0.3195,0],[0,0,2,0],[0,9E9,9E9,9E9,9E9,9E9]];
CONST robtarget Place4:=[[566.32,87.71,0],[0,0.9476,-0.3195,0],[0,0,2,0],[0,9E9,9E9,9E9,9E9,9E9]];
CONST robtarget Place5:=[[566.32,87.71,25],[0,0.9476,-0.3195,0],[0,0,2,0],[0,9E9,9E9,9E9,9E9,9E9]];

    MoveAbsJ TP_home0,Super_high_speed,z1,Gripper_Reed;
    MoveAbsJ TP_home1,Super_high_speed,z1,Gripper_Reed;
    MoveL GrippingPath_A0,Super_high_speed,z1,Gripper_Reed\WObj:=WObj0;
    openGripper 0;
    MoveL GrippingPath_A1,Super_high_speed,z1,Gripper_Reed\WObj:=WObj0;
    closeGripper;
    WaitTime 3;
    MoveL GrippingPath_A2,Super_high_speed,z1,Gripper_Reed\WObj:=WObj0;
    MoveAbsJ TP_home0,Super_high_speed,z1,Gripper_Reed;
    MoveAbsJ TP_home1,Super_high_speed,z1,Gripper_Reed;
    MoveL Place0,Super_high_speed,z1,Gripper_Reed\WObj:=WObj0;
    MoveL Place1,Super_high_speed,z1,Gripper_Reed\WObj:=WObj0;
    MoveL Place2,Super_high_speed,z1,Gripper_Reed\WObj:=WObj0;
    openGripper 3;
    MoveL Place3,Super_high_speed,z1,Gripper_Reed\WObj:=WObj0;
    closeGripper;
    MoveL Place4,Super_high_speed,z1,Gripper_Reed\WObj:=WObj0;
    openGripper 3;
    MoveL Place5,Super_high_speed,z1,Gripper_Reed\WObj:=WObj0;
    MoveAbsJ TP_home0,Super_high_speed,z1,Gripper_Reed;
    MoveAbsJ TP_home1,Super_high_speed,z1,Gripper_Reed;
 MoveL Cut_Path_A3,Medium,z1,Cutter\WObj:=WObj0;
 WaitTime 3;
 MoveL Cut_Path_A4,Medium,z1,Cutter\WObj:=WObj0;
 WaitTime 3;
```

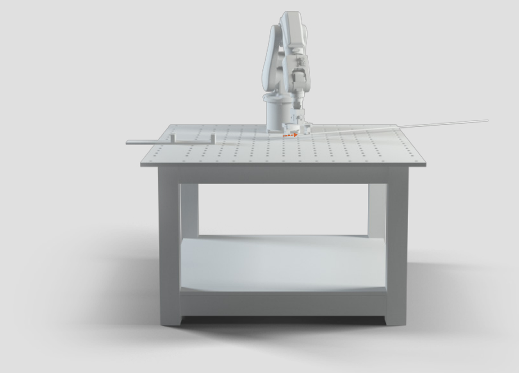
GRABBING AND PLACING EACH REED

Each Step of the Code Displayed as Robotic Movement.

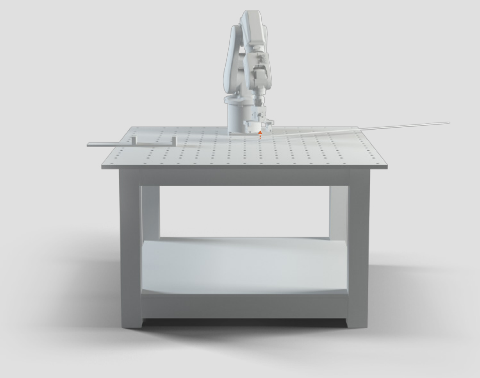


1 GRABBING THE REED

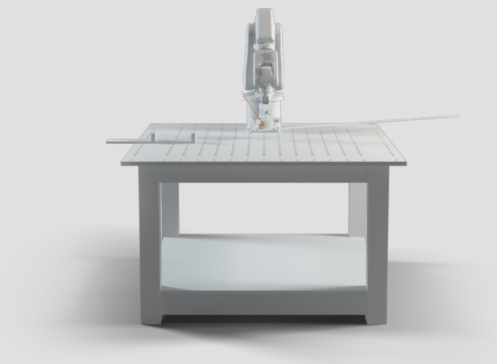
2 HOME POSITION



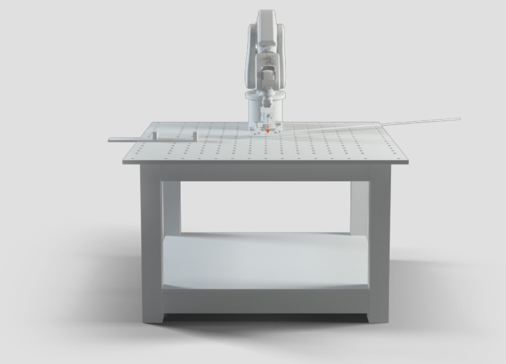
3 MOVING TO SAFETY HEIGHT



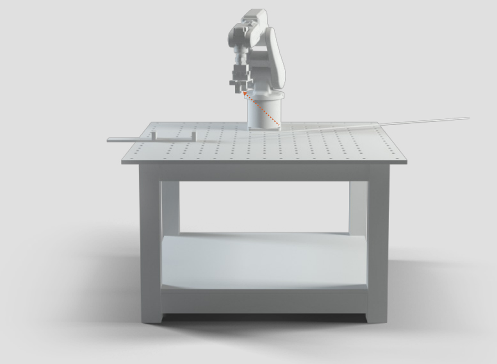
4 PLACING FIRST INTERSECTION



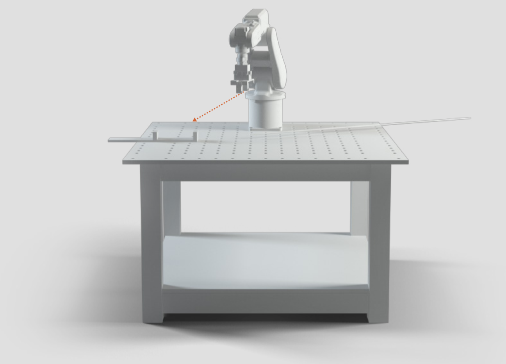
5 PLACING SECOND INTERSECTION



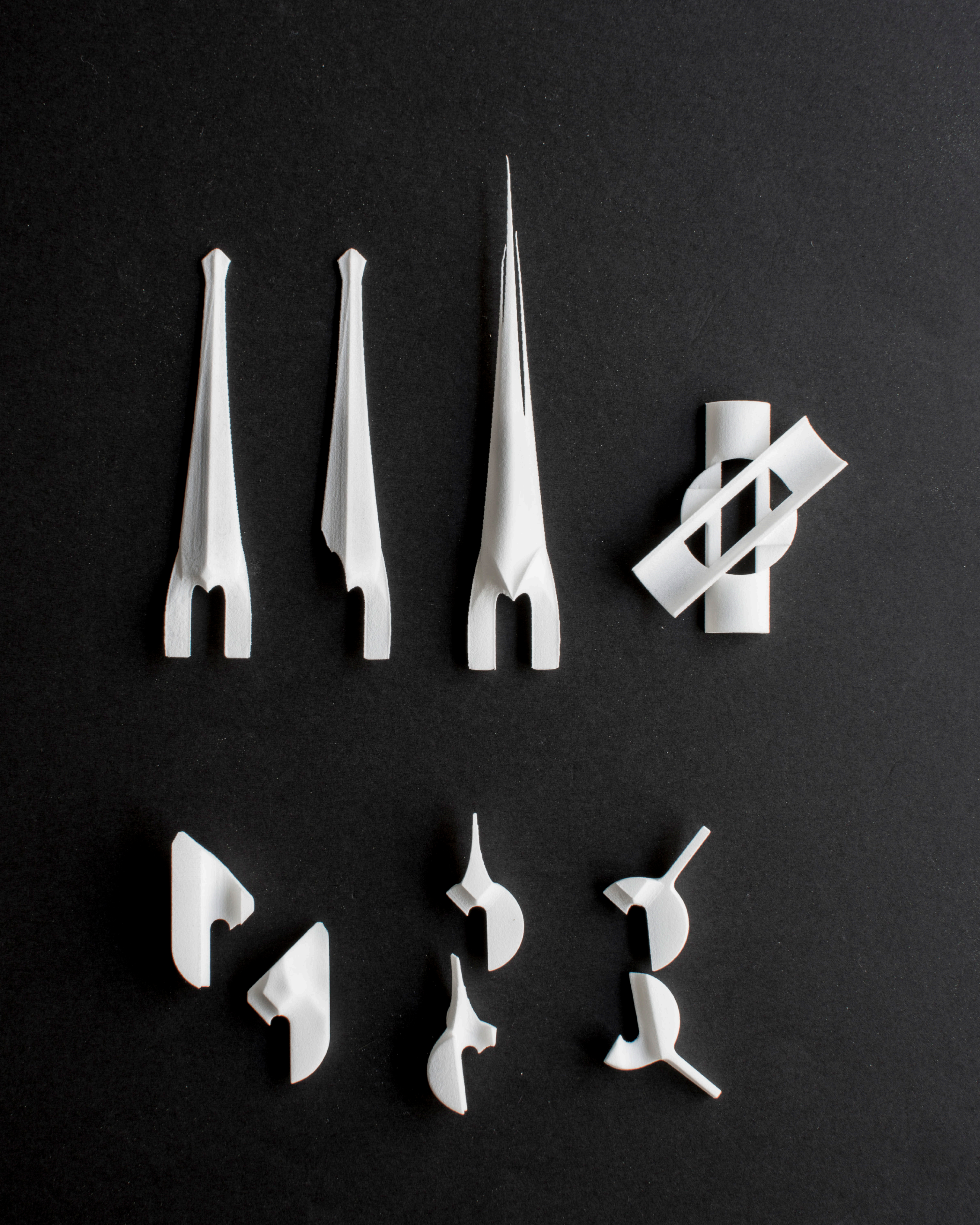
6 MOVING TO SAFETY HEIGHT



7 HOME POSITION



8 MOVING TO SAFETY HEIGHT



JOINERY

The joinery group had been working with both the “messy” and “massy” groups during the design exploration process.

Once the decision was made to pursue the “messy” design ideology, it provided our team with a framework to focus on the design of the connection detail. The major difference between design alternatives was a question of structure: Is the reed held within a structural frame, or does it become part of the structure? Knowing that we needed to integrate the structure *into* the fabrication process, we set to work to define the ways that this could be accomplished.

At the same time, the overall design of the installation began to resolve in a specific direction. reeds would be stacked horizontally in triangular formations. These sections would be rotated 90 degrees vertically and attached to each other to become a dynamic spatial form. This simple process yielded complex results, and the method of attaching each reed to the next became more difficult. Even more difficult was the fact that we could not let the joint add any thickness to the assembly, otherwise the robot would need to be programmed to account for additional depth. The discussions within our team and research ended in three approaches:

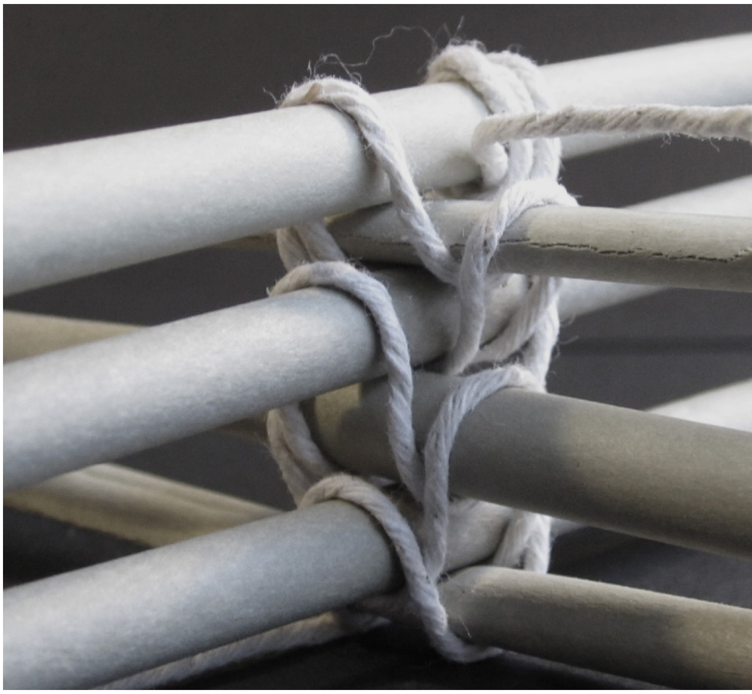
- A method of *tying / weaving* together the connections
- *Discrete elements* designed specifically for each connection
- *Universal elements* designed to fit each connection

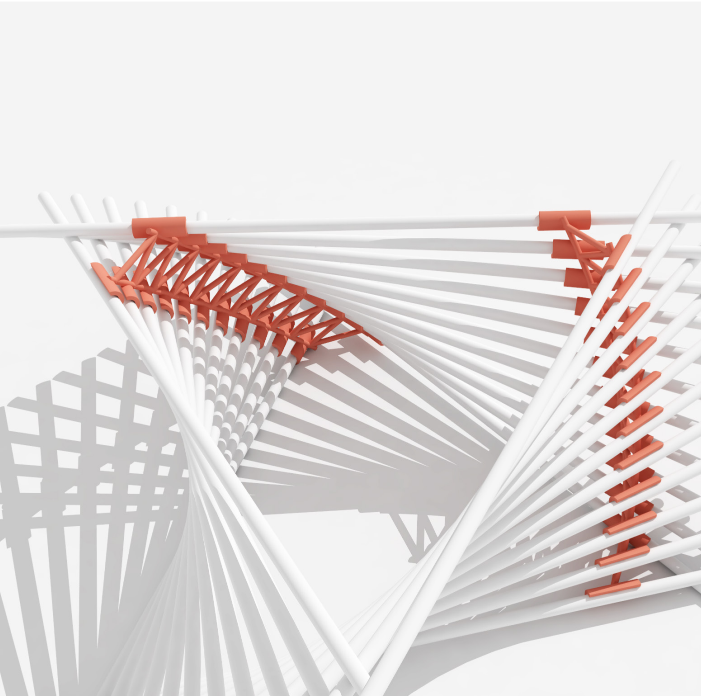
Because the degree of shift in angle changed, and the triangles themselves changed size and proportion, we continually needed to test the connections in physical form, while registering with the overall design provided by the Digital Tectonics team.

Tying/weaving connections
The development proceeded with the traditional craft in mind, connecting traditional thatching, with willows tying together bundles, or rope woven through eaves, and machinal fabrication.

Seeking to integrate the human hand in the process, different tying/weaving techniques are applied. The implementation of the human hand presented issues in fabrication in interaction with the robot, creating a bottleneck in the process.

In testing knots also proved to work in one direction only, compression, holding parts together, not in position.





Connections specific
Using techniques such as 3D print for production, opened up the possibility of designing specific parts for specific connections.

The issue encountered was the coordination of about 2.000 individual pieces, each specific to a different connection. This could be corrected by a mapping system marking parts and connections, or designing connectors for entire sections in the structure.

However, solving the assembly in that manner, renders the robotic precision unnecessary, working against the justification for the use of the robot.

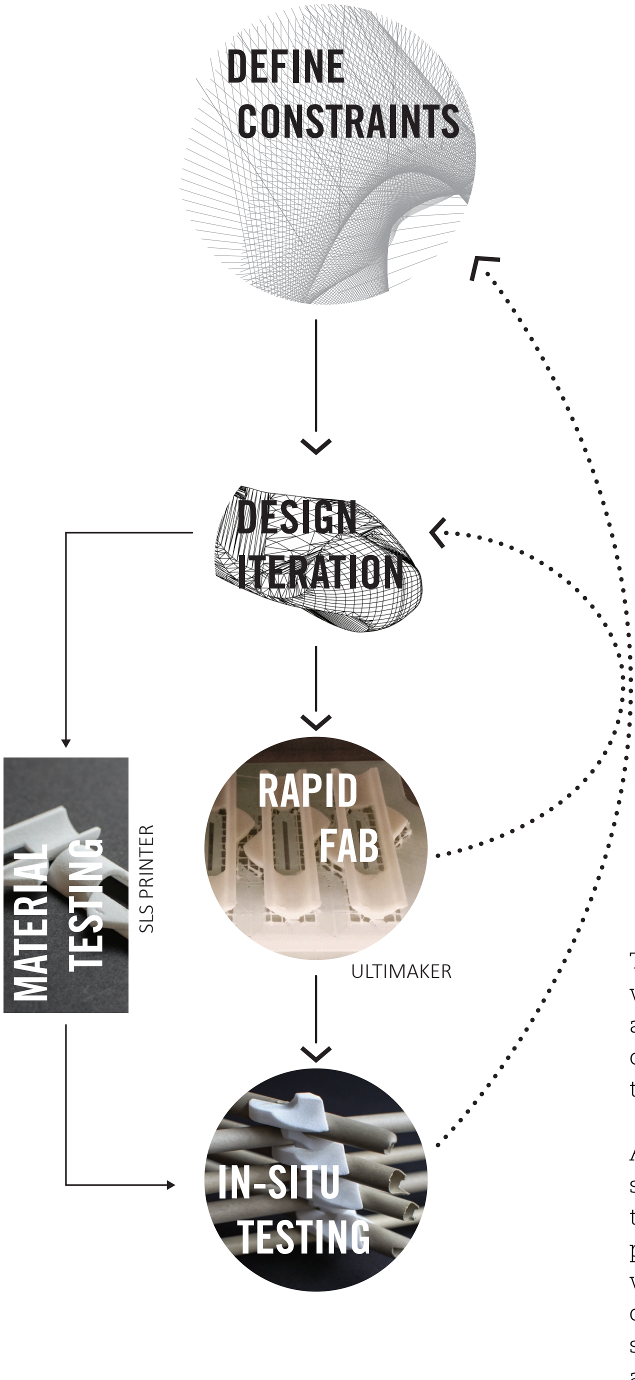
Connections universal
Focusing on utilising the robot to position the elements precisely, a solution that serves a range of connections was needed.

To design a part that fits in every condition you need to understand the universal constraints like min. and max. angle. Through rapid prototyping methods, a variety of shapes enlarging the connection by surrounding gluing area were tested.

Using the same elements repetitively will fasten the production, but how does this visually affect the overall design?

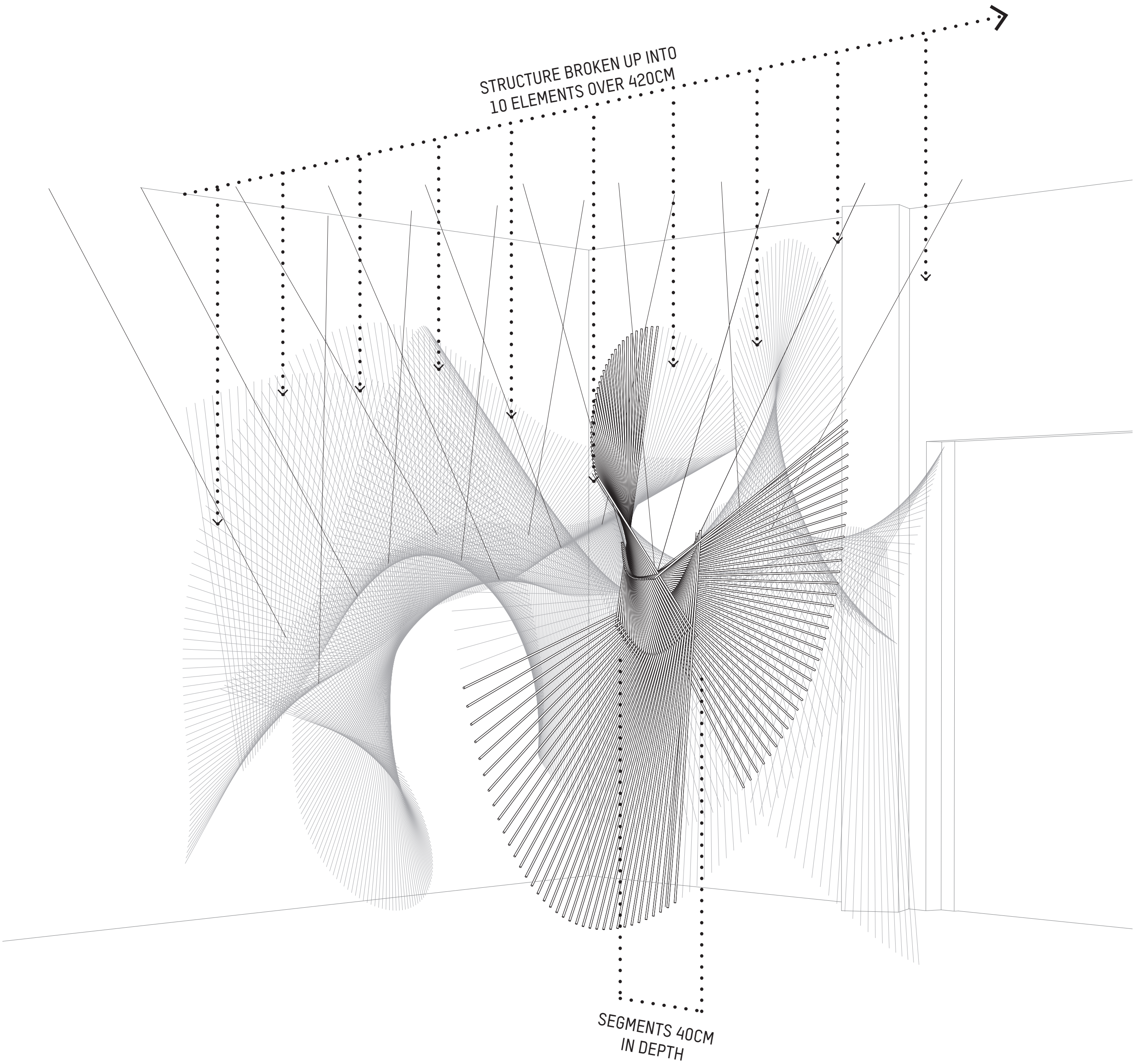
Deciding the optimum shape for the design of the connector was as much about functionality as it was about aesthaetics. Another crucial factor was the implementation of the part in the fabrication process.

To overcome the issue of creating a bottleneck in the robotic fabrication we decided that the connectors would be slided into the structure after the robotic process, enforcing the temporary glued assembly.



The process of design for the joint component was an iterative process that involved digital and physical modeling. As the group received constraints and designs for the overall model, the parameters for the joint also changed.

At the same time, the design of the part specifically also developed. Two fabrication tools were utilized to test the designs. For rapid prototyping, the Ultimaker 2+ was employed which was able to print designs within a couple of hours to a medium level of accuracy. At the same time, the SLS printer was utilized to test actual material response and aesthetics to a high degree of accuracy.



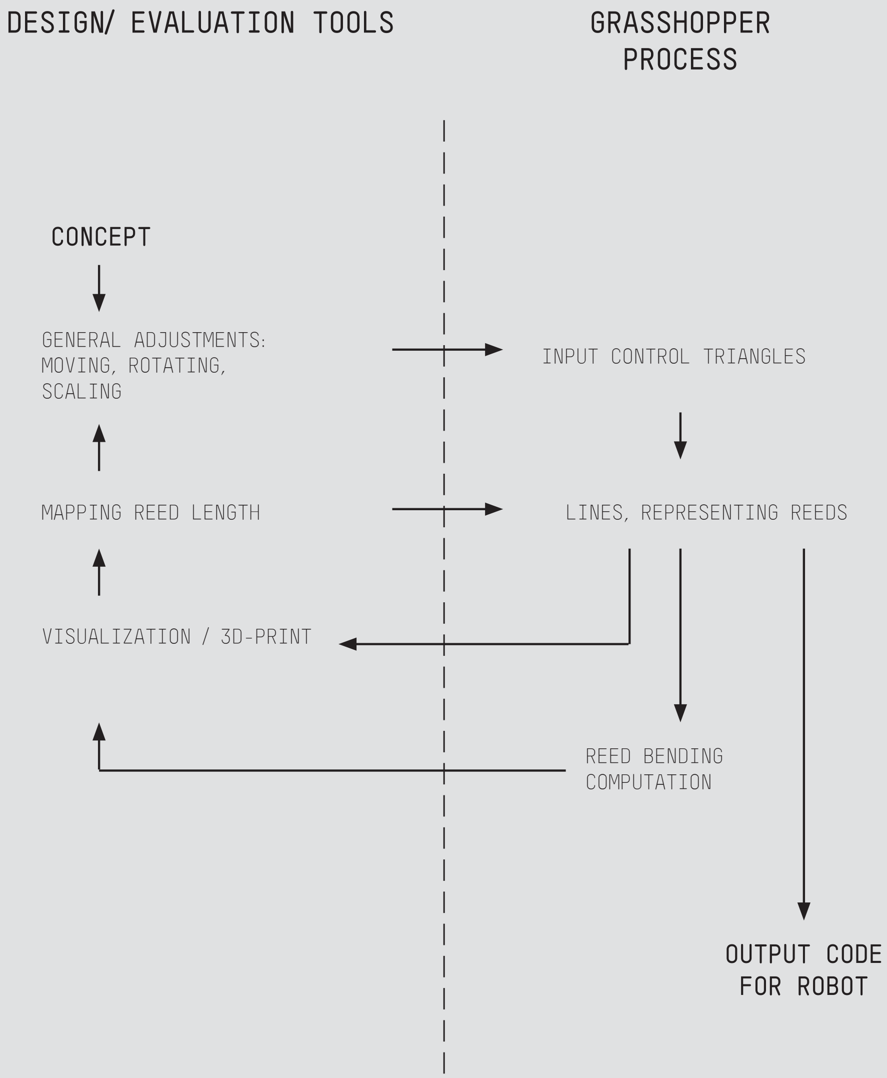
The overall structure is just under 420cm, and broken into sections of 40cm. Each section consisted of 66 connections, as well as temporary connections to allow for assembly / disassembly as well as hanging.

DISCUSSION 03.03.16

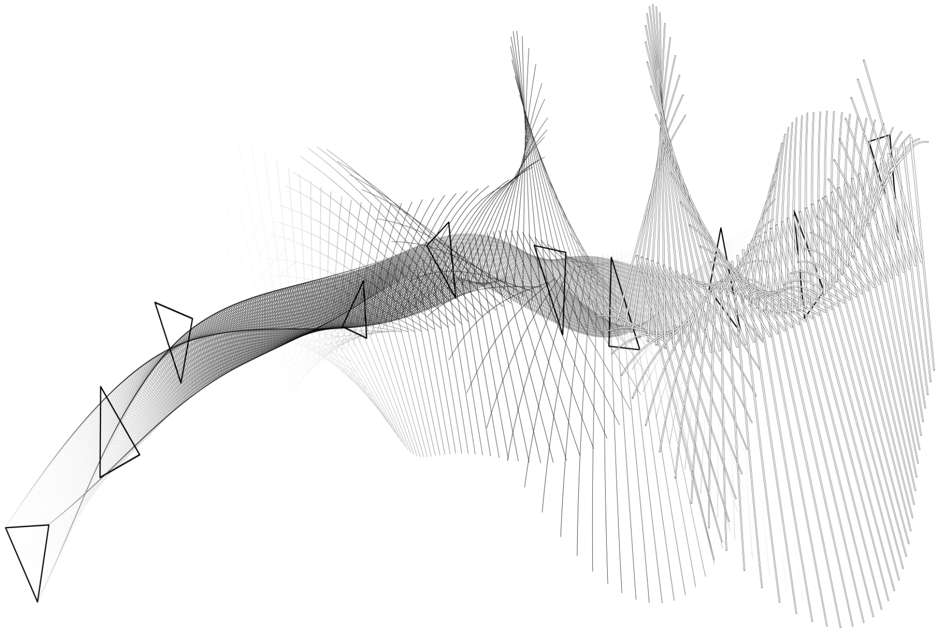
The digital tectonics group worked with the idea of bifurcation of the structure to make it more spatial with more surfaces. We were able to make the bifurcation in an analog model, because of the big variation in the reed. Trying to translate the logic into the digital environment, we found out that it wasn't possible. We also need to take it into consideration that the space in the exhibition is not that big so maybe it is better to have one linear structure which within itself can be complex and playful. If the bifurcation should be visible and done nicely we would need a bigger space for the project. We need to consider the context as a fixed parameter, which also argue against the bifurcation.

The joinery team worked with a traditional way of connecting two pieces to each other by doing knots. The knots should reinforce and tie the structure together, but it seems like the knots with thread speak another language than the structure. Can we make a joint that enhance and show the methods of digital fabrication? Can we make a digital fabricated knot? Having this in mind they tried to 3d-print different joints.
The robotic fabrication made the script for the robots and built the different tools for the robot.

It is very important that the three groups communicate well. The work of the three groups rely on each other and new information or research should be communicated so the groups can work it into their specific field of the project development. It is important that the digital tectonics group develop the overall design quite fast, because otherwise the work and scripting of the robotic fabrication group will be wasted. Furthermore the joinery group also need the final design to develop the most suitable joinery system for the structure. We can't work separately, we need to communicate and pass on knowledge discovered within the process.


DESIGN/ EVALUATION TOOLS
GRASSHOPPER PROCESS
CONCEPT
GENERAL ADJUSTMENTS: MOVING, ROTATING, SCALING
INPUT CONTROL TRIANGLES
MAPPING REED LENGTH
LINES, REPRESENTING REEDS
VISUALIZATION / 3D-PRINT
REED BENDING COMPUTATION
OUTPUT CODE FOR ROBOT

DESIGN TECHNIQUES



Throughout the entire process the digital drawings of our design has been made mainly in Grasshopper. This we found as the smartest choice as the control input used for the Robot “HAL” is also based on Grasshopper. Further more it allowed us to keep many of the inputs parametric, meaning a lot less work for us every time something was changed.

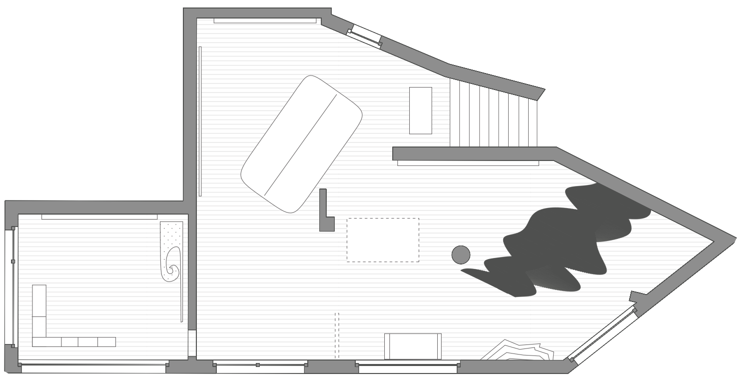
We used control triangles in rhino to drive the digital model. These represented the general flow of the structure. The height, direction, rotation and size of the inner “spine”. Those triangles could later be used to change the design of the structure on the fly at the screen.

Our Grasshopper definition needed to be adjusted and optimised many times during the design process. Our general steps at the final stage were the following:

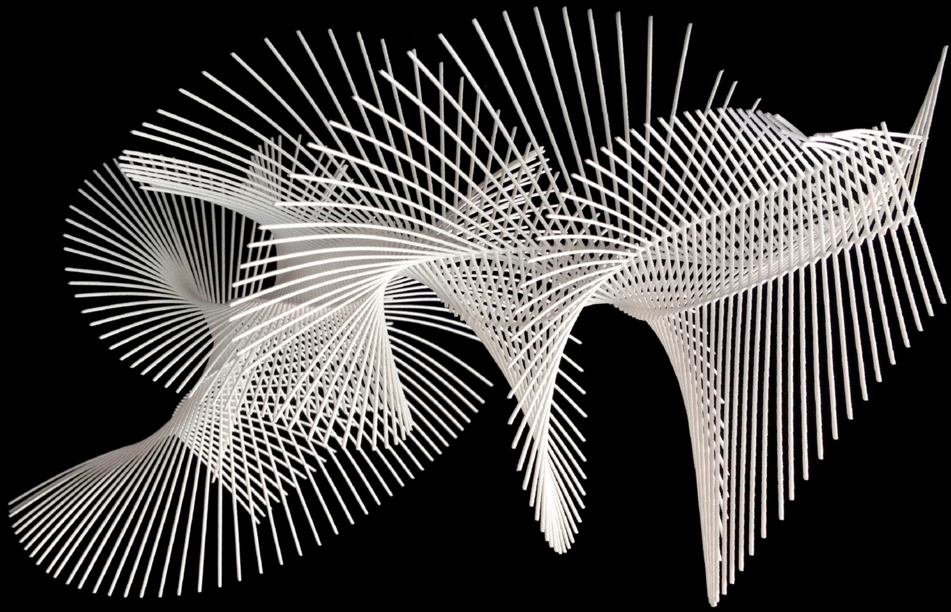
1. Read in the triangles
2. Make smooth curves between the corners
3. Draw new triangles based on the curves. Distance between triangles is defined by the thickness of the reed.
4. Offset and rotate the individual lines of the triangles to simulate the spiral-like stacking motion of the structure.
5. Scale out the lines to determine the various lengths of the single reeds. This was done manually with a graph, mapped out on the individual rows of reed, on the lenght of the entire structure
6. Use the live physics engine for Grashopper; Kangaroo. We applied gravity to the loose end of the reed to get a more realistic simulation of the spatial properties of the structure.

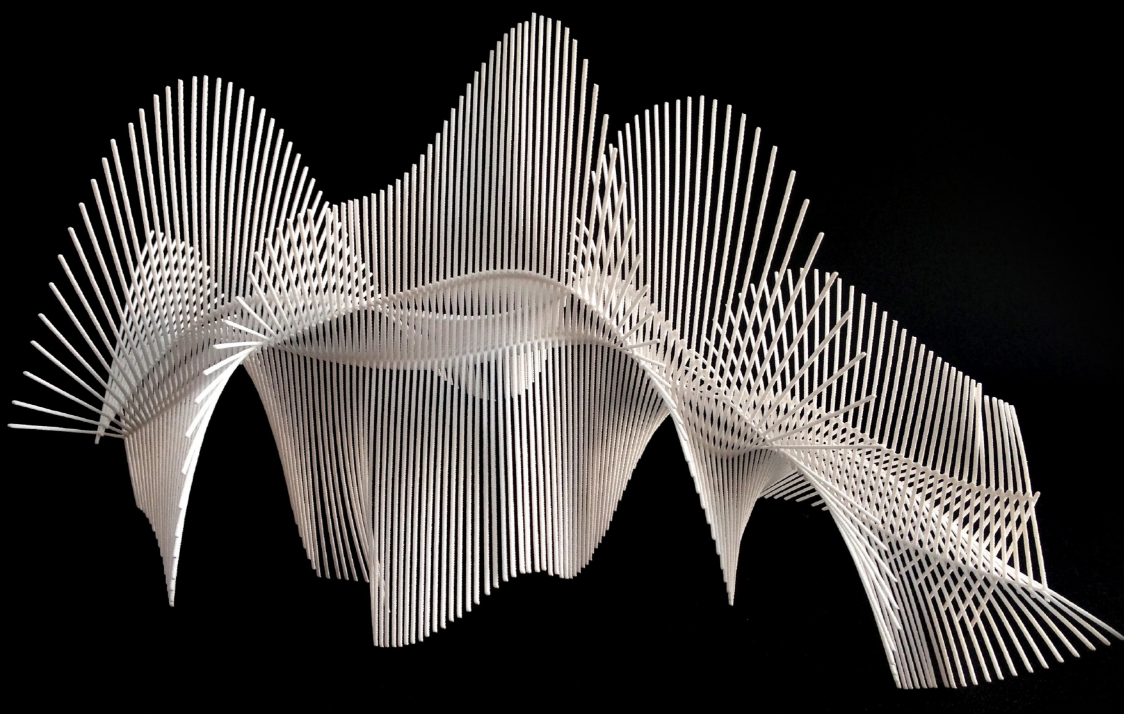
FINAL DESIGN

The final structure ended up with a lot of twists, and mostly reeds in their allmost full length. This allowed for et to make it more fluffy and spatial.
The stacking direction is perpendicular to a wall from were it starts, this kind of ankers it in the room, and holds it from dangeling. It then moves allmost parallel to another wall with a window, defining a space between them for the viewer to get in and take a closer look. The structure is now pointing in the general direction og the acces door, forcing the viewer to get closer to get an idea about the overall shape of the structure. The twisting is made quite aggressive to make it more impenatrable, harder do analyse as a form. This also allows the viewer to get close to it and move between and under the reeds.



PLAN SHOWING THE STRUCTURE IN EXHIBITION AREA





3D PRINTED MODEL 1:20

DISCUSSION 10.03.16

The final design of the structure has become more environmental that an art object. Now it is responding to the building and its context. At least that is what our renderings and plan drawings tell us. But maybe it is behaving in a way we cant predict? The fact that the structure is hanging from the ceiling can make it even more environmental. Can we use the hanging system to tune it? While we are in Milan we can adjust the structure to the context by tweaking the hangers. This should emphasize the structure in its own environment.

The production of the structure is ready to start up. We need to be three people to facilitate the robots and some should also be documenting the production.
The joints are not finished yet, but the production can be started without them as they should be slided in afterwards to reinforce the attachment. The difficulties with the joints is to create an individual piece that fulfill its purpose in a practical way together with the rest of the structure. But the joint also needs to be beautiful and give something back to the overall structure becoming a part of the design and expression.

We also need to find a way for the sections to be transported to Milan. Can we make some kind of box so they can be stabled?

Initially, the design of the joint component began with an efficient, technical design. However, as the constraints required of the piece were overcome, focus on the aesthetics of the design, and how it interacts with the overall installation took hold. We began looking at the joint as a design detail, and searched for inspiration.

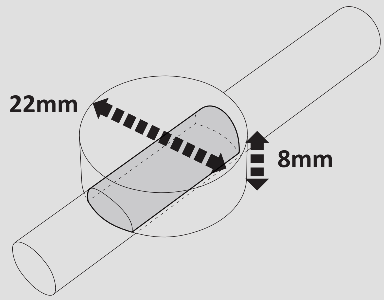
As the title of the piece became “The Spine”, we tried to bring bone structures into the aesthetic, something that added strength and rigidity to a structure that is otherwise too weak to stand on itself.

After testing multiple design iterations, it was decided that the biology aesthetic was too dominating to the overall installation design. We made the design for the joint more reserved, but retained some elements of biological response by adding elements specifically designed for the installer: A small place for the thumb, or a handle to grasp.

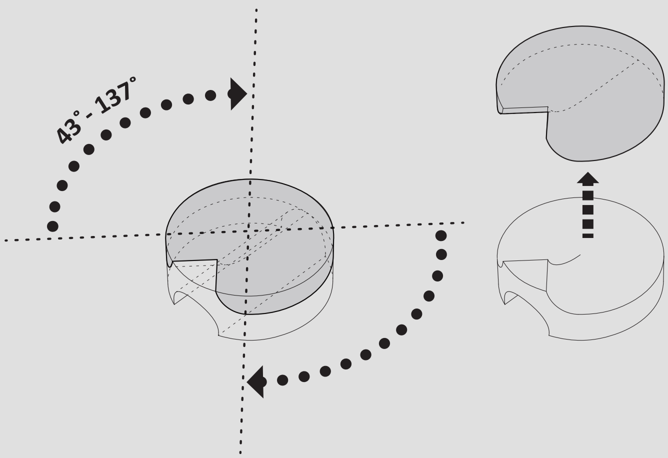
In this, the joint no longer felt so technical, but instead felt as if it were designed for a specific place, and for a specific action. Also, the reserved design let the power of the joint come from repetition, where it began to take on the aesthetic of weaving explored earlier in the process.

FINAL DESIGN RATIONALE

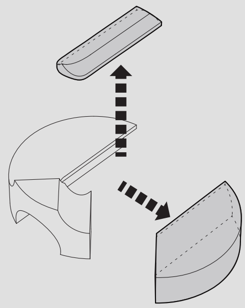
A cylinder of 22mm x 8mm is intersected by a reed of 8mm, creating a large surface area to glue the connection to the reed.



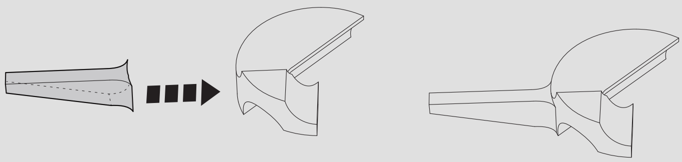
The reeds meet at an angle between 43°-137°. The connector's top was carved away to allow for this.

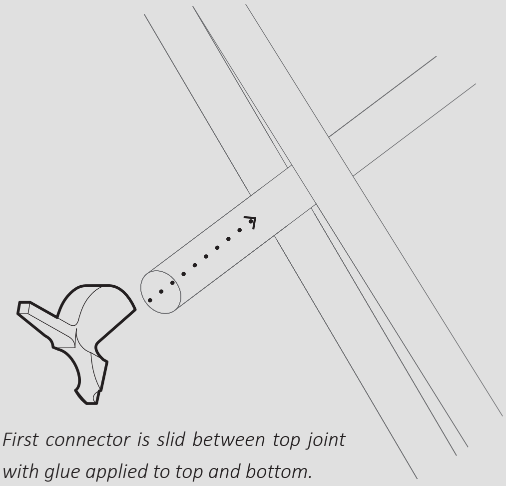


The joint needs to be able to slide into the connection between the reeds which is temporarily glued into place. To achieve this, the center is removed. Also, one side is removed to allow for greater flexibility and reduce redundancy.



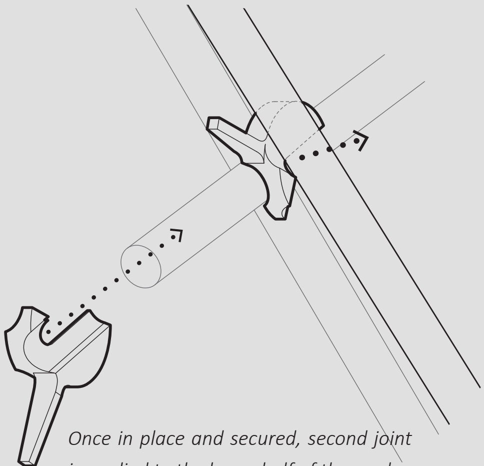
A small handle is added to make installation easier, and to create a more dynamic form for the overall installation once all pieces are applied.





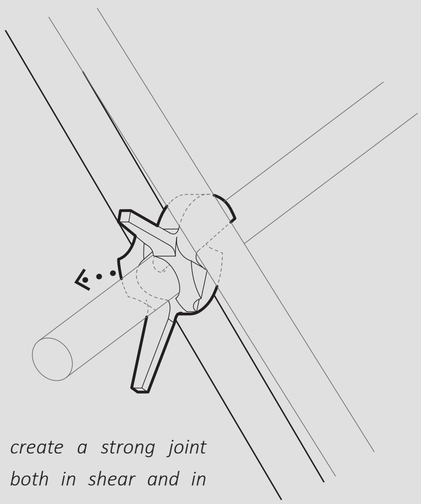
The joint component was design to increase the surface glue area between reeds. However, because of the design constraints, the joint needed to work over a large swath of angles: between 43° and 82°, as well as 98° to 137°. This led to a design that was shaped as a half-circle, providing the swing in angle.

First connector is slid between top joint with glue applied to top and bottom.

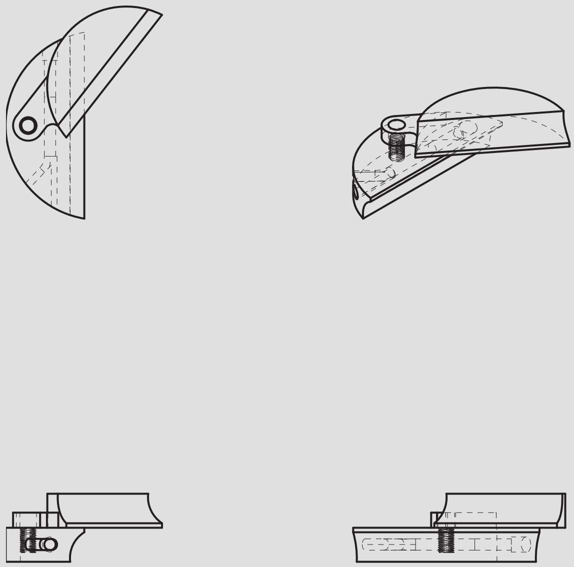


Once in place and secured, second joint is applied to the lower half of the reed.

The component is situated on the short reed at each corner of the triangle of the spine. Two joints sit on each of the short reeds, connecting to the long reeds bypassing it on either side. Over the course of the 40cm segments of the model this creates a strong assembly



Together these create a strong joint between layers both in shear and in deflection.

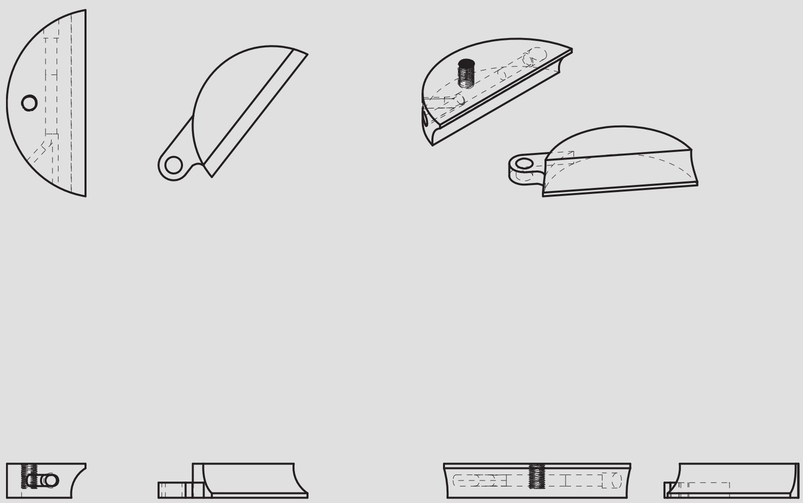


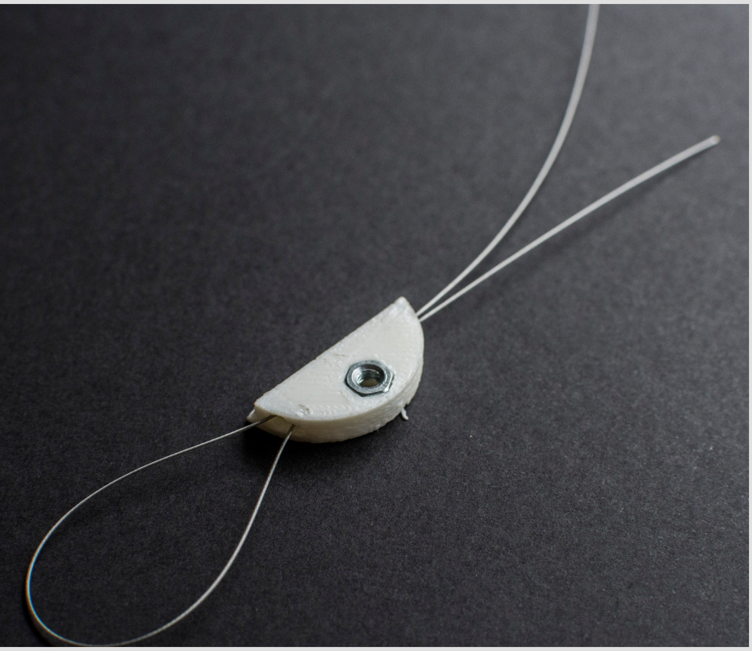
TEMPORARY CONNECTION

With the structure being over 4 m long, it had to be split up in sectional parts for transportation. As such a connector was needed which could join the sections temporarily, facilitating assembly as well as disassembly.

At the same time the structure acquired a solution that would string it up to the ceiling. Looking for an expression that would make the structure float in the air, we wanted to make as few additions as possible. The temporary joinery and the fixture had to be solved in one part.

To keep the temporary connection discrete, the parts are shaped similar to the other connectors in form and generic usage. By joining two parts with bolt and nut for temporary assembly the connection becomes adjustable to all conditions between the sections.

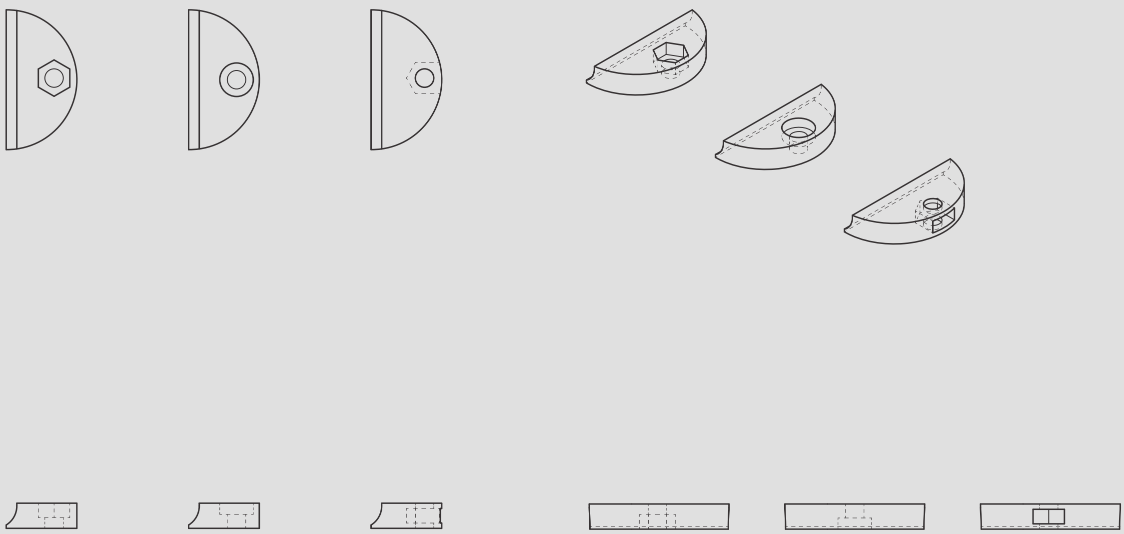


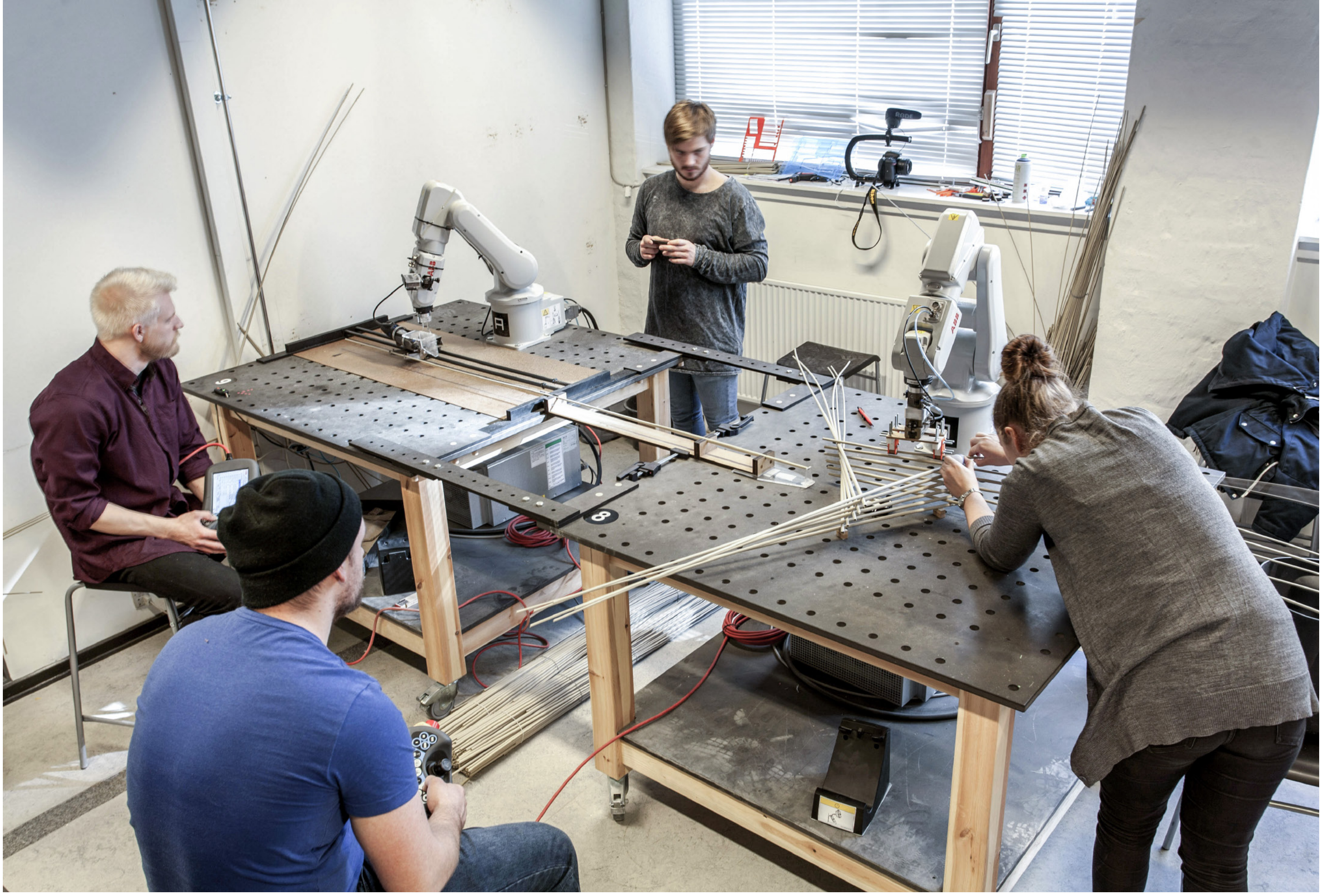


Wanting to be able to control the direction and angle of the wire towards the ceiling, the wire was channeled through the part attached to the reed (as seen in the illustrations on the left).

Being unable to facilitate all possible conditions, it actually created more issues than it solved.

Forced to take a step back, the simple use of the bolt came to mind. By looping the wire around the bolt, it is used as a 360 degree axis, connecting the structure directly to the ceiling, independant of the direction of the reed or the connector.



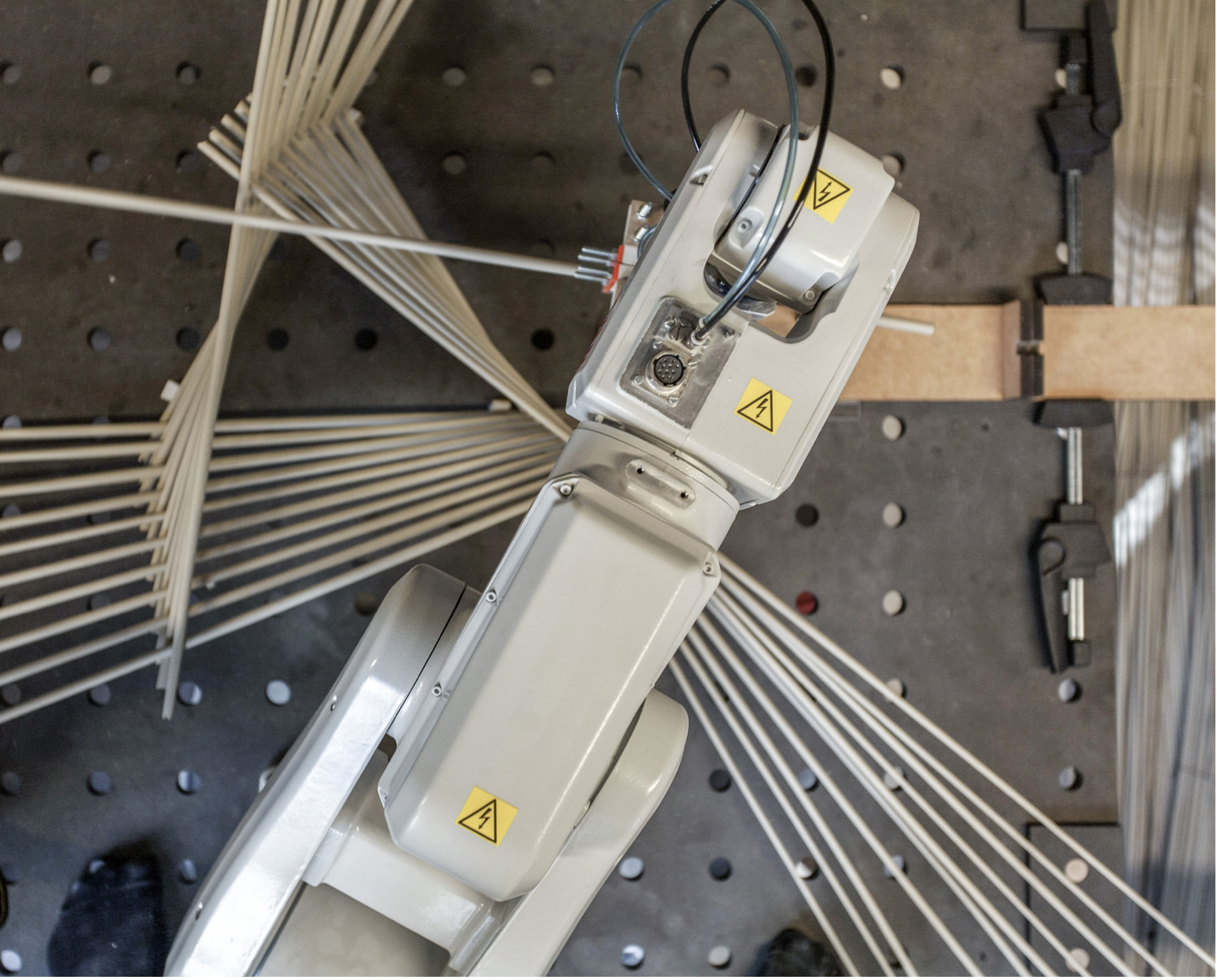


PRODUCTION

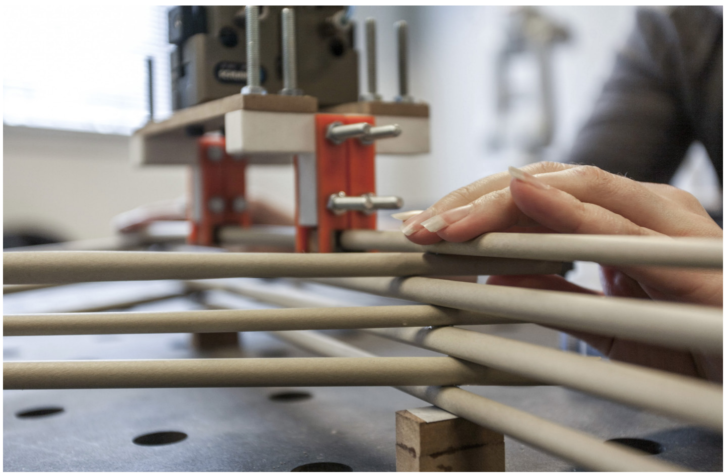
RAPID CODE

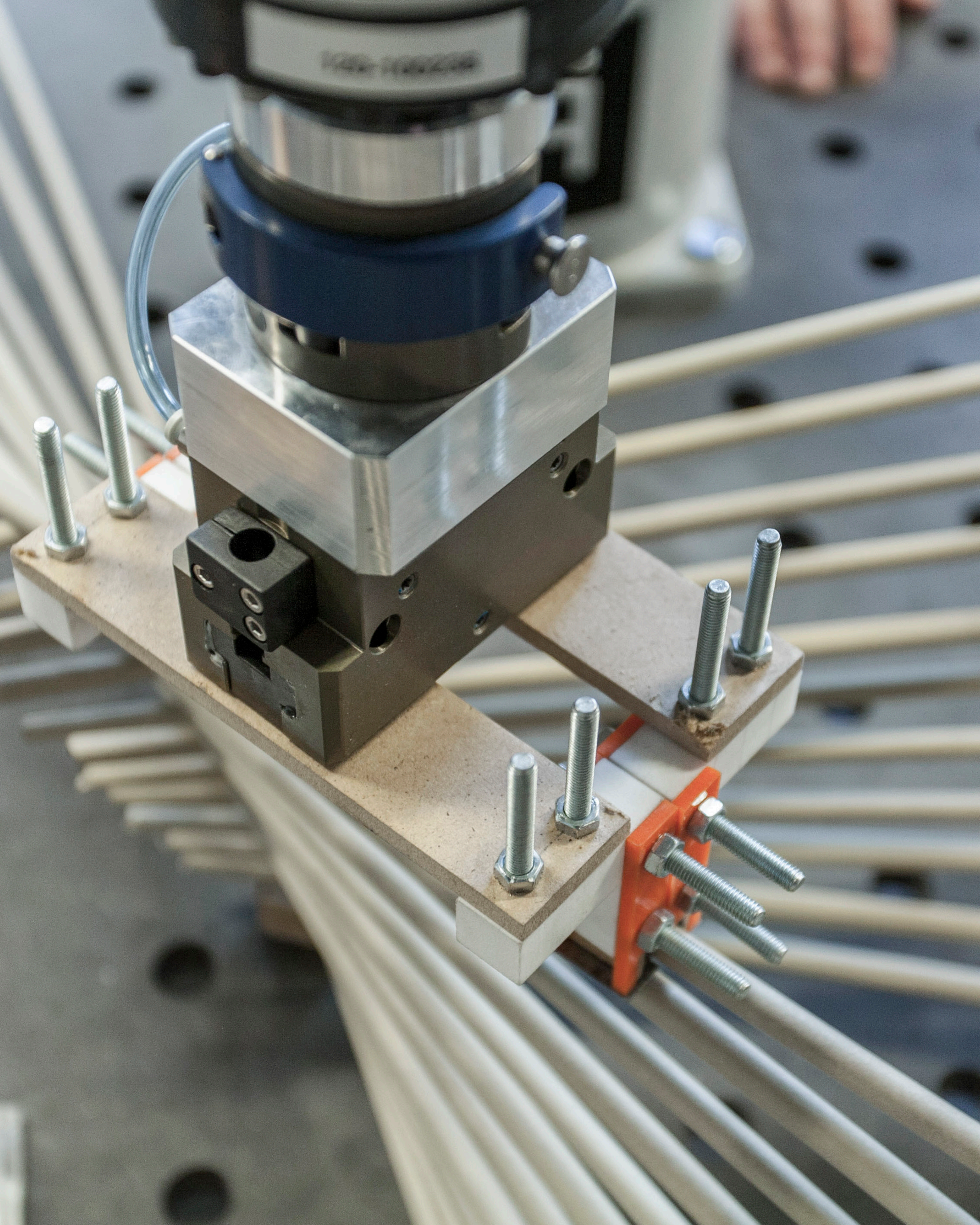

ABB
Modules
Routines
PP to Main
PP to Routine...
Cursor to MP
Call Routine...
View Value
View System Data
PP to Cursor
Cursor to PP
Go to position
Cancel Call Rout.
Check Program
Search Routine
Add Instruction
Edit
Debug
Modify Position
Show Declarations


ABB



PLACING





GRABBING

DISCUSSION 14.03.16

The joinery team had some trouble deciding on the final design of the joints. At this point there were three different suggestions. One with a “handle” created on the basis of holding and placing the joint with your thumb. The two other suggestions were very alike both with small “handles”, the main difference was the direction of the handles and therefore also the way to place the joinery. One of them followed the direction of the reed the other one was perpendicular to the reed making it easier to place.

Making it easier for all of us to decide on one design over the others, we created a set of parameters to judge the componets with; which is the easiest to place? Which creates the best coherence with the overall stucture and logic?

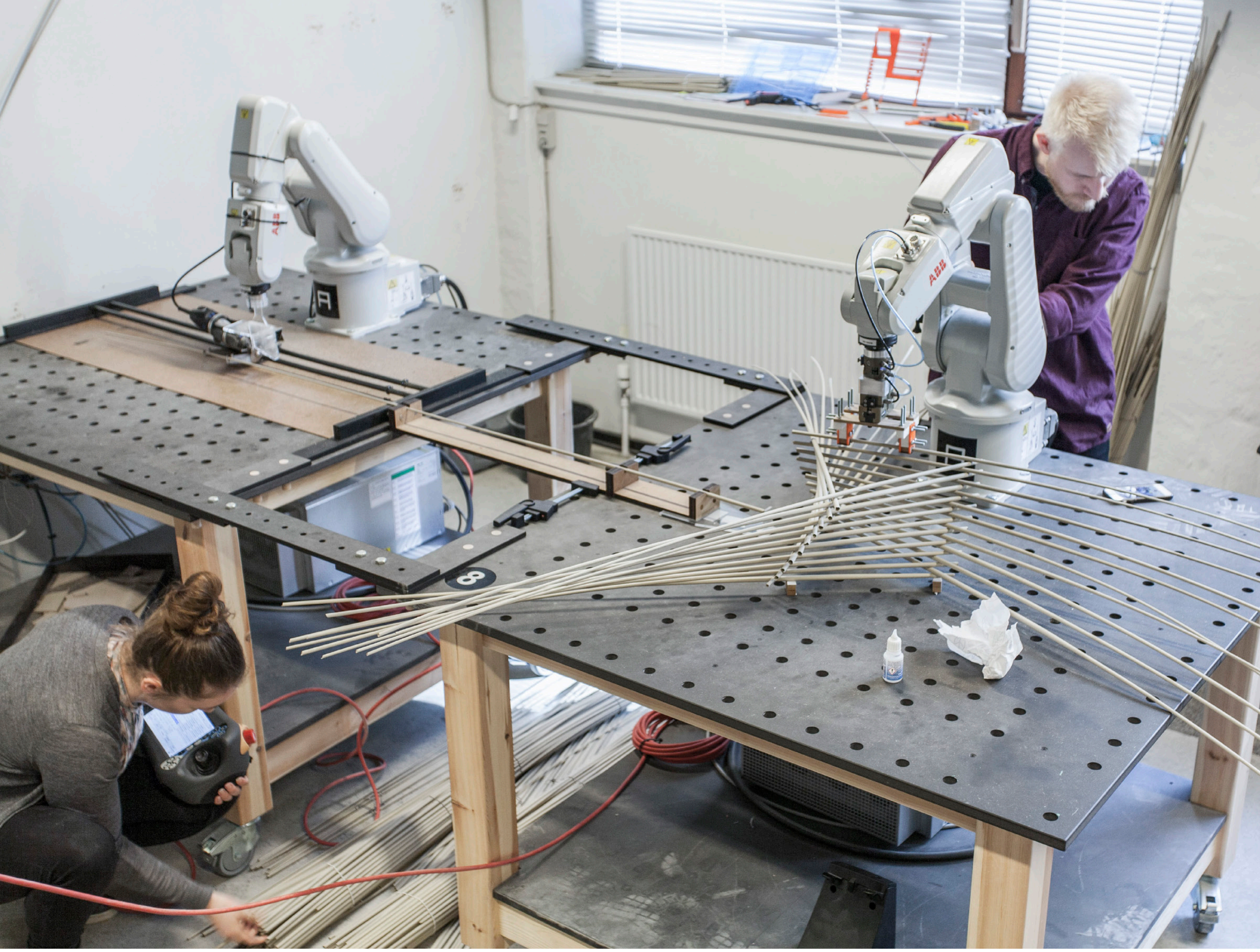
The one created for the placement with the thumb looked very heavy on the stucture and there was no relation bewteen them. So that joint was out of the picture quite fast. The two other joints were very similar in form but different in expression. The one with the handle parallel to the reed was almost hiding itself - but do we want to hide the joint? Because of the handle following the reed it was also easier to see small mistakes and inaccuracy. The other one with the handle perpendicular to the reed created its own beautiful language but still in correlation to the structure. It emphasizes the rythm and logic of the overall structure strengthening the expression.

On the basis of the discussions, we decided on the last described joint, with the handle perpendicular to the reed.
The temporary joints to assemble the sections will also be easier to develop. Maybe we can connect them with bolts?

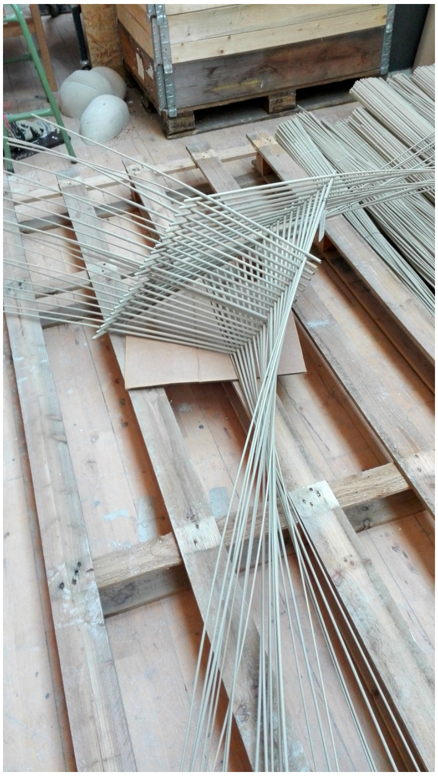
We had a lot of trouble trying to solve the problem about the packaging of the sections because they are all so different. We would have to make 13 different boxes in order to ship them to Milan. The curator of the exhibition suggested that we wrapped the sections in bubble wrap and just place them in the truck. They should be strong enough with the joints attached on th sections.

We also had trouble developing a system for hanging the whole structure at the school for the final crit. Our space in mock-up is too small, and it would also require that we made some kind of temporary ceiling. We made an agreement with the curator to hang it in the exhibition hall at the school in between two exhibitions.

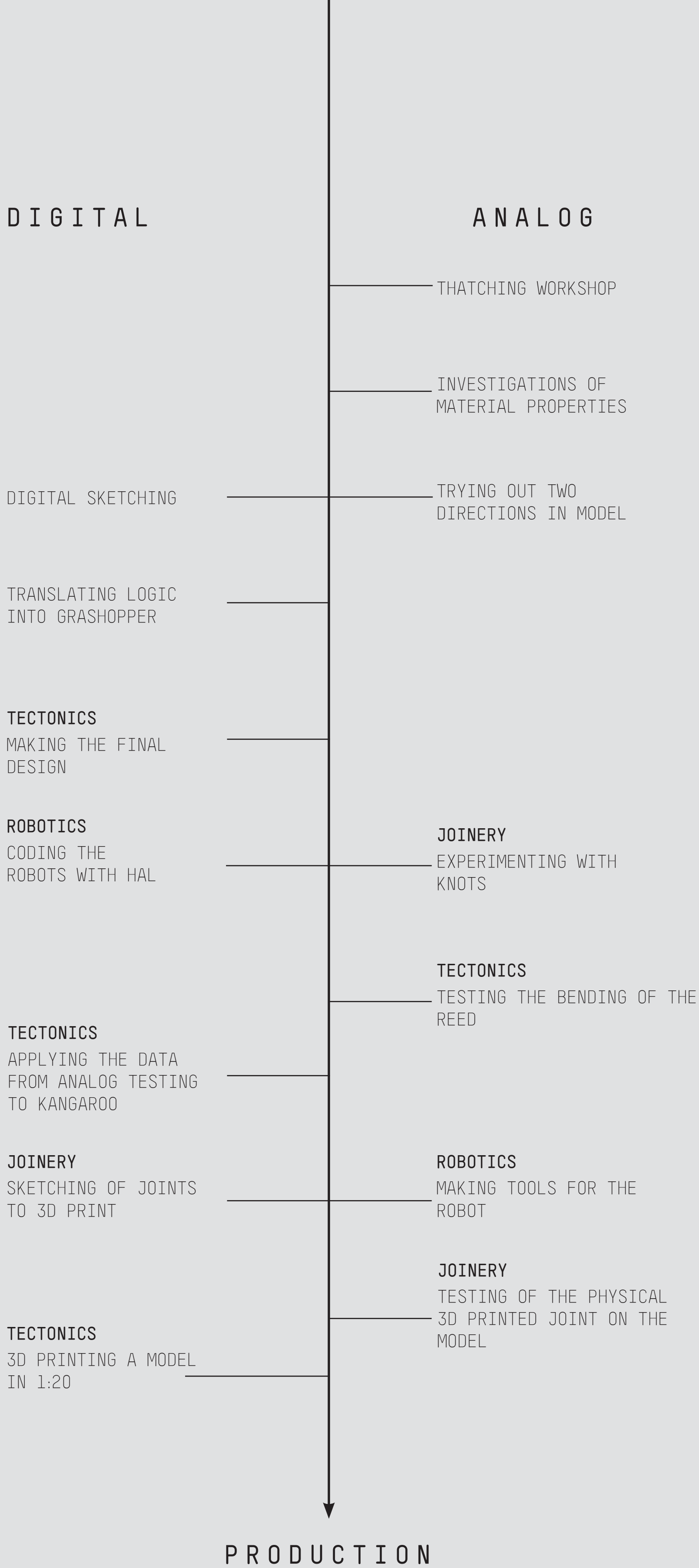
The production of the structure should be done by tomorrow.



CUTTING



STORAGE


DIGITAL
ANALOG
THATCHING WORKSHOP
INVESTIGATIONS OF MATERIAL PROPERTIES
DIGITAL SKETCHING
TRYING OUT TWO DIRECTIONS IN MODEL
TRANSLATING LOGIC INTO GRASHOPPER
TECTONICS
MAKING THE FINAL DESIGN
ROBOTICS
CODING THE ROBOTS WITH HAL
JOINERY
EXPERIMENTING WITH KNOTS
TECTONICS
TESTING THE BENDING OF THE REED
TECTONICS
APPLYING THE DATA FROM ANALOG TESTING TO KANGAROO
JOINERY
SKETCHING OF JOINTS TO 3D PRINT
ROBOTICS
MAKING TOOLS FOR THE ROBOT
JOINERY
TESTING OF THE PHYSICAL 3D PRINTED JOINT ON THE MODEL
TECTONICS
3D PRINTING A MODEL IN 1:20
PRODUCTION

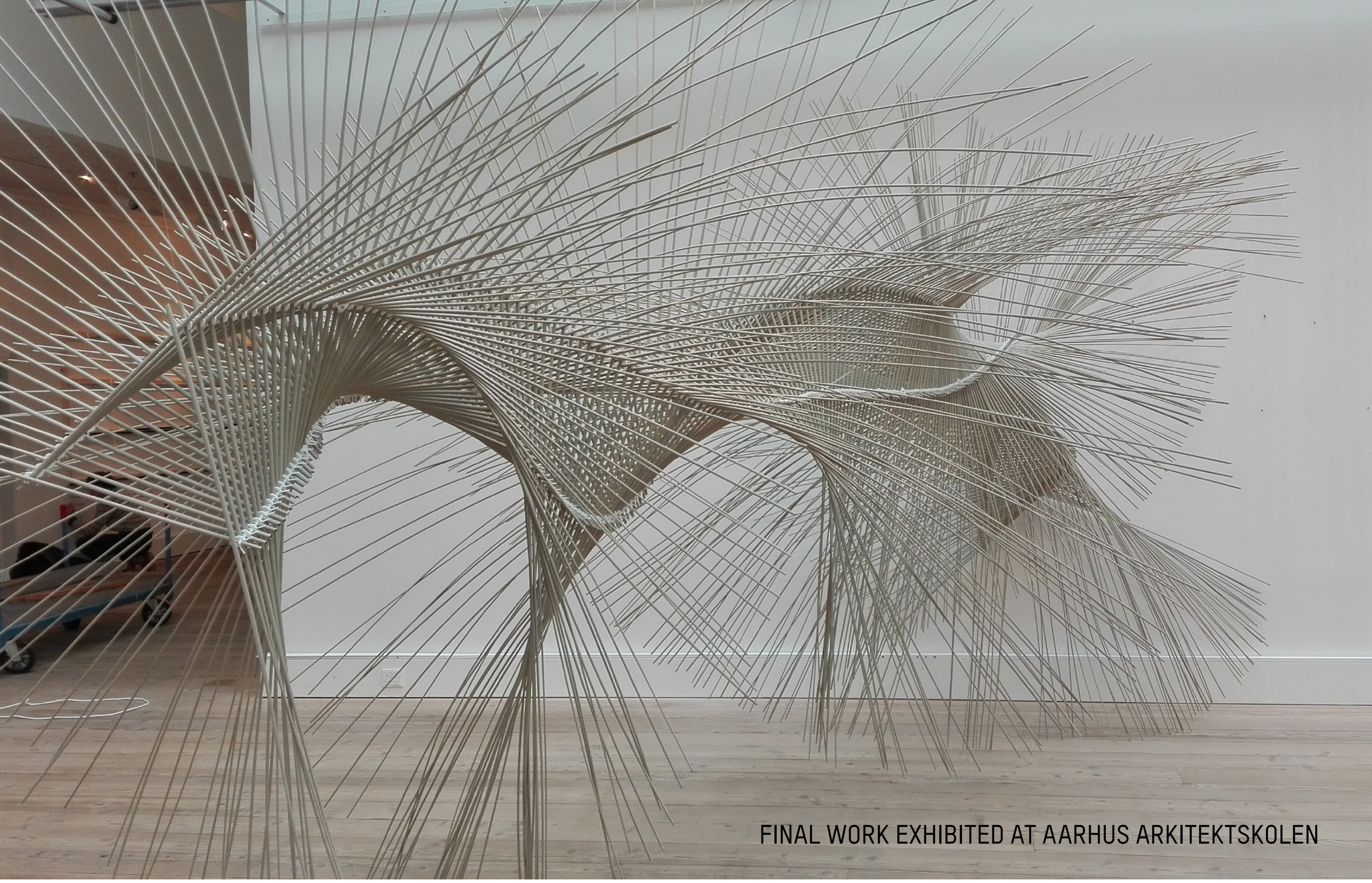
CONCLUSIONS

The process of design our team implemented for “The Spine” installation worked the problem from multiple angles and with a wide array of tools. Using a modeling process that was rooted in physical explorations and material testing was balanced with deep investigations into the use of parametric design tools and coupling them with a fabrication tool. Rather than the physical and digital running separately, these two systems communicated with each other freely and influenced the final design.

As real-world investigations of material bending began to influence the physics engine inside Grasshopper, both became stronger. Similarly, material properties were evaluated for the joint group, which translated the analysis back into the digital model. The fast-paced timeline for the project required that rapid prototyping be used while the slower SLS machine finished final quality models.
The effect of real-world constraints on the digital design was also evident in the process that Digital Fabrication used. The synthetic reed ended up having more variation in size and structure than was anticipated, and required many real-world tests to calibrate the robotic production to proceed smoothly. This intersection between the physical and the digital processes became a continual theme throughout the design process.

The final design is the product of the coupling of real-world investigations with digital parametrics and fabrication, giving rise to a dynamic spatial structure that responds to its context, and reacts to its own materiality. By questioning the traditional process and material of thatching, we learned what can and cannot be done through automation, and what processes could be converted into new fabrication methods. This has enlightened the possibilities of new technology, and could create new ideas for the development of crafts into the digital environments - using history as a catalyst.

TIMELAPSE OF INSTALLATION AT ARKITEKTSKOLEN



FINAL WORK EXHIBITED AT AARHUS ARKITEKTSKOLEN

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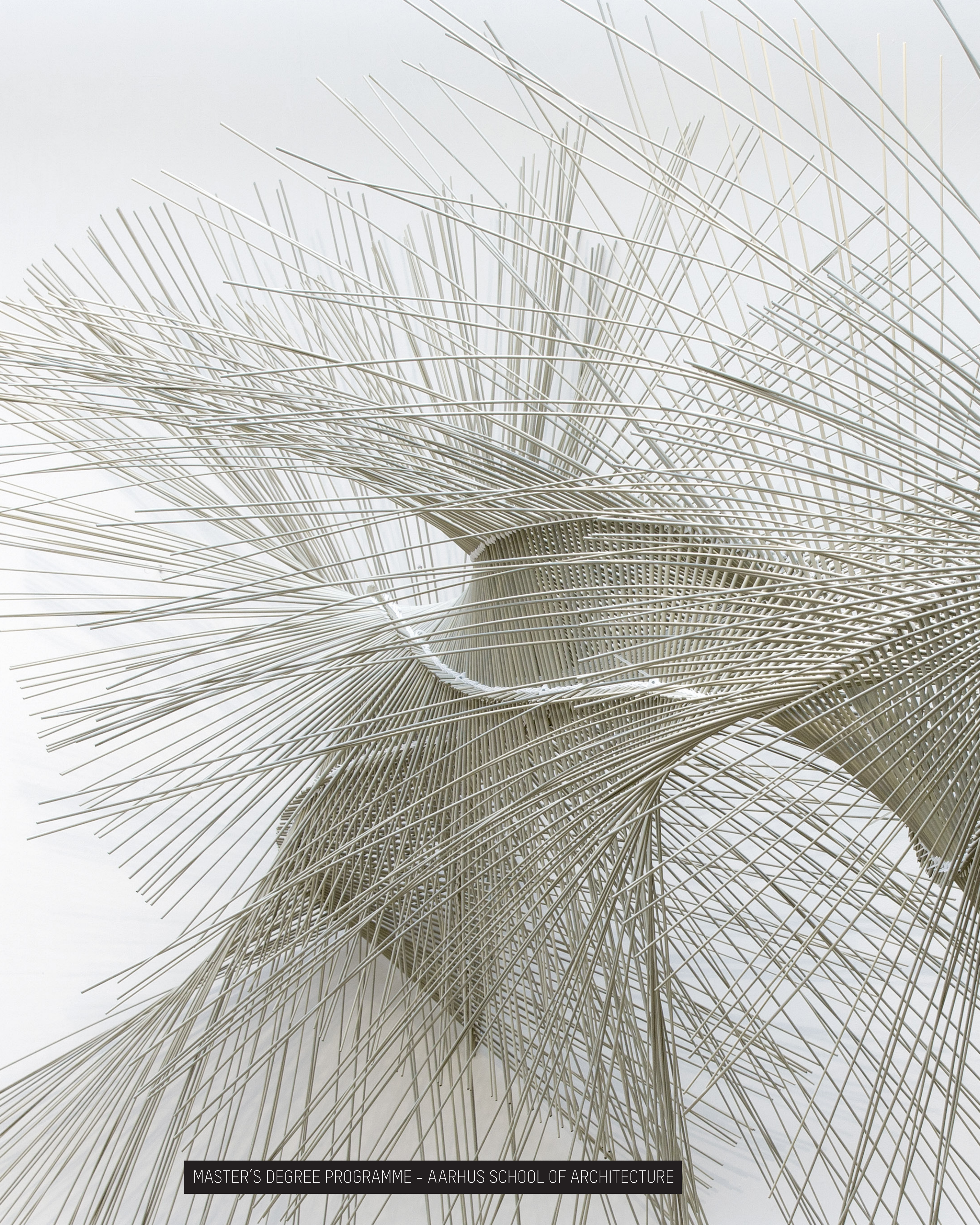

MASTER'S DEGREE PROGRAMME – AARHUS SCHOOL OF ARCHITECTURE