Digital Wood

Design & fabrication of a full-scale exhibition structure in plywood

CHALMERS

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Design & Fabrication of a Full-scale Exhibition Structure in Plywood

OSCAR GILLKVIST, VIKTORIA HENRIKSSON, EMIL POULSEN

Master thesis at Chalmers Architecture 2016
Architecture & Urban Design
Material Turn studio
Examiner & supervisor: Daniel Norell & Jonas Lundgren

ABSTRACT

Wood has always been a common building material in Sweden, where both the nature and the timber itself have provided a source of inspiration for Swedish artists and architects.
Now with the use of modern technology and new treatment methods, the boundaries are pushed for how this conventional material can be used to unleash new creative potentials.
The possibilities of digital fabrication help us as designers to stretch the domains of timber construction. With full scale experiments, a representative model of wood properties and details can be studied. Plywood has many times before been used for temporary structures in architecture, mainly because of the relatively low cost and availability. Plywood is often seen as a perfectly flat sheet material, free from otherwise common properties of timber such as imperfections and grain direction. However, plywood is actually a diverse material with inherent dynamic associated with the tree is once came from. This is something that is rarely seen in contemporary plywood design but could be emphasized and more accessible through computational design and digital fabrication.
Through investigations, full-scale experiments and digital tools this thesis seeks to explore new perspectives of programing timber in the field of architecture and design.
In collaboration with our sponsors a temporary structure was designed and built for the “Tomorrow’s Wood Production” venue which functioned as a gathering place and visual label for visitors, while exploring new unexpected ways of materializing wood.

CONTENT

1 INTRODUCTION

2 DESIGN PROCESS

1

INTRODUCTION

ABOUT US

"This project has been carried out as a collaborative Master Thesis project between Oscar, Viktoria and Emil at Chalmers University of Technology 2016. With their different backgrounds and knowledge, they have managed to complete the project in a satisfactory manner and have delivered an excellent project in terms of architectural and structural design as well as documented research. The work of each contributor is equal to a Master's thesis as performed by a single student. In the interest of promoting collaboration, the work of all three contributors has been compiled into a single booklet."
- Daniel Norell, Senior lecturer and Director of Master's Programme in Architecture and Urban Design

OSCAR GILLKVIST
Architect

Oscar recieved his bachelor degree from the Architecture school at Chalmers University of Technology in 2013. After experiencing concept development and design at a local architecture office, he decided to start his own architecture and design practice *Bower Studio* together with a close friend. He has a strong interest for form and has been in charge of architectural design with a special focus on form and experience.

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VIKTORIA HENRIKSSON
Architect & Structural Engineer

Viktoria is studying to recieve a double master's degree in Architecture & Structual engineering at Chalmers University of Technology in Sweden. She has both studied and worked as an architect and engineer in Berlin, Shanghai, New York and Sydney. The double degree has influences her way of thinking in both fields which has been practiced in this thesis project where she has been in charge of architectural design with a special focus on structural and material performance

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EMIL POULSEN
Architect & Structural Engineer

Emil is also studying to receive a double master's degree in Architecture & Structural engineering. He is extra passionate about computational design and programming, in which he has been holding courses at Chalmers University of Technology. Emil has previously had internships in both Sweden and the UK. Emil has been in charge of architectural design with a special focus on computation and programming.

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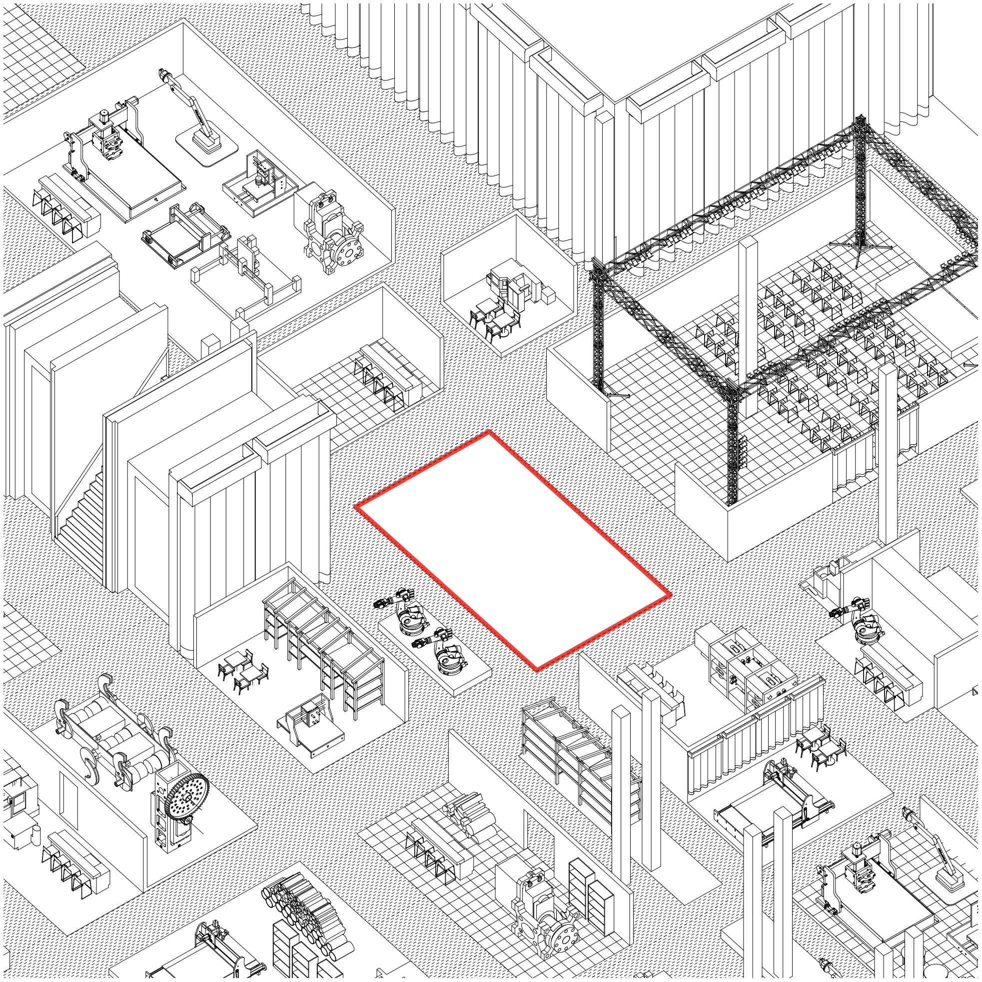
CONTEXT

EXHIBITIION / SVENSKA MÄSSAN

The rapid development of the wood industry, production technologies and materials demands an increasing need for exhibiting these new knowledges and ideas. The Swedish Exhibition and Congress Centre (Svenska mässan) in Gothenburg have since 1989 annually arranged the Wood Products & Technology exhibition, a platform for exhibiting this technical and digital revolution. It is a complete venue for inspiration, knowledge and meetings where a large mix of different stakeholders in the Scandinavian wood industry are present. The 2016 exhibition will feature a new venue called "Tomorrow's Wood Production" where the latest technology will be presented through exhibitors, seminars and technology walks. In collaboration with Svenska mässan, this thesis project willl investigate the potentials of timber architecture through new perspectives. A temporary structure shall be designed and built for the "Tomorrow's Wood Production" venue which shall function as a gathering place for visitors to rest while exploring new unexpected ways of materializing wood.



BACKGROUND

TIMBER & PLYWOOD

Wood has always been a common building material in Sweden, where both the nature and the timber it-self have provided a source of inspiration for Swedish artists and architects. Now with the use of modern technology and new treatment methods, the boundaries are pushed for how this conventional material can be used to unleash new creative potentials.

As a renewable building material whose versatility allows for complex spatial experimentation, wood seems to be the material of the moment. New products such as Cross Laminated Timber and Glulam are changing the face of construction by contributing to a wider range of timber-based solutions. Whether loosely bound in aggregate systems, or utilized to mimic the performative capacities of living organisms, wood allows for a multifaceted and exciting exploration of the material, structural, and experimental properties of space.
One of the main differences between wood products and engineered materials is the anisotropic properties. Anisotropy describes the difference in physical properties (stiffness, strength etc) in relation to the grain direction. Plywood is an engineered wood product, resulted from the aim of removing these anisotropic characteristics, by gluing multiple plies of wood veneer. These veneer plies are rotated up to 90 degrees to one another, which results in a more stable product with more consistent strength across all directions. A plywood usually consists of an odd number of plies, making a balanced board that reduces warping. Because of this odd number strategy, the direction of the surface ply will still have an impact of the bending capacity of the plywood - since it has more plies in that direction.

BACKGROUND

CONTEMPORARY PLYWOOD STRUCTURES

Plywood has many times before been used for temporary structures in architecture, mainly because of the relatively low cost and availability. Plywood is often seen as a perfectly flat sheet material, free from otherwise common properties of timber such as imperfections and grain direction. However, plywood is actually a diverse material with inherent dynamic associated with the tree it once came from. This is something that is rarely seen in contemporary plywood design but could be emphasized and more accessible through computational design and digital fabrication. With this thesis, we wanted to investigate how the inherent bending properties and dynamics of plywood could be utilized in architectural design.

Custore pavilion

ICD pavilion

Metropol parasol

BACKGROUND

BENDING OF WOOD

Wood is a material with a relatively low bending stiffness compared to its bending capacity. This is utilized when designing so called actively bent structures. The central concept of actively bent structures is to turn a two a dimensional configuration of building elements into a three dimensional shape by utilizing the material's bending capacity. The most common types of actively bent structures when considering wood as the material of choice are timber gridshells. These are shell structures which are constructed by slender continuous members that are elastically bent into position. a network of flat elements can be assembled on ground prior to the erection of the structure. This was first developed by professor Frei Otto in the 1960s. [7] For the German building exhibition at Essen 1962 professor Otto designed a small prototype which became the first of this type ever built. However, a vital part of this concept is to assemble the whole structure in its flat condition. This is not always possible as the available space on site can be limited. Moreover, the elements of an actively bent gridshell are long which can be a drawback if transportation is considered. No elements can be pre-bent prior to erection.


Centre Pompidou Metz

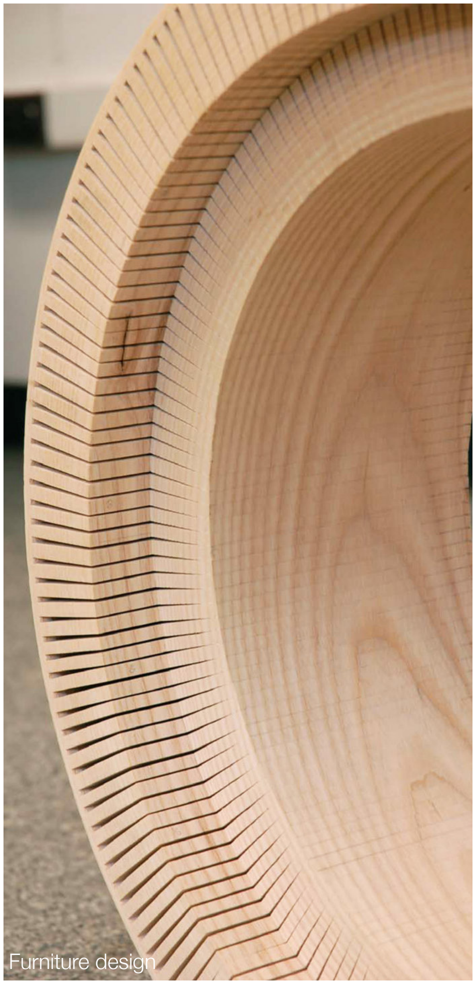

Steam bent furniture


Selinunte Gridshell

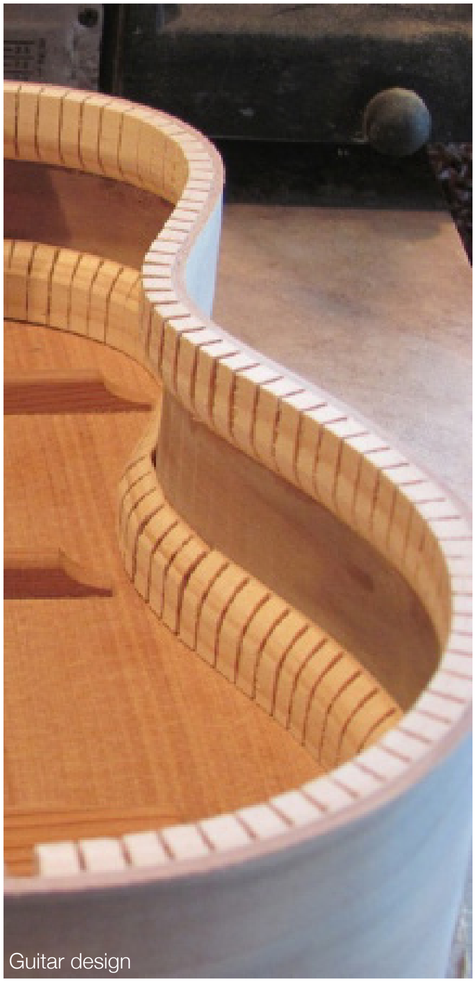
BACKGROUND

KERFING OF PLYWOOD

Kerfing of wood has a long history when it comes to for example furniture design and boat construction, but it has in large extent been used for bending 1D bars. This project will explore bending of sheets (2D), in particular plywood. Through digital fabrication methods and computational simulation, the potentials and possibilities of plywood will be explored. One of the main differences between wood products and engineered materials is the anisotropic properties. Anisotropy describes the difference in physical properties (stiffness, strength etc) in relation to the grain direction. Plywood is an engineered wood product, resulted from the aim of removing these anisotropic characteristics, by gluing multiple plies of wood veneer. These veneer plies are rotated up to 90 degrees to one another.



Furniture design



Guitar design

MIT Kerf pavilion

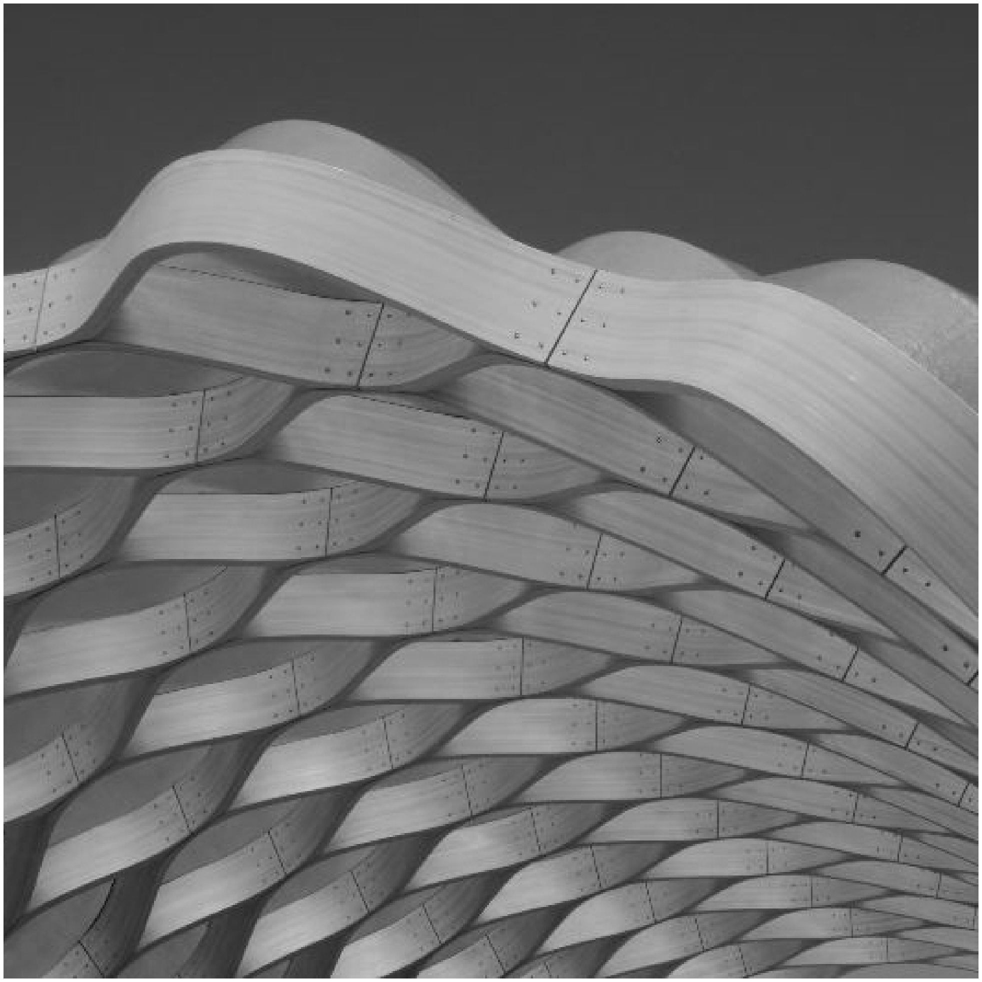
BACKGROUND

TEMPORARY STRUCTURES

In the early 20th century, the pavilion was firmly established as a place of architectural experimentation. The pavilions shaped future architecture more than permanent buildings, because of their very temporariness freed them from prevailing habits, enabling them to materialize concepts not yet readily available.

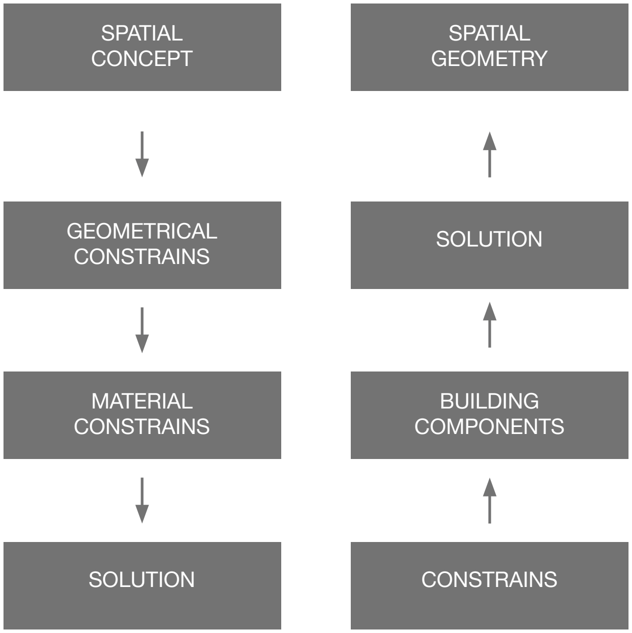
Temporary structures belong to a hybrid typology that fluctuates between art and architecture and keeps up with the ever-changing building trends. Thanks to their short life span and small scale, short-lived structures have become vehicles for testing out new ideas and progressive building technologies — playgrounds for architects to build architectural prototypes unburdened by high construction costs and long-term social, cultural, and economic impacts on the environment.

One of the advantages of the pavilion typology is in fact that these structures are temporary, as they create opportunities for testing out ideas very quickly. In a sense perhaps the pavilion is akin to performing a piece of music, as music can only be experienced while you listen or play it at any given moment. The pavilion could in fact be said to behave in a similar way; perhaps because of their temporary nature pavilions provide an experience, and this is in fact the strength of the form.



DESIGN PROCESS

TOP-DOWN / BOTTOM-UP APPROACH



Two different ways of approaching a design task is the top-down and the bottom-up
approach. The top-down approach is sometimes called stepwise or decomposition approach. It starts with the overall picture in mind which is broken down into subsystems/more refined levels. A strength of the top-down approach is that a clear and simple vision can be followed all the way through the design, but sometimes the design can be too specified for detailed systems to fit in the end.

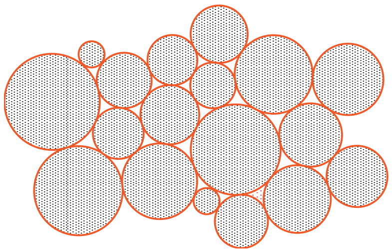
Bottom-up however, is an approach where the system is put together by individual elements that are linked together until a complete top-level system is formed. The bottom-up approach can give a great freedom of designing. the individual parts, but can lead to problems when putting the parts together and perhaps create a too complex result.
A combination of the top-down and the bottom-up approach can sometimes be very useful for complex design tasks. A clear vision of what the desired design should look like, together with real-world constrains can help to guarantee a final product that is realizable. This way of working can create a shape that is optimized with respect to both global structural efficiency and manufacturing possibilities, which at the same time

RESEARCH FOCUS

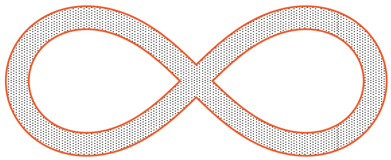
THESIS QUESTIONS

The final design is the result of many small improvements over time. However, 3 main topics have been the focus of the research; Advancing plywood, Temporary structures & Concept of continuity.

ADVANCING PLYWOOD ARCHITECTURE



TEMPORARY STRUCTURES



CONCEPT OF CONTINUITY

Plywood has many times before been used for temporary structures in architecture, mainly because of the relatively low cost and availability. Plywood is often seen as a perfectly flat sheet material, free from otherwise common properties of timber such as imperfections and grain direction. However, plywood is actually a diverse material with inherent dynamic associated with the tree is once came from. This is something that is rarely seen in contemporary plywood design but could be emphasized and more accessible through computational design and digital fabrication.

Thanks to their short life span and small scale, temporary structures have become vehicles for testing out new ideas and progressive building technologies — playgrounds for architects to build prototypes unburdened by high construction costs and long-term social, cultural, and economic impacts on the environment. However, exhibition installations often become single purpose building systems where the actual research and tools behind it is hard to access. With this thesis, we want to explore and elaborate on the scalability of a small-scale system and how the tools developed can be utilized in other contexts. For instance how a topology of a component-based system can be designed to allow reconfiguration to serve multiple purposes.

Most exhibition halls are organized according to a strict and formal layout, where visitors are forced to follow straight paths that are optimized to expose as many exhibitors as possible. One strategy for contrasting the orthogonal landscape is to strive for a more dynamic and unexpected visitor experience. The shape of continuity has for long fascinated designers and architects because of the geometrical endlessness. This concept is however hard to materialize and express in architectural terms because of the need for aperatures and other building elements. For instance, placing standard element such as doors and windows on a freeform surface is often problematic.

COLLABORATORS

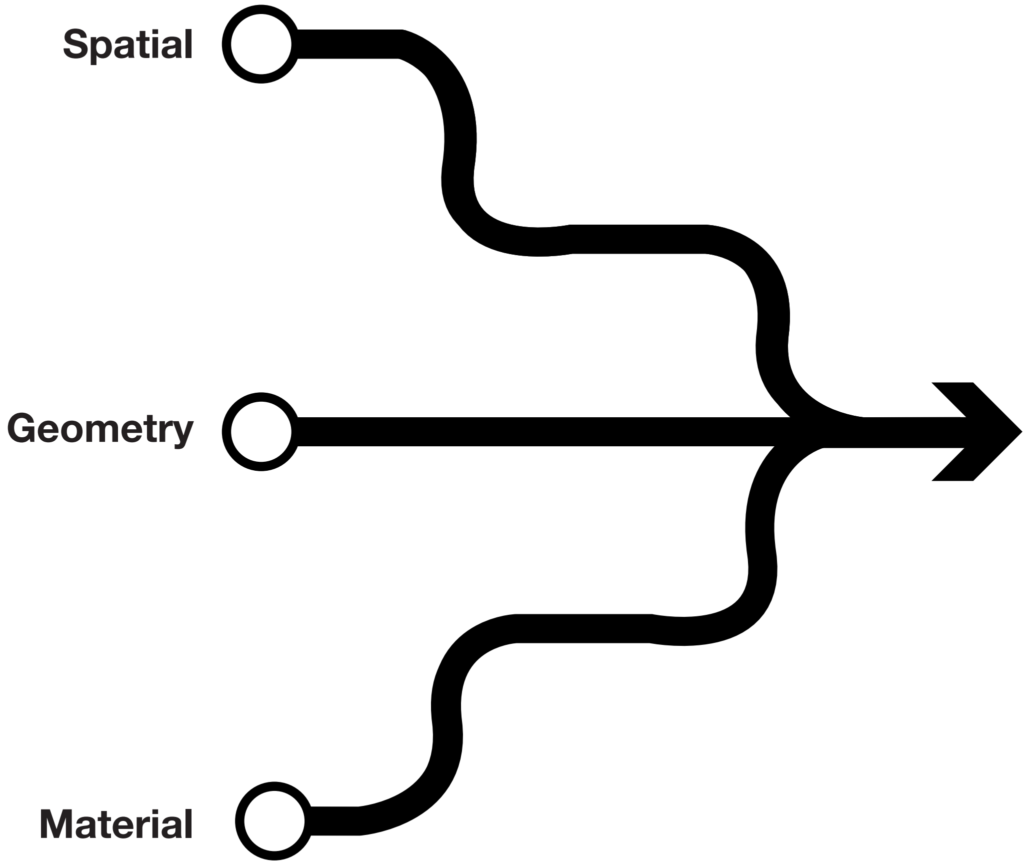
The construction of this pavilion would not have been possible without the generous contribution by the following companies.

2
DESIGN PROCESS

INITIAL DESIGN

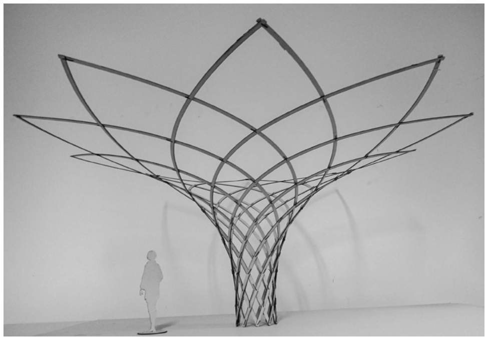
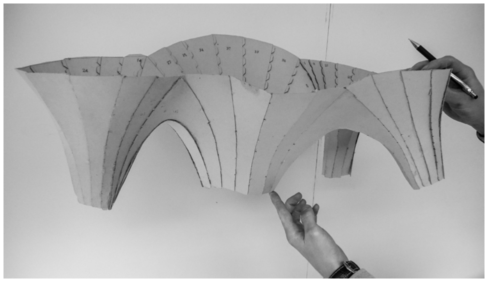
3 LEVELS OF DESIGN

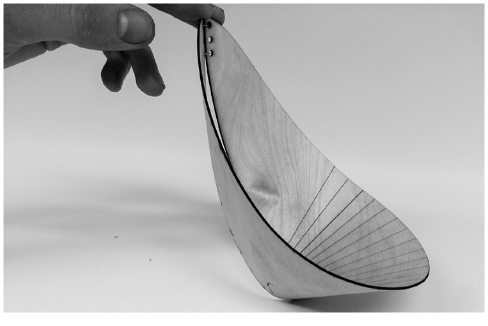
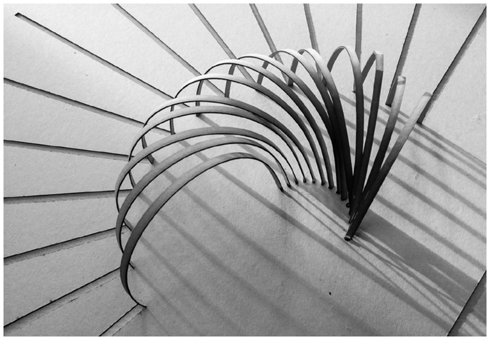
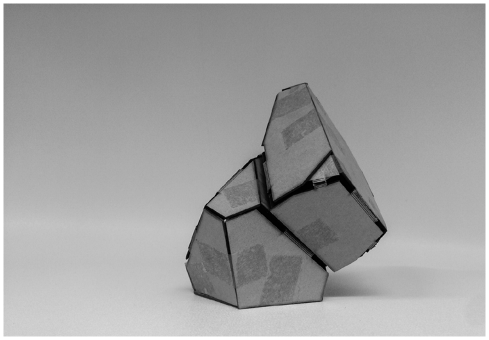
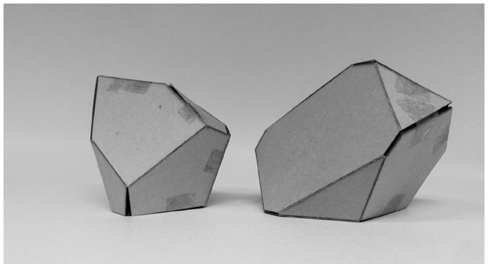
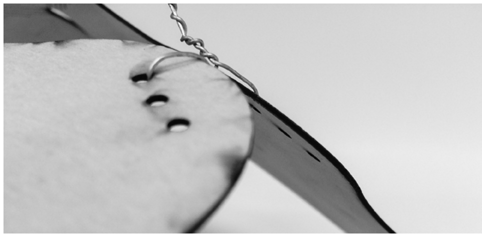
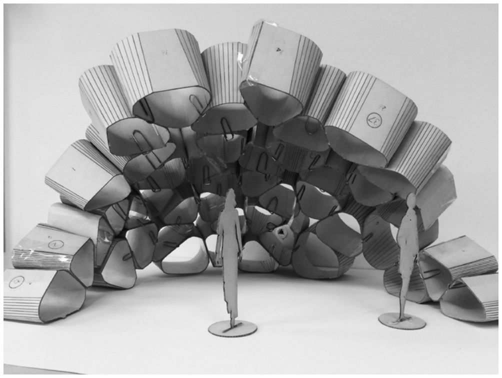
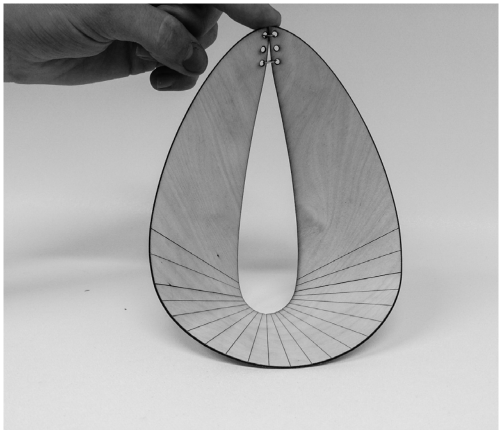
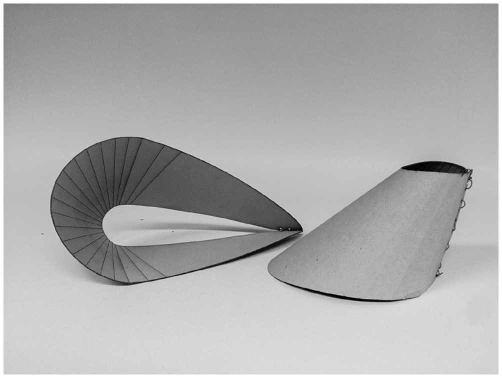
The design process has been approached in three different levels; Spatial, Structural and Material. In this way, a combination of the top down and bottom up approach is followed in order to guarantee a realizable design without compromising the overall design.



INITIAL DESIGN

SKETCH MODELS

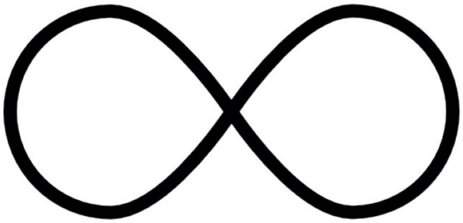



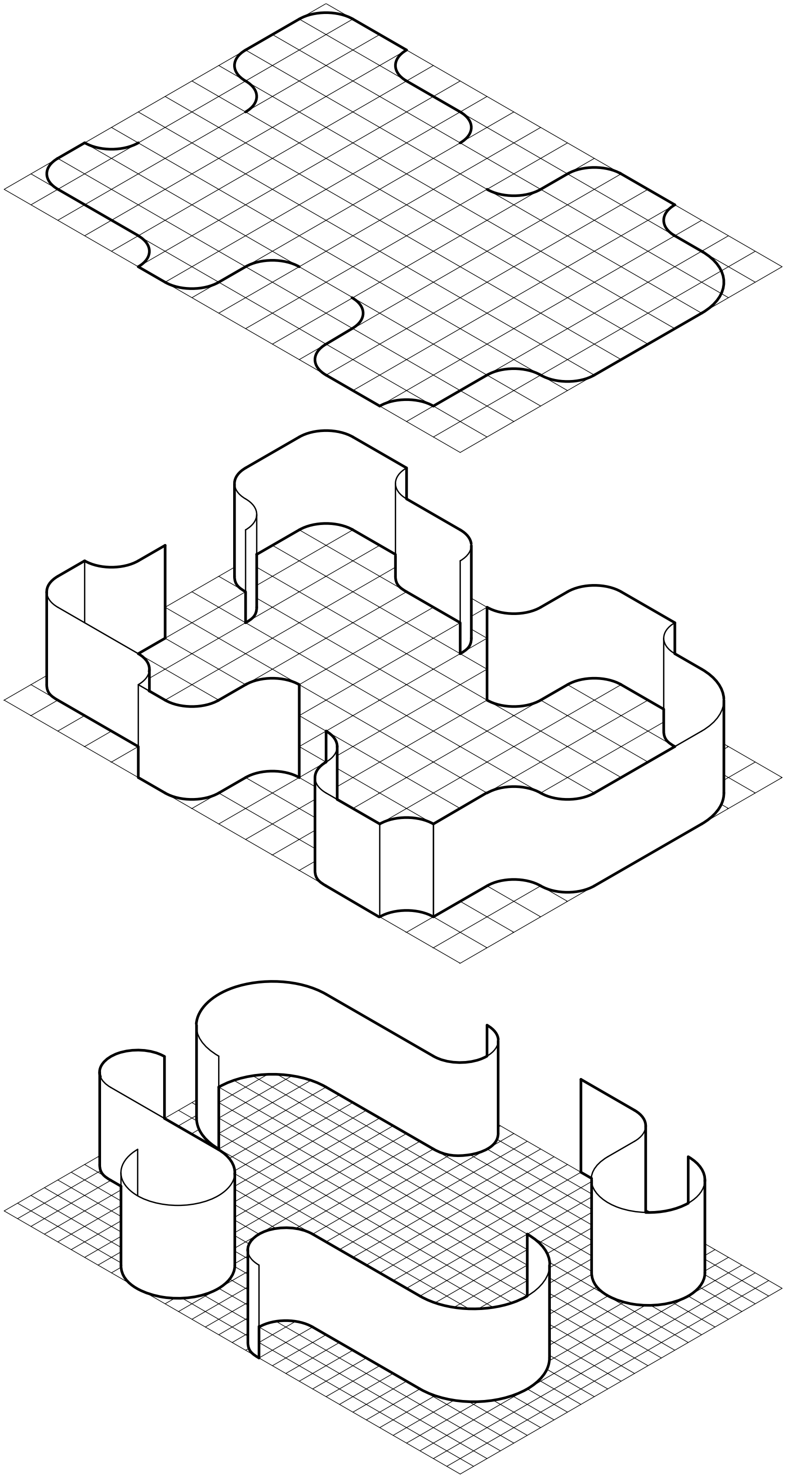









INITIAL SKETCHES

CONCEPT OF INFINITY

The infinity symbol, sometimes called the leminscate, is a mathematical symbol representing the concept of infinity. The circular curves of each structure results in an infinite loop, with non-visible ends. The shape of the structures encourages movement to and through the space, and creates architectural space on the inside but also between the structure and other exhibition screens. The gradient of small and large units creates a transparency of the walls, which loosens up the otherwise strict exhibition space.

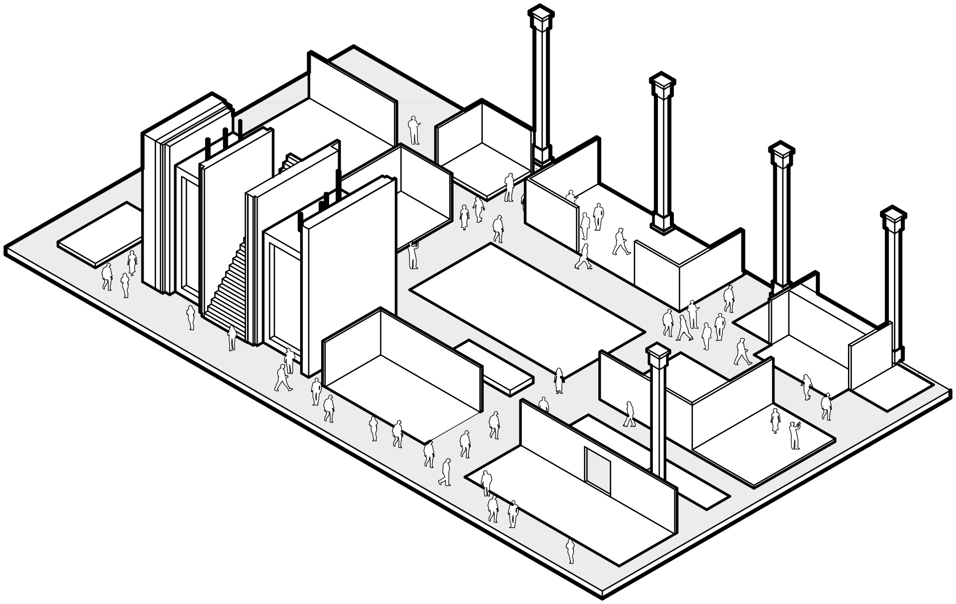


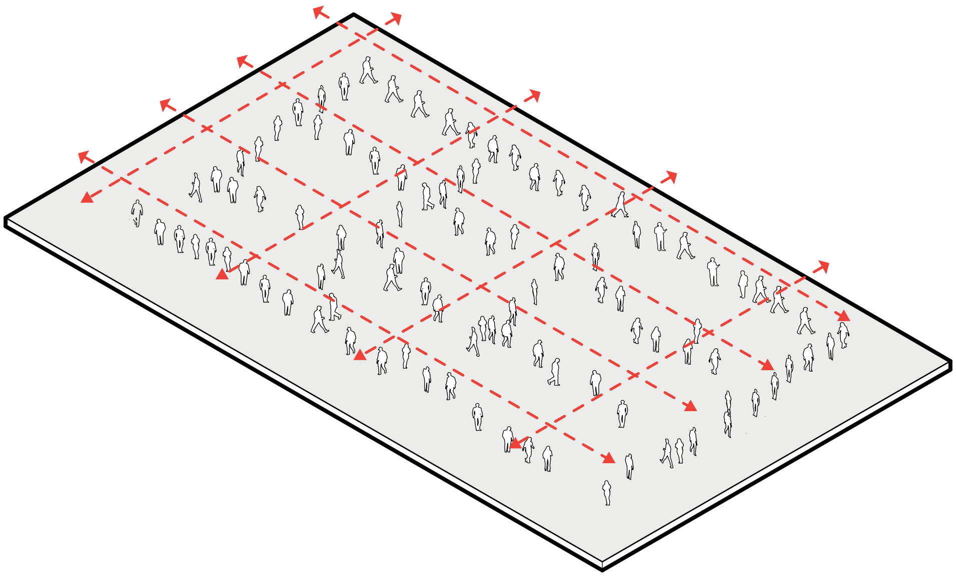


SPATIAL DESIGN

EXHIBITION GRID & PEOPLE FLOW

Like many other exhibition halls The Swedish Congress and Exhibition Centre consists of temporary partition areas where exhibitors are trying to attract customers. The rectangular volumes sets rules for the spatial experience and the function oriented architecture provides few interesting spaces. There are limited places for respite in the hectic environment and most of the seating areas are occupied. The movement pattern is influenced by the spatial orthogonality. Like cars on a freeway the visitors travel along the transport distances until they find something that capture their attention. This results in a clear movement pattern with straight lines crossing each other at the nodes.
As visitors are programmed to move along the room's orthogonality the need for the unexpected is imminent.

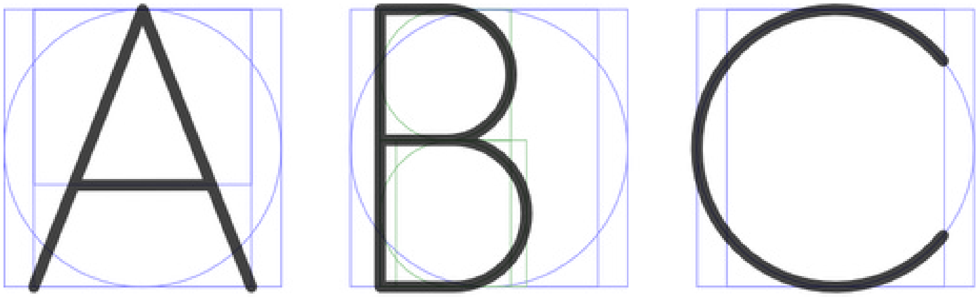


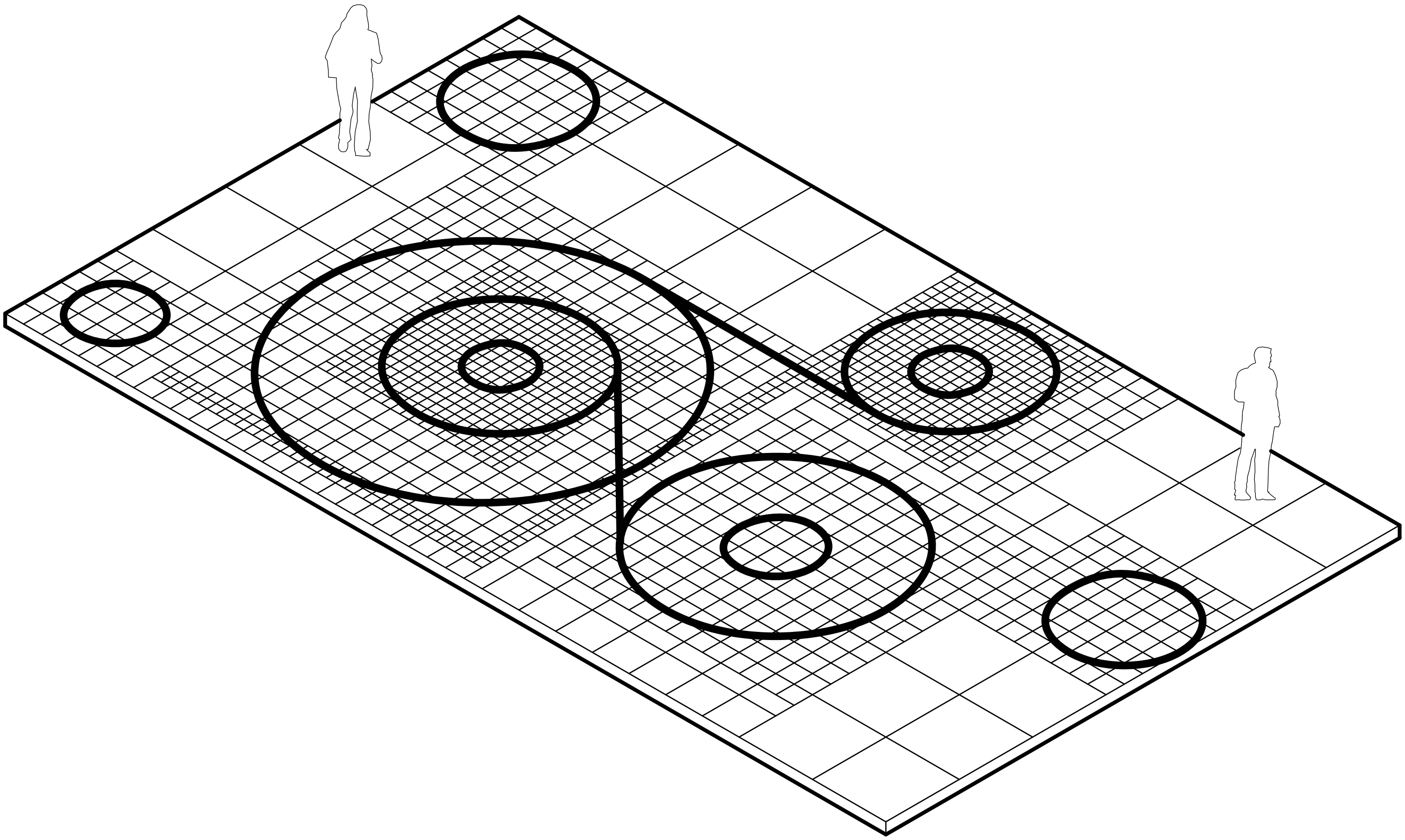


SPATIAL DESIGN

FONT GRID

The font grid system has been used as guidelines when constructing the overall floor plan. Much like in the field of graphic design the grid is to be considered as a starting point for the design, rather than a final proposal. With a set grid, other qualities such as rhythm, proportions and
movement can be explored freely. As a contrast to the surrounding area the placing of various sized circles becomes a first step in the strive for the unexpected.



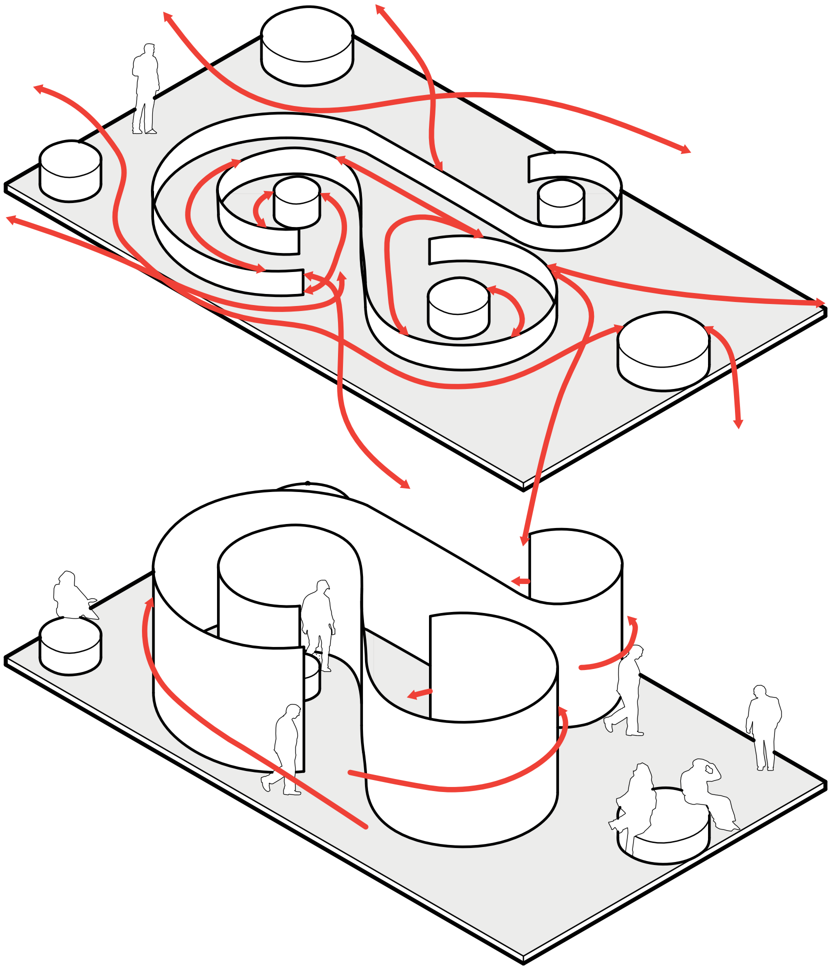


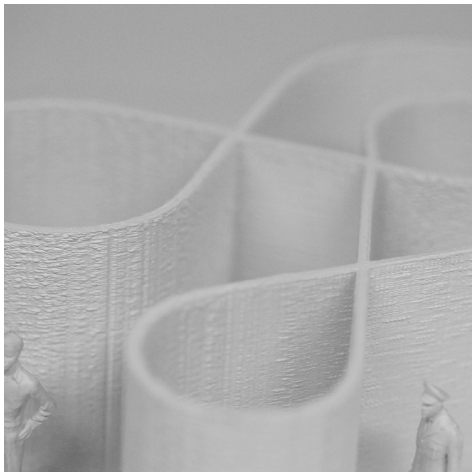
SPATIAL DESIGN

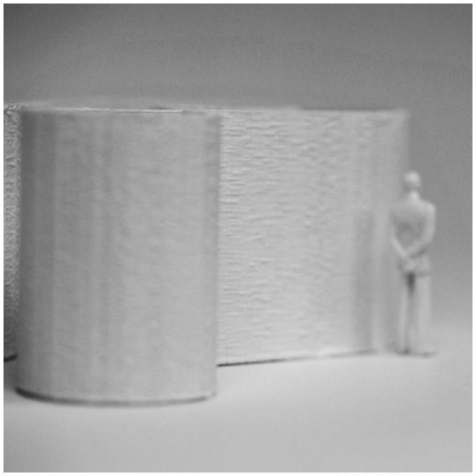
MOVEMENT & CORNERS

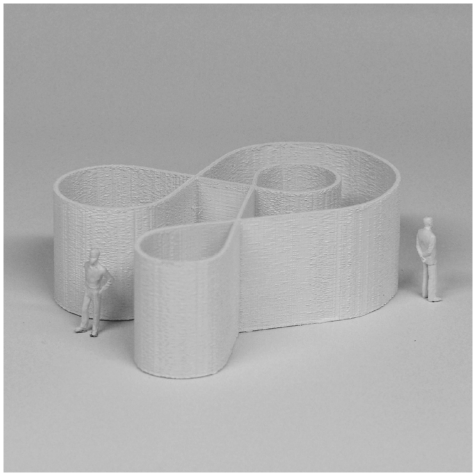
The slightly extruded floorplan symbolizes the different ways of entering the spot. Due to the existing movement in the hall the visitors are expected to enter the structure from its corners, which will come to influence the global form in general. The design of a fluid form is a strategy for changing the movement pattern and as visitors approaches the structure the orthogonal movement dissolves. By programing the movement in the area the visitors will be forced to experience new spatiality.

Once inside the form the double sided walls leadsyou along a guided path, where the end is hard to detect. The two walls stand independently to each other but well within the structure it ́s perceived as one. The fascination for the unknown, hidden and infinite is a keystone in the overall concept, as well as a source of inspiration.





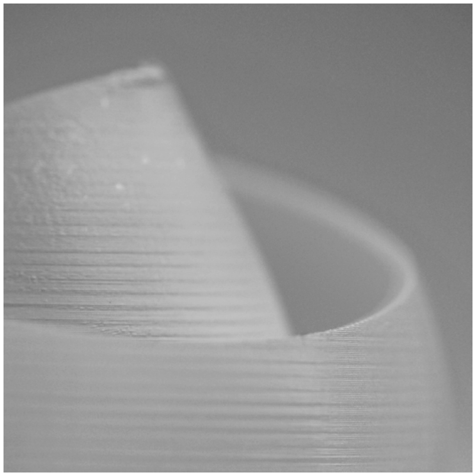


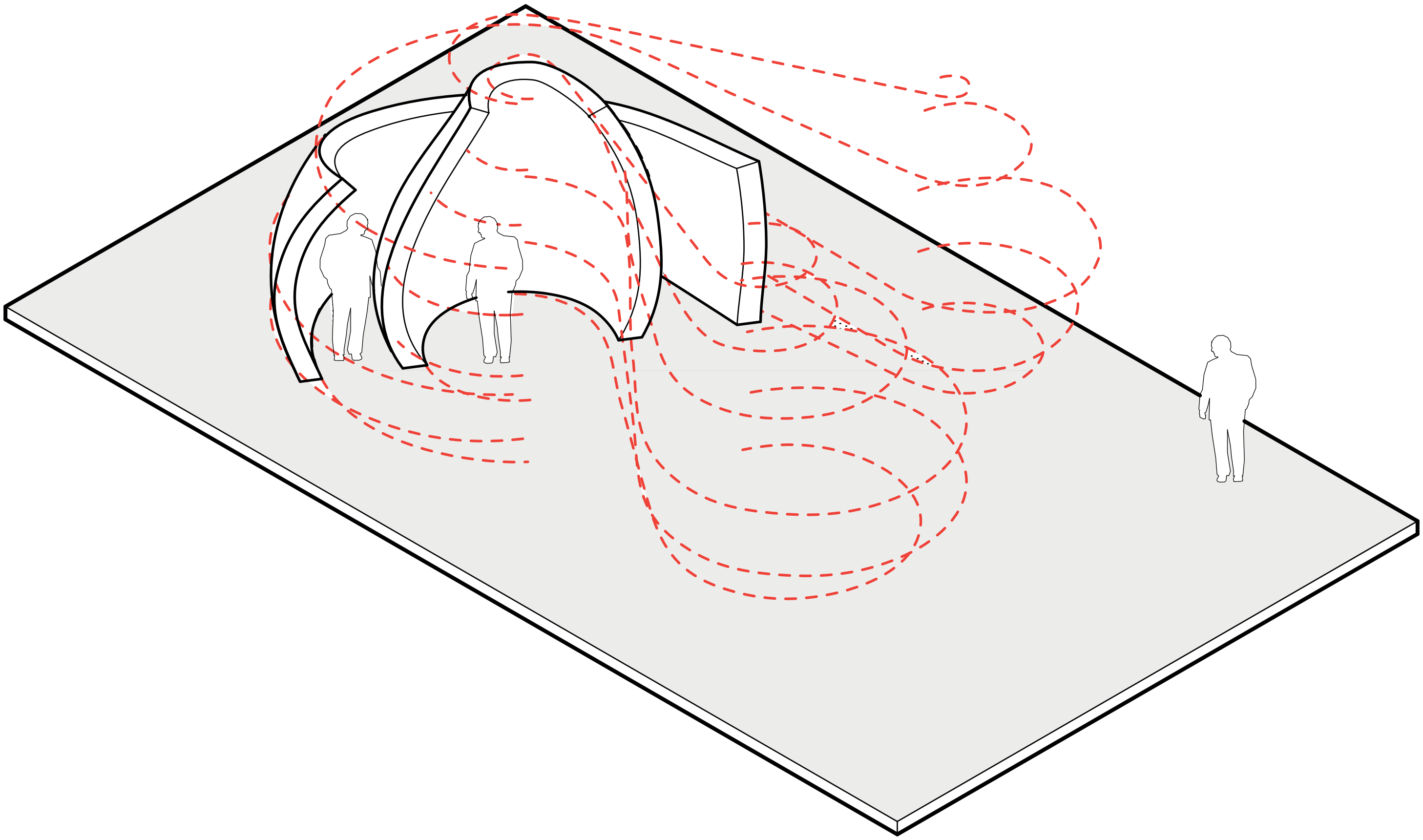


SPATIAL DESIGN

3-DIMENSIONAL SHAPE

Since we never thought of the form as an extruded version of the floorplan the adding of control points and curves was necessary to able a more free way of programing the interior space? The inside fluctuates between dense and loose and by working carefully with different elements, the interpretation of the global form changes. Overhanging walls, encapsulated cocoons and a foundation that takes the shape of a bowl and hovers above the ground. As well as an interesting space
on the inside the structure creates interesting gaps between itself and other exhibition screens

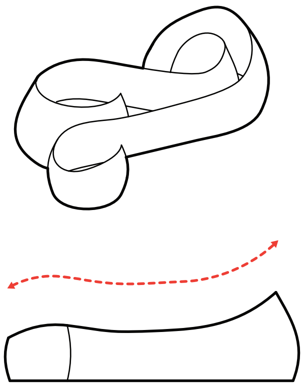


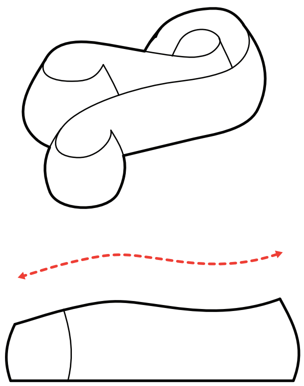


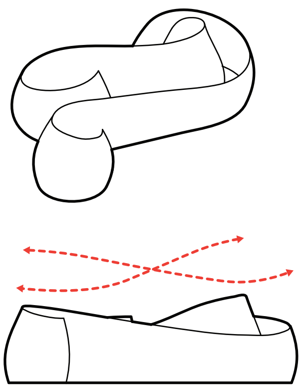
SPATIAL DESIGN

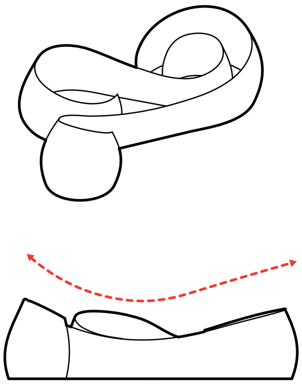
FORM STUDY

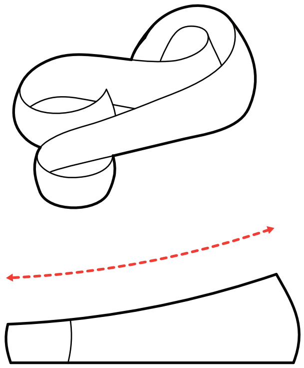
In order to enhance the global shape, cuts are placed along two different flat planes. The placing of cutting planes in relation to the four corner entrances is a strategy were the structure is shown from its best side no matter what corner you arrive from.

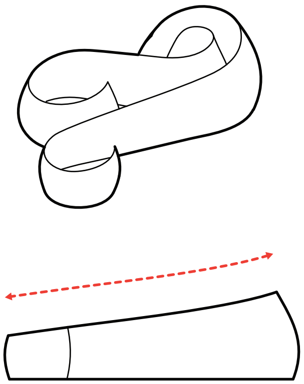


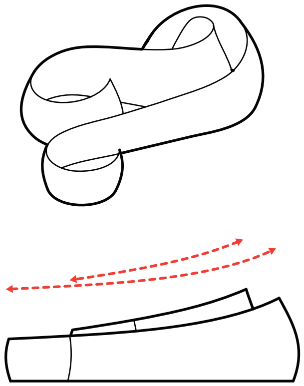


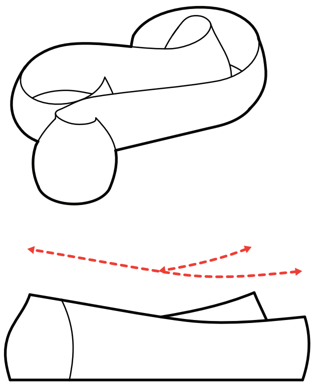










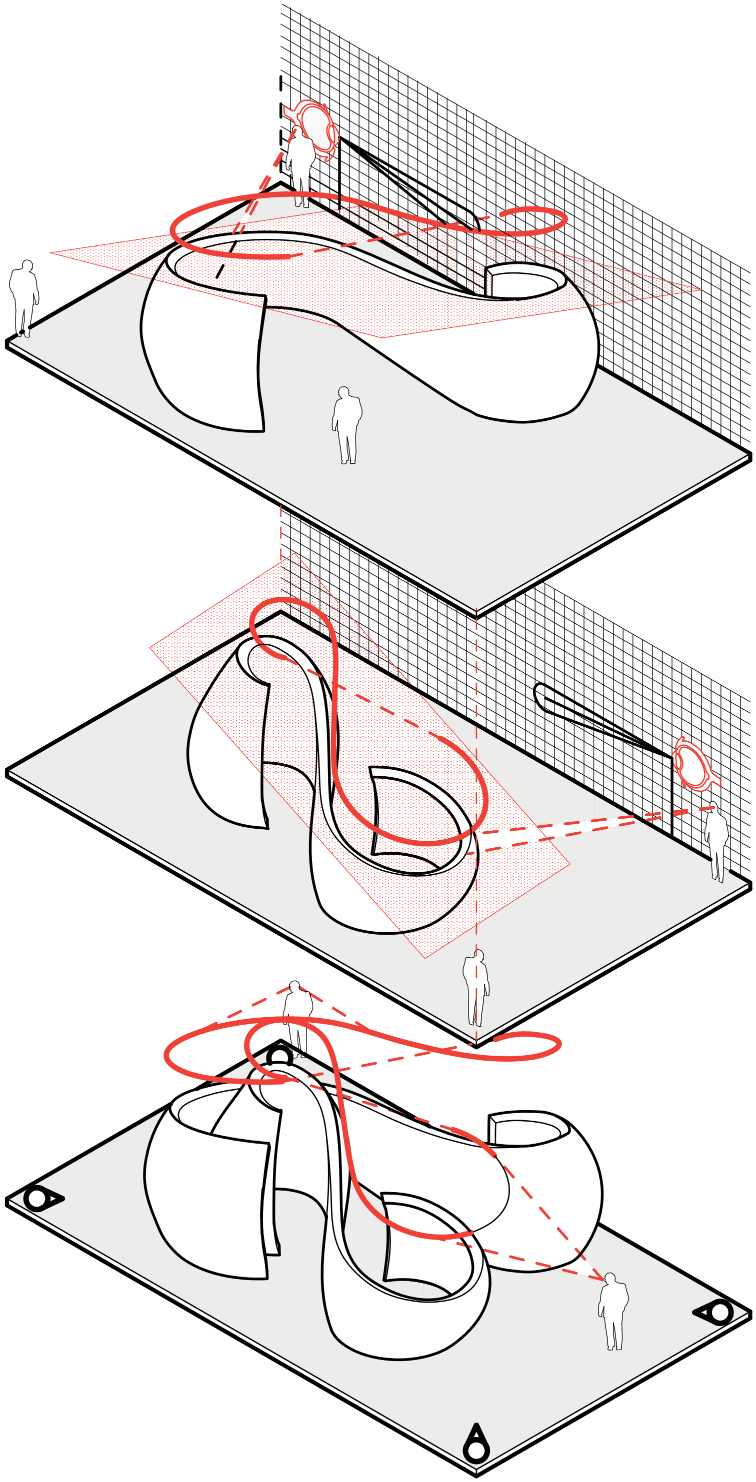


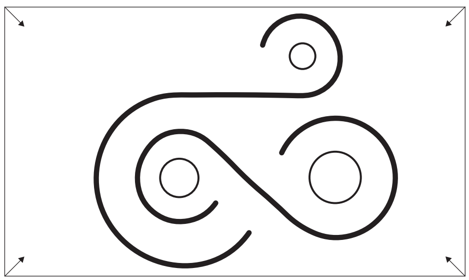
SPATIAL DESIGN

CUTTING PLANES

The cutting planes are placed slightly below the normal eye perception of an adult, which increases the readability of the path. When cutting the global shape with angled planes, the different layers of the structure becomes visible and overlay each other like an onion. The transparency of the walls gives a hint of what lies behind the next layer. The angular cuts are placed so that the highest point of one wall coincide the lower part of the other. The combined strategy of font-logic system and strategically placed cuts increases the possible perception of detecting the lemniscate symbol.

Apart from detecting the lemniscate curve as a visual symbol it also strives for a subtle way of encouraging a new movement pattern through and along the structure. Through the cellular walls the path of infinity erases the border between the independent walls.

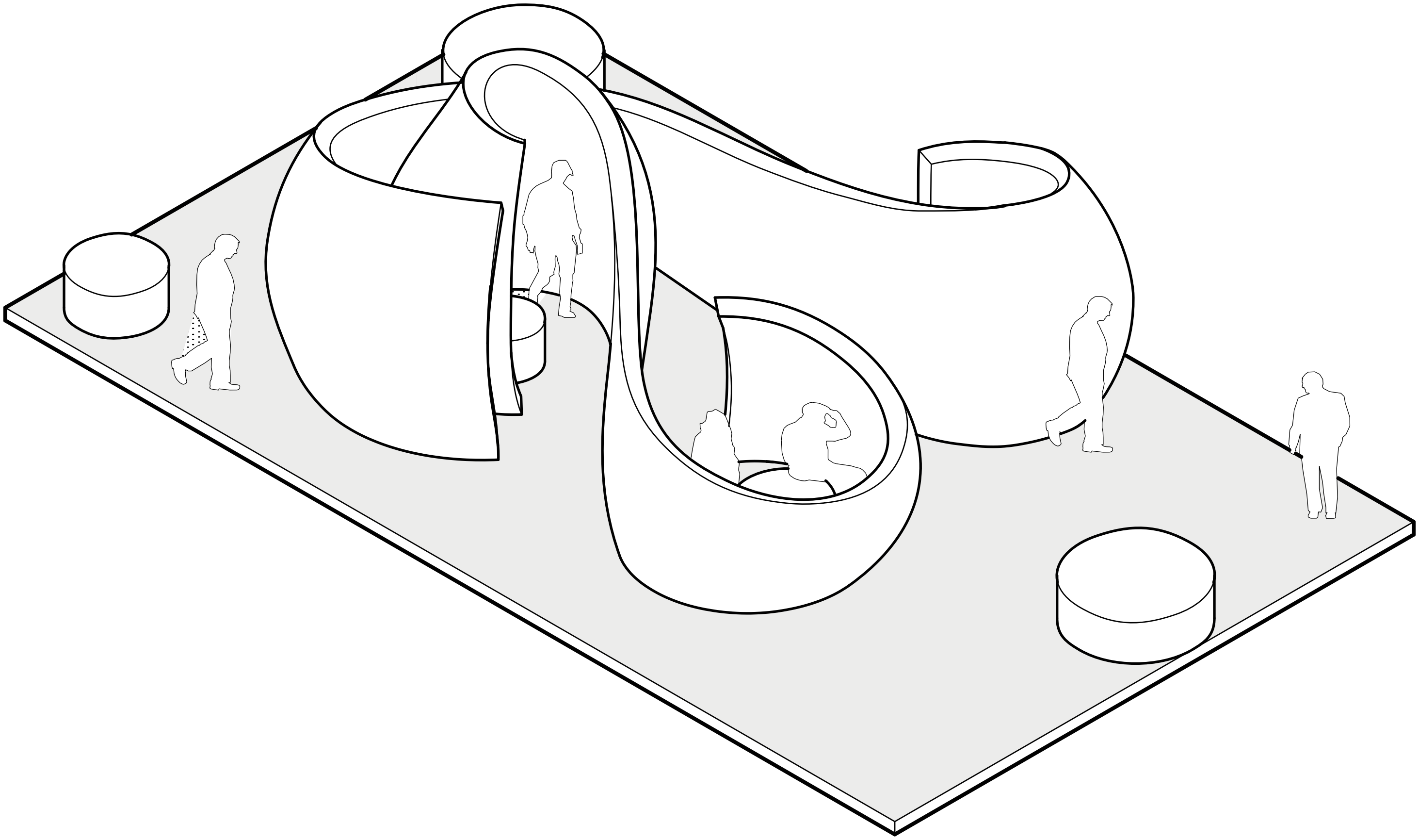




SPATIAL DESIGN

GLOBAL FORM

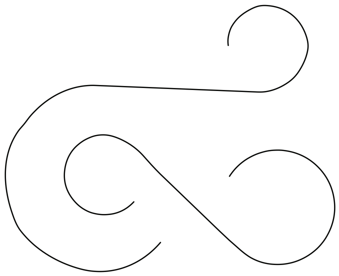
The structure shall act as a pause/break in the exhibition area. A Place to sit down and a zone for a contrasting spatial experience. Stools are placed to provide seating both within the structure as well along the outside. By using the same font-logic system the stools become one with the design

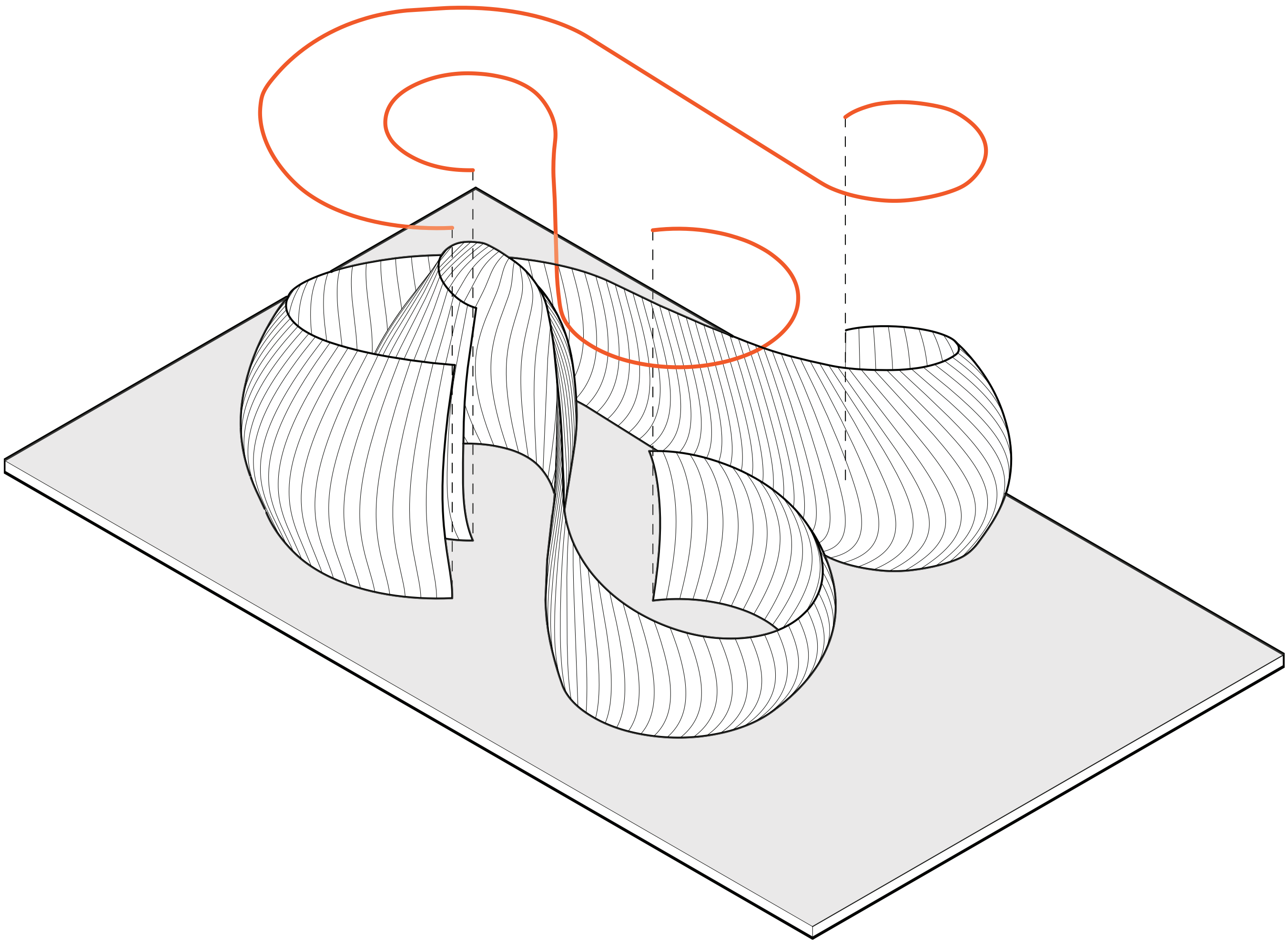


GEOMETRY

GLOBAL S-SHAPE

The global shape meets the ground as a S-shape, which in its form itself helps to simplify the stability of the global form. The S-shape balances in a way where in theory no extra supports are needed except for vertical and friction of the ground. The spatially curving of the global form is also designed such that the forces can be transferred from the structure to the ground.

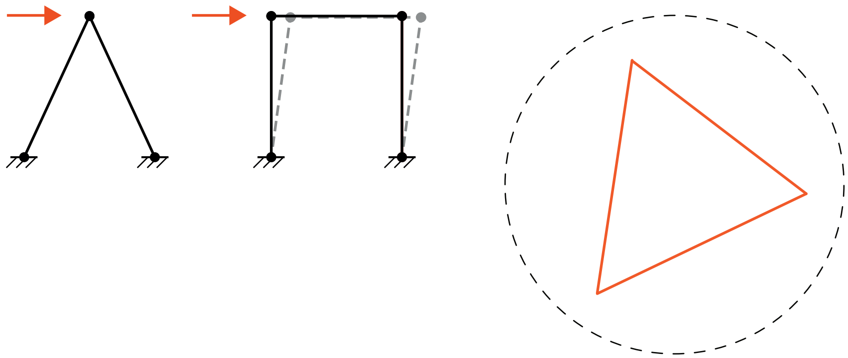


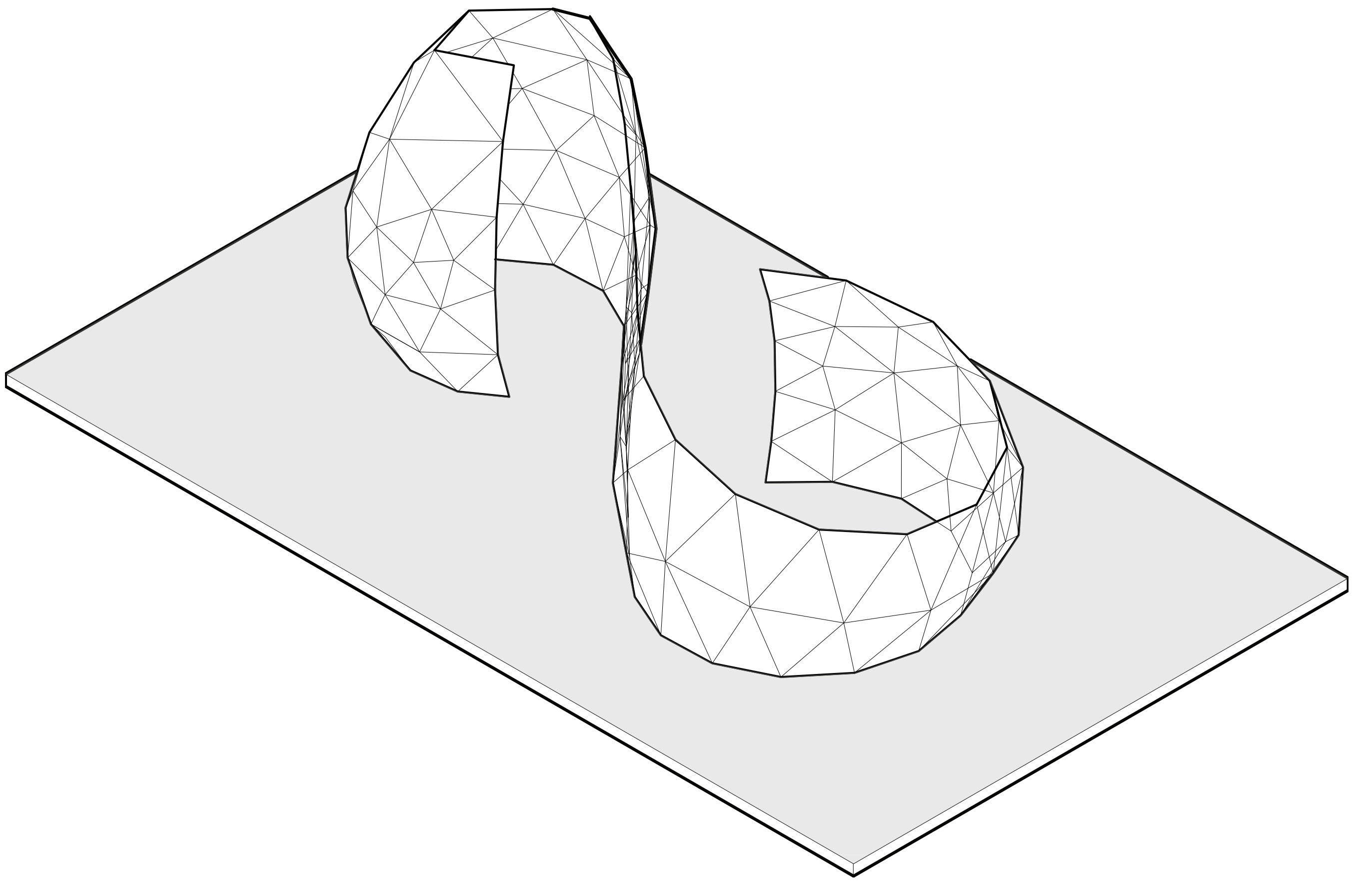


GEOMETRY

DISCRETIZATION

Since we decided to work with plywood as a sheet material, the first step was to discretize this surface into smaller segments. One common surface discretization method is triangulation, which has the advantage of being able to approximate any given surface in an accurate way. A triangular mesh is particularly good in this aspect where each element is stable for in-plane forces.

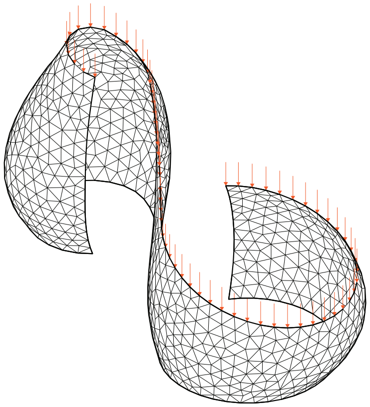


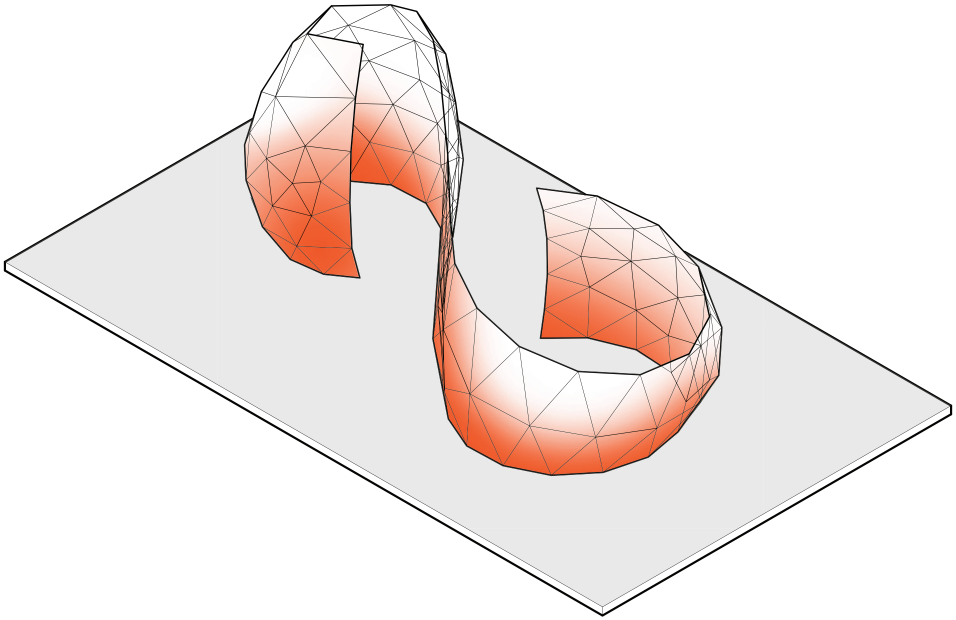


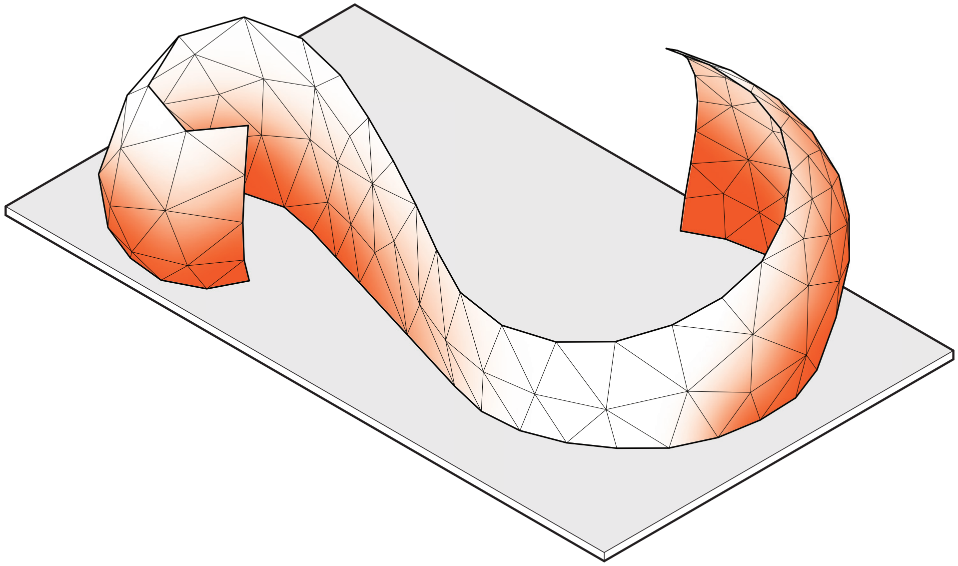
GEOMETRY

RE-MESHING - STRUCTURAL PERFORMANCE

There are many possible ways one can triangulate a surface, making it relatively easy to adjust the mesh to fit the force paths or concentrations. A finite element analysis was performed on the global shape, which informed the design by creating smaller triangles in the areas where the stress concentrations are the highest. More structural mass is therefore placed in these areas, making the structure more resistant.



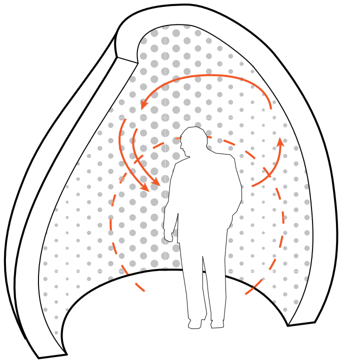


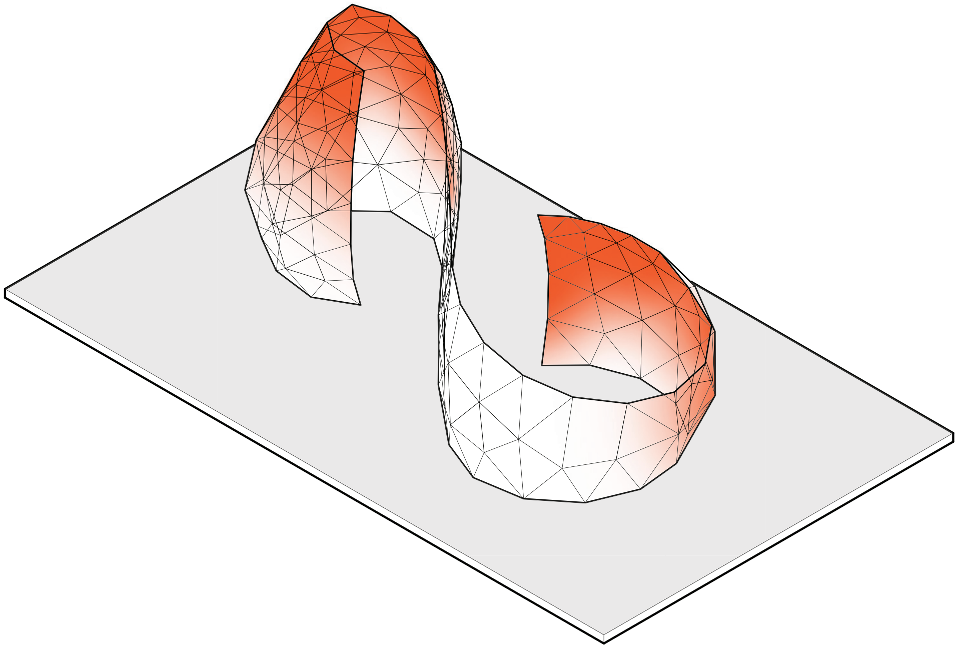


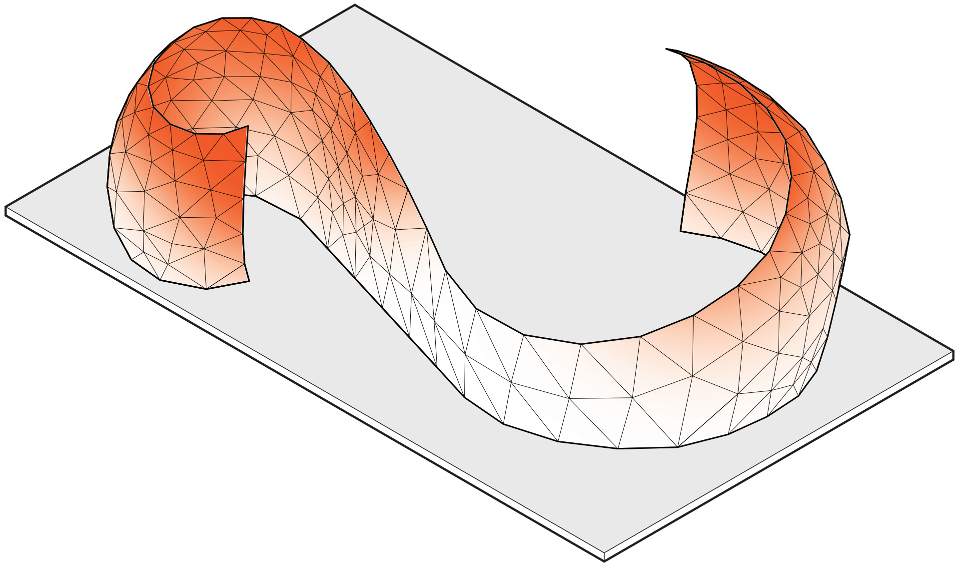
GEOMETRY

RE-MESHING - SPATIAL PERFORMANCE

A second layer of re-meshing was performed in order to fulfil and enhance the wanted architectural qualities. This includes more density around the cocoons to create a more intimate space with less visibility. Furthermore, the triangles are adjusted to create a denser mesh where there is more curvature.



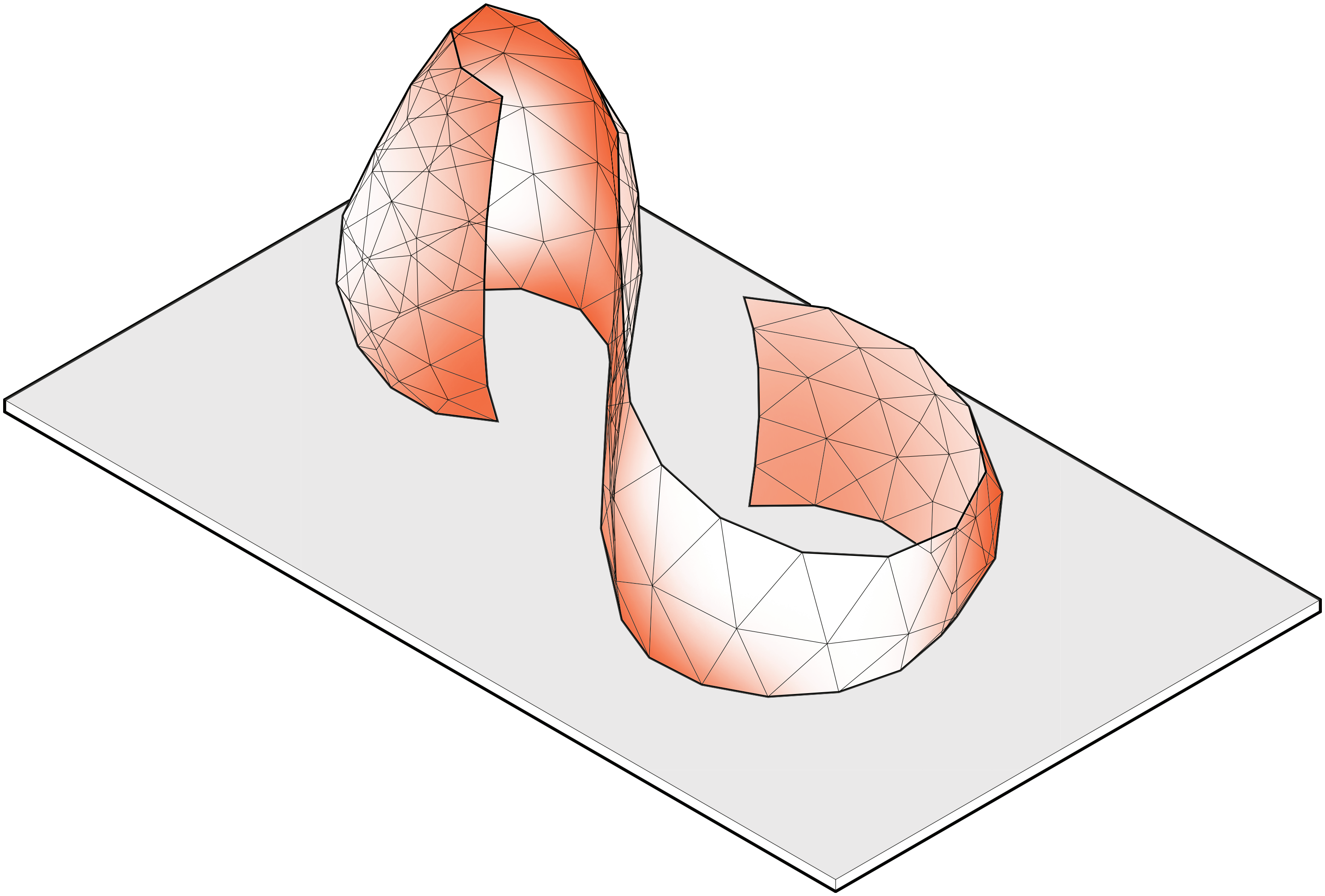




GEOMETRY

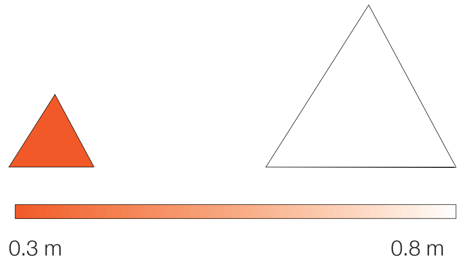
FINAL RE-MESHED INNER SURFACES

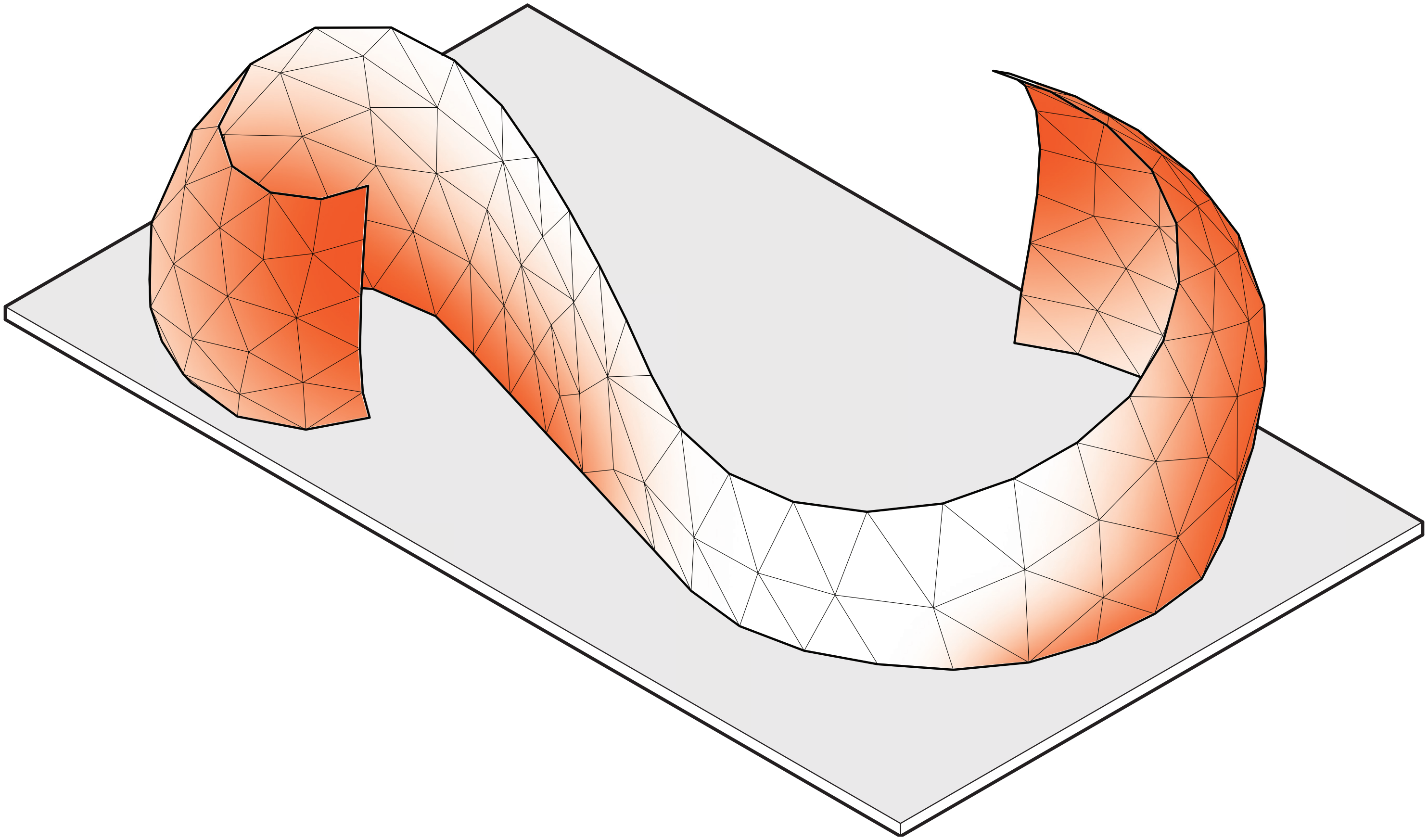
The final input mesh for the next steps is a combination of the two layers of re-meshing. The triangular units vary between units of 0.3 m edge length (which is the smallest considered to be possible) and 0.8 which is the maximum length in order to fit these units on one sheet of plywood.



GEOMETRY

FINAL RE-MESHED OUTER SURFACE

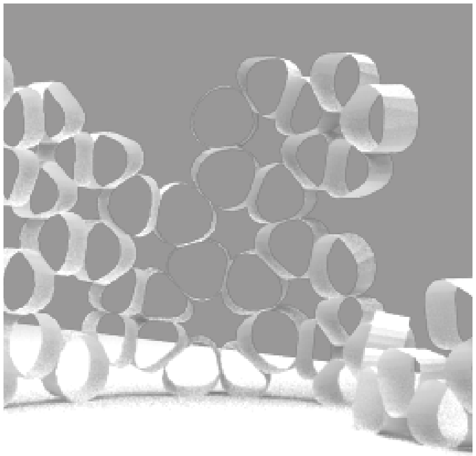


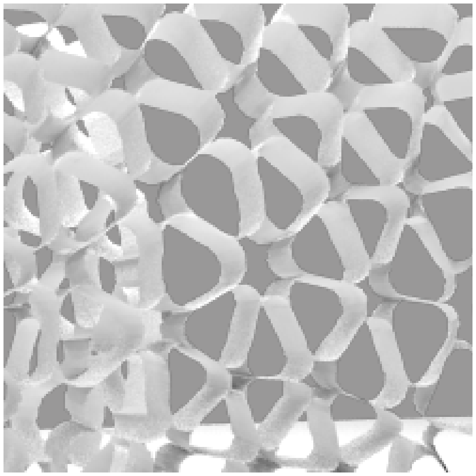


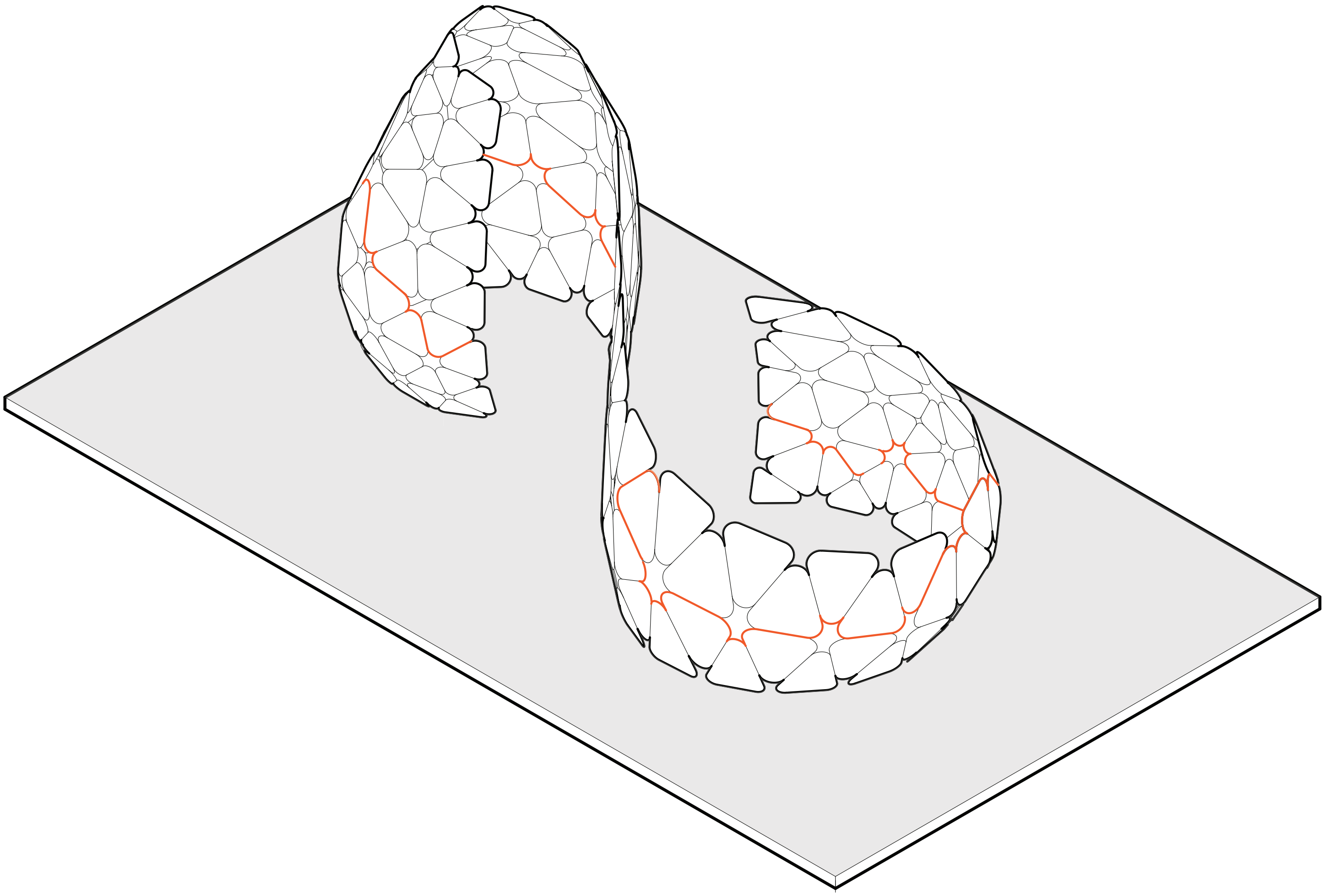
GEOMETRY

MESH FILLET

When looking at the final mesh aesthetically, it was lacking qualities such as continuity and 3-dimensionallity. By doing a fillet, is suddenly becomes possible to read the structure not only as separated units, but as continuous strips running along the surface. A fillet also makes it possible for the unit to be folded without introducing kinks. The selected fillet is based on the shortest side of each triangle, to ensure that no side becomes too short after a fillet is performed. A too large fillet will result in circles instead of triangles, which didn’t meet the visual preferences.



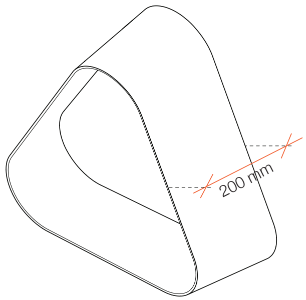


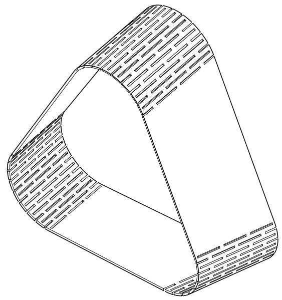


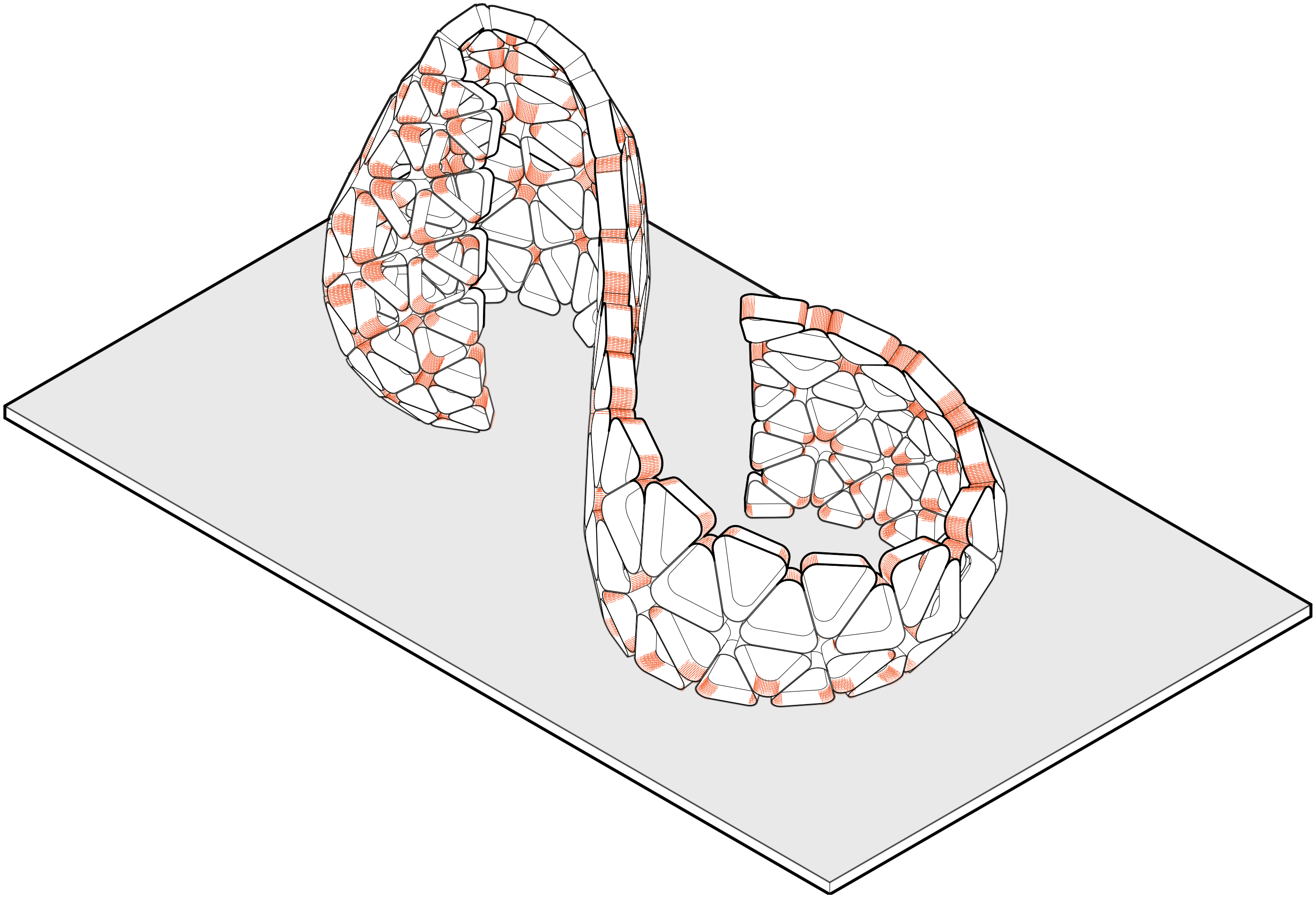
GEOMETRY

EXTRUSION & KERFING OF UNITS

The filleted mesh is in a next step offset both in- and out-wards. Because of the global shapes, the offset units create a sidedness, where if you look at the unit from one side, the opening is larger than if you look at it from the other side. This is particularly visible at the places of highest curvature. In order to create these units from flat plywood sheets, the edges where we do the fillet is kerfed in order to be able to bend these areas. In order to make the units stay in their folded 3-dimensional state, the two free ends need attached to their neighbouring unit.



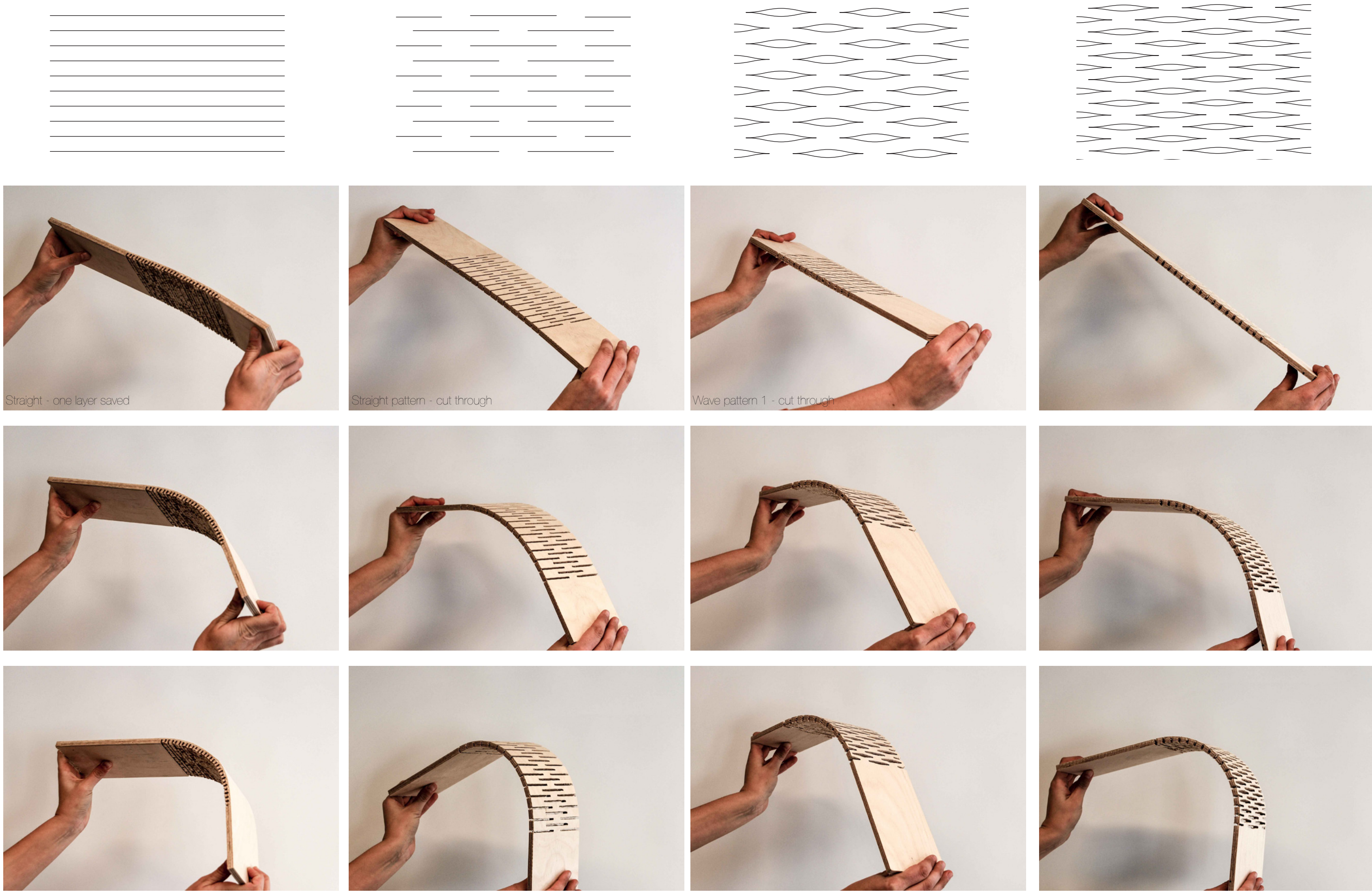




MATERIAL CONCEPT

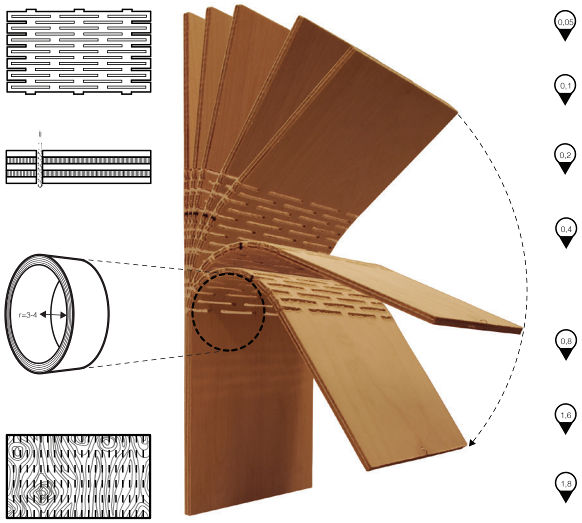
DIFFERENT KERF PATTERNS

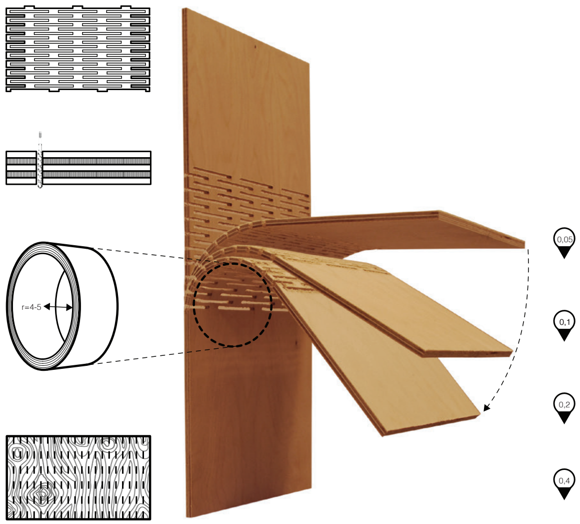
Multiple different kerf patterns were studied in order to get an understanding of how they affected the bending properties of the plywood. Initial studies were performed by laser cutting 3 mm birch plywood (right) but due to the uncertainties of scaling wood, full scale tests became an early method for design studies.

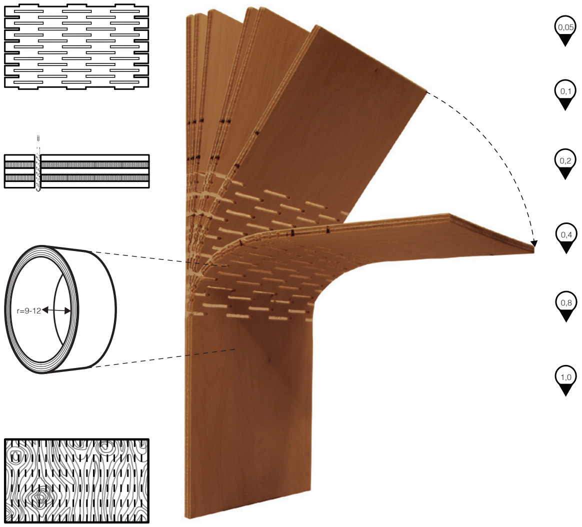


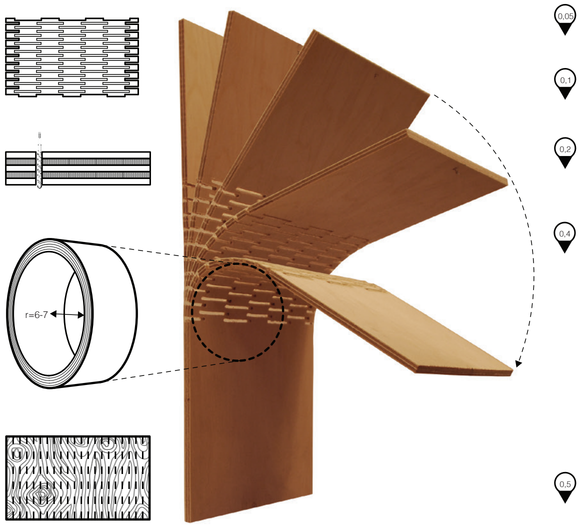
MATERIAL CONCEPT

LOADING TESTS









MATERIAL CONCEPT

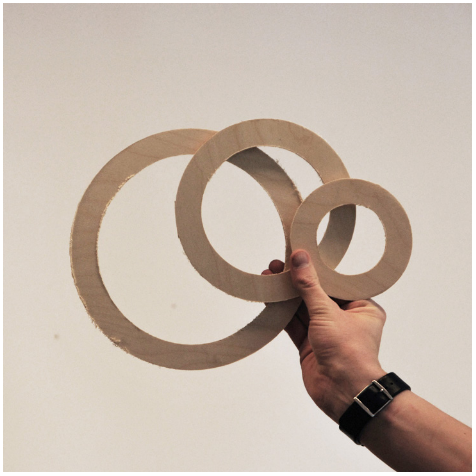
BENDING RADIUS STUDIES

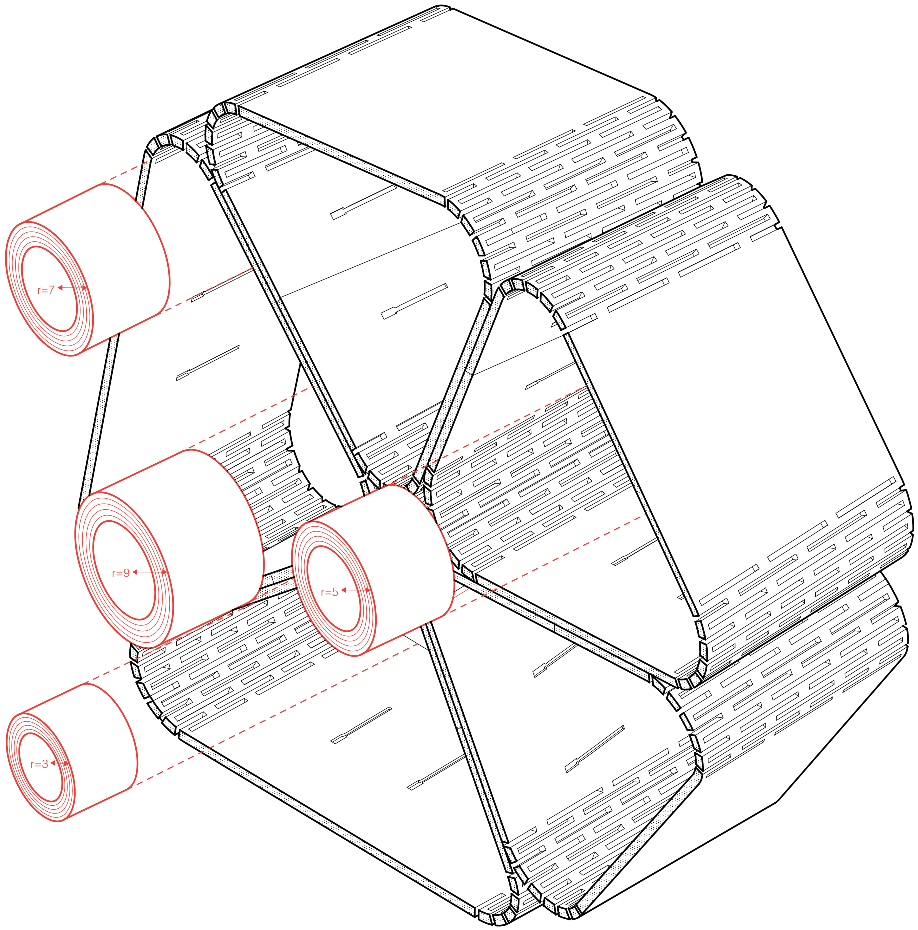
In order to test the different bending radius found in the structure, different kerf-patterns were studied. The following radii have been tests:

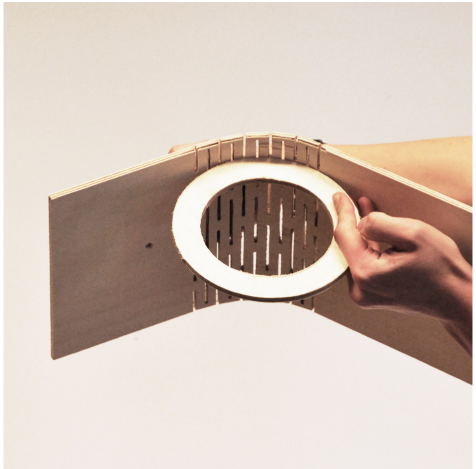
- r= 35 mm (smallest radius found in structure)
- r= 50 mm
- r= 80 mm
- r= 110 mm (largest radius found in structure)

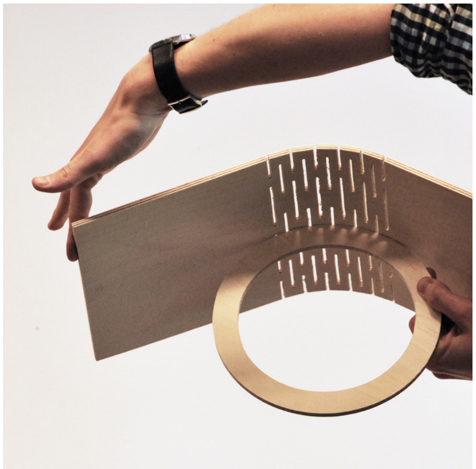
The chart to the right shows the result from the testing of bending radius. The different kerf-patterns were tested and evaluated according to the colour scheme to the right. The orange evaluation class (3) is assumed to represent a good kerf-pattern according to bending radius, where a substantial force is needed with minor cracking occurring.

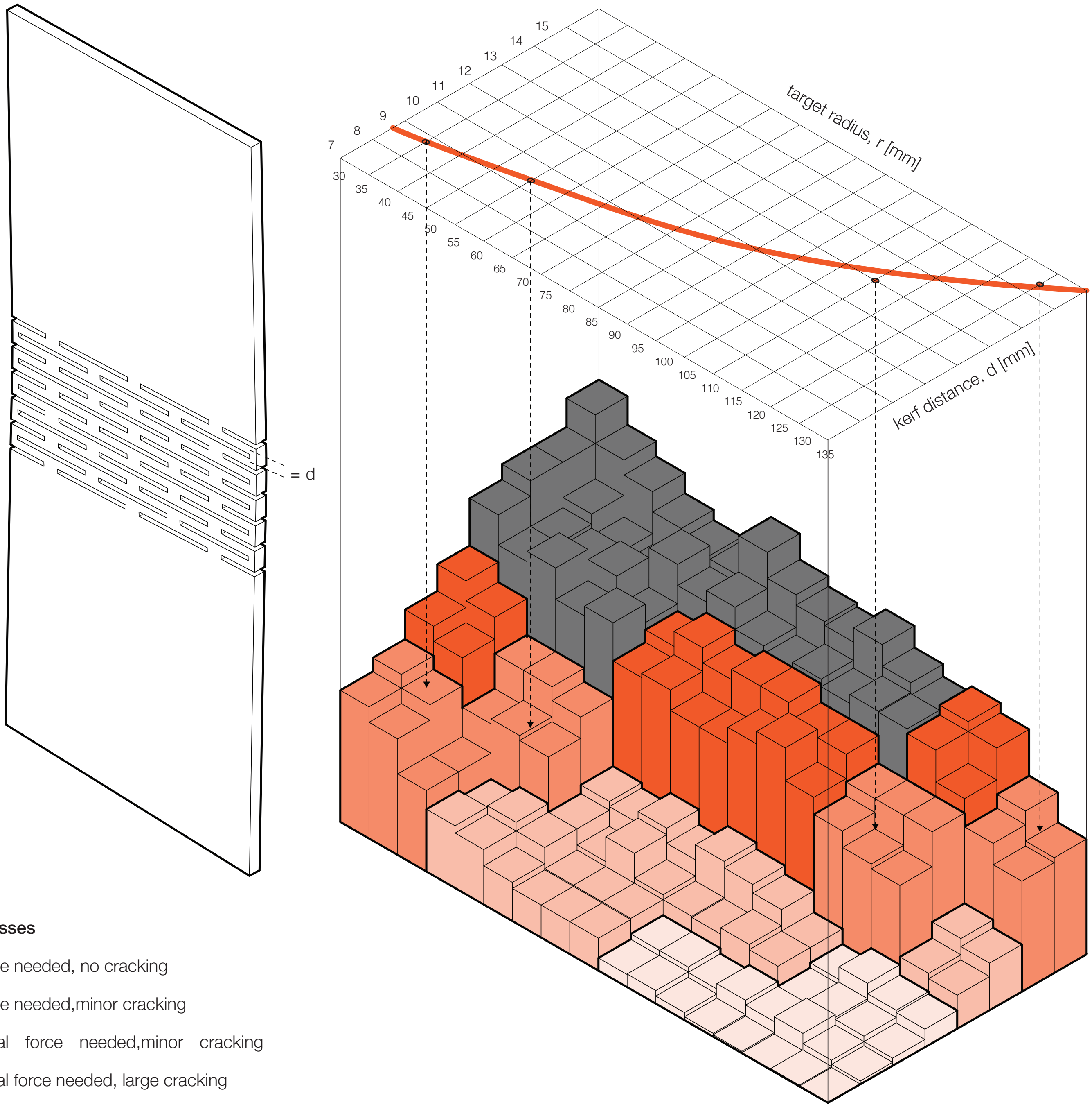
The result from the evaluation was used in order to create a regression graph that could be used when estimating the needed kerf-patterns according to a specific radius. This information is then implemented in the parametric model in order to design a specific kerf-pattern according to each individual radius of each unit.











Evalutation classes

Small force needed, no cracking

Small force needed,minor cracking

Substantial force needed,minor cracking (Target)

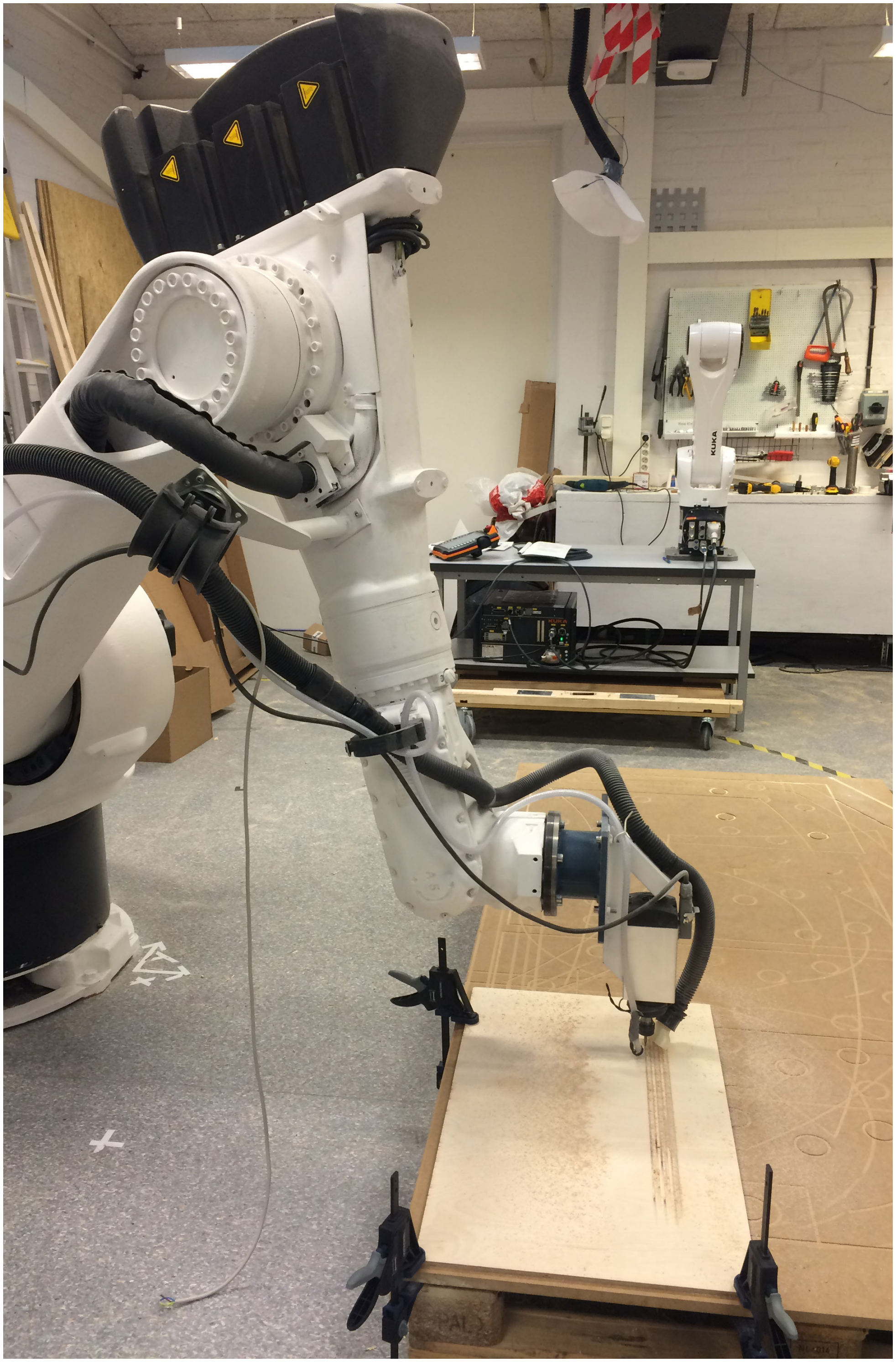
Substantial force needed, large cracking

Non applicable, Impossible to bend without risk of breakage

MATERIAL CONCEPT

PROTOTYPING LIMITATIONS

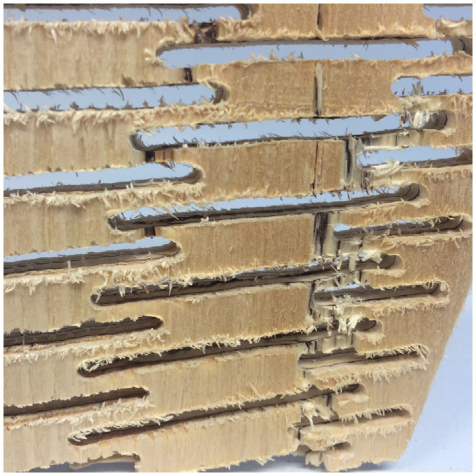
Since the material aspects are very important for the overall design, full scale prototyping has been a main design tool. A 6-axis robot at the MAKE:lab of Chalmers has been used for prototyping different full scale kerf patterns and units. However, the robot was lacking milling precision, which is one of the reasons why a kerf pattern that cuts completely through the material was chosen.

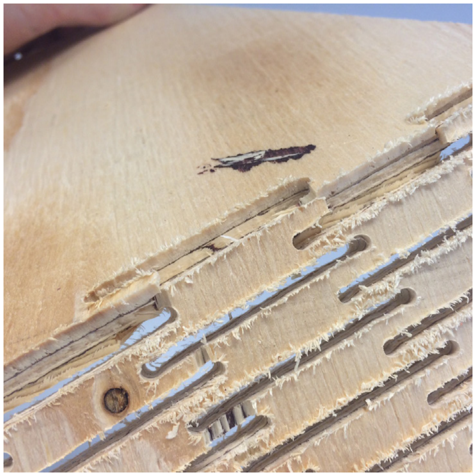


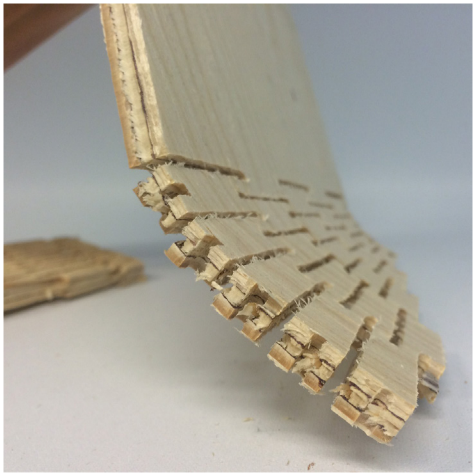
MATERIAL CONCEPT

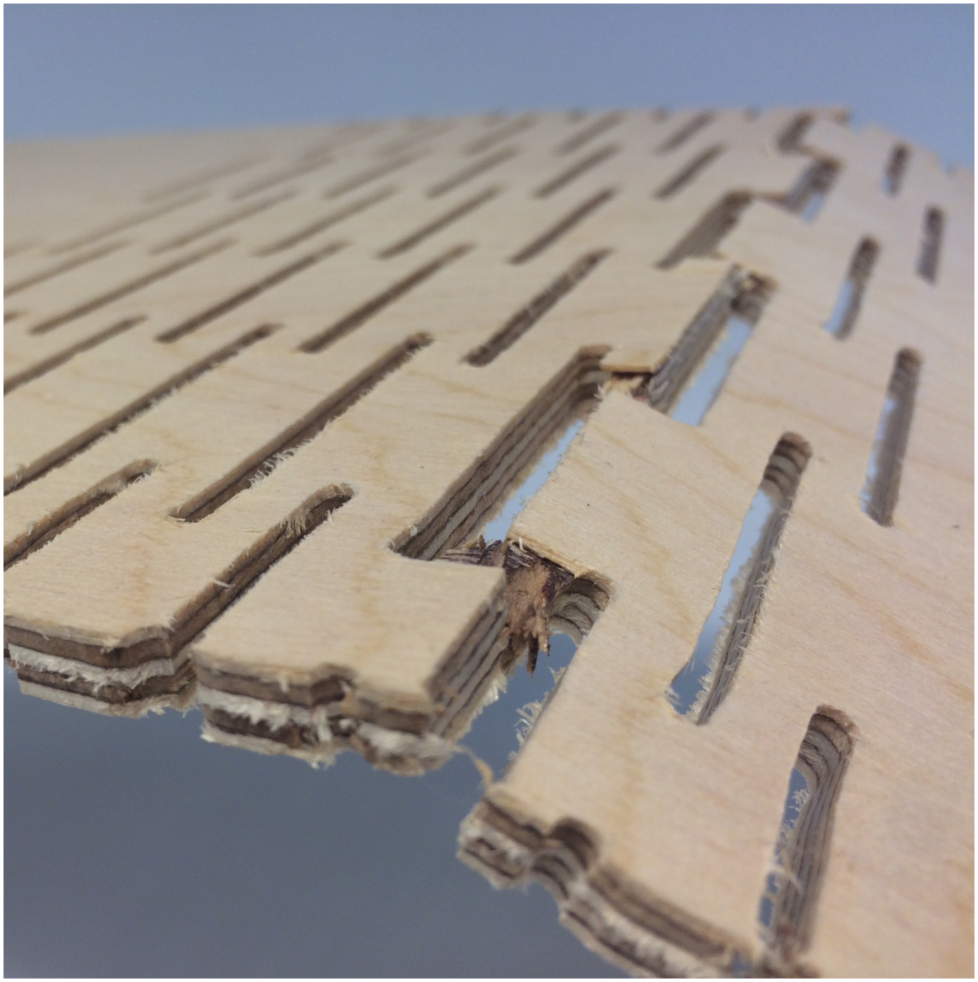
MATERIAL FAILURES

Many different kinds of plywood have been used during the design process, which had notable quality differences. Plywood made from Swedish pine was used for initial test, which had very coarse fibres compared to birch plywood. The fibre coarseness and lack of milling precision made it very hard to create kerf-patterns with enough bending capacity, and instead the tests became very brittle and failed easily.





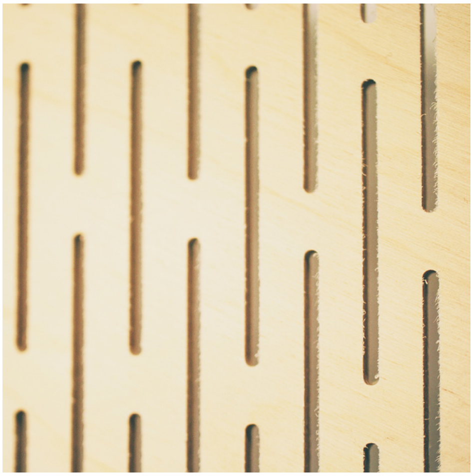


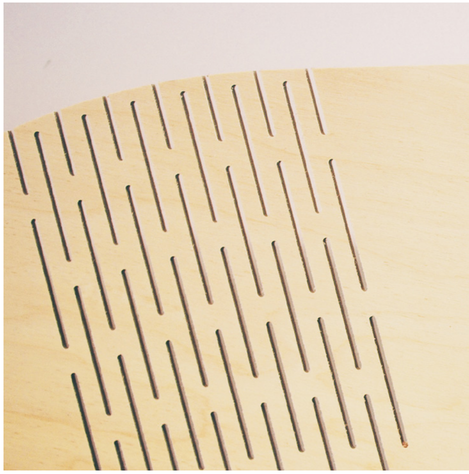


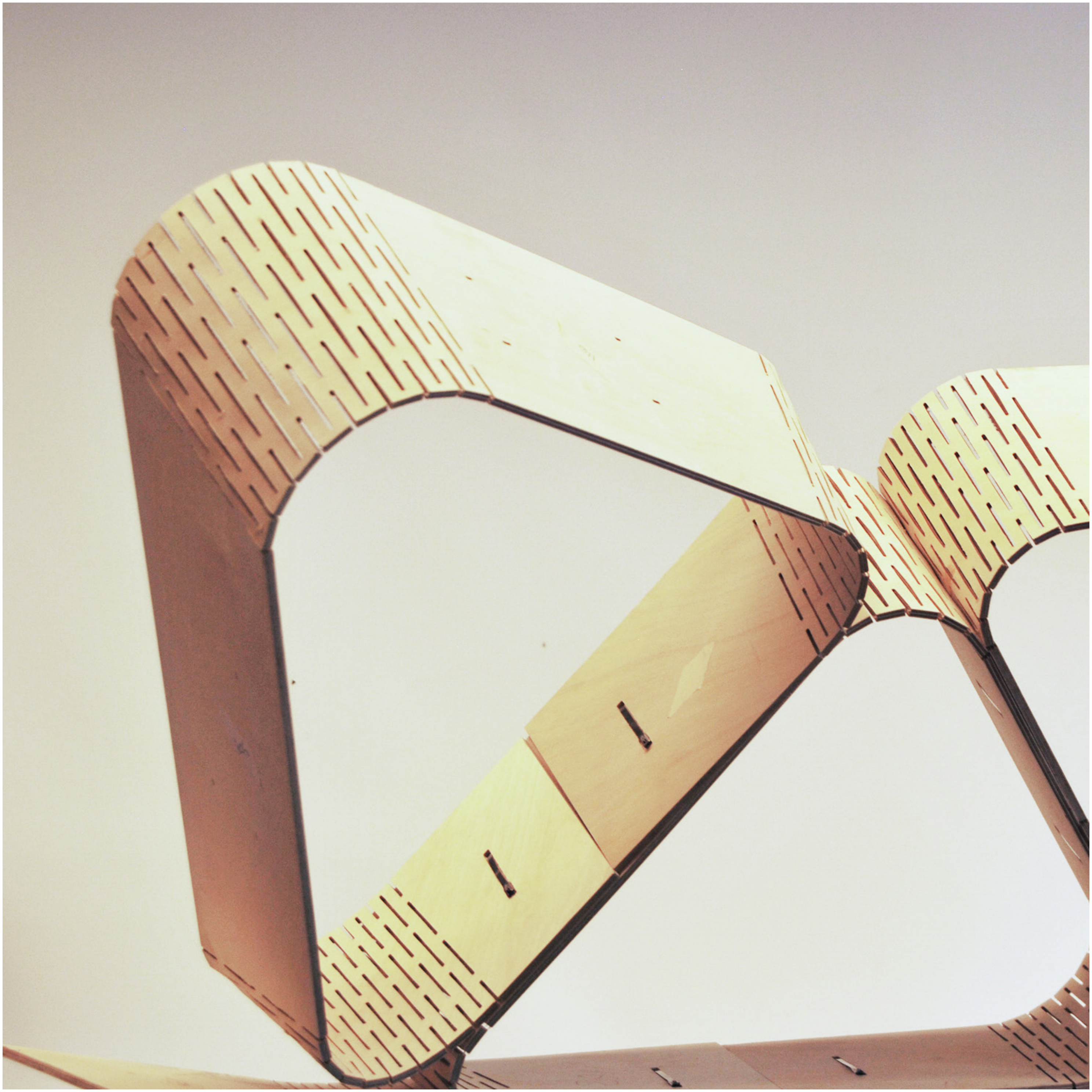
MATERIAL CONCEPT

FINAL MATERIAL TESTS

The professional CNC-milling machines together with increased quality of the plywood used (birch plywood B/BB quality), made a huge difference on the result.



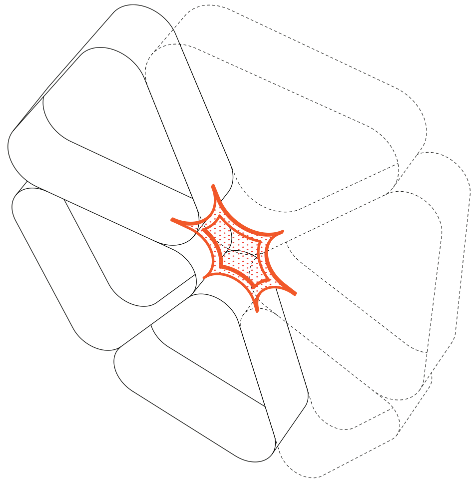


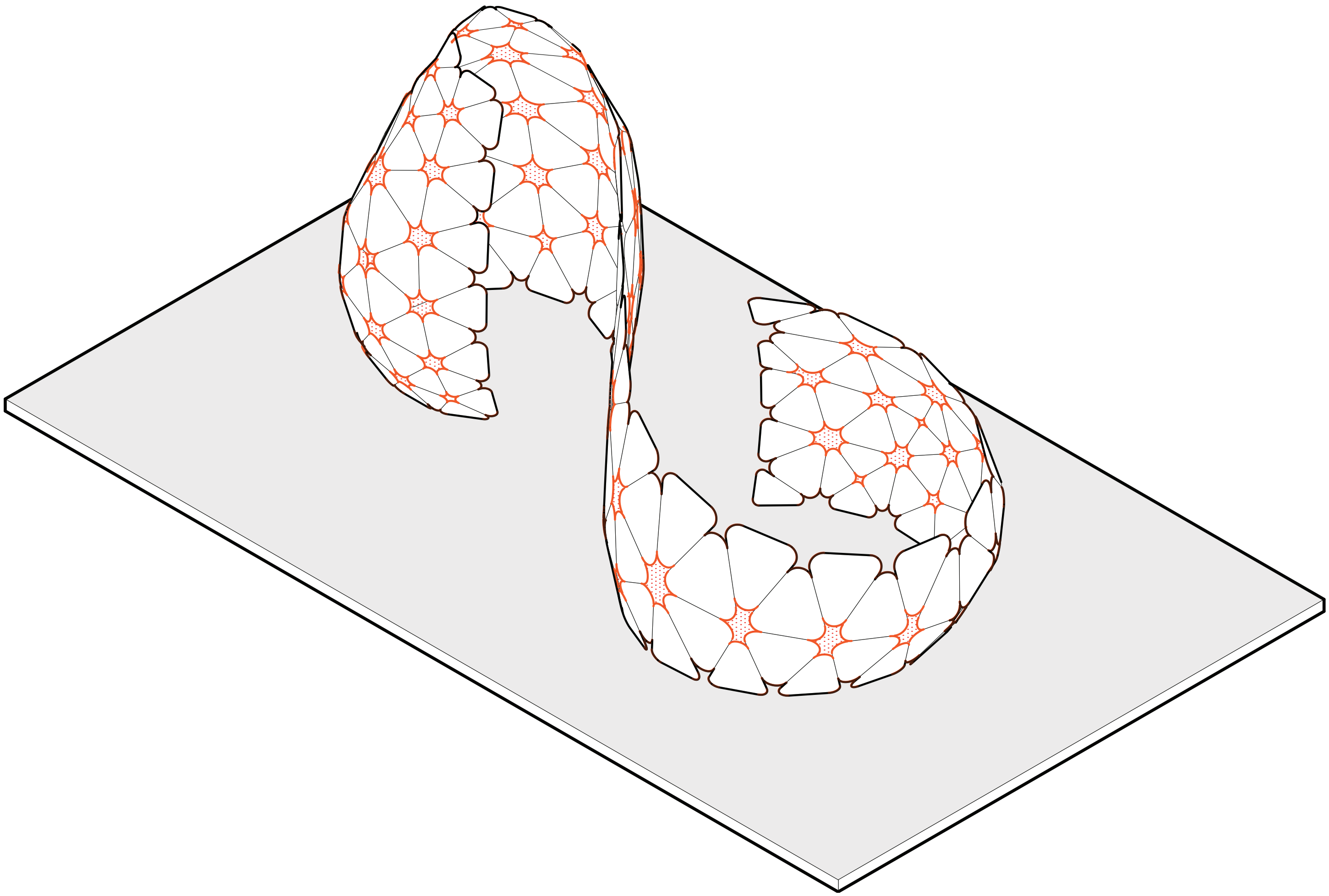


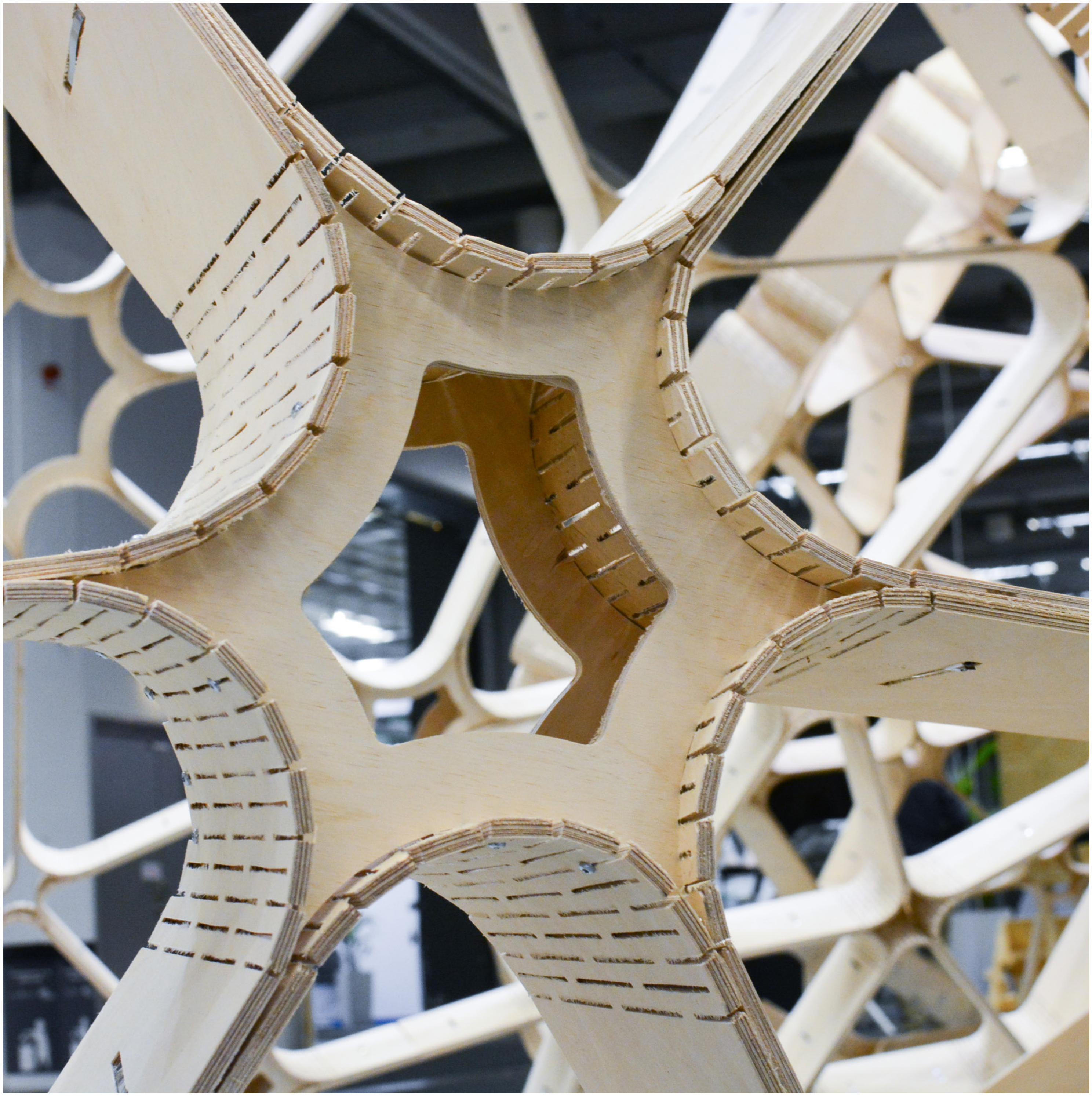
MATERIAL CONCEPT

NODE STIFFNERS

The concept of the component was partly developed from the method of fabrication in mind. With this technique we have now created a component that can be mapped to almost any given surface. However, the overall structural behaviour will then become somewhat springy due to the elastic nature of the component. In the desire to make it stiffer, we started to see the structure as an instrument we now could fine tuned by placing a kind of node stiffener. Using this method we could now program the structural behaviour of the global shape by placing node stiffeners where they are needed.

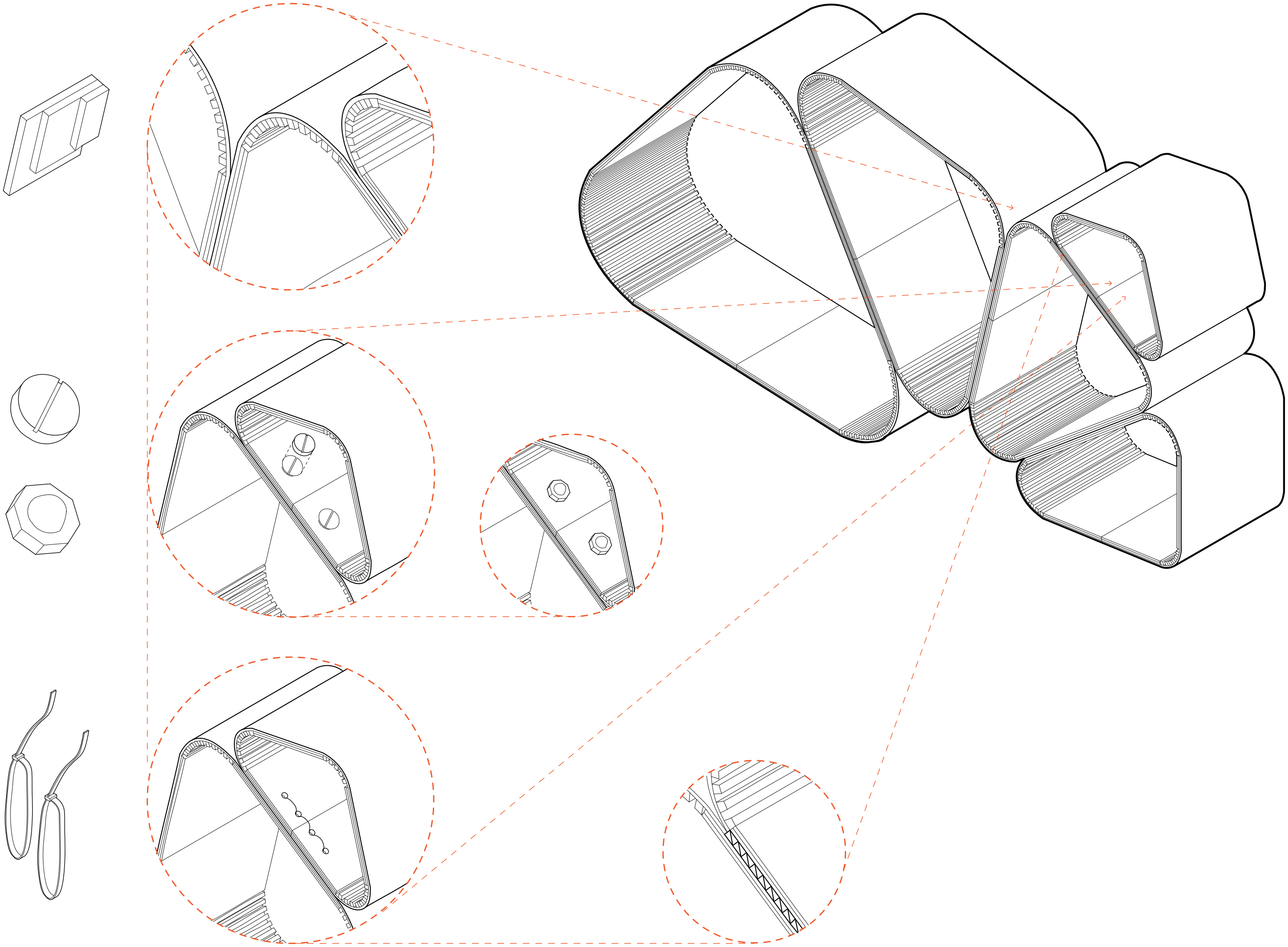






DETAIL STUDIES

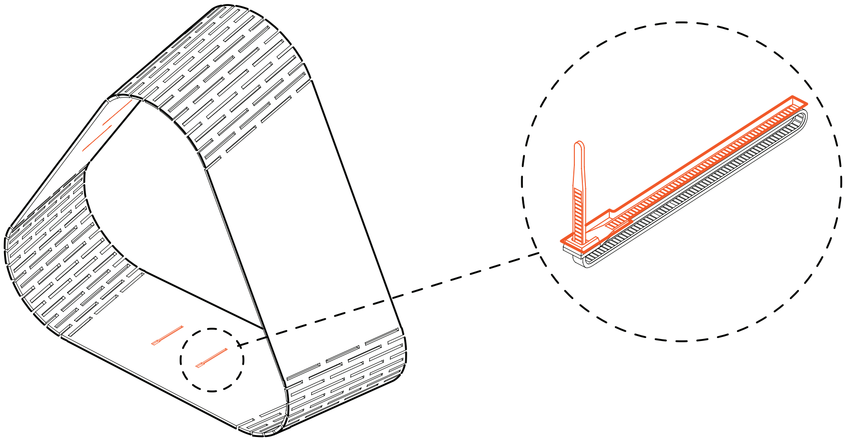
INITIAL JOINT SKETCH

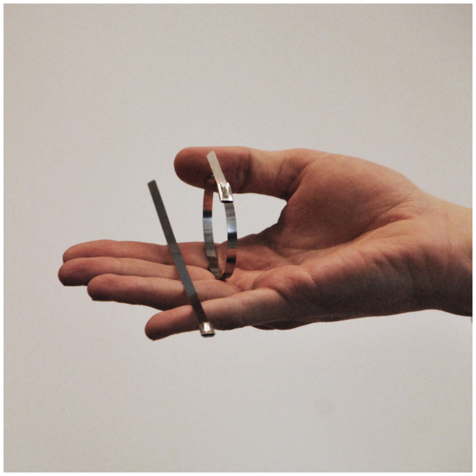


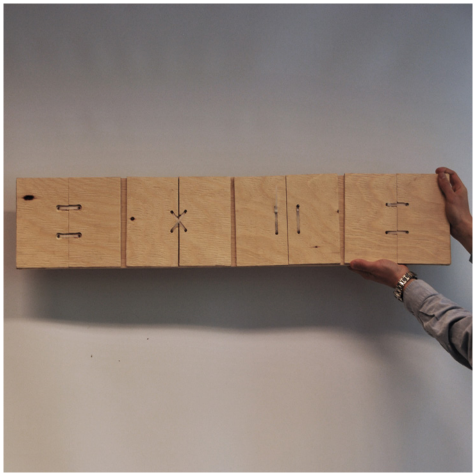
DETAIL STUDIES

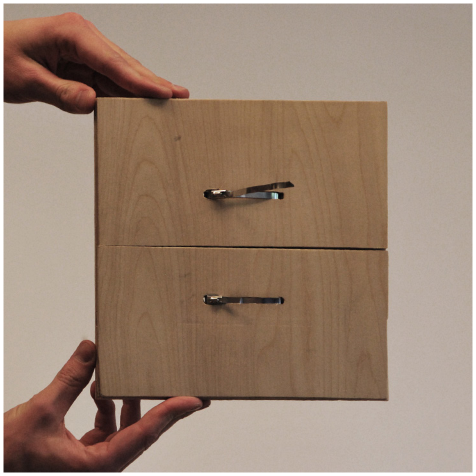
PHYSICAL TESTING OF JOINTS

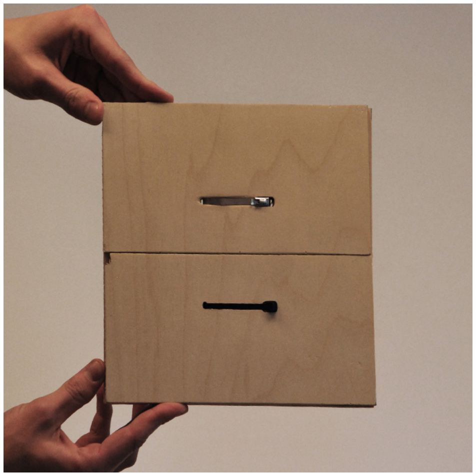
In order to attach the units together, we have studied multiple different options, such as bolts, nails and timber joints. The selected joint are based on and has the same direction as the kerf patterns. The joining of the units is done with metallic strips that are placed in cut out grooves where the strip is recessed into the plywood to create a nice continuous surface.









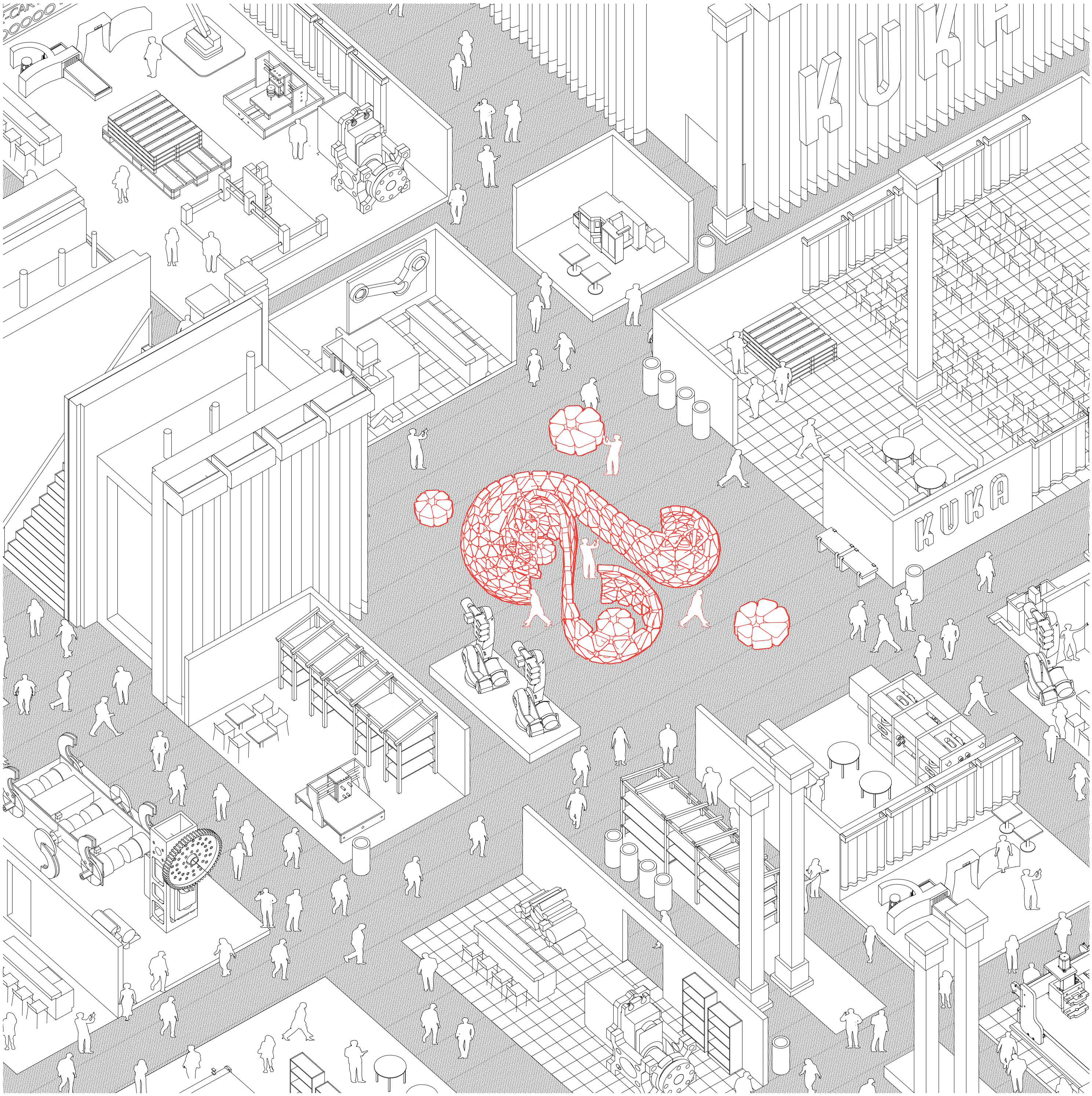


3
FINAL DESIGN

GLOBAL FORM

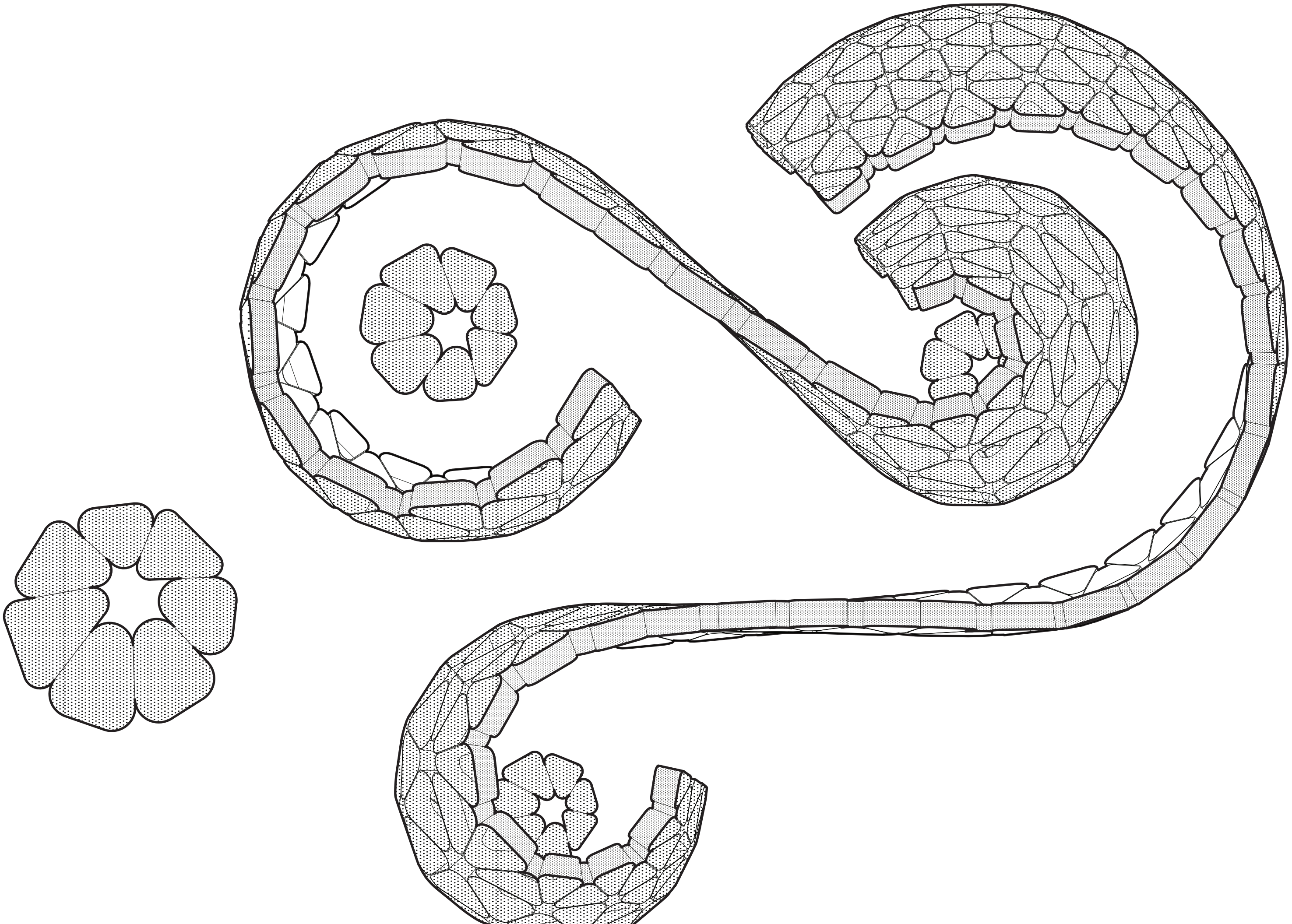
RENDERING

The global form seeks to provide different aspects of design. Both in terms of spatial and interior qualities but also as a hub for reprograming the existing movement in the exhibition hall. It is a pause/break in the hectic fair trade landscape and a contrasting interior space that fluctuates between dense and open. The structure embraces the room and provides a gathering place for people with an interest for wood and technology. It´s is an eye-catcher and will according to the customer act as a visual label for 2016 Tomorrows Wood Production. Different design treatments has been performed to enhance the spatial experience as well as creating a more dynamic form that will act as a visual attraction in the exhibition hall Svenska mässan.


KUKA
KUKA

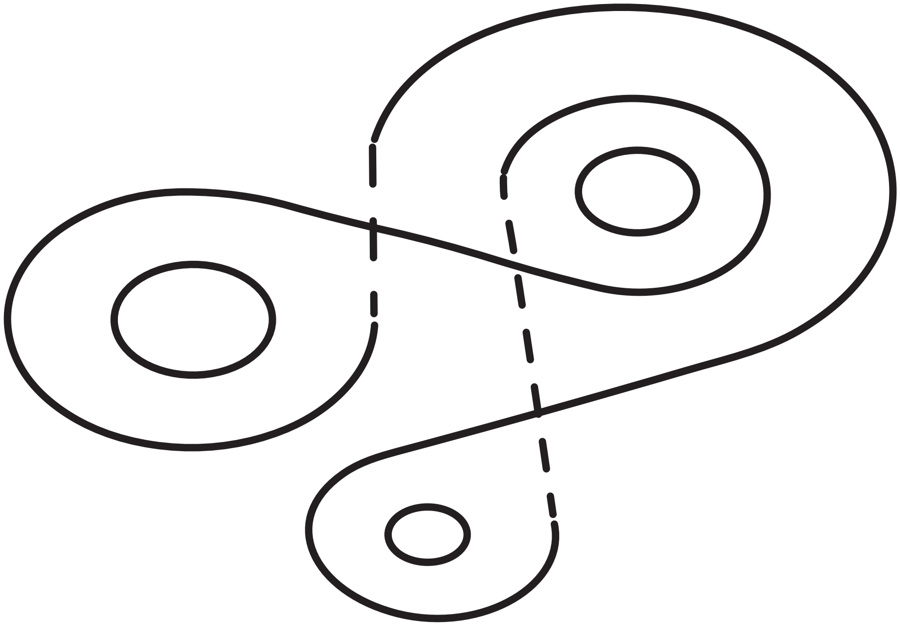
GLOBAL FORM

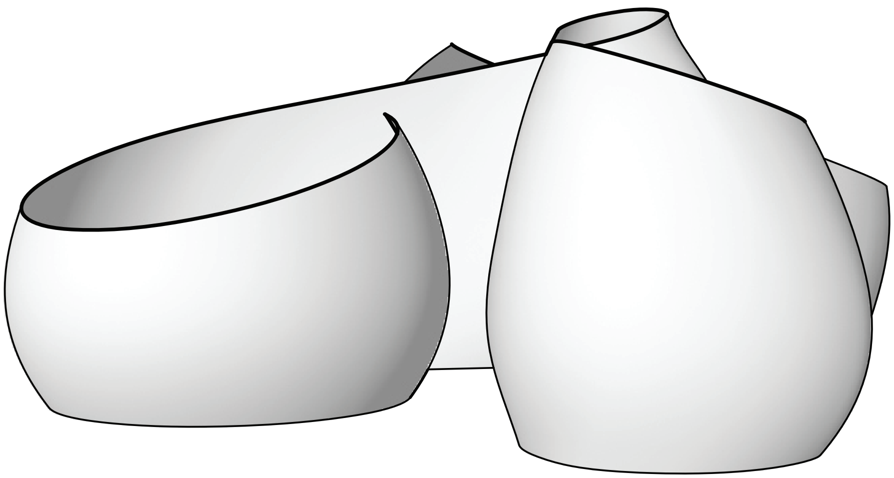
FLOORPLAN 1:50



GLOBAL FORM

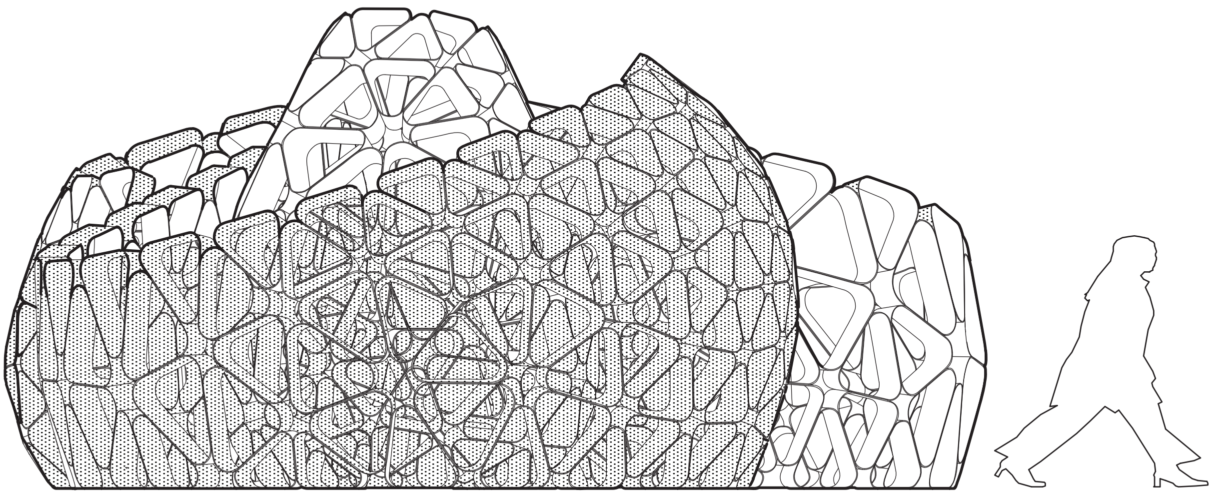
3-DIMENSIONAL SHAPE



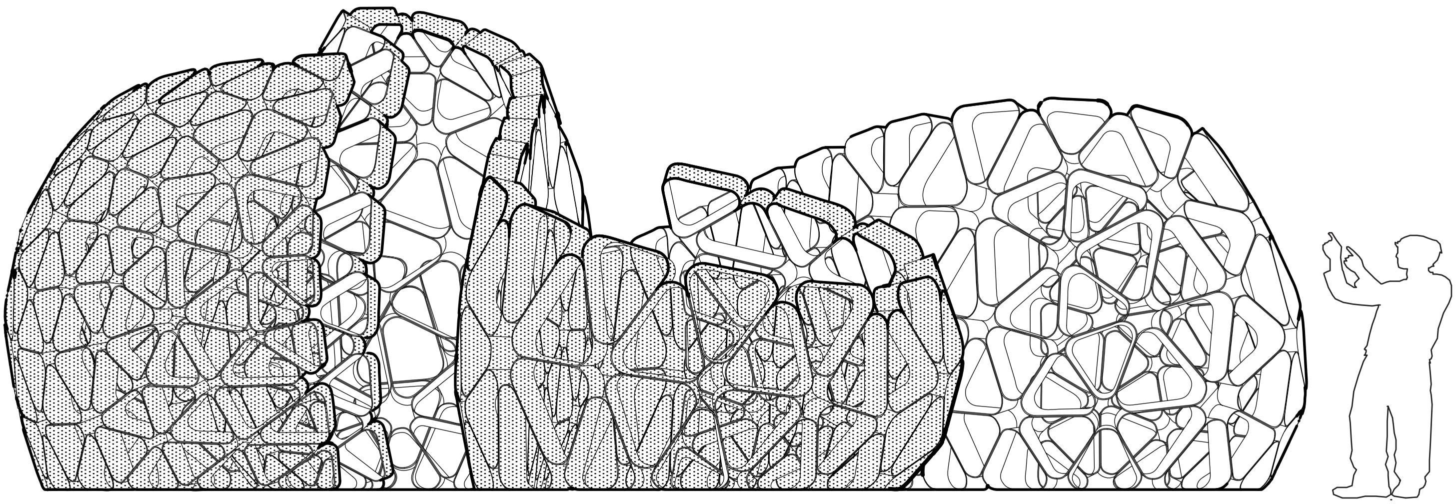


FINAL DESIGN

CORNER ELEVATIONS 1:50



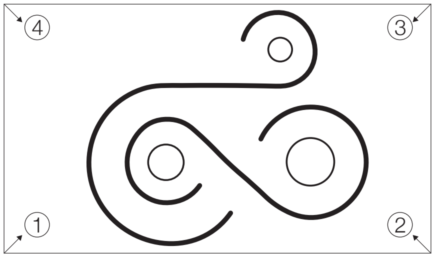
Corner 1

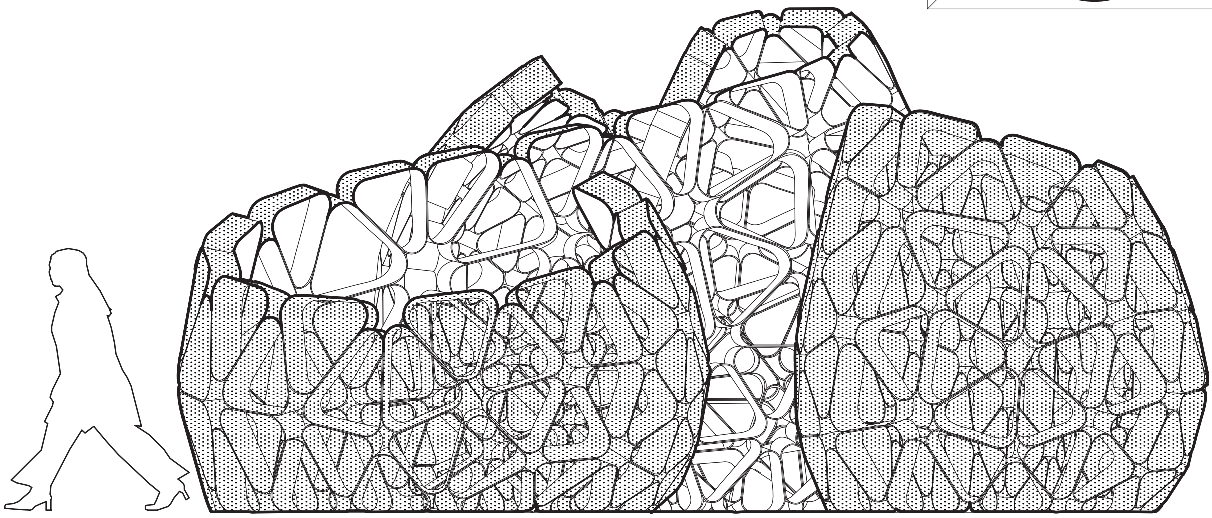


Corner 2

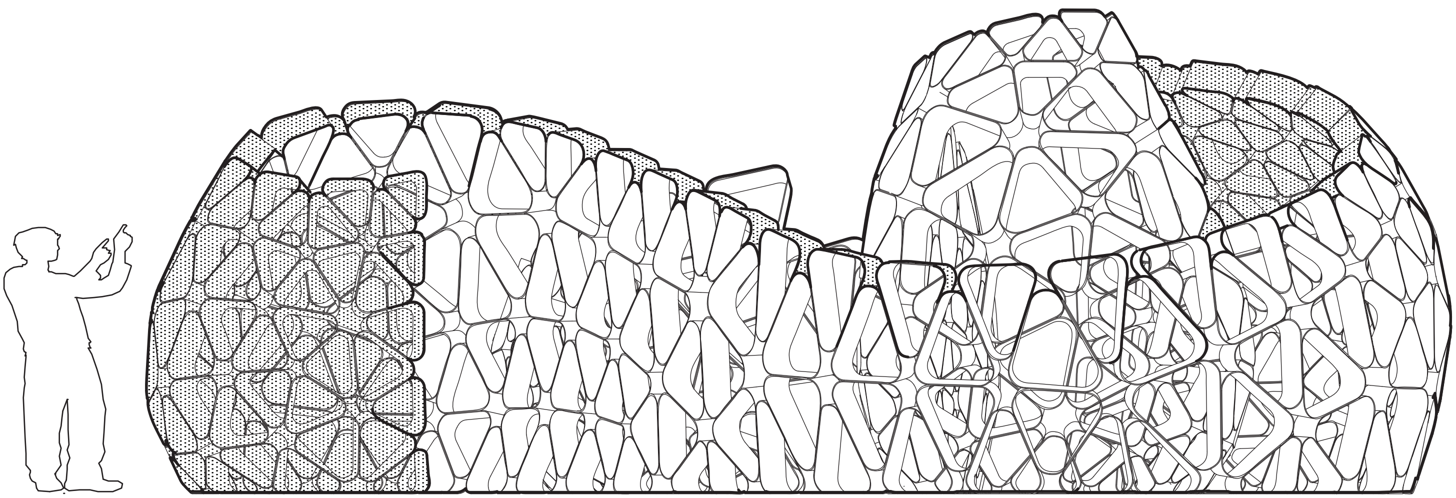
FINAL DESIGN

CORNER ELEVATIONS 1:50





Corner 3

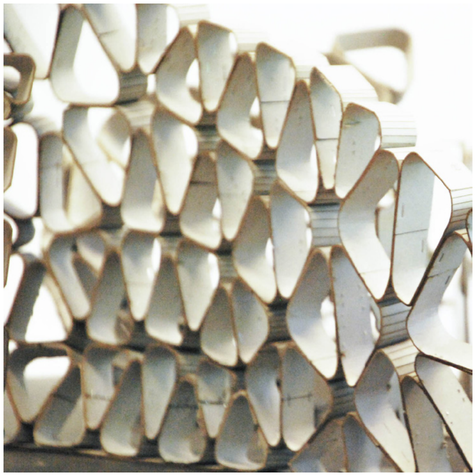


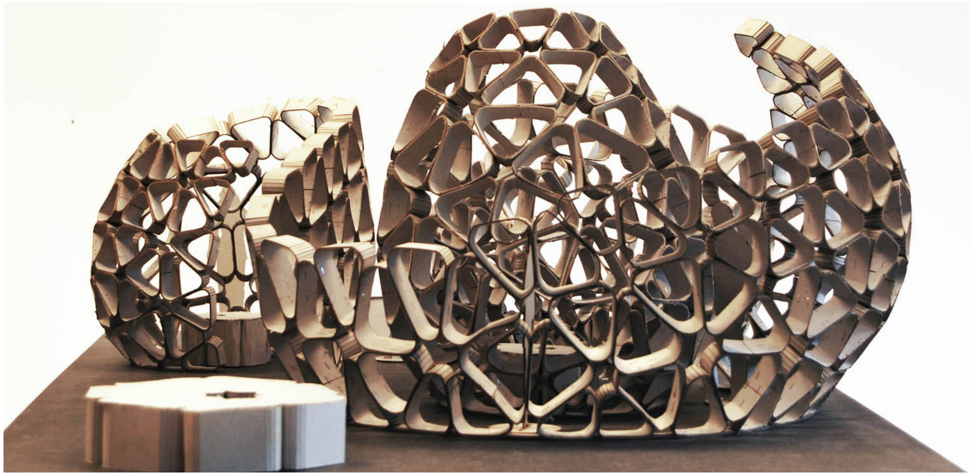
Corner 4

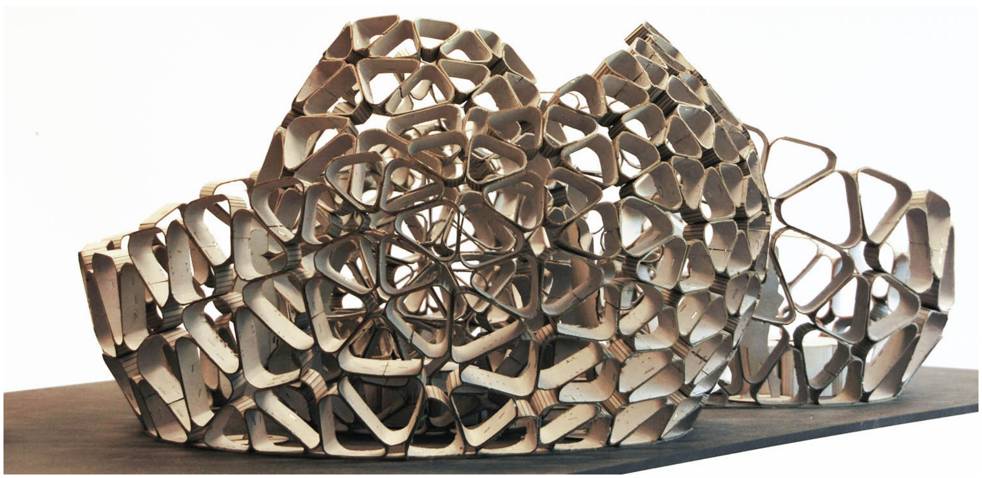
FINAL DESIGN

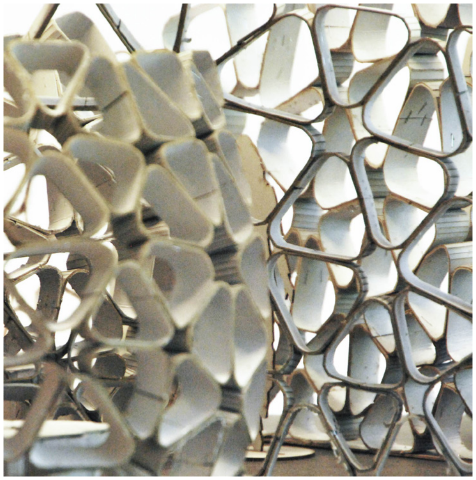
1:10 model

In order to simulate the assembly process, a 1:10 scale model was built of the structure. 469 pieces were laser cut on 6 sheets of 600 x 900 x 1.25 mm grey cardboard. The first step in the assembly process was to identify and sort the pieces by loops (about 50 in total). These were folded and connected using a stapler. Subsequently, the loops were connected with each other to form the overall structure. It was realized that a high level of parallel work could be conducted which is thought to be applicable also into the context of the full-scale structure. Using the scale model, it was possible to control that the placement of the unit seams were correct. Also, by placing loads on the scale model, a sense of structural behaviour could be confirmed.







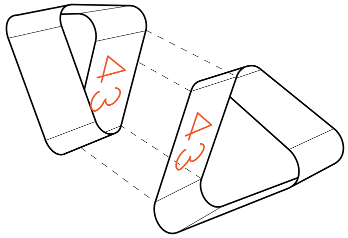


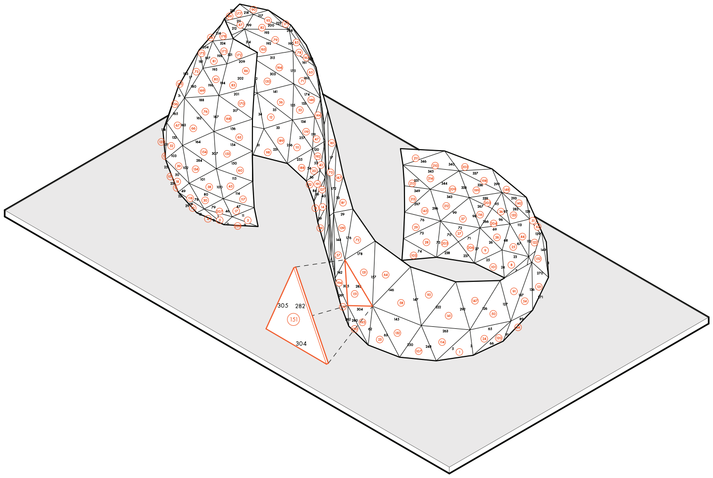
4
FABRICATION PHASE

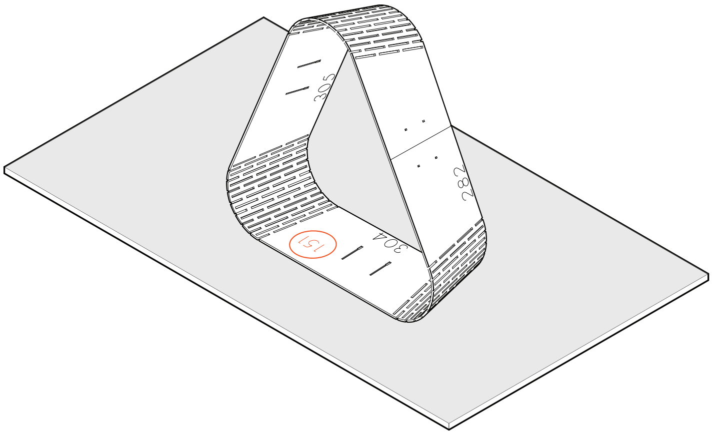
FABRICATION

MESH TOPOLOGY

To control the underlying geometry of the structure, a triangular multi-valent mesh has been used. The mesh consists of three types of elements - faces, vertices and edges. Using an object oriented programming approach in the information modelling process, the connectivity is stored in the geometrical unit itself. For instance, face 1 is adjacent to face 0 and 2, and edges 2,3,4. To the right, this is exemplified by face 151. The topology information of the mesh is passed on to the individual units. After the three dimensional representation have been generated (including the fillet), the indices of the mesh faces become the indices to the units (151 to the right), and the edge indices becomes the offset surface face indices (304, 405 and 282 to the right). This data becomes absolutely essential for the physical assembly process. Two units are paired up through a shared surface index.



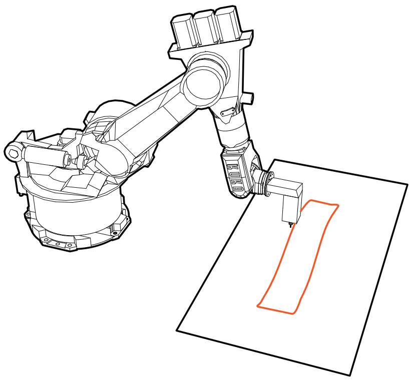


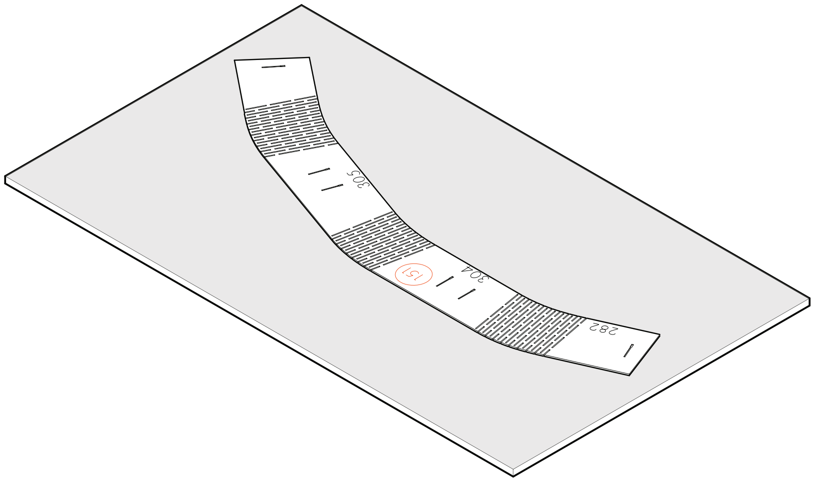


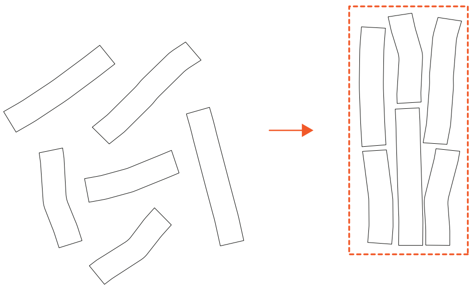
FABRICATION

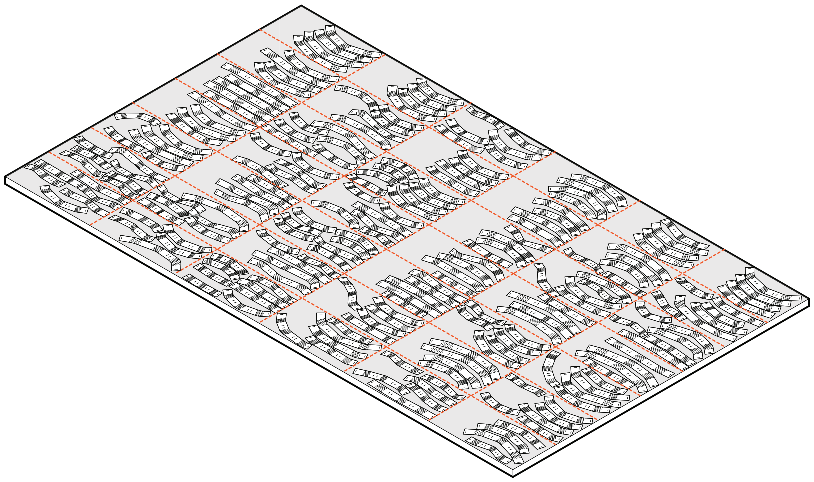
SHEET LAYOUT / NESTING

Since all surfaces in an individual unit are singly curved, an unrolled (i.e. flatten out) representation can easily be created. The topology information of the flat piece is inherited from it's deriving 3D shape. This makes it possible to orient it when it has been folded. Both geometries are stored in the same digital object during the modelling phase to ensure their connection. Once the unit has been unrolled it can be fabricated using a 3 axis CNC cutter. Packing arbitrary geometrical shapes on to a defined outer frame in such way that in-between space is minimized, is classical mathematical problem which has clear applications in this case. Using the correctly oriented geometry from the previous step, the unrolled representations are places on 2500 x 1250 mm rectangles using an optimization algorithm. For the inner structure, the total amount





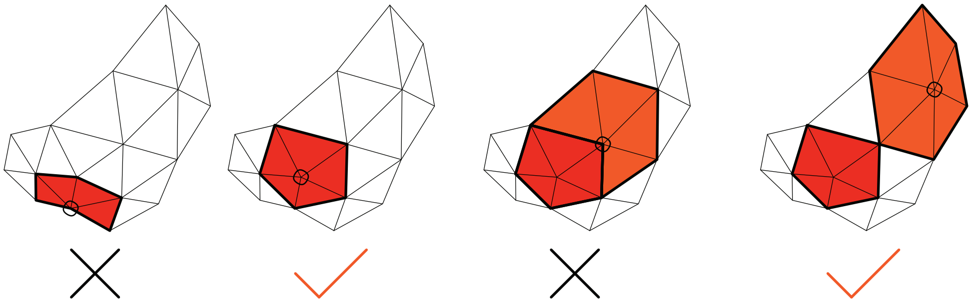


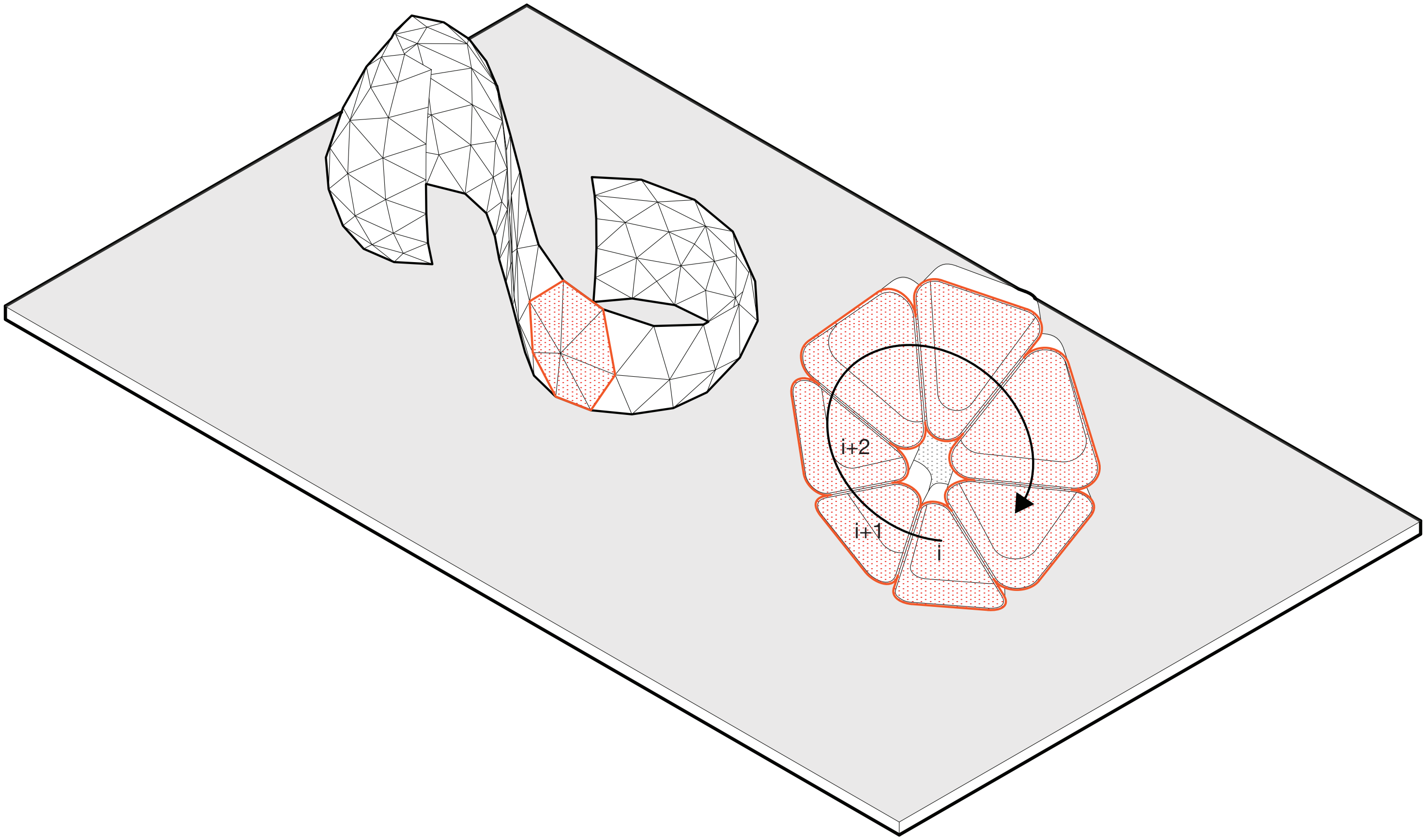


FABRICATION

UNIT SEAMS & LOOPS

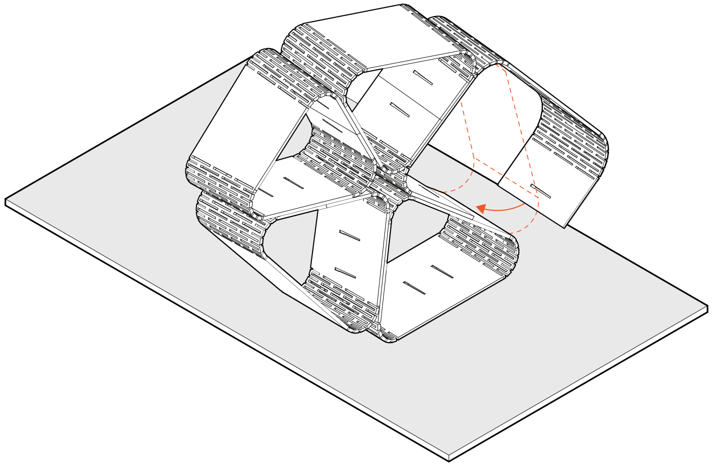
As previously described, the detail of the joint is solved by attaching the two free ends to its neighbouring unit. This means that seams from two units must not meet in a neighbouring surface. As an approach to solving this, finding rings of triangles within the mesh closed loops can be created since the free ends will always meet a solid unit surface. (unit i can be attached to unit i+1 in the loop). An algorithm for finding these loops was developed following the logic that a ring cannot be created if the loop contains any naked edges or faces that are already occupied by other loops.



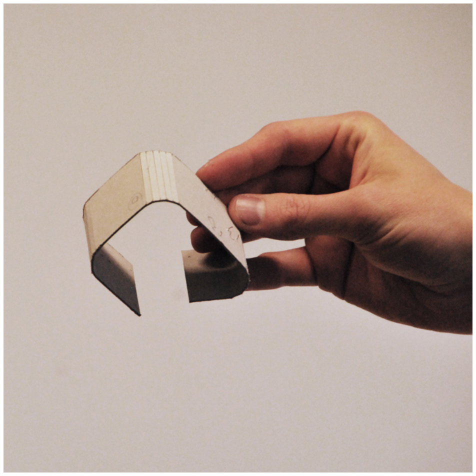


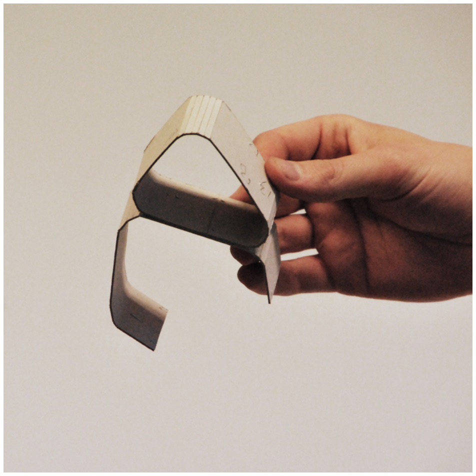
FABRICATION

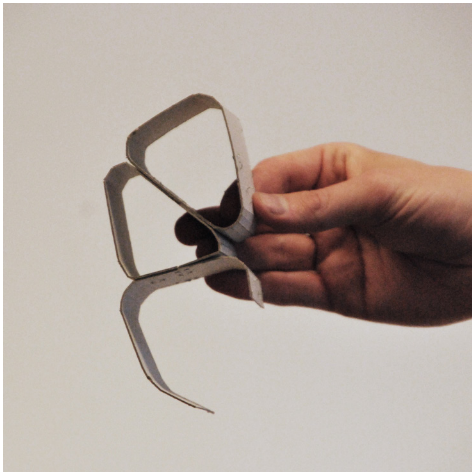
LOOP LOGICS

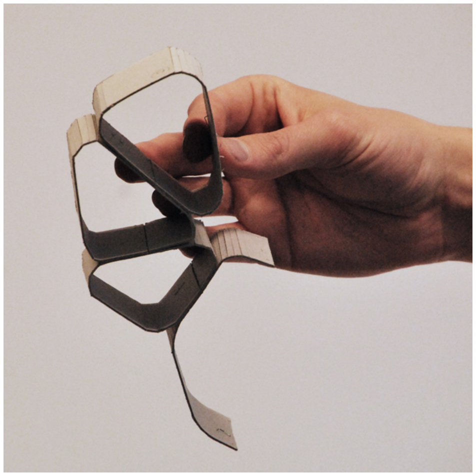


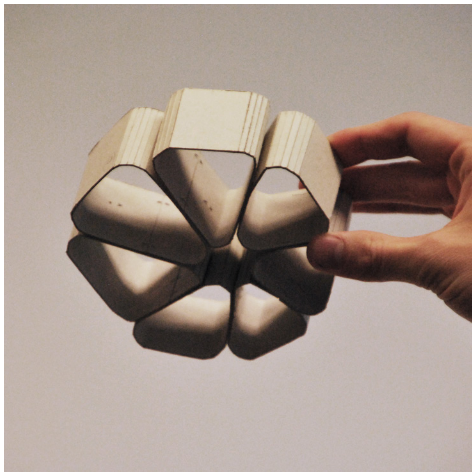
As previously described, the detail of the joint is solved by attaching the two free ends to its neighbouring unit. This means that seams from two units must not meet in a neighbouring surface. As an approach to solving this, finding rings of triangles within the mesh closed loops can be created since the free ends will alway meet a solid unit surface. (unit i can be attached to unit i+1 in the loop). An algorithm for finding these loops was developed following the logic that a ring cannot be created if the loop contains any naked edges or faces that are already occupied by other loops.









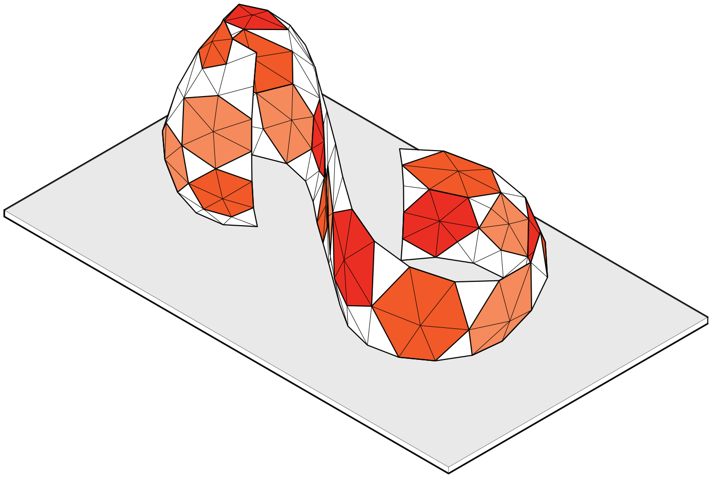


FABRICATION

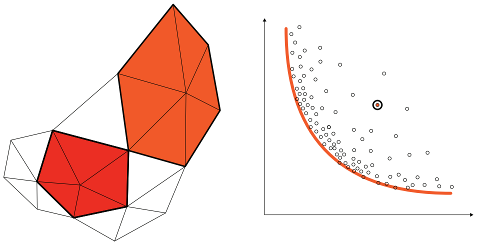
LOOP OPTIMIATION

For an arbitrary mesh all faces are not guaranteed to become members of rings. However, a goal was to maximize the number of faces included in the rings to simplify the assembly process. To quantify this, a ratio between the number of faces members of loops and the total number of faces in the mesh was computed. For instance, the mesh above would give the ratio 11/20 = 55%. As a first iteration, the mesh for our temporary structure had a loop ratio of 53.2%.

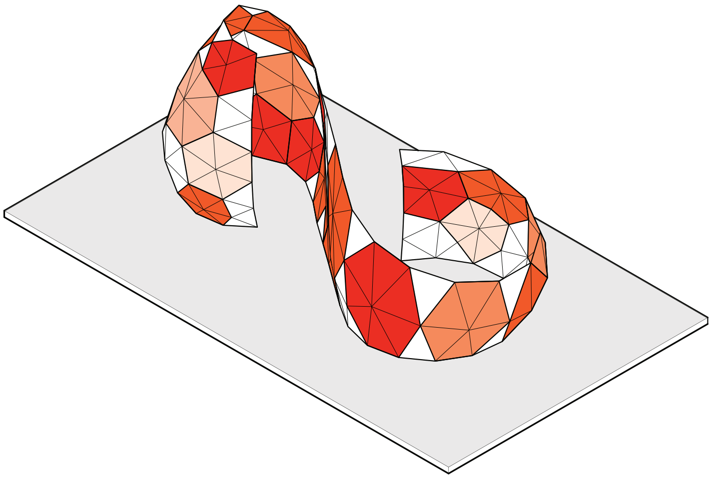
By looking at the grid, one clearly realizes that many loop options are possible within a multivalent mesh. As previously mentioned, the looping algorithm will not create a loop if the center vertex contains any adjacent faces that are already occupied by a loop. Therefore, the order of vertices sought by the procedure becomes essential for the loop ratio outcome. By using genetic algorithms, it was possible to to find the vertex order that gave maximum amount of loops. The mesh for our temporary structure was improved to 71.3%.



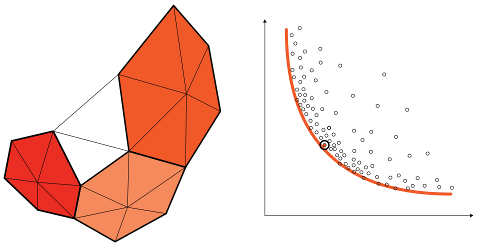
Loop distribution initial attempt



Initial individual on Pareto front



Loop distribution after optimization algorithm



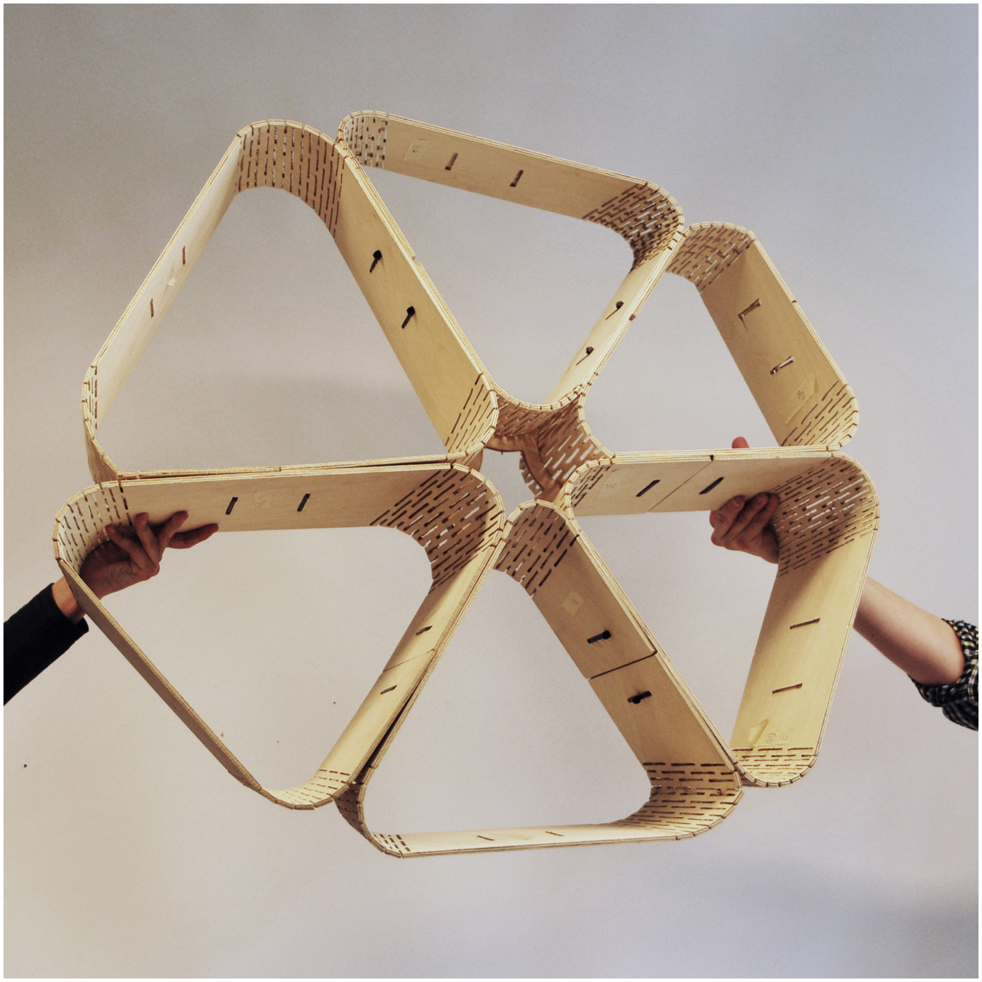
Optimized individual on Pareto front

FABRICATION

FULL SCALE LOOP MOCK-UP

A full scale mock-up was created in order to make sure all different parts of the script are accurate. This includes the kerf-patterns (depending on bending radius), joint details, unrolling of units.
After we had fabricated a few units, we realized the structural capacity had decreased more than we had expected due to the kerfing. There is a fine balance between removing enough material to decrease the bending stiffness, while still keeping enough structural capacity.

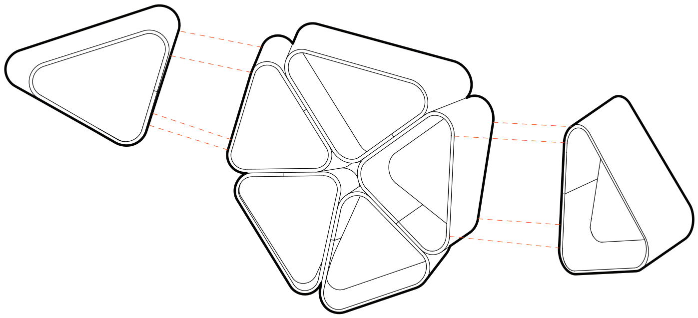
The path the forces will follow is dependent on the stiffness of the elements in the system, which in a way creates a possibility for us to fine tune the structural behavior of the global structure just like an instrument, placing more or thicker elements in the areas of larger forces, or two layers of them where we have large moment forces.

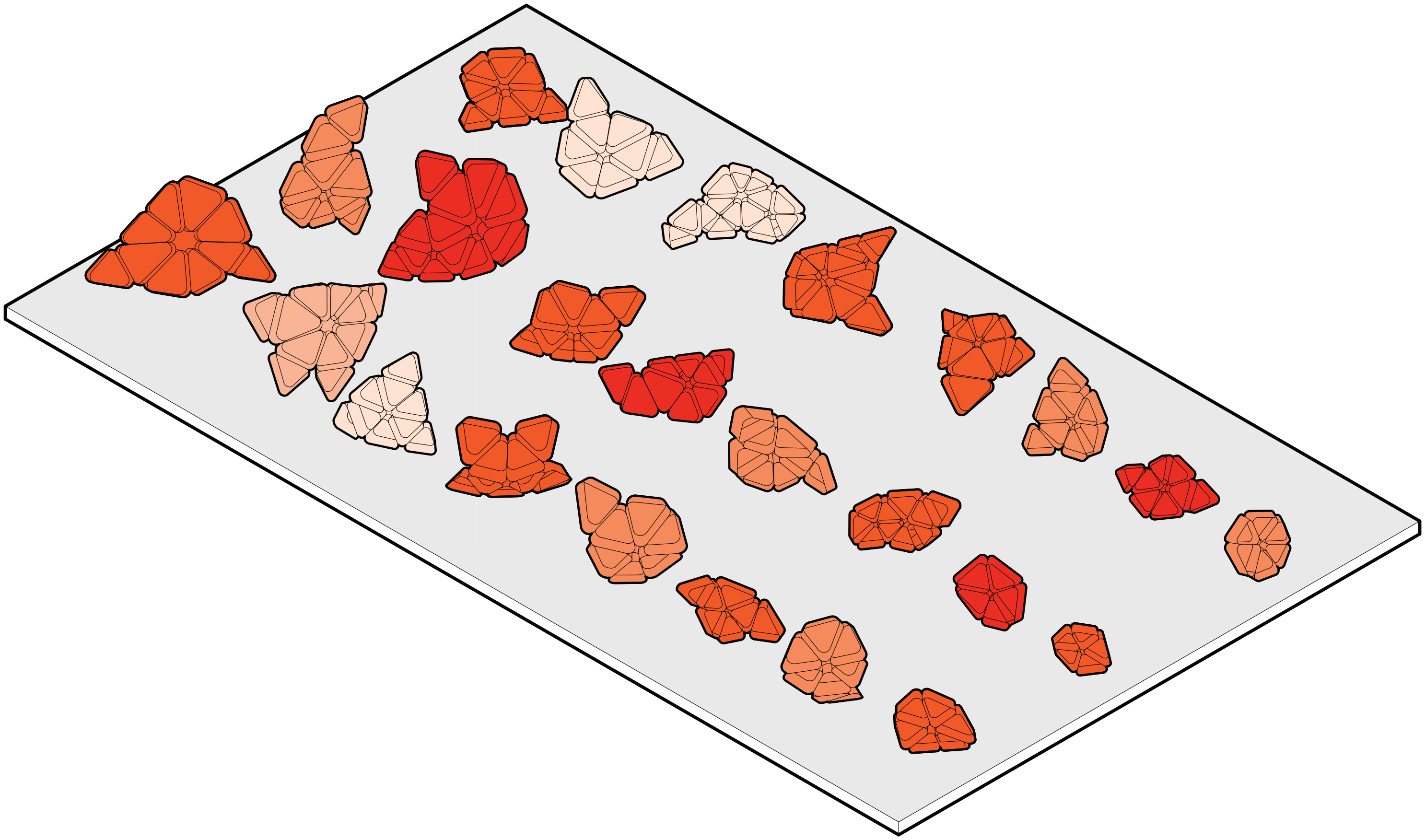


FABRICATION

LOOP APPENCIES

For an arbitrary mesh all faces are not guaranteed to become member of a ring. Some will be left over (here referenced to as appendices), but due to the fact that all units in a ring will have a non-seamed face facing outwards, they can easily be attached its closest ring.

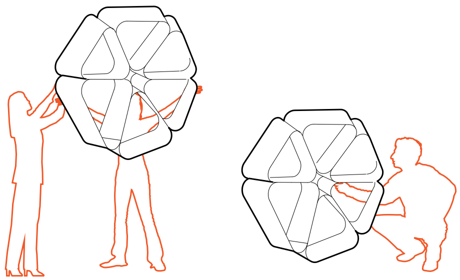


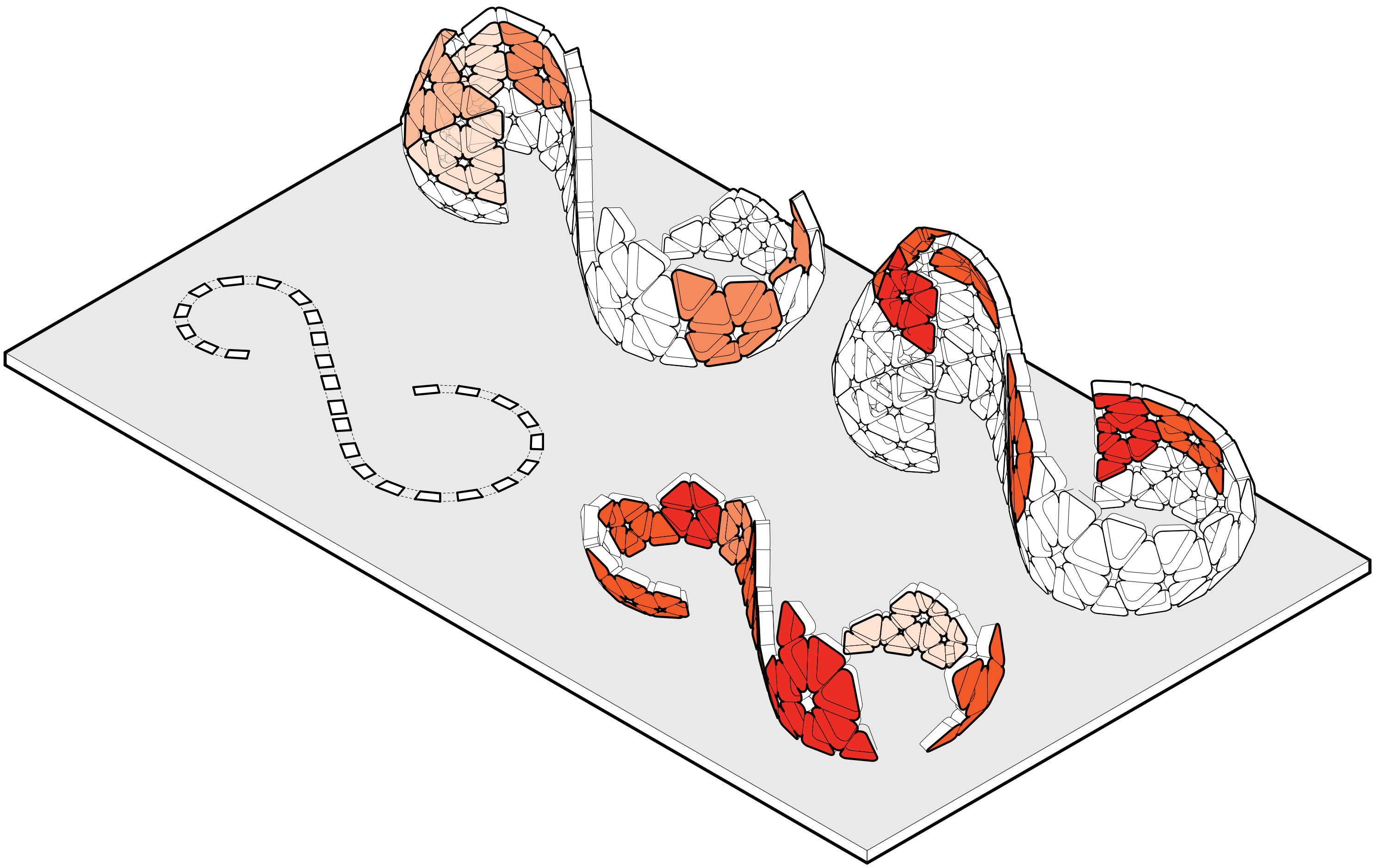


FABRICATION

CONSTRUCTION SEQUENCE

The structure in the context has in total 24 loops which can be transported to the site. The assembly process of the units to become loops doesn't necessarily have to occur on spot. The first step on spot is to built the base on which the structure will be placed onto. It will also function as a guide during the assembly. The loops can now be placed sequentially.

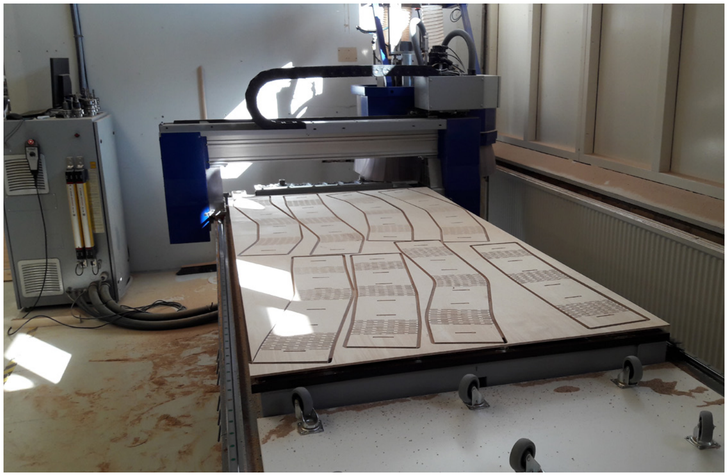




ASSEMBLY

ASSEMBLY OF UNITS TO LOOPS

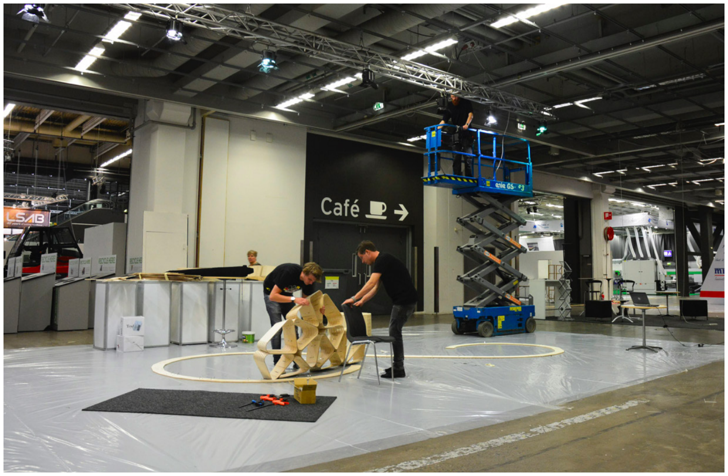
As a first phase of the assembly process, all units were combined to loops and appendices. With this method, the number of pieces to handle went from 216 individual units to 25 loops. The units were first sorted and grouped into loops (top left picture) and then assembled together to form a stable loop. With help from friends and fellow students, the 25 loops could be assembled during two days.



ASSEMBLY

ASSEMBLY OF LOOPS ON SITE

The loops were then moved to the site, where a base plate had been placed in order certify that the structure is placed in the correct position. The units are attached to the base plate using the same connection detail as for the joining of two units. Three bolts were used in order to secure the structure to the ground.



5
RESULT & CONCLUSION

FINAL RESULT

CONCLUSION

The core question this Master's Thesis addresses revolves around the the interconnected relationship between digital tooling and architectural design development in the context of wood as modern building material. By using a research by design approach, different concepts of a temporary structure were developed. One was selected and realized in full scale for the 2016 Wood and Technology exhibition in Gothenburg, Sweden. By making automation in geometry generation an integral part of the design and fabrication process, more than 200 unique triangular pieces were produced. Each triangular unit had a unique kerfing pattern corresponding to their specific requirements. As the scope of the research mainly targeted the architectural qualities in relation to the materialization of structure, the accuracy of structural modeling and simulation was deprioritized and is recommended as focus for further research. All in all, considering our research focus as a point of departure for design development, we consider the results of the project as successful both in terms of the realized structure and the developed design methodology.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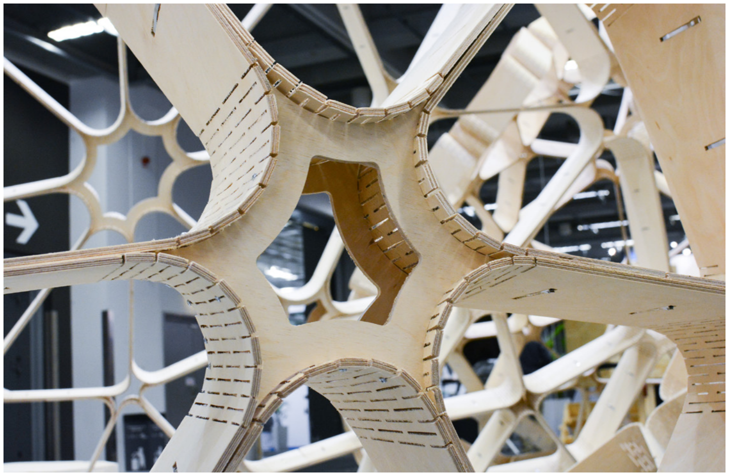


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Kerfing – Bending wood on the tablesaw ©Stu's Shed URL: *https://stusshed.files.wordpress.com/2007/07/3-the-resulting-curve.jpg* [Accessed 20 February 2016]