Lightweight structures - Project report

SKYWAVES

Workshop lightweight structures - Marijke Mollaert
2016-2017

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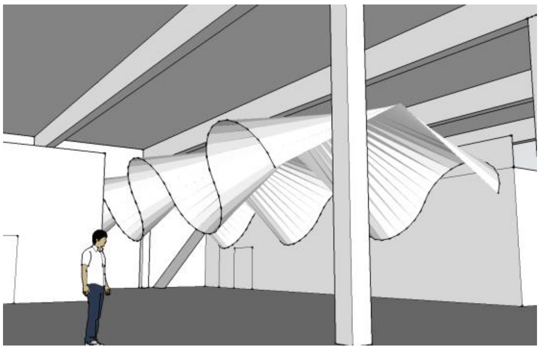
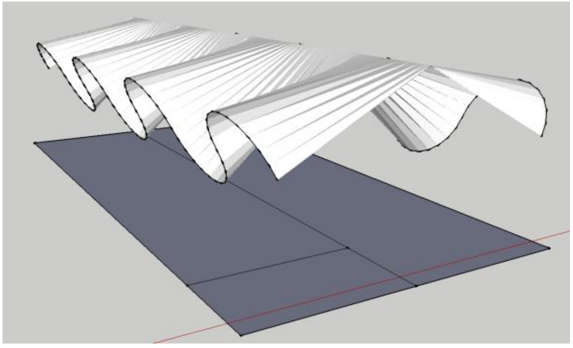
1. **Genesis** the design evolution

The aim of the exercise proposed by the course Workshop lightweight structures is to realize an experimental setup. This year's proposal is to create an architectural installation that gives an extra dimension to the reception area of the SIOEN company factory. The point is to showcase the possibilities of textile architecture.

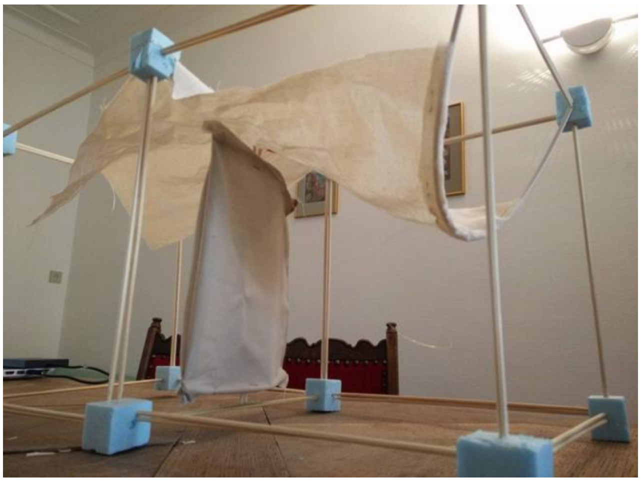
The first design proposal for Skywaves was based on simple rectangular sheets given a double curvature to cover the central area.





After the basic idea of structure, the first model was made as the picture shows, a frame was used to define the site and space of structure, and one modular membrane wall panel was set in the middle because it can be used not only as a wall to make the space more interesting but also be used as an ornament after decorating this membrane.

As a part of this first approach, it was also planned to create wall textile panels with a the curve form.

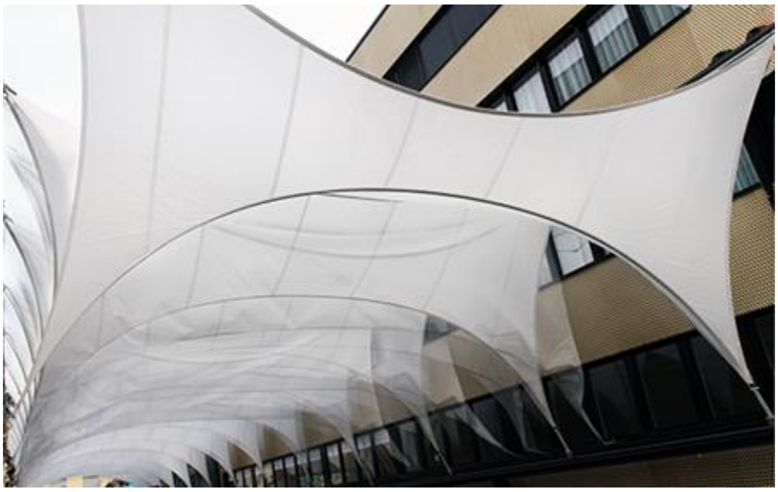


However, the basic concept had some disadvantages. On one hand, the rigid curve element in the end of the membrane made it static and heavy. For that reason this configuration was not able to give us any transformability. On the other hand, once we try to translate this into a modular elements, the joining between elements was almost impossible. Moreover the textile material was not as elastic as we expected making it even more difficult to support this solution.

After this failure we decided to keep the idea of a large textile element but with improved modularity and looking for a transformable surface.

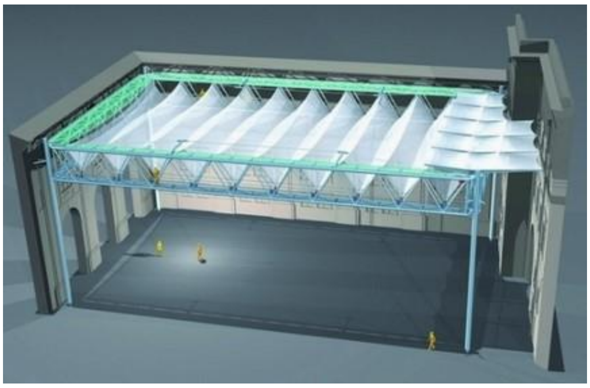
Based on the shortages of the intitial idea, the structure was improved. The work in the center of Buchs, Switzerland, designed by Kugel Architekten inspired us. This structure is a retractable membrane structure that is 50m long through copying a basic pattern. The membrane can be folded or opened by using sliding tracks.

The reason why it can be deployed easily is because it has only two main elements: the wave shaped membrane and tracks.
Another reason for inspiration is the configuration of the membrane. It is a repetition of a basic pattern, giving it a certain aesthetic perception.



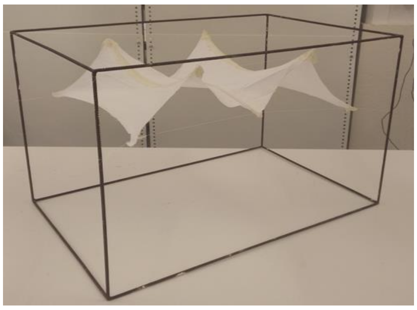
Therefore the concept evolved and is shown in following pictures. the pieces of membrane was cut like the work in Switzerland, their longer edges were connected with each other. This structure consisted of four pieces of membrane with supported boundaries. There are several sticks along the boundary in order to fix the shape so the structure can be opened or folded easily like the pictures show. The entire structure would be lifted into the ceiling through pullies. Its form (open or folded) would be controllable by special facility.

This structure still has several shortcomings. we realize that making a deployable frame may be too complex, and making it heavier then desired.
Hanging the structure with a pulley system even adds more complexity then needed.



Add a reference for the pictures where appropriate
We decided to change the attachment system, with boundary poles, for a tensile cables system, that can be fixed to the main structure of the site.

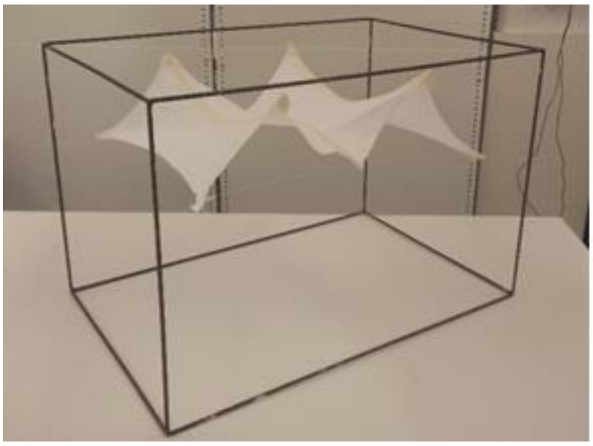
At this point we were close of the final shape of the membrane but still dealing with the deployable and transformable aspects.

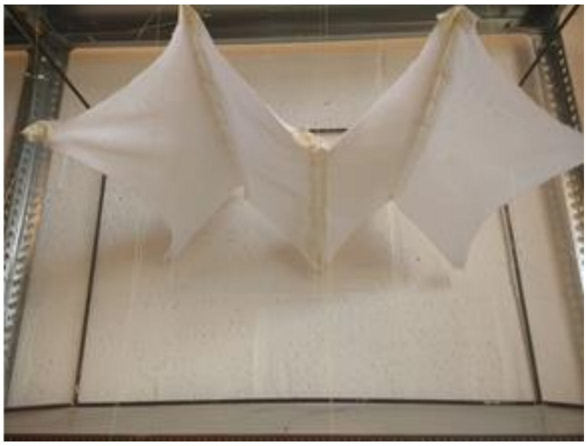


2. Final Design - General Concept

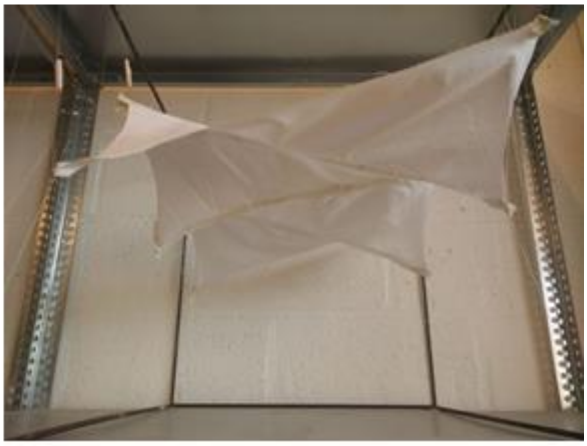
Because of the drawbacks of the first two concepts and their structural models, the concept was improved once again. The aim was to have a lighter object by minimizing structure and using cables. The new concept is to make a structure that can cover the entire indoor site and create a special and attractive space for mixed-use functions. In order to achieve this goal, the frame of the first concept model was used for space definition. The concept of deployability and transformability were meant to be kept.
The membrane structure is hanging in the air. This way, the whole structure only needs a few connection points, making assembly and disassembly really easy. For the membrane, the concept of a repeatable pattern was kept, This way different configurations of the membrane are possible by changing the position of the connection points.

From the concept model it can be seen that this model is transformable. The connection points of membrane can move vertically, with the semi-folded or opened it can show different configuration according to different use of structure.
For example, these following pictures are the standard position of each corner points and the configuration of structure.

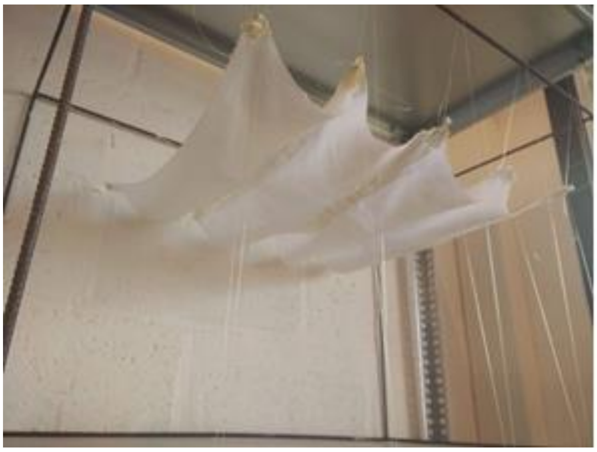
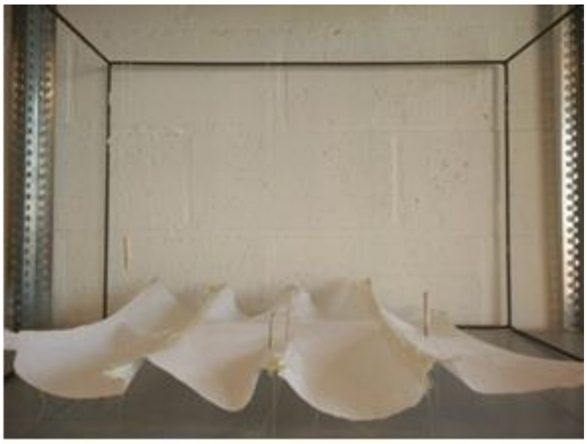




When the position of corner points along the vertical direction are changed, the different configuration of structure can be obtained. Below is an alternating shape where high and low points alternate on each side.

Because the corner points are controlled by pulleys and cables so that the entire structure can be deployed or dismantled easily, and it is convenient for cleaning or replacing the membrane, like the pictures show.

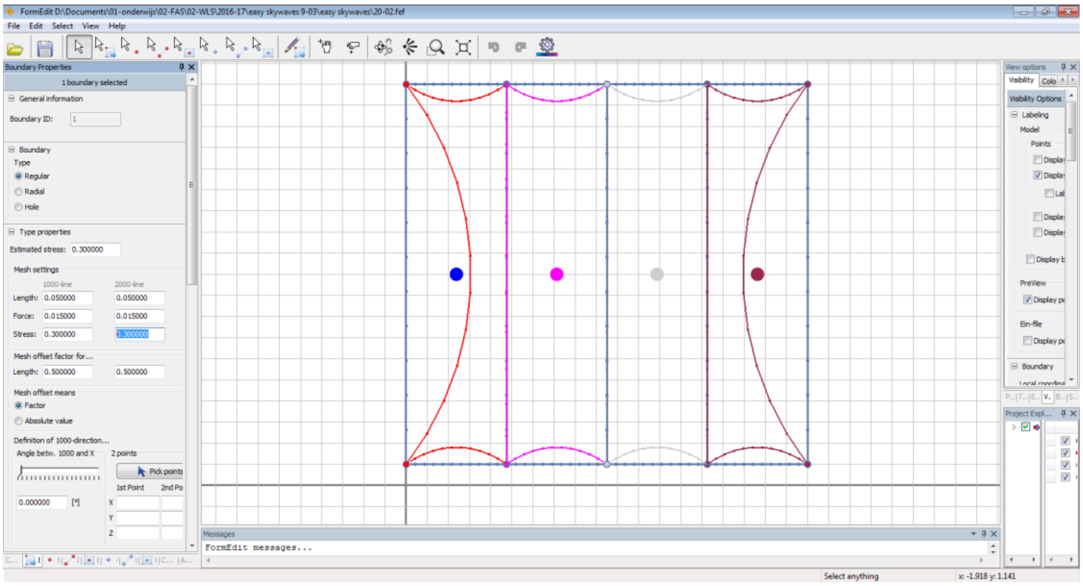
 

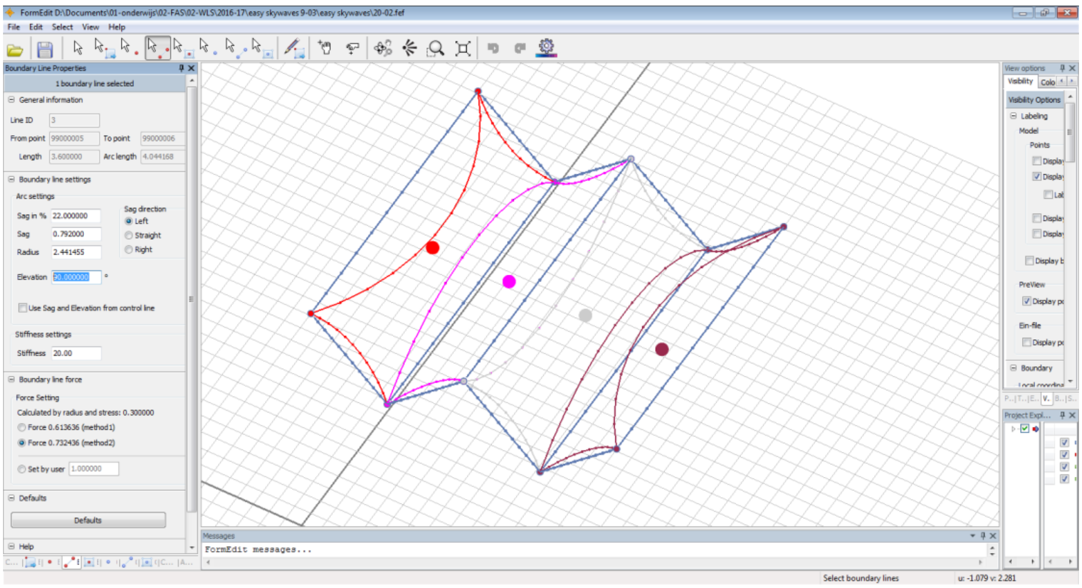
For practical reasons during the analysis and set-up, we work with fixed connection points. We have high and low points on specific heights, making it easy to connect and disconnect.

3. Analysis

For the analysis, we use the calculation software 'easy'.
We start off with the standard configuration of three high points and two low points on both sides of the membrane.

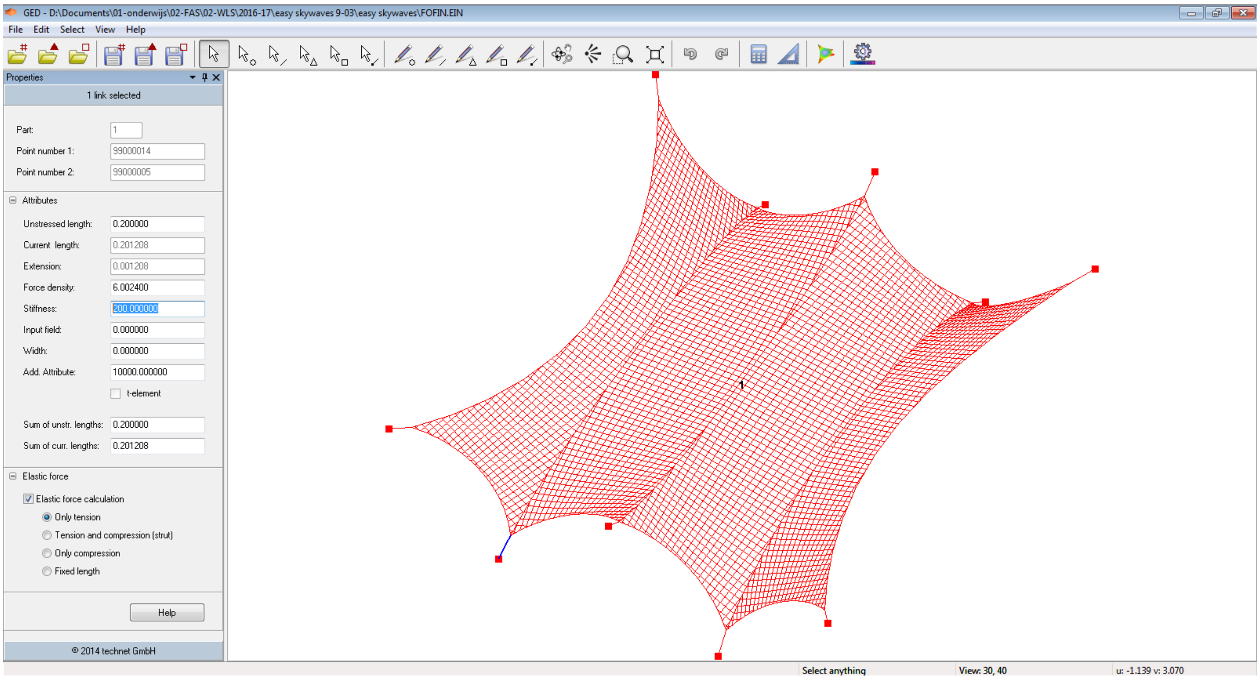
A pre-stress of 0.3 kN/m is applied on the membrane
The sag in the boundary's is defined in such a way that there is an almost straight line through the centre of the membranes (in the middle of the structure). This makes it possible to have multiple configurations without deforming the membrane too much.
The boundaries were also adjusted to approximate the 'serial configuration' (ridge and valley lines in vertical planes) in the middle. This limits the horizontal movement of the boundaries.





With these boundary conditions we can start the form-finding.

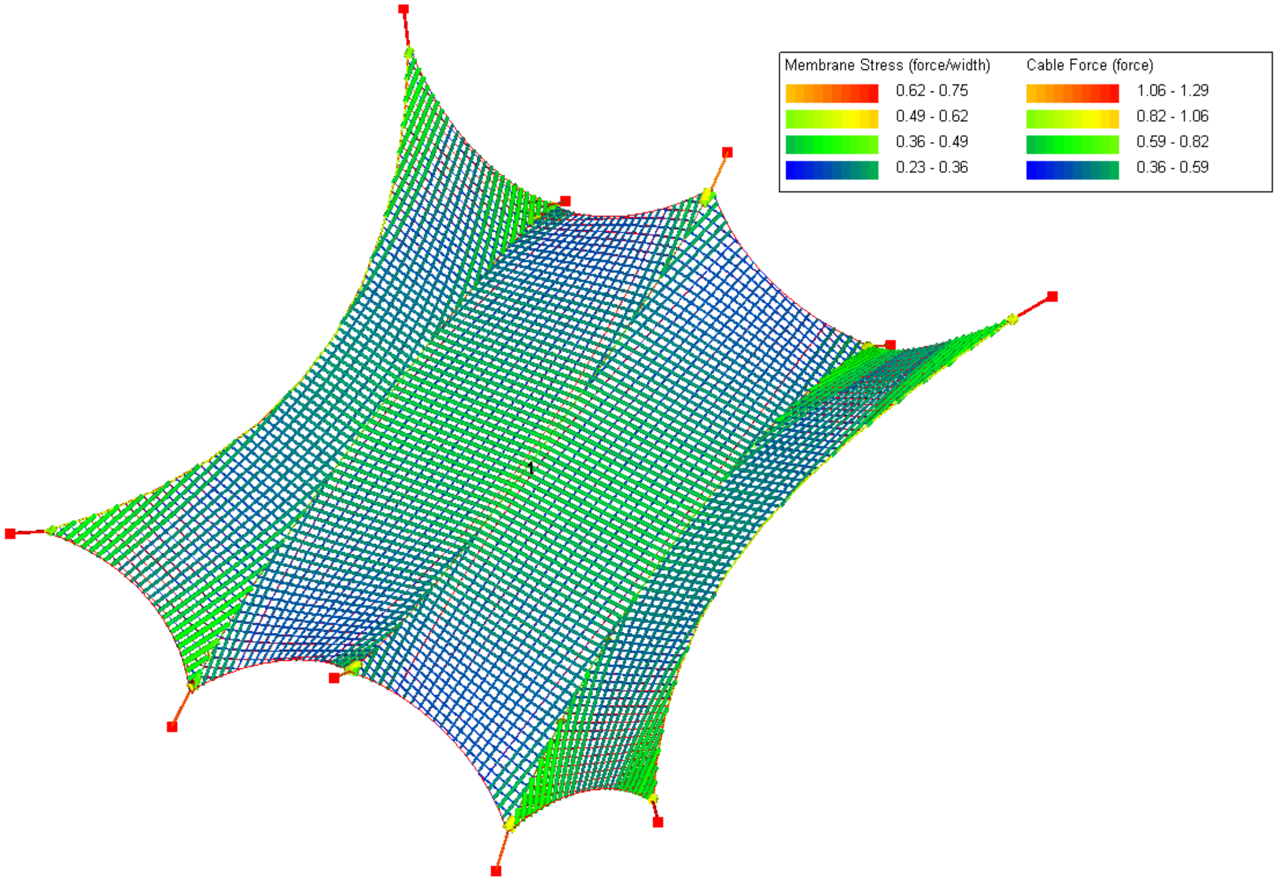
Additional links with a stiffness off 200kN are added. These links will act as the belts that are connected to our connection points, which are explained later in the detailing.



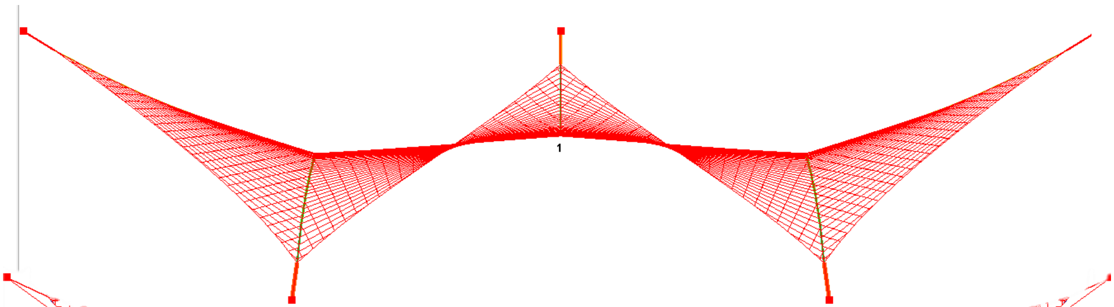
From this form-finding, we can go into the static calculations where the material characteristics and the gravity are added.

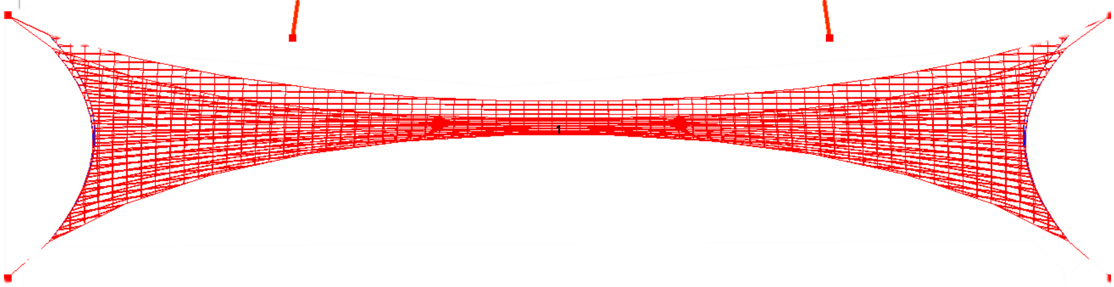
We use an extended material with a stiffness of 400kN/m in the warp direction and 390kN/m in the weft direction. A crimp of 130 is allowed and we use shear modulus of 20kN/m. For the gravity, a weight of 650g/m² is considered for the membrane.

This is the normal shape with stresses in the membrane between 0.23 and 0.36 kN/m.



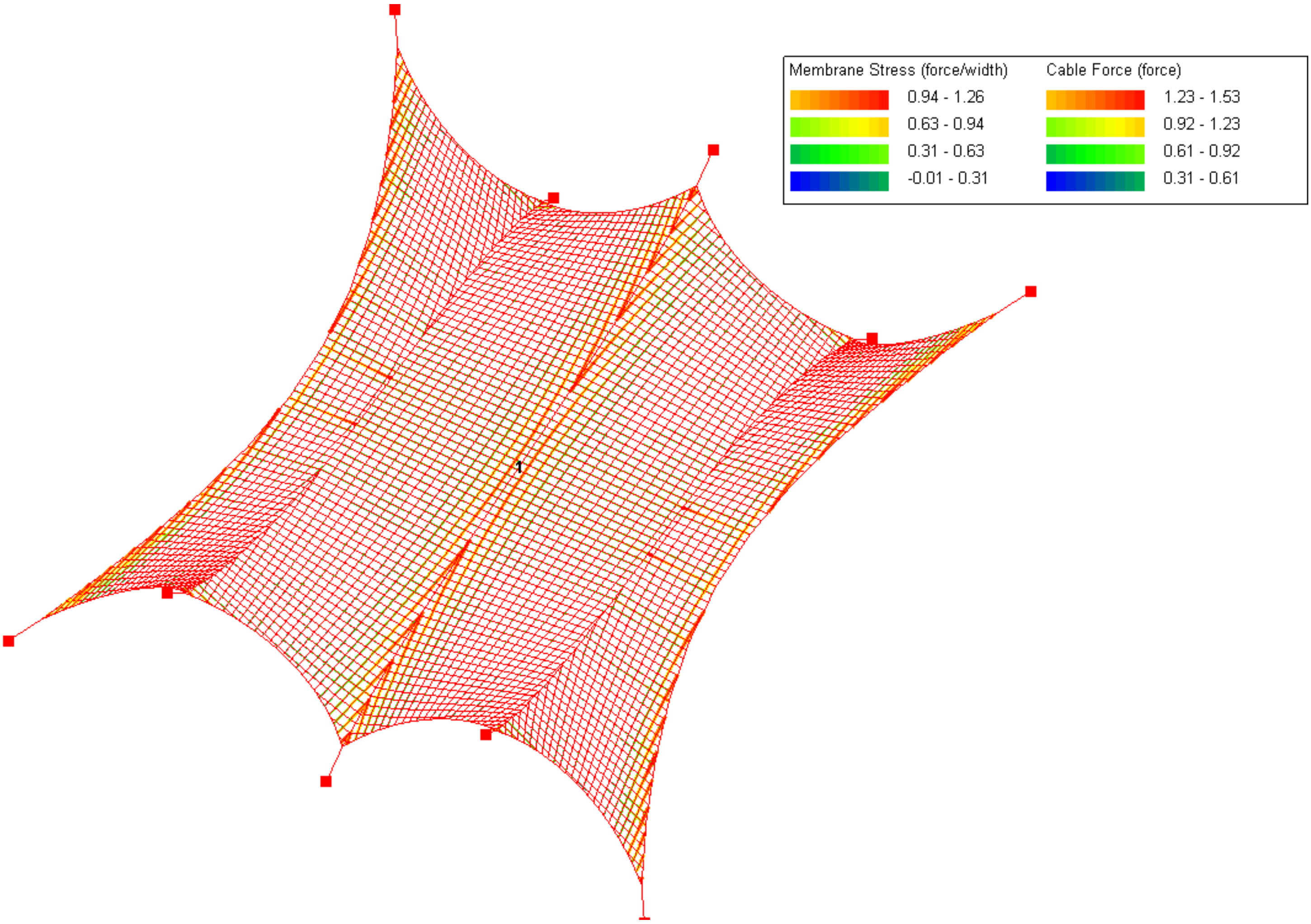
Here are the front view and a side view of the structure in this position:



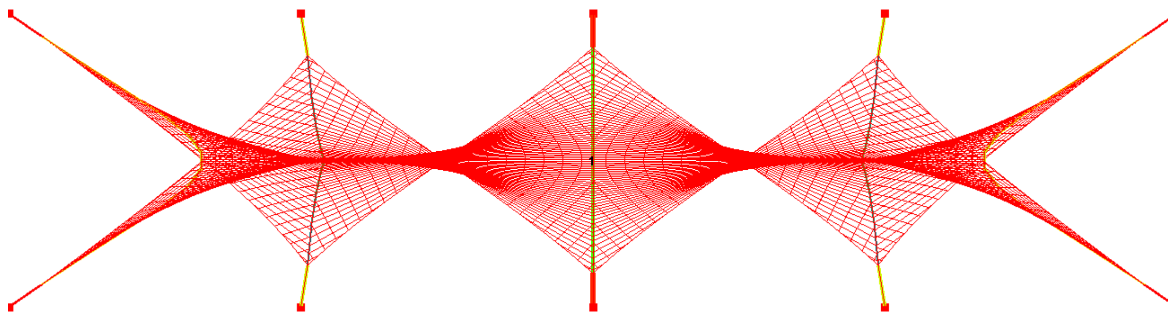


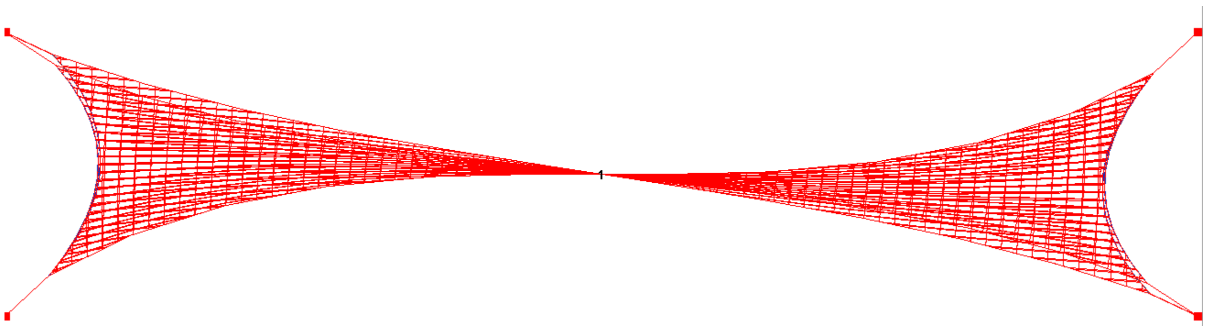
We simulated the inverse shape, where all high points become low points and vice versa, but since the shape is just the inverse of the calculated one above, we did not include it in this report.

After the calculation of the normal shape, we simulate the alternating shape, where the high and low points on one side are changed. In this configuration, the highest stresses inside the membrane are around 1.26 kN/m.

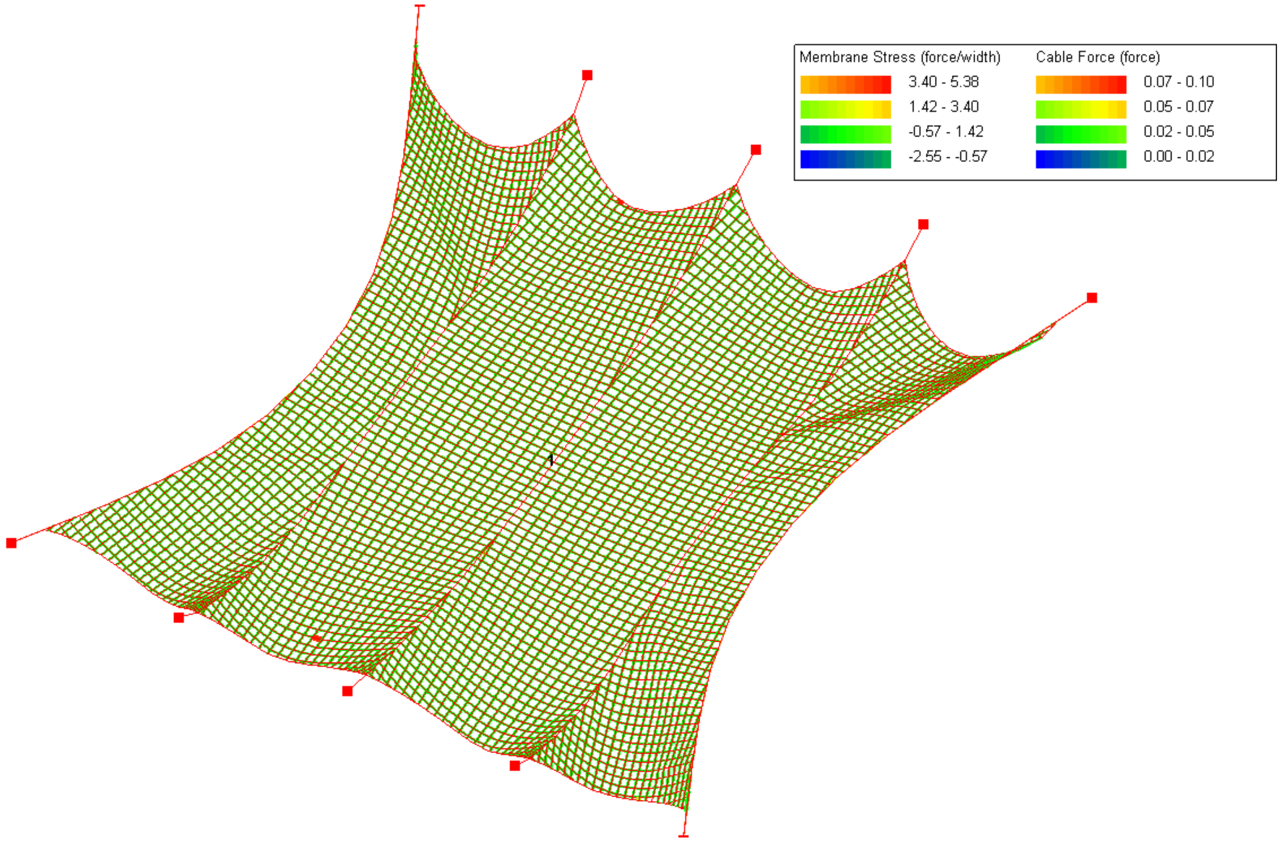


Here are again the front view and a side view:

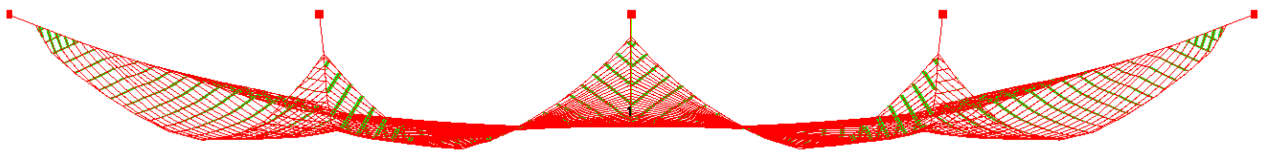


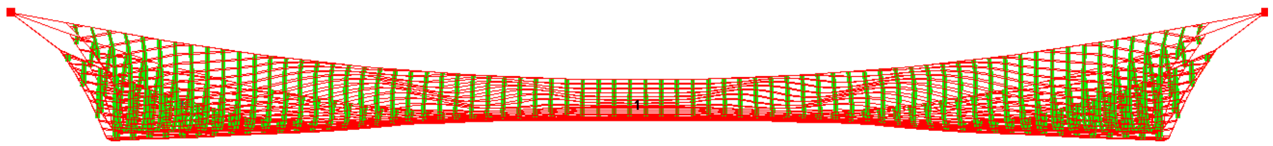


We also tried a configuration where all points are placed on the same height. This configuration did not fully converge and some wrinkles will appear while hanging the membrane in this position. Of course, with the belts attached to the membrane, we can change the stresses in the membrane locally to have less wrinkles.



Here are again the front and a side view:

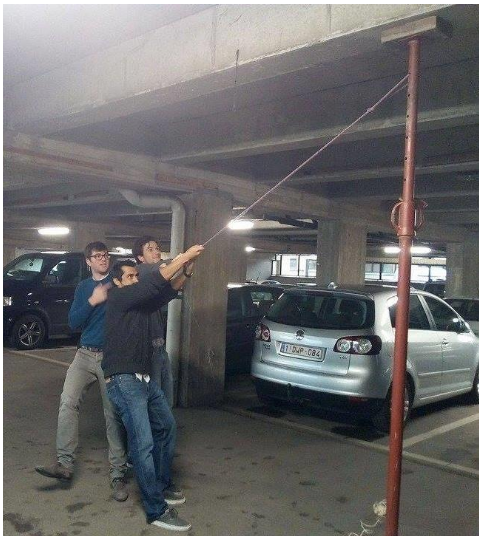




4. Fabrication and Detailing

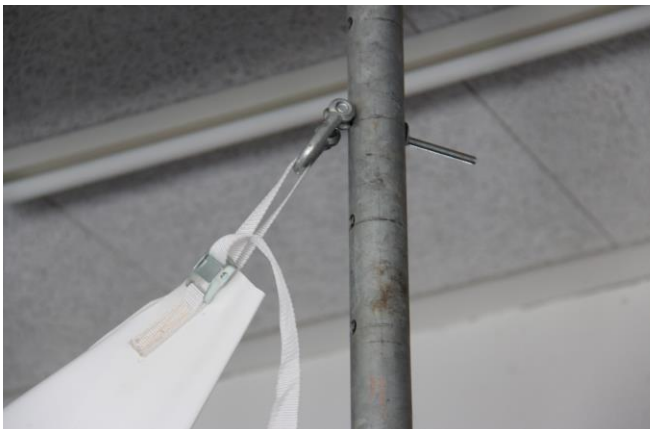
connections, anchor points, cutting patterns and fabrication.

For the test set-up at the VUB, we will use struts. This way we can control the position of the connection points, without damaging the existing structure of the space. Since struts are designed for downwards compression, we needed to test how much force it could take in the perpendicular direction.



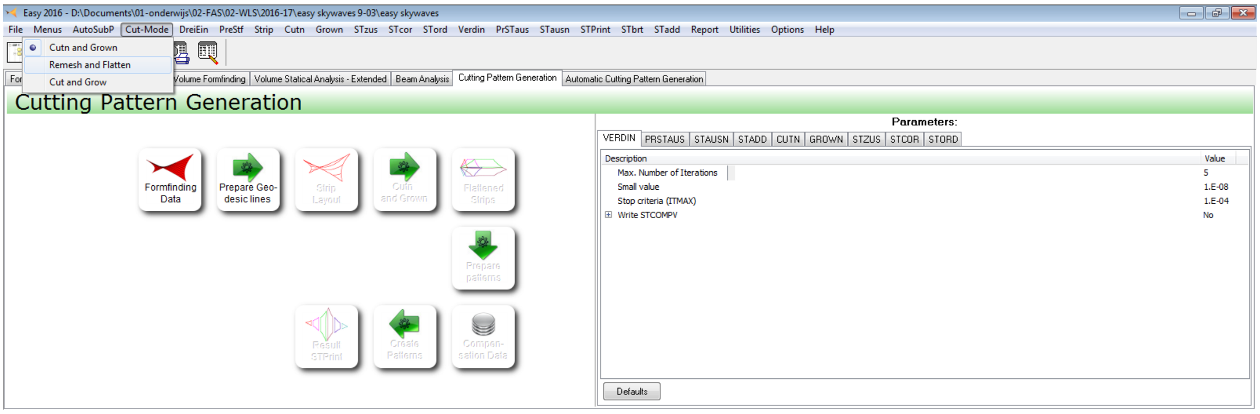
With these basic methods of testing we can conclude that around 2kN of force perpendicular to the element can be taken.

For the connection to the struts we use a bolt with a ring at the end. This will be connected to a U loop screw where the belt from the membrane will fit through.
This is a picture from the final set-up showing this principle.

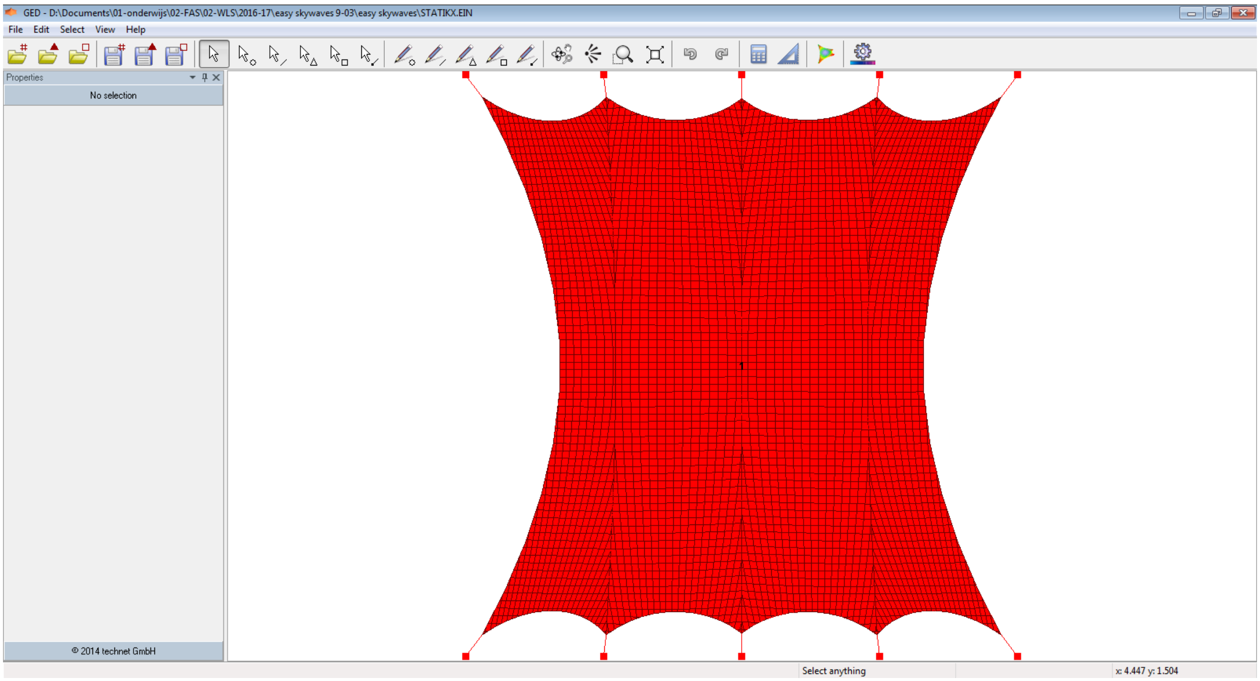



For the fabrication of the membrane we first needed a suitable cutting pattern (a well explained guide is available on Pointcarré).

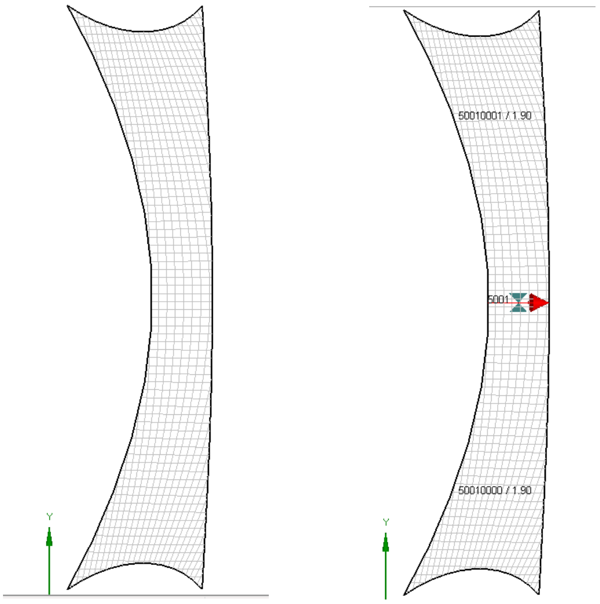
We use ‘cutting pattern generation’ and under ‘cut-mode’ we select remesh and flatten.



After doing this you will find the following under ‘formfinding data’

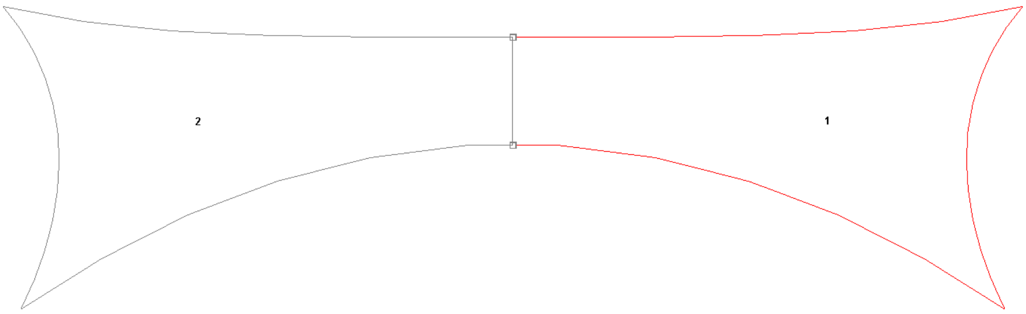


We click Prepare geodesic lines and open Strip layout.



We then open triangle file, in Edit we click Parallel geodesic lines, Fill in the data and create lines. We can now order and orient the membranes as needed.

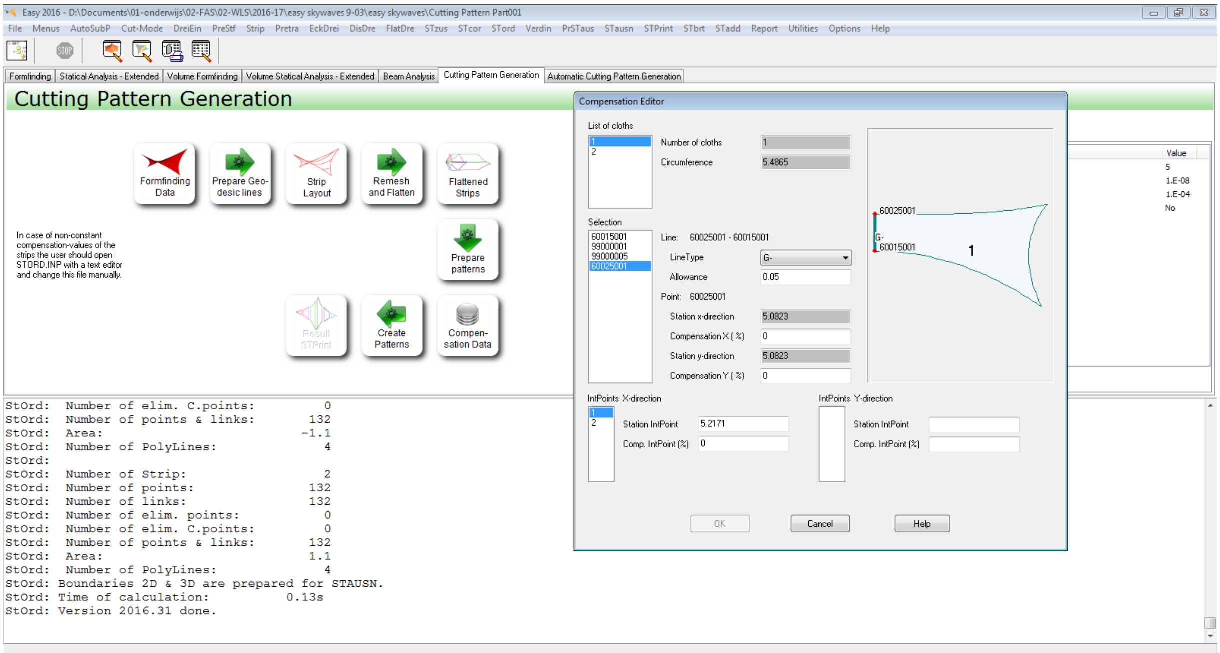
After saving we can click 'Remesh and flatten' and open the flattened strip



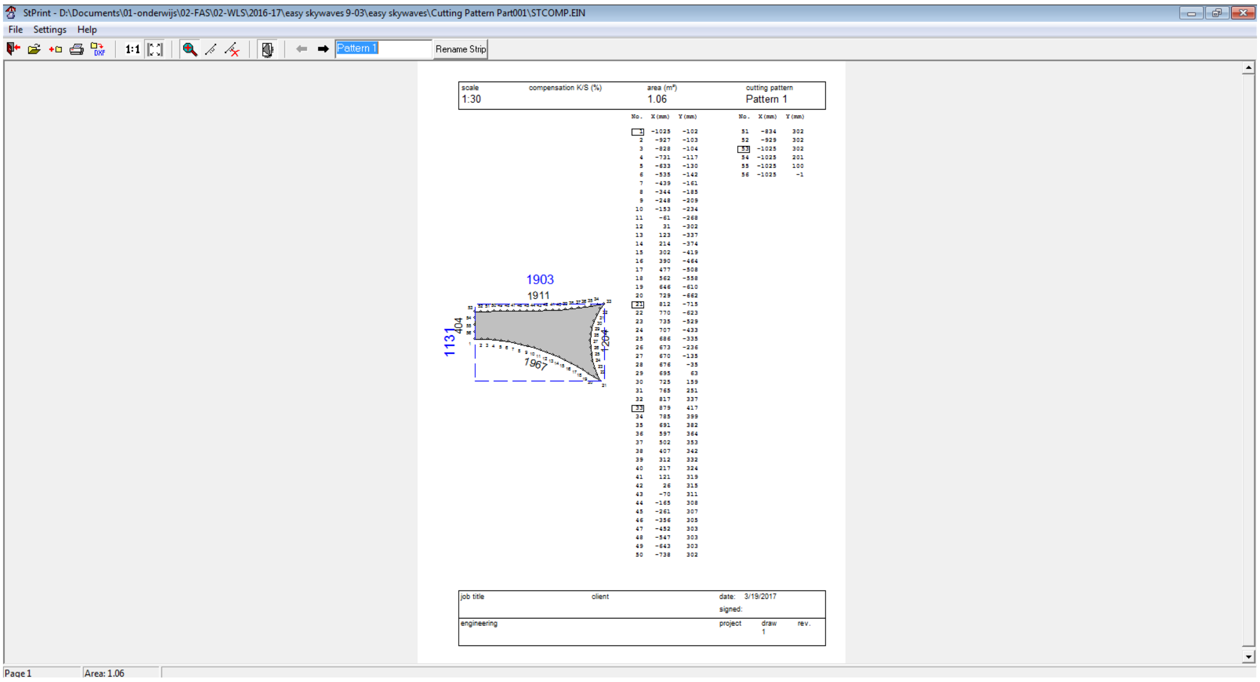
We use STord to set the spacing on the lines at 10cm. This is the precision of the curved lines.

Now we can prepare the patterns.

Click Compensation data and Specify the parameters. In this project, we consider no compensation as the stresses are only ~0.5kN/m. Adjustments can be done with the links we added earlier.

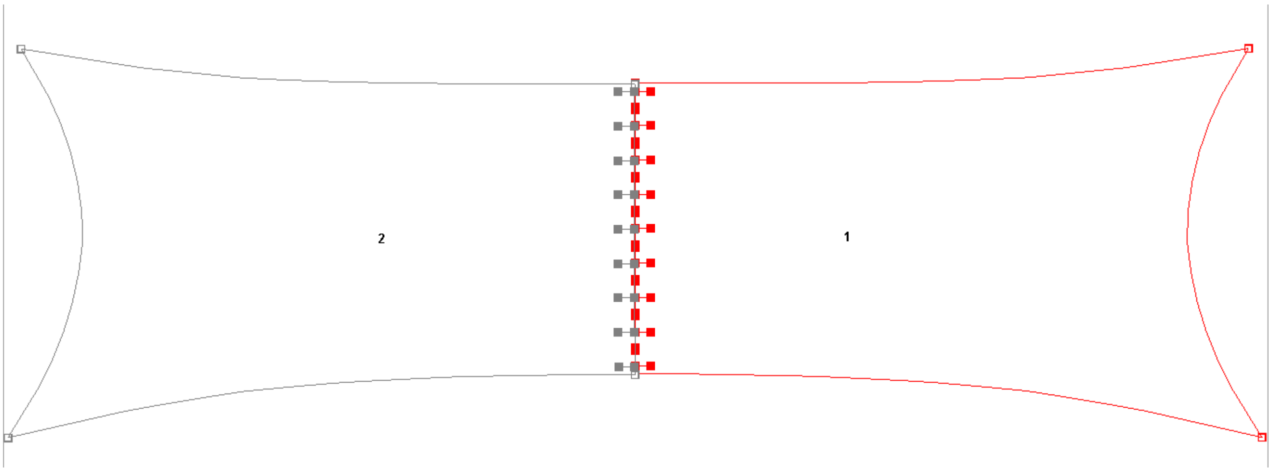


When satisfied, we click Create patterns.



This can now be repeated for all the parts.

STadd can be used to write the cutting patterns in a STadd.ein file. As the two parts can be cut as 1 panel, we can join them in the correct way, using the crosses as a guide.

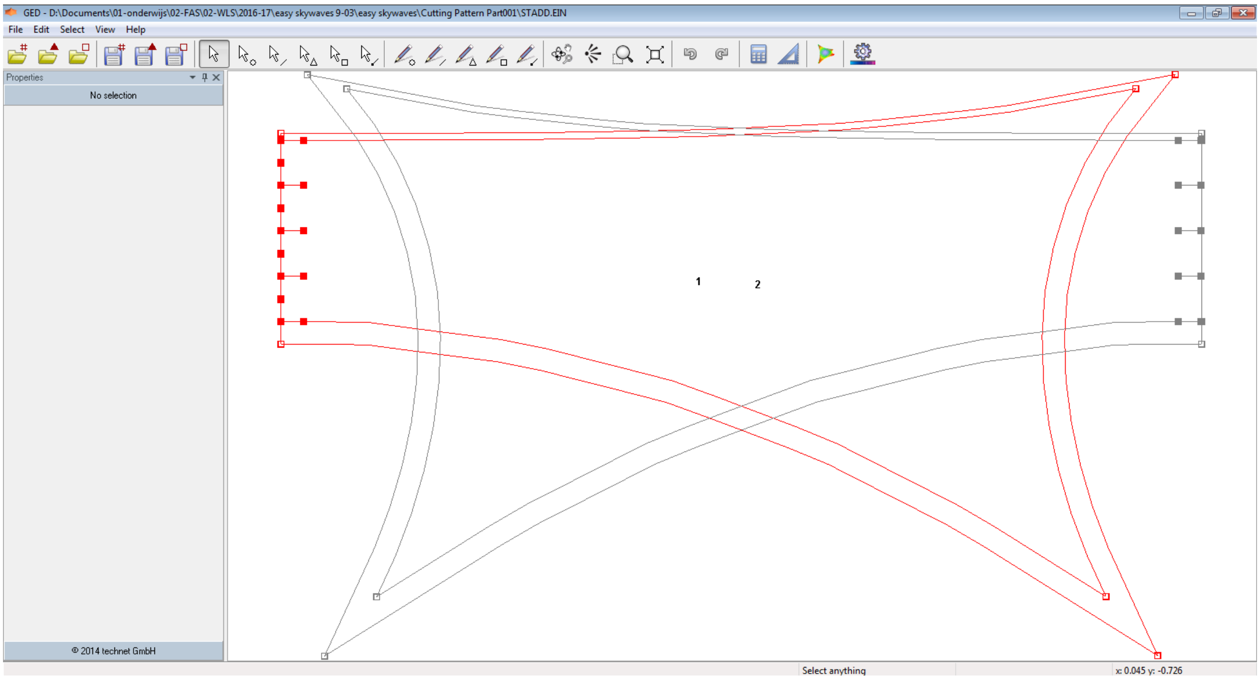


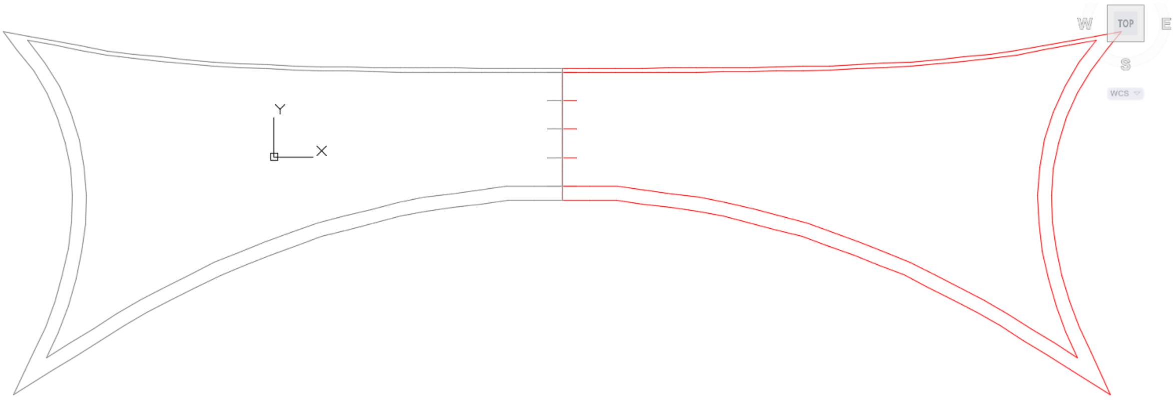
The system lines are crucial and should be drawn. These are used as guides during the fabrication process. No markers are foreseen for the connection at this stage, these will be added during the fabrication.

For welded joints, we have a total overlap 3cm, meaning 1.5cm extra is foreseen for each panel. At the geodesic lines we use no overlap as it will be cut as 1 panel.

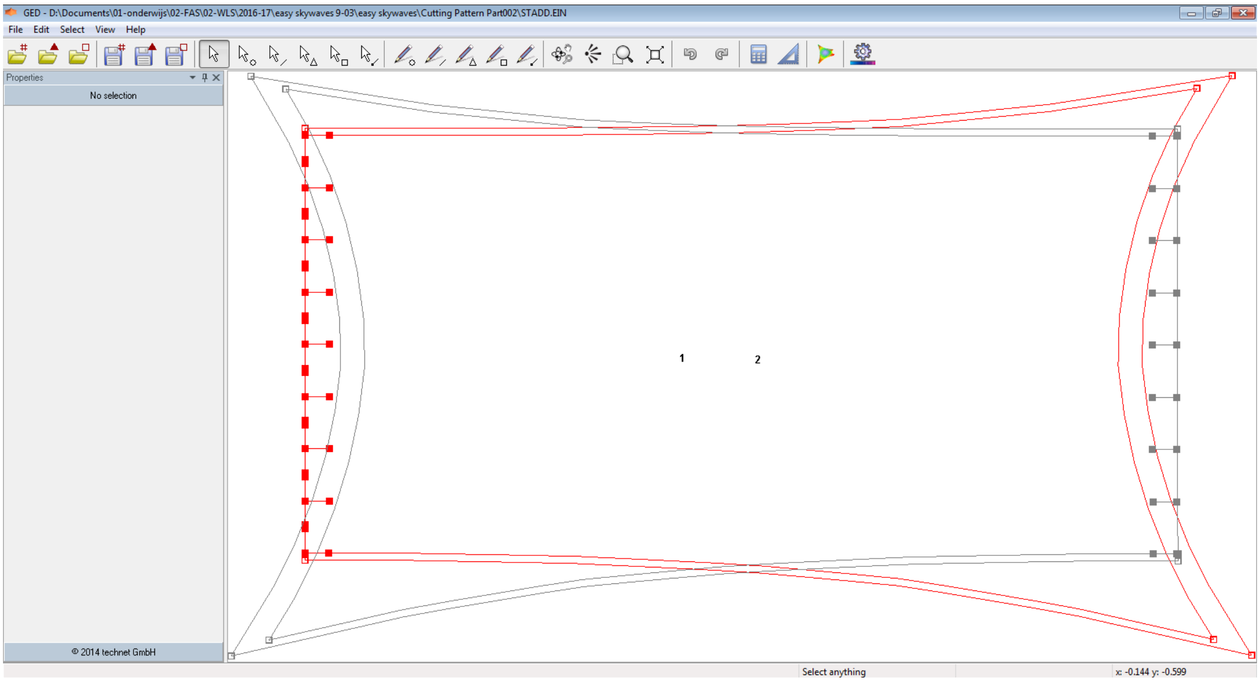
At the boundary's we foresee 5cm extra.

This generates following STADD file, which we can export to AutoCAD.

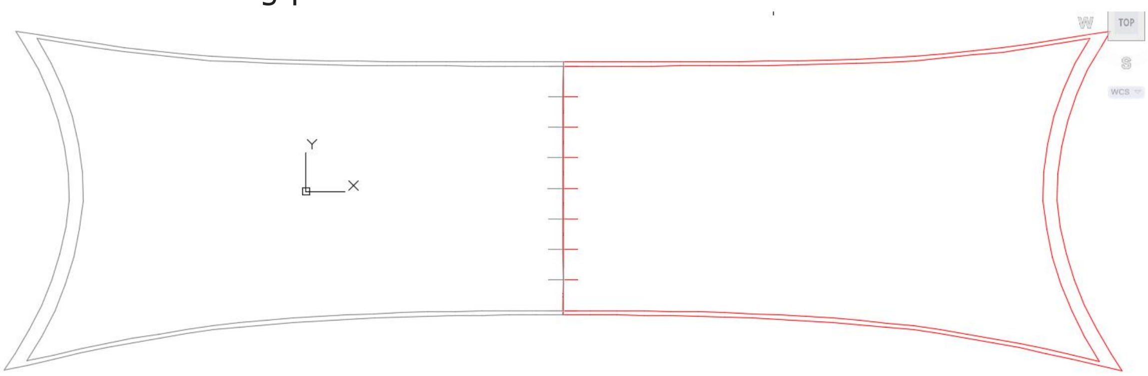




This is repeated for the middle membrane.

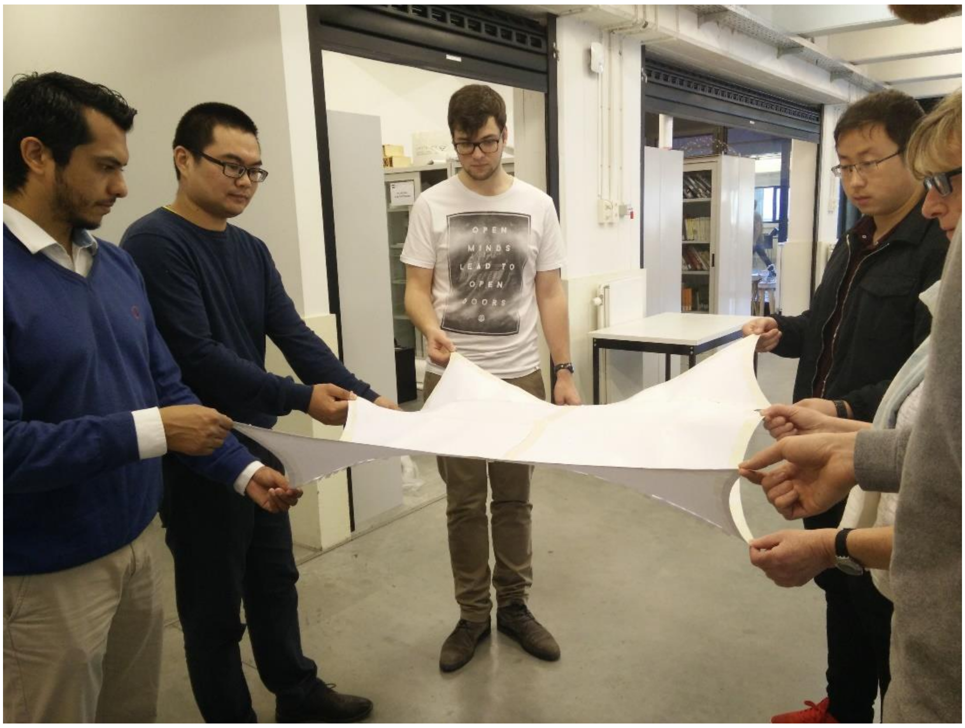


This is the cutting pattern in AutoCAD:

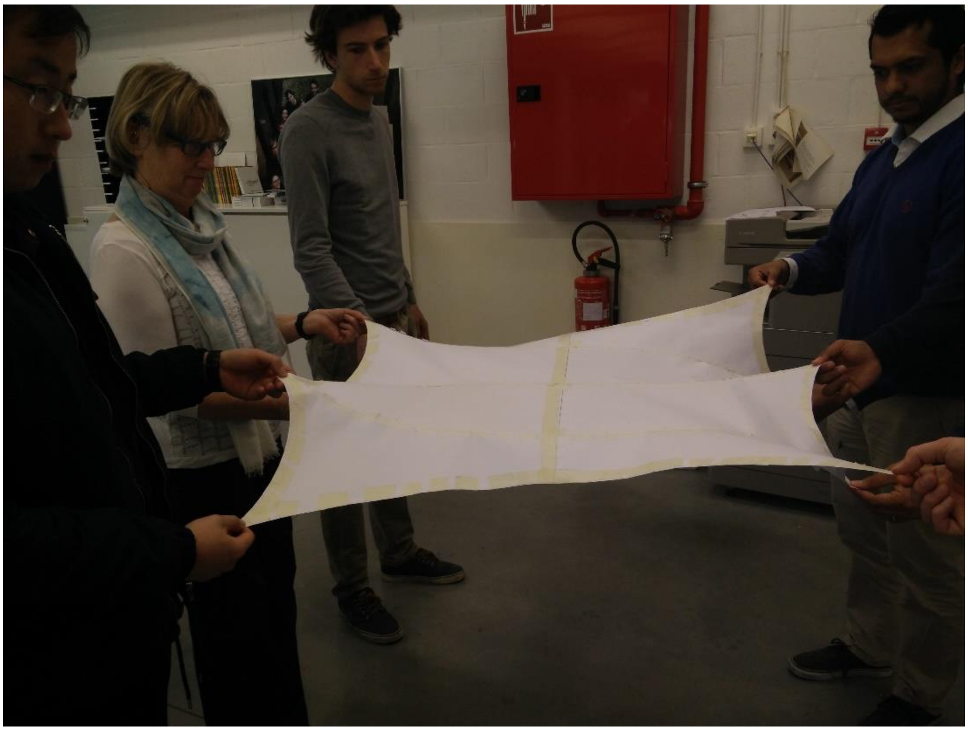


Since the membrane is symmetrical, we can copy these two membranes to have all necessary cutting patterns.

We tested the cutting patterns using a paper scale model.
In the normal configuration:

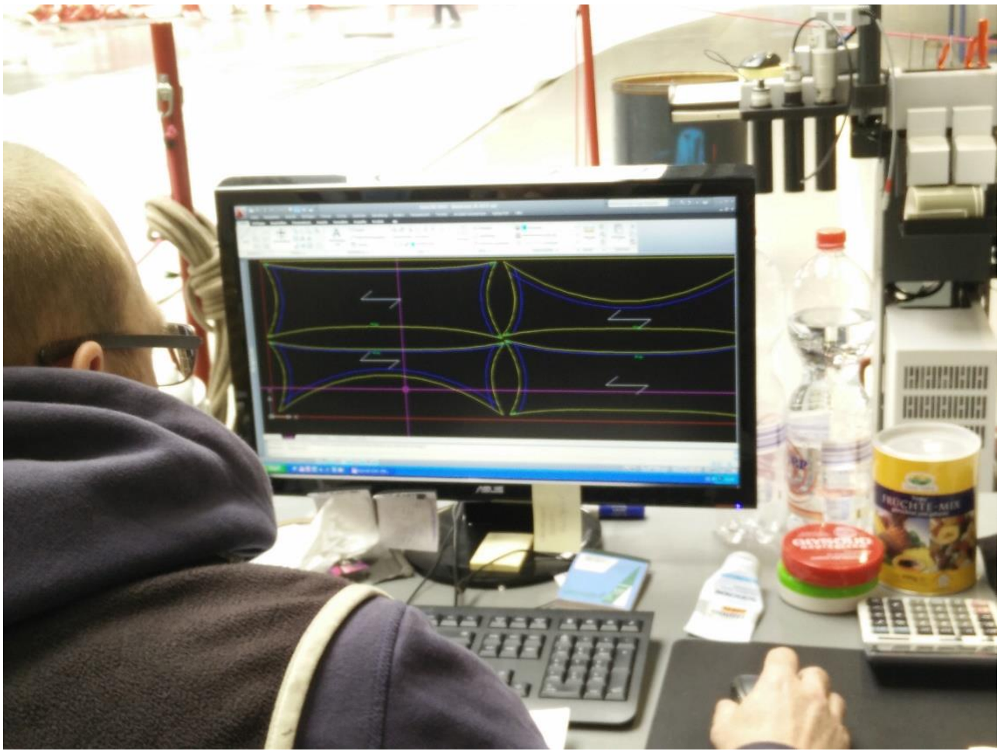


And alternating configuration:

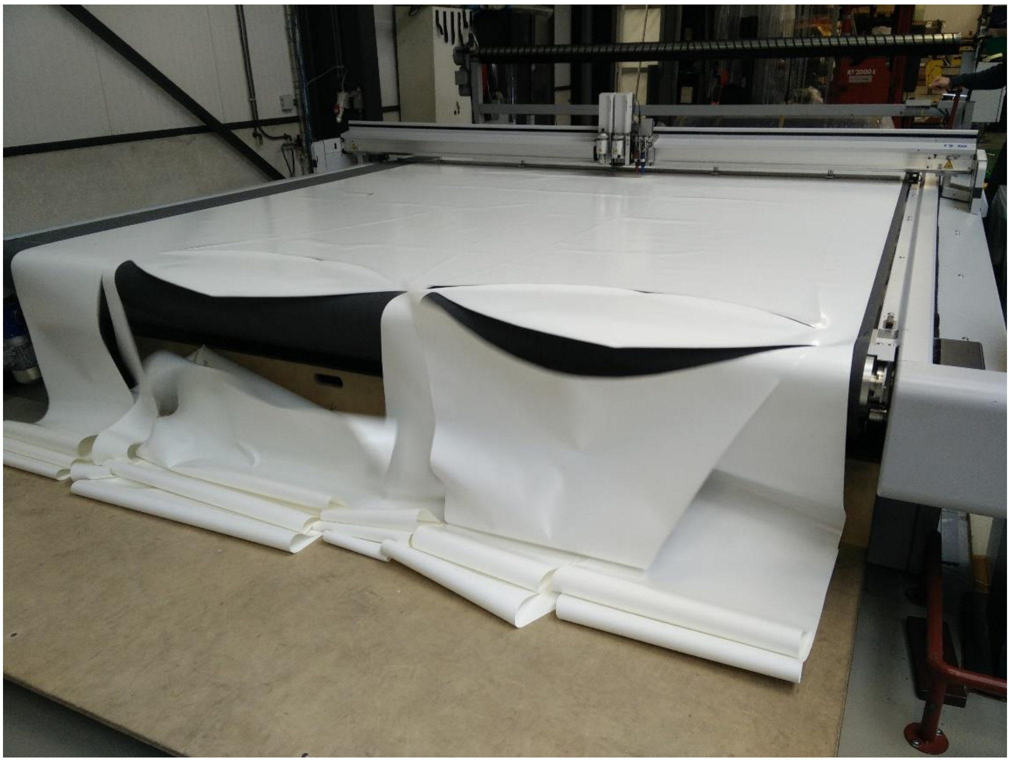


Some wrinkles were showing, but since paper is a slightly stiff material this was to be expected. Satisfied with this test, we could start the fabrication of the membrane. To do this, we went to Carpro in Eynatten.

The first important part is the nesting of the membranes. This is important for the welding procedure. The nesting makes sure that the orientation of fibres in the fabric is aligned properly. This way two membranes that are welded together have a similar edge and the orientation of the fibres are matching.



After nesting, the fabric could be cut. This is done in one go using the cutting machine on the picture below. The machine uses suction to keep the fabric flat on the table while cutting. It also adds the markings for the welding.



Before we can weld we must first put the membranes together using a small amount of fast setting glue. This makes the welding much easier as the membrane is already in place.

For the welding itself, we use a High Frequency welder, as seen in following picture.

After welding the membranes together, we started to prepare the details. For the small edges, we added a strip of 3 cm. To the large edges we added a border of 5 cm that was folded over and attached to both sides, creating a pocket. This way we are still able to add a boundary cable if necessary.
Here you can see the strips that were added:

For the connection points, a semi-circle was added for strength. On this semi-circle we can now stitch our boundary cables that will be connected to the struts.

Here is a picture of the finalised membrane.

With a more detailed look at a connection point during set-up.

5. Final set-up.

During the final set-up we ran in to some unforeseen problems.
The floor of the space was much smoother than expected. This made it difficult to fix the struts securely because they rotated out of place and could not be completely secured. While tensioning the membrane the struts began to slide and came loose. This was solved by moving the poles a bit back so that the top point was not on the upper beam, but just beside it. This way the beam was able to take some of the horizontal forces making the struts more secure.


(positioning of the struts before and after)

Another problem was the connection point on some struts. We accidentally had two different kind of struts. Making the lower connection the same way on each strut became impossible so an improvised connection was made.
We used a small red belt, connected by two small ratchets with a loop in the middle. This was held down in place by the tensioning handles of the struts.


Here are some pictures of the final structure in the two main configurations
First the normal configuration:

And then the alternating configuration: