Modular membrane elements for dismountable structures.

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Abstract.

The present study is part of an iWT research project. The objective is to construct (temporary) buildings from a system of modular parts that are transportable and dry assembled. These constructions can be dismantled after use and components can be re-used for new projects.
To explore the specific formfinding methodology, required for the assembly of identical components, two case studies are analysed.
First a *planar* membrane module is considered. It is tensioned into a (slightly) curved shape and verified to withstand snow and wind loads. Several of these *identical membrane elements* are than combined into larger *saddle shaped* compositions. *Different configurations* are possible.
Secondly a *waveform* is analysed. Floating bars, additional cable elements and full span cables (as superstructure) are required to generate large free spans.

A Planar Unit.

The main objective of this research is to combine identical membrane entities into a larger (free span) structure. First a planar diamond shaped membrane module is considered. A special feature of the proposed diamond shape is that it consists of two equilateral triangles, so that the angles of the diamond are 60° and 120° degrees.

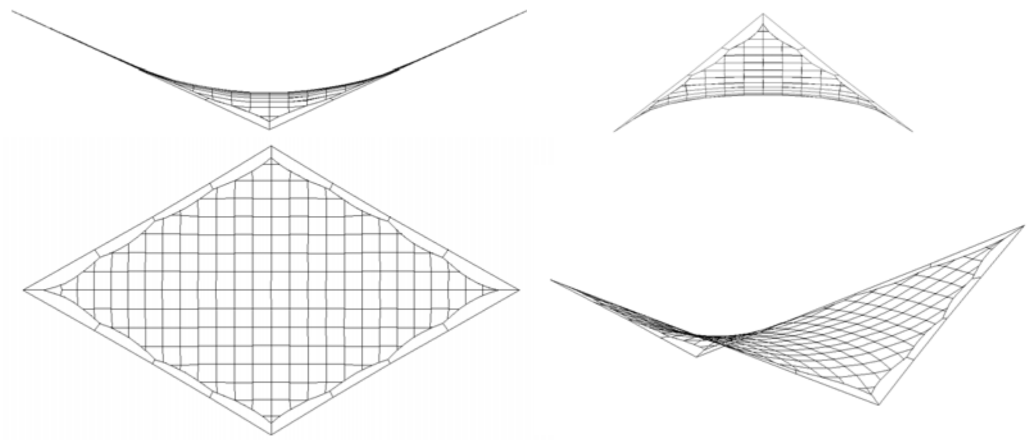


Fig. 1. Planar module, after pre-tension.

The side of the basic module was chosen to be 300cm, the membrane characteristics correspond to a PVC/polyester type III fabric. The edge cables are taken to be steel cables with a diameter of 8mm.
Starting from a planar diamond shape one can generate the most basic form of a stretched membrane, namely the saddle shape (two points high, two points low). First the planar equilibrium form was calculated (using EASY [1,2]) with a very small force density. Lengths were fixed from that moment onwards. Pre-tension was induced together with the double curvature by moving the four corner points in the Z-direction (a difference of 125cm) and in the X- and Y-direction (cornerpoints along the X- and Y-axis 10cm and 5cm respectively) inwards to the centre of the module (Fig. 1).

Planar Compositions.

The most simple composition is the diamond shape consisting of four modules (Fig. 2). It is possible to pre-tension the composed membrane with similar parameters as used to pre-tension one module. In the membrane an average pre-tension of 1.8 kN/20cm is obtained. In the internal edge cables the force is about 12 kN. When four additional boundary cables are used, only the four corner points have to be supported.

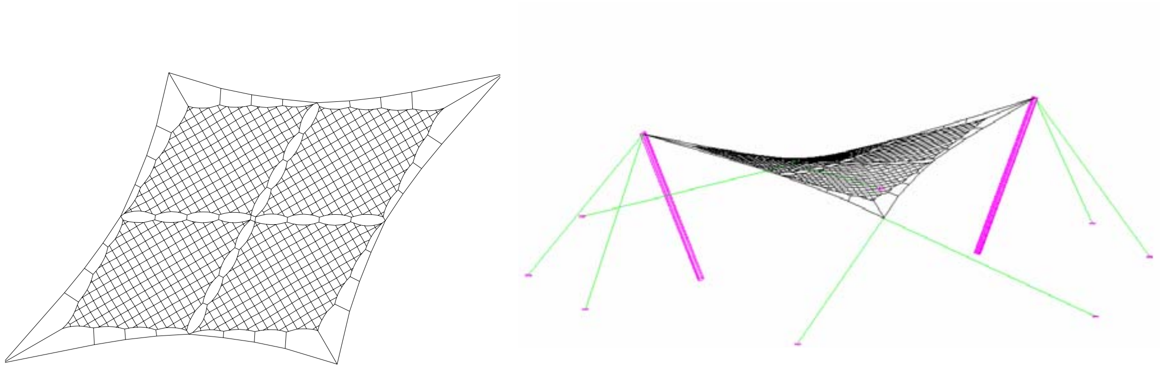
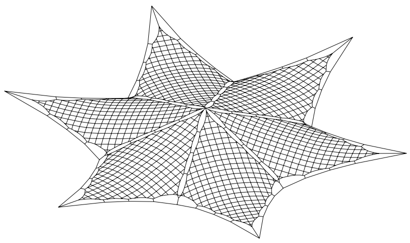


Fig. 2. Four modules tensioned in between four cornerpoints.

Another possibility is the hexagonal composition of six modules (Fig. 3). The center point has been moved up 125cm, the six outermost points up 75cm and the twelve fixed points on the perimeter inwards 10cm (horizontally). A similar star-shaped structure could be obtained from six times four modules. Considering the size of the basic module (edge length 3m) this composed membrane has a span of about 20m (free span: 10m).
This membrane can be supported by one internal mast and six masts on the perimeter of the structure together with stabilizing cables (Fig. 5) or by a frame (Fig. 6). This could also be composed of modular elements, designed to be compatible with the membrane modules.



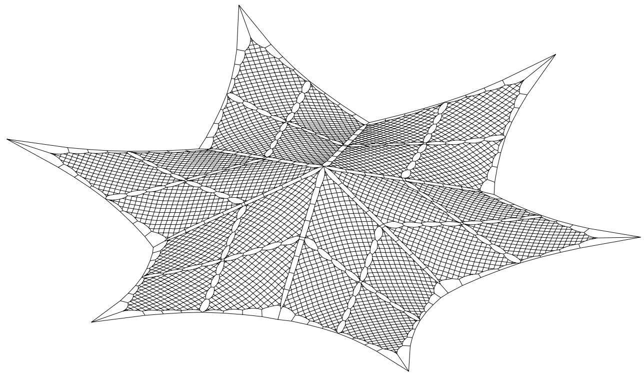
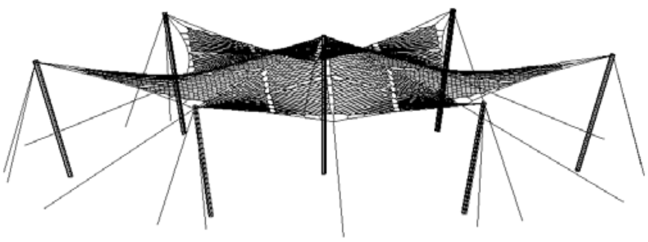


Fig.3. Six modules.

Fig. 4. Twenty-four modules.



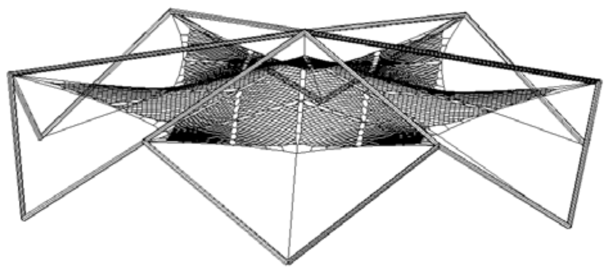


Fig. 5. Supported by masts and cables.

Fig. 6. Supported by a frame.

The last configuration (Fig. 6) clearly illustrates that the assembly of membrane modules not only requires ensuring geometric compatibility, but also needs to solve the equilibrium of the forces due to pre-tension. The system has to be considered as a whole: the membrane does not withstand any load if not supported, the frame in this case is a mechanism held into position by the tensions in the membrane.

A similar methodology could be used for a membrane with a diamond plan but with an initial curvature. Its initial formfinding can be performed with the appropriate force densities. The assembly is calculated with the additional constraint that the initial size of the membrane elements is fixed.

A Wave form.

The approach for the next composition is based on the structural behaviour of a wave membrane, tensioned between six fixed cornerpoints (in plan view 6mx4.5m).

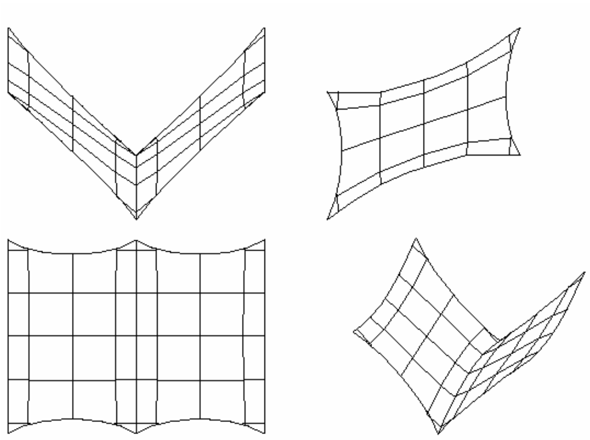


Fig. 7. One module: geometry.

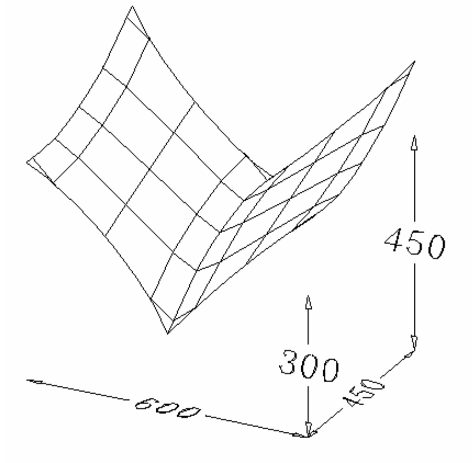


Fig. 8. Dimensions.

The formfinding of this module was performed with EASY [1,2], with the internal force densities set to 1kN/m. The resulting tensions are drawn in Fig. 9. The reaction forces are drawn in Fig. 10. The values in the lowest right point are (9.5kN,0.0,-7.1kN) and in the lowest left point (-9.5kN,0.0,-13.5kN) (with the X-direction parallel to the symmetry plane, and Z vertical).

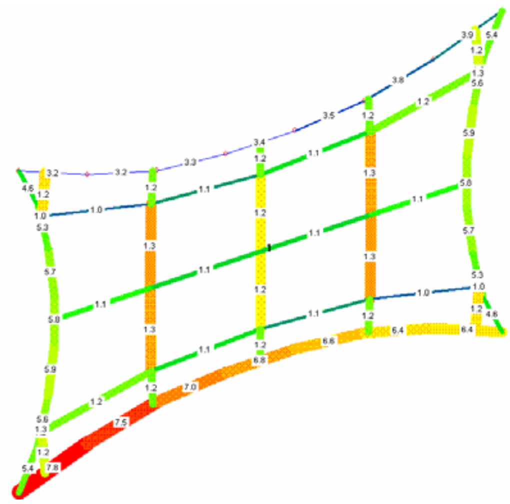


Fig. 9. Stresses in the equilibrium form.

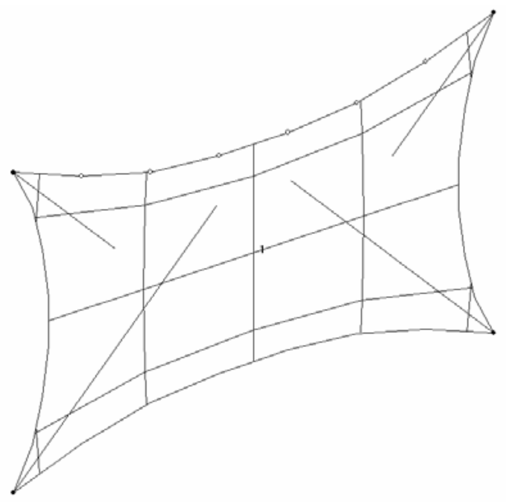


Fig. 10. Reaction forces.

This membrane could be tensioned in slightly different forms. If the horizontal width is 500cm or 700cm instead of 600cm, and the upper corner points have slightly been moved in the X-direction to prevent wrinkling, a different stress pattern occurs.

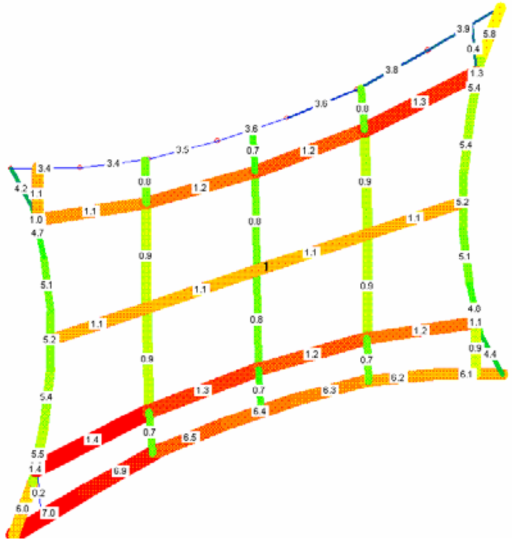


Fig. 11. Equilibrium for a width of 500cm

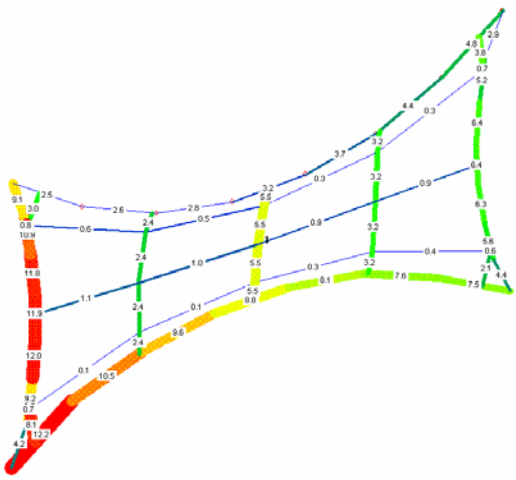


Fig. 12. Equilibrium for a width of 700cm.

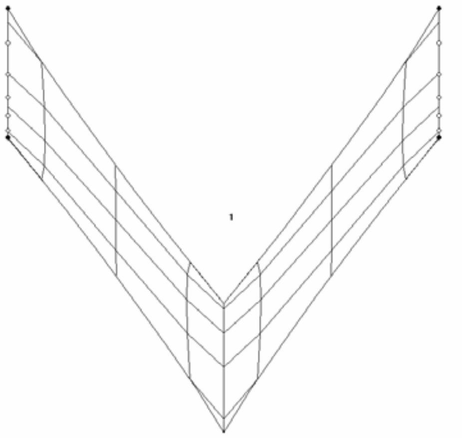


Fig. 13. Left hand view for a width of 500cm.

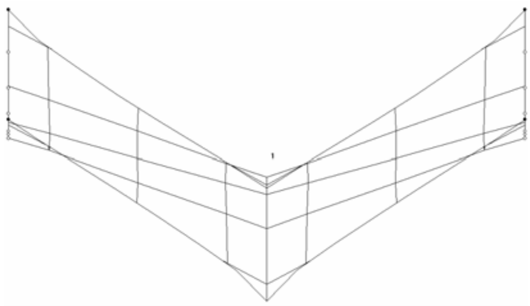


Fig. 14. Left hand view for a width of 700cm.

Compositions of the Wave Unit.

The membrane is extended with three compression bars and a number of cable elements forming a basic unit to be used as a building block for larger assemblies. The basic unit is not self-supporting.
The combination of two units is verified. The six compression bars are added to be able to resist the compression reaction force component (Fig. 10 and Fig. 15).
The downward force component in node A is taken by two cables, similarly the upward force components in C’ and E’ (Fig. 16) are taken by two times two diagonal cables.

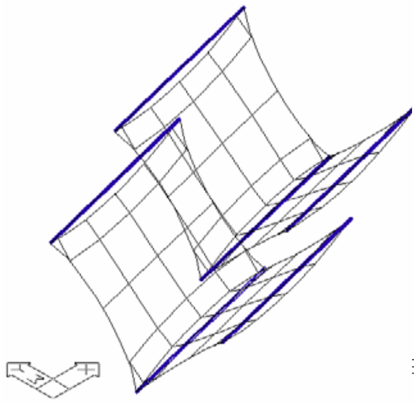


Fig. 15. Compression elements.

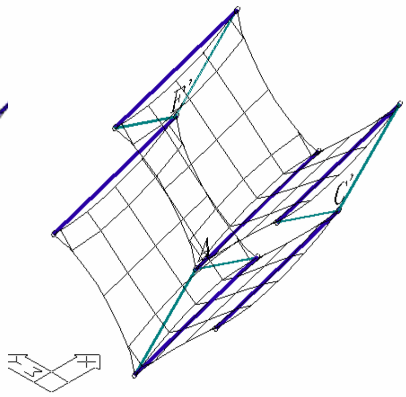


Fig. 16. Diagonal cable elements.

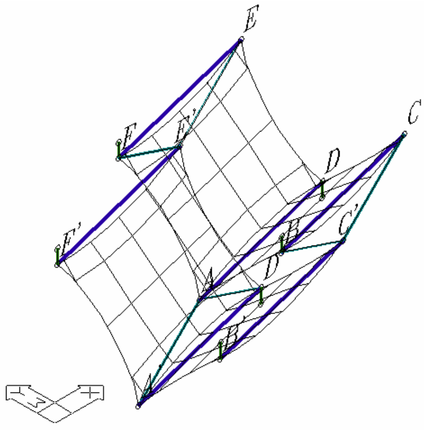


Fig. 17. Connecting cable elements.

Downward cable elements which could be connected to a transverse tensioning cable are added in D and D', similarly to upward cable elements in F, B, F' and B' (Fig. 17).

The boundaries lying in the XZ-plane are constraint with the additional condition Y=cte. This means symmetry according to the corresponding XZ-plane.
To make sure that the assembly is constructed with identical elements, all connection points are fixed in the formfinding process.

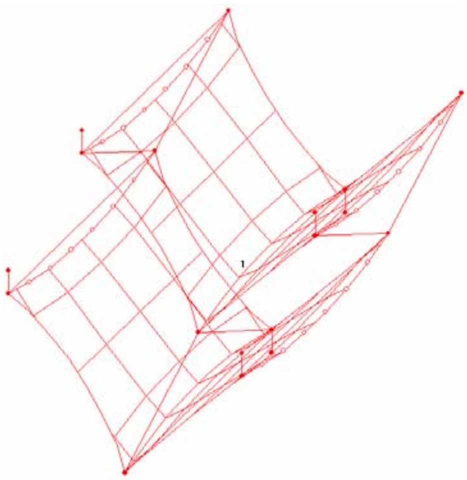


Fig. 18. Fixed points: filled dots.

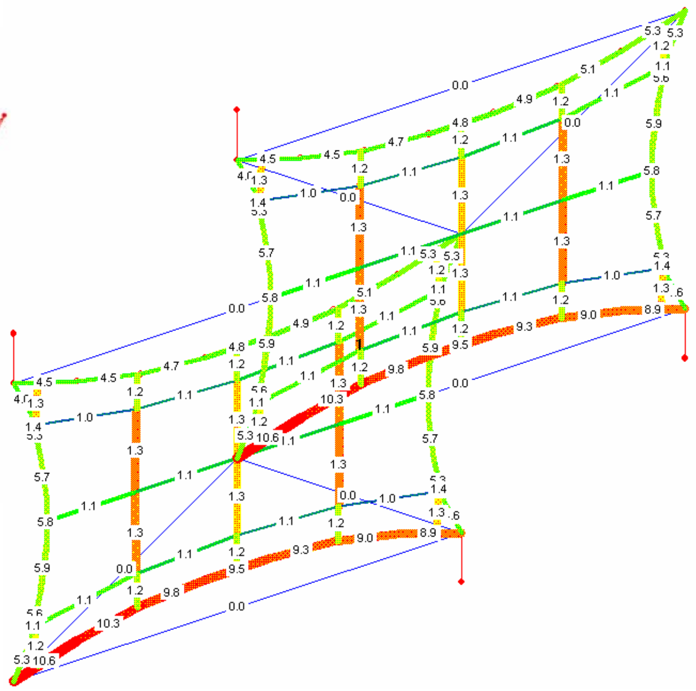
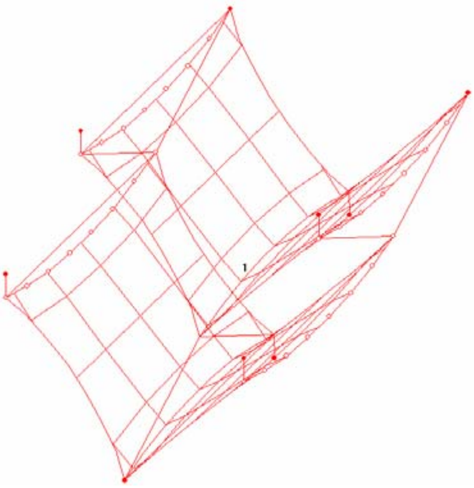


Fig. 19. Stresses after formfinding: internal cornerpoints fixed.

In the second stage an equilibrium form is calculated where all internal nodes are set to be free. This means that corresponding reaction forces act as external loads on the structure.



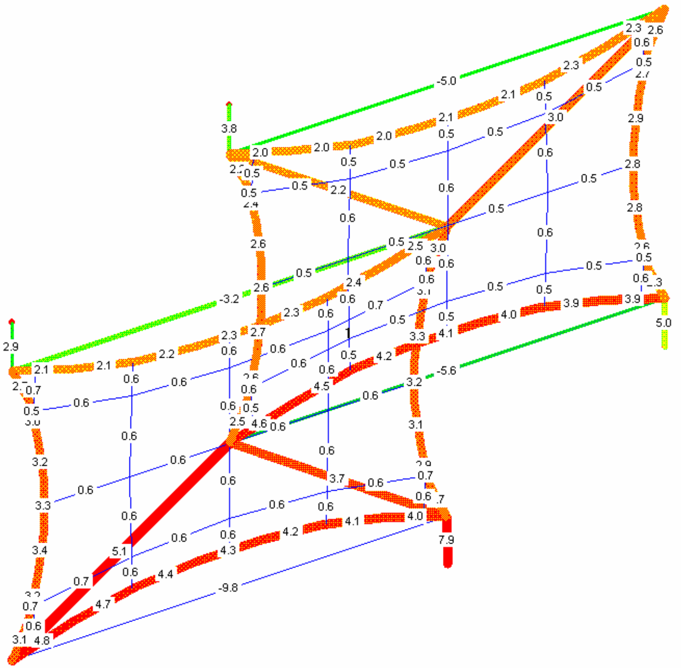


Fig. 20. Fixed boundary points: filled dots. Fig. 21. Equilibrium form with all internal points free.

Adding basic units in the X- or Y-direction could generate larger spans.
All components are identical except the cable elements connecting the units to the transverse load bearing and tensioning cables.

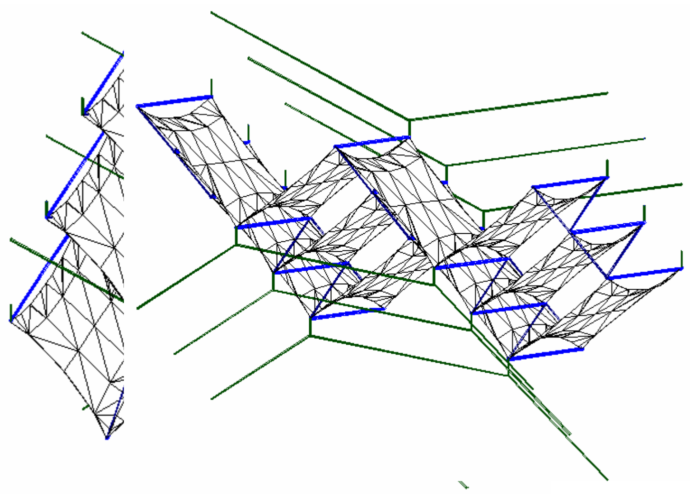


Fig. 22. The composition of 6 modules.

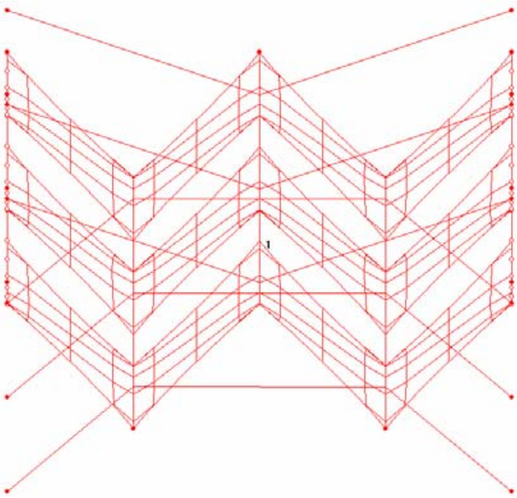


Fig. 24. The 6 modules fixed in between the nodes with filled dots (side view).

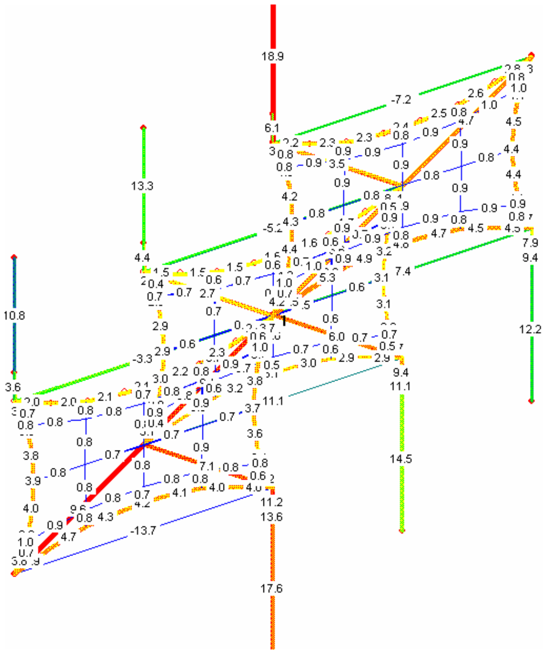


Fig. 25. Stresses in the equilibrium form (front view).

The overall stress pattern remains similar to the one for the assembly of two units. The displacements from the initial formfinding (internal cornerpoints fixed) to the released structure (internal cornerpoints free) is only about 1cm for a span of 12m.

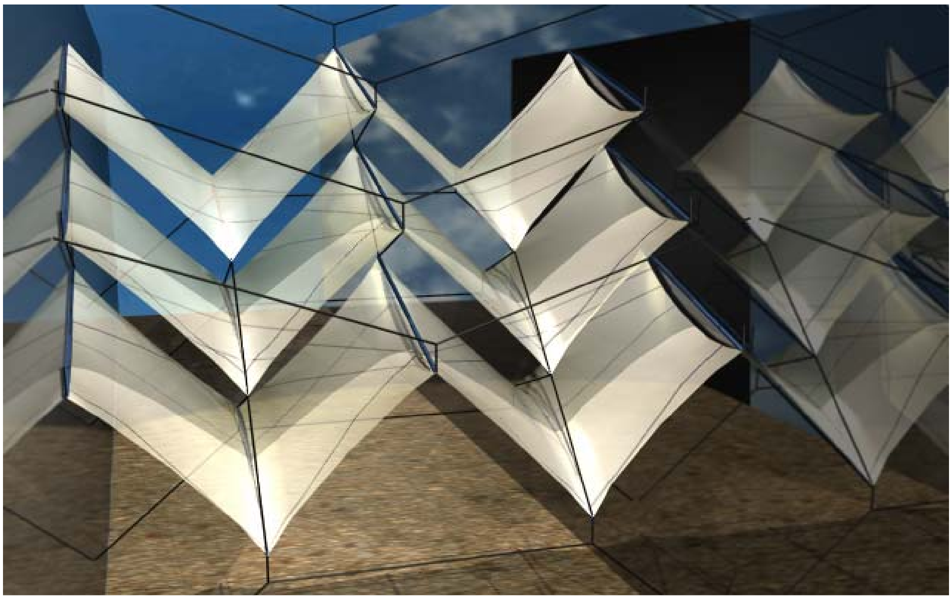


Fig. 26. Fixed between 2 walls.

Conclusion.

The two casestudies for the generation of larger membrane assemblies based on a planar diamond membrane or on a basic waveform have been studied numerically. The validity of these simulations strongly depends upon the connection techniques and components. Further research will concentrate on prototypes and will study the dismountability in practice.

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