ACTIVE BENDING TO FACILITATE THE INSTALLATION PROCESS OF MEMBRANES IN STATICALLY SELF-LOCKING SPATIAL STRUCTURES - COMPARISON OF TWO CASE STUDIES

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Summary. ***This paper presents the compressed usage of elastic material in statically self-locking configurations facilitating the assembly of hybrid structures based on the steady state balance.***

The full scale realized case study 01 "A Cloud for fresh Snow" - a commissioned research for the Austrian Neuschnee-Gmbh - is compared with the case study 02 "The violin unit". In the case study 01 the classical type of bending (Indian bow) is applied in a configuration of six elastic members and four minimal surface membranes in the form of a spherical tetrahedron. The other type of active bending – applied in the case study 02 - consists of the ***phenomenon of the violin bow****, where a curved member is bent by tensile forces towards its straight form. Both case studies have in common that their patterned membranes can be installed easily without tension-forces in a first step and that these membranes can be comfortably pre-stressed in their determined form without additional tools in a second step.*

1 INTRODUCTION

As described by Lienhard, Alpermann, Gengnagel and Knippers [1] active bending structures use bending as a self-forming process. The described case studies 01 and 02 of this paper take use of the self-forming equilibrium of active bending members and membranes to facilitate the installation process. The new approach focuses on the idea to provide boundary conditions in that way that the structures inherently find their forms without external forcing and with a minimum need of resources during assembly. This study aims to investigate the potential reduction of material use in statically self-locking solutions by analyzing two different configurations. Wood was chosen as an elastic material of both case studies.

2 THE VIOLIN BOW AND THE INDIAN BOW

Wooden members can be produced in various curved forms by different advanced techniques. Figure 1 shows a classical Indian bow-form merged in the centre-point with a radial curved bow oriented in the opposite direction. The model is produced out of 1mm oak veneer in prefabricated forms. The type of bow is not defined by the form of the bow, but by the bending direction as follows:

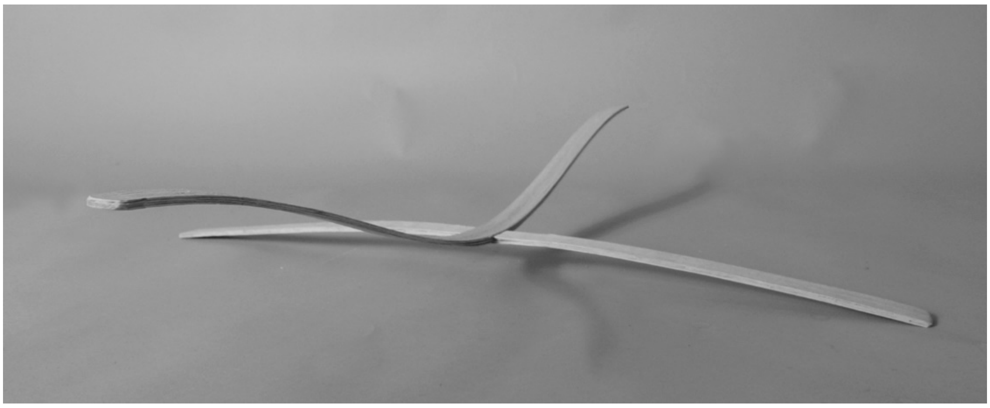

Figure 1: Model of two differently curved wooden members merged in one structure

2.1 The Violin bow

The violin bow is determined by bending it at the longer side of the bow. Figure 2 shows the deformation of a 60cm long bow with a section profile of 25mm to 4mm. A shortening of the steel-cable connection for 4 mm, causes a reduction of the amplitude in the range of 20 mm. The dimensions of the bend-proof end-detail have a direct influence on the form of the deformation and on the necessary tension force for the deformation.

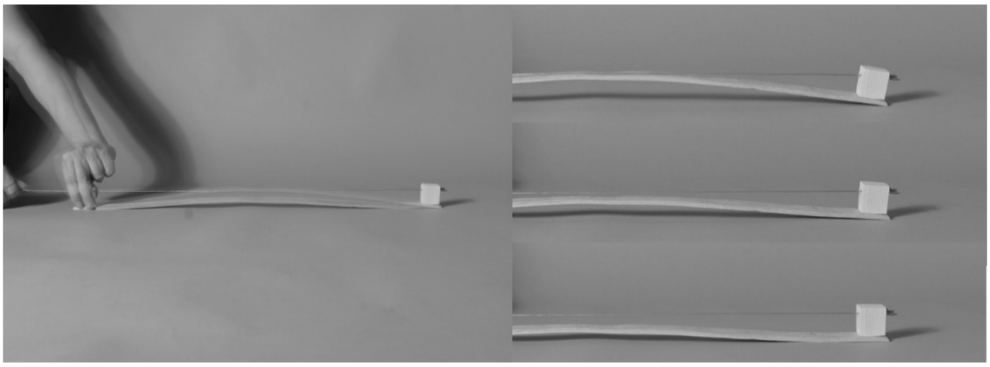

Figure 2: Model of a violin bow - sequence of its deformation during stressing the cable

The bend-proof end detail can be substituted in a spatial configuration by a membrane in that way that the tension force and the end of the wooden member merge in one point or one line as shown in the model with the patterned not stretchable PVC - membrane (Figure 3).

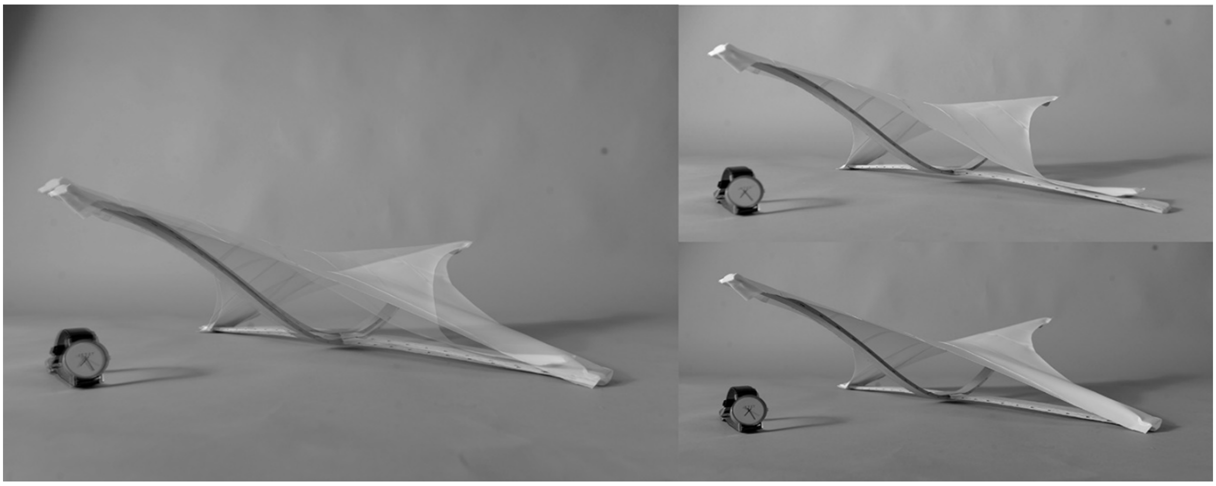

Figure 3: Basic study 02_A - basic concept model comparing the stressed configuration to the released one

2.2 The Indian bow

The Indian bow is derived by actively bending a bow at the short side – respectively at the short connection of the bow-ends [2]. This can be done by a direct cable connection or by a membrane as shown in the hybrid construction above (Figure 3).

2.3 Material fatigue

In practical application a classical Indian bow is released when it is not used because of the material fatigue of the wood. On the other side the violin bow is released mainly because of the material fatigue of the cables - respectively the hair of the bow. Violin bows remain bearing load for many decades depending on the used material, the production technique and climatic conditions such as humidity.

Figure 4 shows this observation in the context of structural design. The hybrid construction of an Indian bow and a violin bow with the patterned PVC-membrane finds its own balance of forces. At the starting point the violin bow is stressed to its almost straight form leaving a gap of 2mm to the flat surface. After 10 hours the gap increases to 4mm, which shows that the tension force of the violin bow is resistant over long time scales, whereas the Indian bow reduces tension soon (As the membrane was consciously patterned in the direction of the violin bow, the strong overlapping seams are directed into the same direction. Therefore the material fatigue of the membrane plays no relevant role in this study).

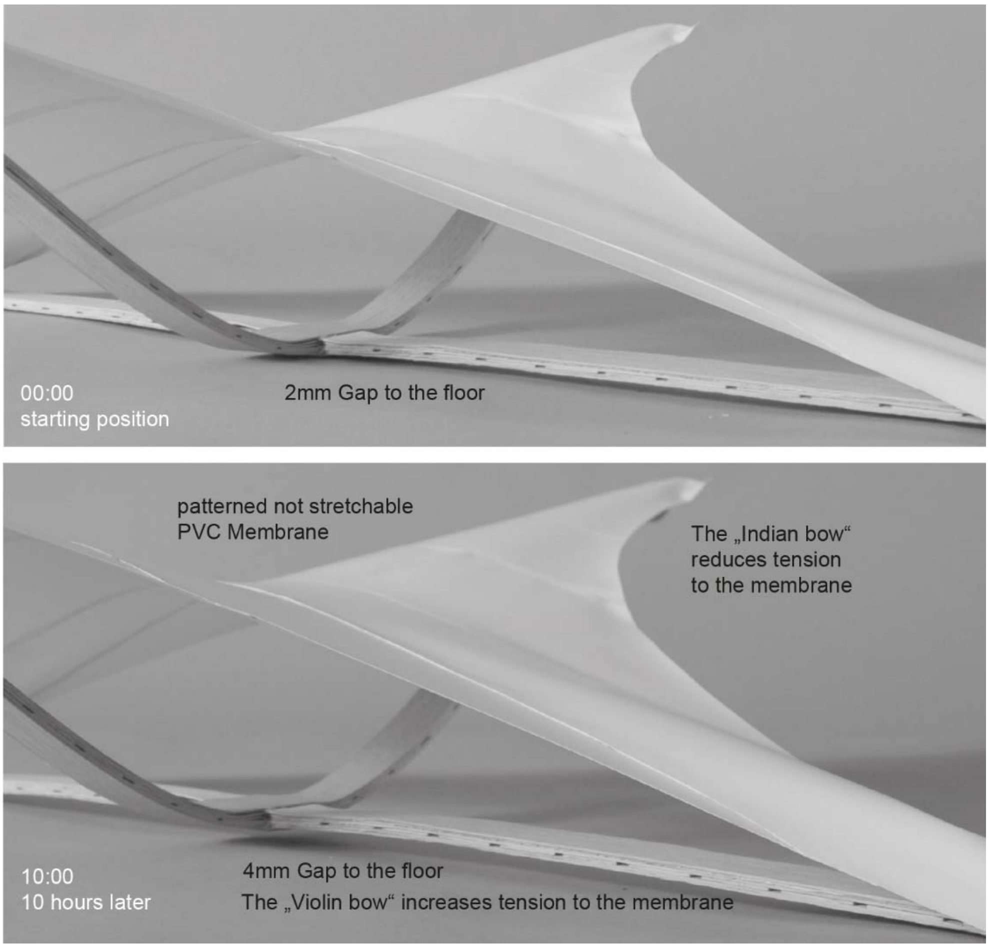

Figure 4: Basic study 02_B - basic concept model to study material fatigue of the bows

The described study proves objectively that the Indian bow loses load bearing capacity whereas the violin bow of the same hybrid structure keeps remaining load bearing capacity (Figure 4). The application of the elasticity of wood in hybrid membrane constructions to simplify the assembly without being affected by the disadvantage of the material fatigue is subsequently described in two case studies.

3 CASE STUDY 01 “A CLOUD FOR FRESH SNOW”

The realized case study 01 is described in detail in the paper “A Cloud for Fresh Snow - Research Lab – a hybrid solution of minimal surface pre-stressed by bending active boundary conditions forming a spherical tetrahedron” [3]. Based on this studies a scaled model of the pure form (without other high points like in the full scale research lab - Figure 8) was done with patterned – not stretchable - membranes to investigate the changing statically behaviour during assembling and in the final configuration.

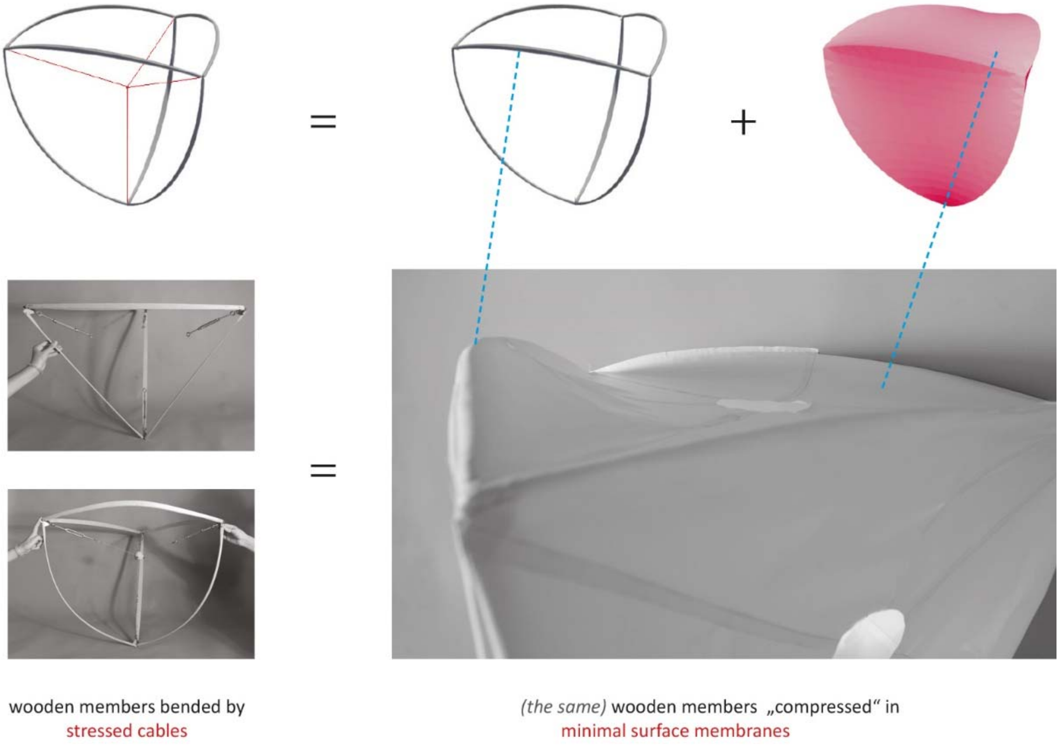

Figure 5: Basic Study 01, Model 1:10, changing geometry and forces during assembling

Six straight wooden members are tensioned and pre-bent by four cables to the centre point, which enables the comfortable fixing of the patterned membranes by hand even in full scale (see Figure 8). As soon as all four minimal surface membranes are continuously attached to each other, the four cables can be released, because the wooden members are compressed in the statically self-locking structure in a steady state balance (Figure 5 and 7).

As known patterned membranes are an approximation of the minimal form. The spherical tetrahedron has four times the same minimal surface with its flattest area in the middle zone, which allows to cut out round holes at each façade. Each patterned membrane of the basic study 01 was produced out of six identical plane parts - three of them being mirrored (Figure 6).

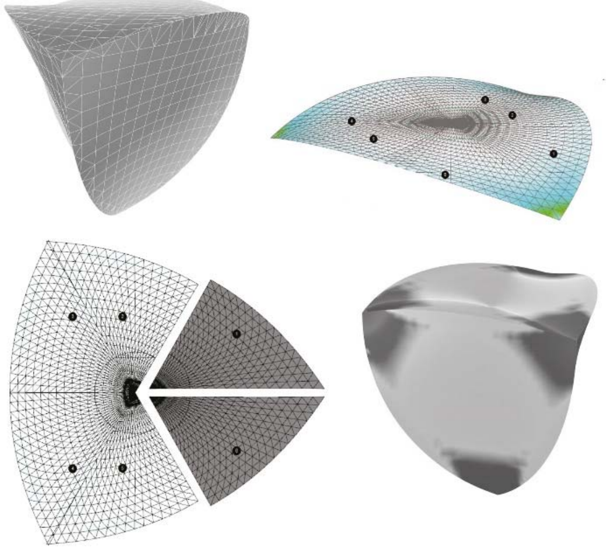

Figure 6: Basic study 01, Digital model of the spherical tetrahedron - pattering of the minimal surfaces

In the 1:10 scaled model the holes provide access to the interior, which enables shooting photos from the free interior (Figure 7). Whereas for the assembling a flat cross section of the wooden members is of benefit, since it keeps the desired direction of bending, the section of the wooden members could also be unidirectional for the long time load bearing capacity (Figure 7). After dismantling the structure, the primarily straight wooden sticks remain slightly bent, which reflects the material fatigue of wood. Due to the compressed bending in the hybrid configuration this material fatigue has no relevant influence on the load bearing capacity of the whole structure, which is also proven in a six-months test of the full scale research lab in heavily changing weather conditions in the community of Obergurgl, AUT at 2000m above sea-level (Figure 8).

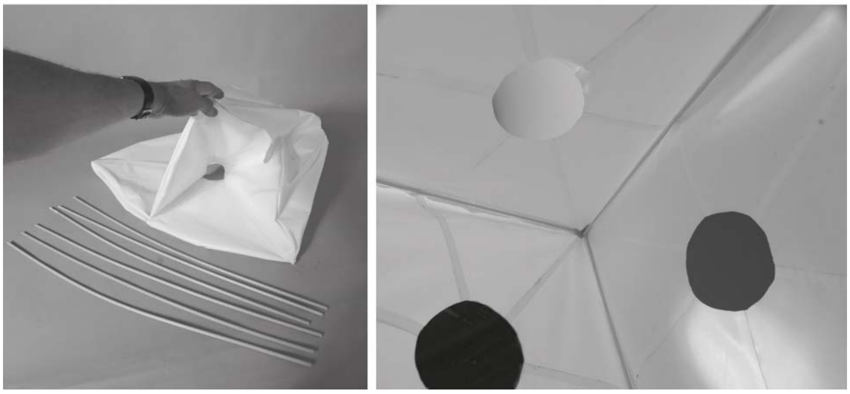

Figure 7 Case Study 01, Model 1:10, Self-found final form without cables to the centre point

Concerning the comfortable assembling of the 155 m³ voluminous construction in full scale the sliding connections of the membranes to the wooden members and the open edges of the membranes are important details to enable the self-finding equilibrium of forces in the structure.

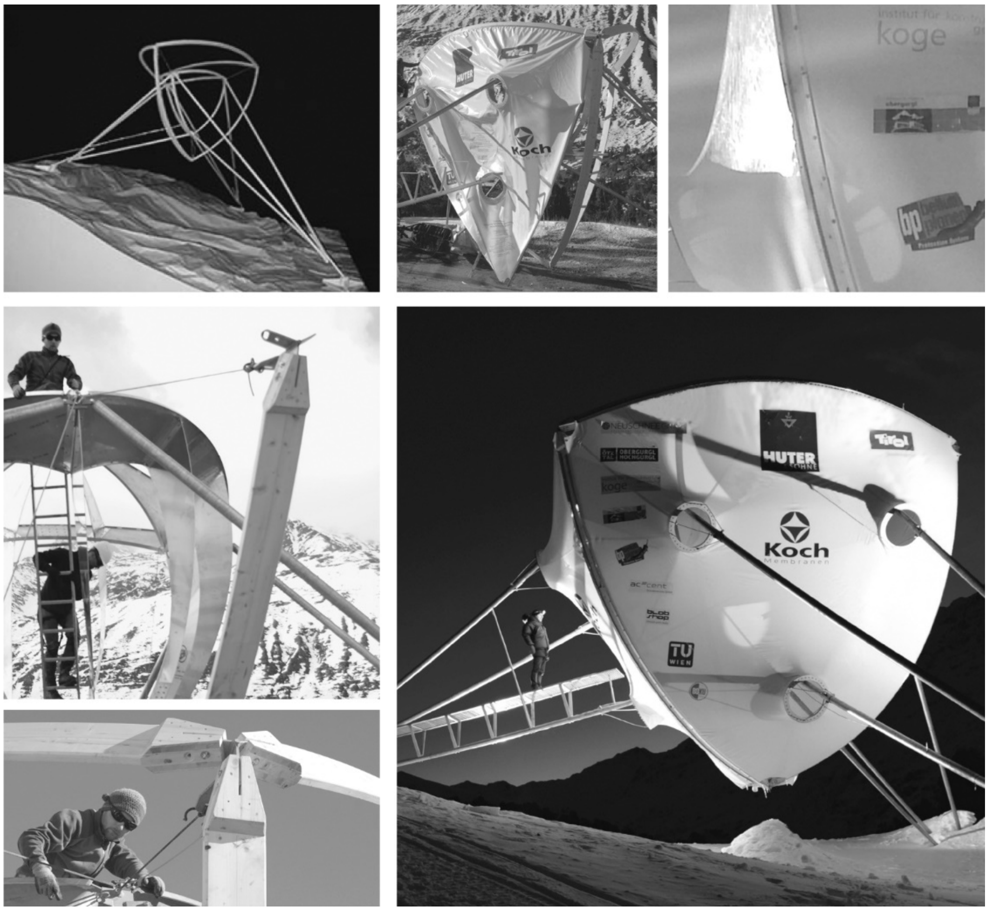

Figure 8 Full scale Case Study 01, Documentation of the assembly, Nov. 2014, Above left static concept model in 1:50

3 CASE STUDY 02 – "VIOLIN UNIT"

The case study 02 combines the two types of active bending (Indian bow and violin bow) described in chapter two and it demonstrates the benefit of a statically self-locking membrane configuration as described in chapter 3 as a solution to avoid negative effects of material fatigue (Figure 5). In the basic-study 02_A (Figure 9) the Indian bow was sub-tensioned by a steel cable to investigate the possible deformations of the wooden member in an S-form.

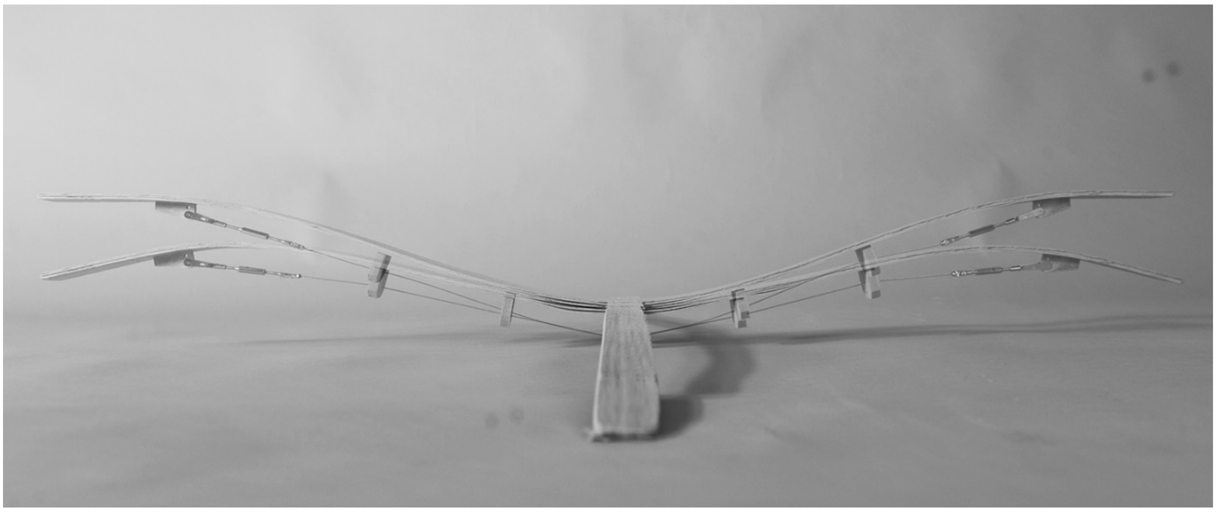

Figure 9: Basic-study 02_A – Testing the deformations while using a classical steel-cable sub-tension

In the basic-study 02_B (Figure10) the tension cables have been replaced by wooden veneer. Depending on the material-thickness this reinforcement works in both directions, although the material must be able to deal with the changing angles at the connecting points.

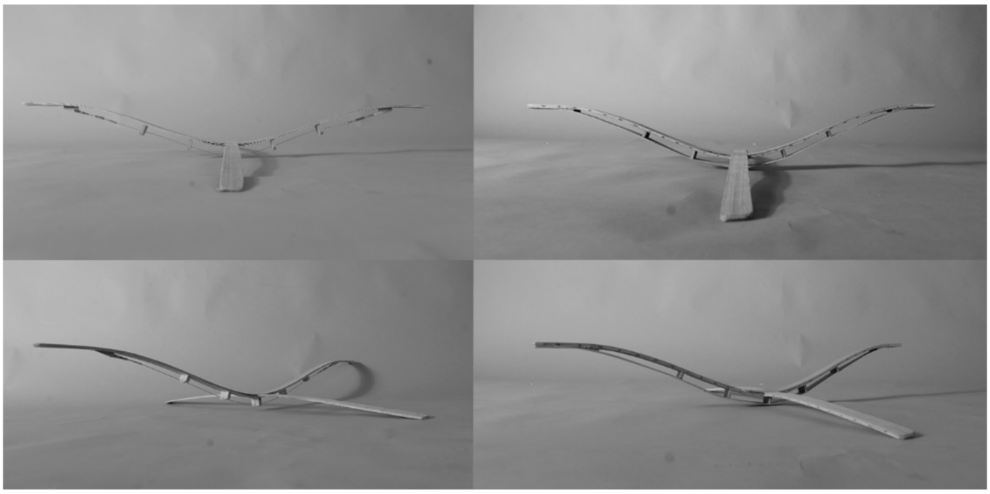

Figure 10: Basic-study 02_B – different reinforcements of the Indian bow

Keeping in mind the goal of this research (reduction of material usage and thus weight and facilitating the assembling), the following solution is found: in the central concave area the wooden offset bow strengthens the main bow in its load bearing capacity and keeps the distance of the lower structural membrane connection to the ends of both bows.

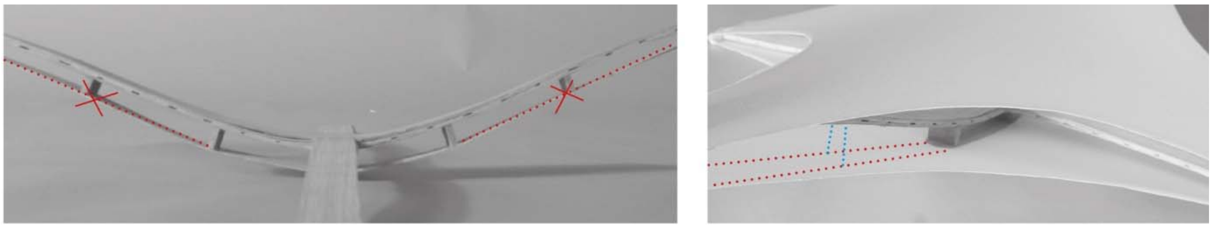

Figure 11 Basic-study 02_C – changing reinforcement of the bow related to the forces

In Figure 11 the blue dotted lines symbolize a tensile connection between the lower structural membrane and the upper bow. These connectors are architecturally not detailed but the effect of stressing those components is conceptually shown in Figure 12. The membrane and the bent wood member move closer to each other and simultaneously the endpoints move ahead causing a final-stressing of the complete membrane configuration.

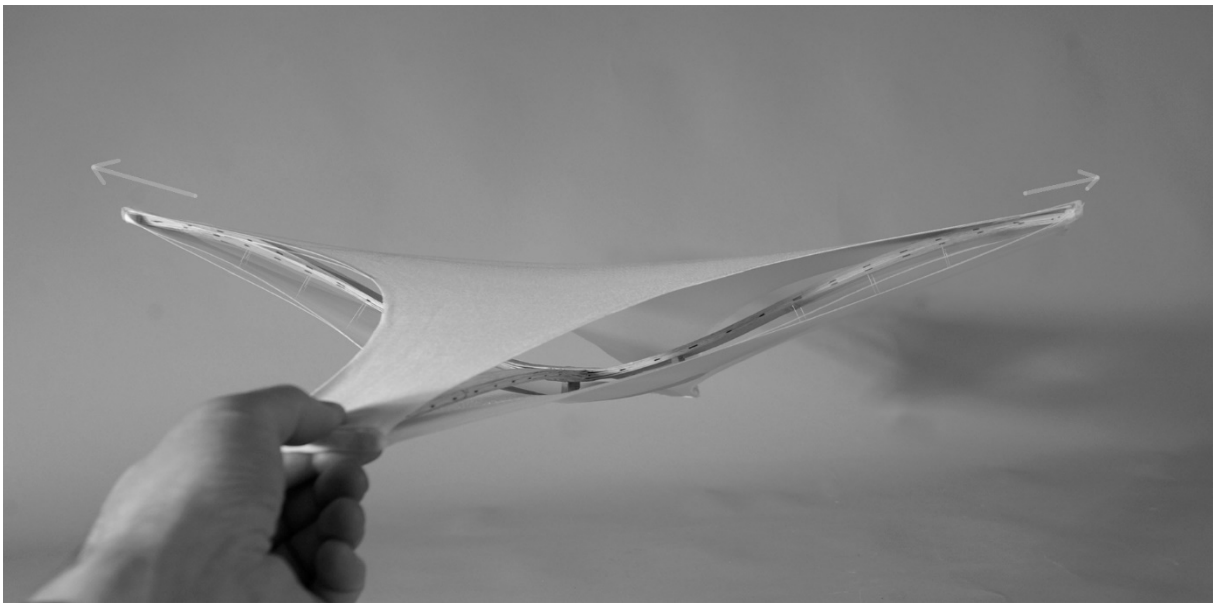

Figure 12: Case study 02 – the self-forming process while final-stressing the hybrid structure

Figure 13 gives a view to the interior of the provided space, which has no main direction. The structure can be applied for many different uses in different orientations. It can be realized with any materials matching the material properties of the case study.

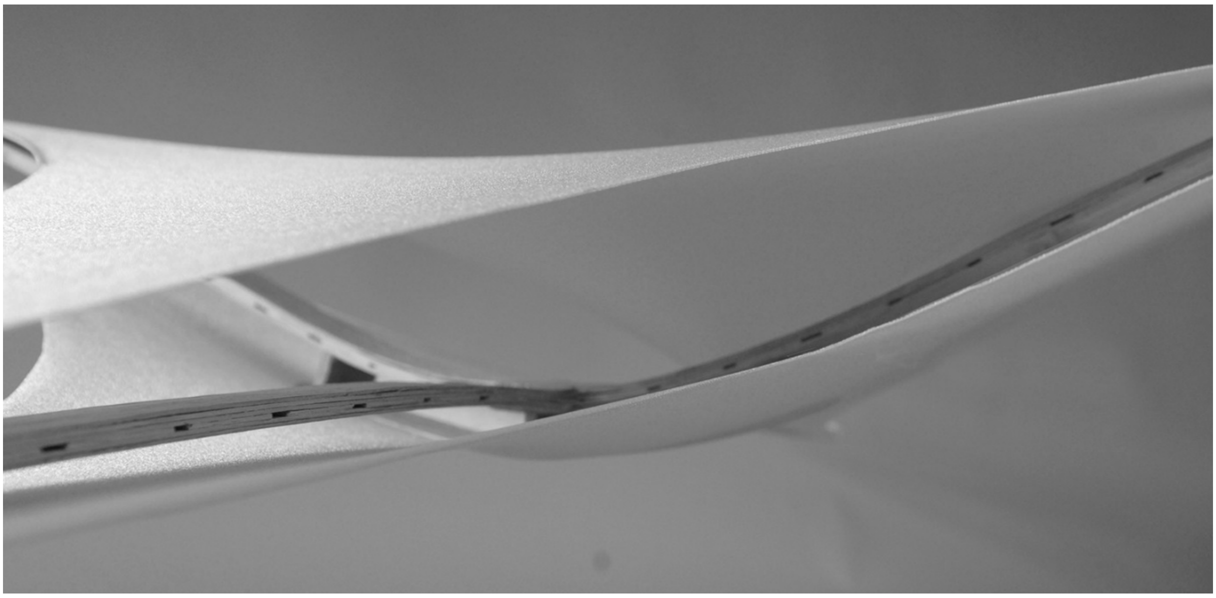

Figure 13: Case study 02 – close up view of the hybrid structure in its self-found equilibrium

4 COMPARISON OF THE TWO CASE STUDIES – COMPRESSURE BENDING

Case study 01 uses temporarily four tension cables to the central point during assembling to actively bend the members (figure 5). In the final configuration there would be the opportunity to final-stress the minimal surface membranes by prolongation of all six members simultaneously. The loadbearing capacity of the members of case study 01 can be compared with the phenomenon of the violin bow in case study 02. In both case studies the elastic members are compressed in their final configuration. The main benefit of the case study 02 consists in the system inherent opportunity to comfortably final-stress the membranes as shown in Figure 12.

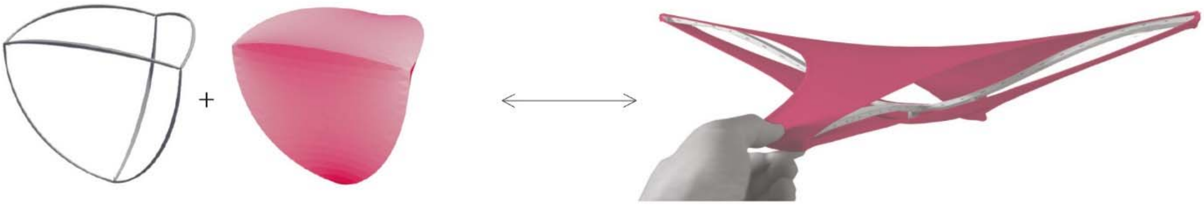

Figure 14: Comparison of the two hybrid configurations – option for final-stressing in case study 02 (right)

5 CONCLUSIONS

- Stressing a bow at the longer side in a hybrid spatial configuration with membranes allows taking advantage of the phenomenon of the **violin bow** without using the bent proof end detail of the violin bow: Stressing causes **a deformation** of the primarily curved bow **towards its straight form**, which causes in turn a prolongation of the whole structure **stressing and interlocking the configuration itself**.
- A spherical tetrahedron consisting of minimal surface membranes can be assembled easily by taking advantage of the elasticity of wood during the installation process. Six equal **elastic members are compressed into four closed minimal surface membranes**, causing a self-forming process, in which the membranes find their minimal form themselves.
- A common feature of the phenomenon of **the violin bow and the spherical tetrahedron is that the elastic members are mainly compressed.** This type of active bending causes a load capacity over long time scales.

6 PERSPECTIVES

Ongoing research focuses on the development of a matrix of self-forming processes applying the phenomenon of the violin bow in hybrid statically self-locking configurations with membranes. Future research should aim to quantify long term stress distributions within the members. Material fatigue of different types of wood and different types of bows should be investigated for realistic life cycle assessment of the hybrid structures.

REFERENCES

[1] Julian Lienhard*, Holger Alpermann, Christoph Gengnagel and Jan Knippers: Active Bending, A Review on Structures where Bending is used as a Self-Formation Process; Institute of Building Structures and Structural Design, University of Stuttgart, Germany; 2013

[2] Steve Allely, Time Baker, Paul Comstock, Jim Hamm, Ron Hardcastle, Jay Massey, John Strunk: Die Bibel des Traditionellen Bogenbaus, Band 1, Verlag Angelika Hörnig, 2008, 3. Auflage, ISBN: 978-3-9808743-2-8

[3] Klasz Walter, Filz H. Günther: “A Cloud for Fresh Snow - Research Lab – a hybrid solution of minimal surface prestressed by bending active boundary conditions forming a spherical tetrahedron” IASS Amsterdam 2015

[4] Lienhard, Julian: *Bending-Active Structures* ; Institut für Tragkonstruktionen und Konstruktives Entwerfen der Universität Stuttgart, 2014, Forschungsbericht 36