

# Timberfabric: Innovative Lightweight Structures

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## Summary

This paper addresses current questions of the research project “Timberfabric: Applying Textile Principles on Building Scale”. In particular, it discusses the question of how different Timberfabric structures based on differing spatial arrays of Textile Modules can be generated. In this context, double-layered build-ups are proposed as a solution which is not only lightweight but also light-transmissive. Several recently developed examples of double layered build-ups are discussed in detail.

**Keywords:** *Timberfabric, Macro-textiles, Form-active Timber Structures*

## 1. Introduction

The research project “Timberfabric: Applying Textile Principles on Building Scale” follows an innovative and experimental approach to develop novel lightweight timber structures. It examines structural and aesthetic qualities of textiles and textile techniques to assess their potential for large-scale application. From a structural-engineering point of view, the system-effect inherent to textiles is of special interest: textiles are made up of a multitude of elements that work together as one coherent structure. Failure of one or several elements does not entail the global failure of the structure. In addition to this technical advantage, from an aesthetic point of view, the application of textile principles at the building scale holds out the prospect of generating aesthetically outstanding timber structures. The visually appealing patterns that can be generated with such techniques are virtually limitless, and could increase the incentive for sustainable construction with timber.

But the importance of timber for this research goes beyond its qualities as a renewable resource. Exploitation of its mechanical properties is a prerequisite for the structural system that it is the goal to develop. Furthermore, the usage of timber for structural fabrics makes sense from a conceptual point of view: textile fabrics are fibre-based systems, and timber is a fibre-based material.

Based on the above starting assumptions, the research methodology relies on an iterative process of reciprocal exchange between theoretical knowledge and insights gained from practical studies of physical models and prototypes. An important achievement, the development of the Textile Module, results from this approach. This Textile Module can be summarized as an arch-like structural unit that consists of two interlaced timber panel stripes.

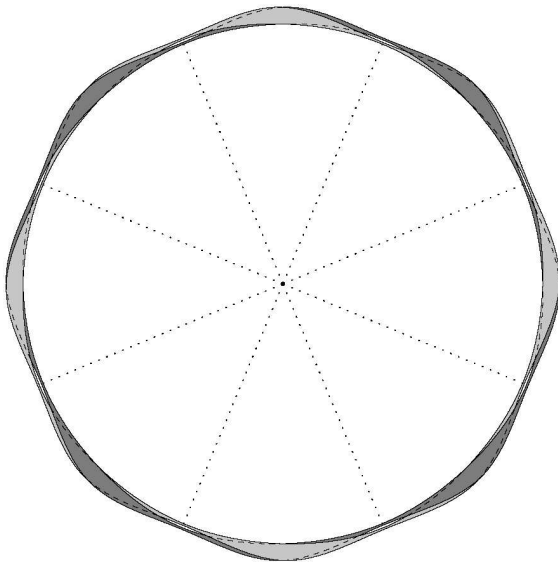
## 2. Origins and Principles of Double-layered Timberfabric

In previous studies, various solutions based on single-layered Timberfabric were examined [1]. The most evolved of those solutions employ the principle of shifting elements. The idea behind this

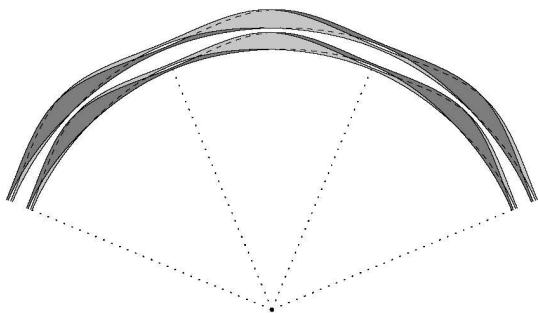
principle is to favour the prevalence of connections between structurally stronger and weaker zones in order to create more homogeneous Timber Fabric structures with an improved load bearing capacity.

The structurally stronger zones are located in the centre of a Textile Module, the weaker ones at its extremities. As a result of this design strategy, if two adjacent modules are shifted against each other by the distance of half a module, the extremity of one module is aligned with the centre of the adjacent one.

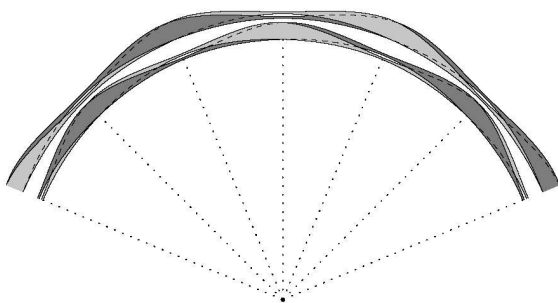
This shifting principle can be described in geometric terms as rotational displacement. The linear addition of Textile Modules leads towards 'braided' arches which geometrically correspond to segments of circles. It follows that by continuously adding modules in a linear way, a closed circle can be obtained (see fig. 1) if certain conditions are met. This is the case if the length of the used module is an integral fraction of the circumference. Shifting the elements of a pattern in a two-dimensional drawing therefore corresponds to a rotational movement in the three-dimensional context.



*Fig. 1: Eight Textile Modules connected to a closed circle, side view.*



*Fig. 2: Side view of two arches of differing radii and composed of three modules each.*



*Fig. 3: Here, the smaller arch is composed of three modules, the larger one is rotationally displaced and consists of two full and two half modules.*

Double-layered Timberfabric represents an advance in application of the shifting principle. Its main aim is to improve the desirable structural properties of Timberfabric. Double-layered Timberfabric allows for the application of displacement not only in a rotational way, but also radially to the centre of the circle segment that is created by the braided arches (see fig. 2 & 3). With arches of different radii, it becomes possible to overlap and interconnect them and to create a double layered structure. By doing so the structural height of the arches is increased, while the resulting construct shows a higher rigidity.

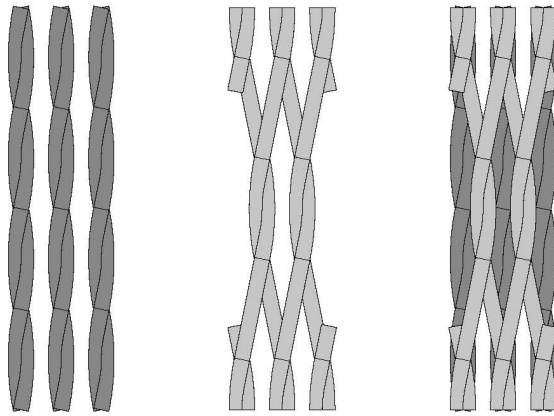
### 3. Advancing double-layered Timberfabric

The principles described above were implemented in the first double-layered prototype, which was on display during the Timber Project exhibition [2]. This prototype represents the foundation of a new phase of studies described below, which aim to develop alternative variants of double-layered Timberfabric. These studies address several questions in parallel. Some of the questions are related to the assembly and construction process of Timberfabric structures. However, the main concern is to further enhance the structures' stability and to select one of the solutions as template for a large-scale prototype. Possible evaluation criteria for the selection are structural properties and light transmission.

A first line of investigation can be described as follows. The inner layer of the structure consists of a series of straight arches of two different types of higher order units. The first of these units is composed of three plain Textile Modules in a linear array. The second unit type has identical length to the first but contains only two complete modules located symmetrically around the mid-point of the unit. The two extremities of this second unit arch

each consist of a half module such that if the two types of higher order units are aligned, their arches are maximally out of phase with each other. In building the overall structure of the inner layer, units of the two types are assembled next to each other in an alternating way.

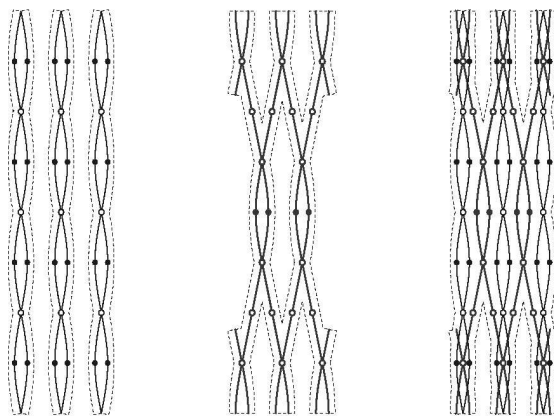
The outer layer is composed of the same two types. Here the arches have a bigger radius and are 'offset' in the radial direction. Additionally, there is a displacement by the width of one arch, perpendicular to the arch direction. Thus, if the inner layer arch is type one, than the outer arch is type two and vice versa. Horizontal connectors were projected between the two layers. Although the result is a valid option, it overly resembles a series of independent double-layered arches,



suggesting that structural calculations might not benefit from the aspired system effect.

Consequently, the following studies aim at a multilayer solution with improved connectivity and continuity between the separate elements. Different strategies are developed, each based upon a common global geometry, the barrel vault. Geometrically the barrel vault can be described as segment of a cylindrical surface. This global geometry derives from the local geometry of the Textile Module and the way it is assembled.

### 3.1 'Differentiated Patterns'



The approach we have applied at this early stage of investigation is to work with two different principles on the respective layers. One of the layers consists of a series of independent braided arches, as was the case in the aforementioned study. In this particular case the arches of one layer are placed next to each other in a parallel way, while the elements of the other layer are interlaced in a different way in order to establish the desired continuity in the direction perpendicular to the span. Along the summit of this layer, two of the interlaced stripes form a configuration that equates to the single Textile Module. The stripes then continue in both directions in a diagonal way, forming a V-like shape. The extremities of the stripes then reconnect at the bearings, in a configuration that equates to half a Textile Module (see fig. 4 & 5).

Fig.4: The upper row shows the patterns of the interior and the exterior layer, as well as the superimposition of the two. Below, the center lines are indicated. Stronger zones are marked with a filled dot, weaker zones with a hollow one.

With regard to the span of the layers, the aim is to achieve a length that corresponds to the length of one Textile Module multiplied by an integral number. The rational underlying this constraint is to facilitate the matching of the different layers. Here, the span of each layer is equal to the length of four Textile Modules. This span results from the constraint of achieving a continuous pattern with interbraided elements both in the centre and at the bearings. Four textile modules is the minimum span necessary for this pattern. Consequently, the length of each arch of the other layer must also correspond to a length of four Textile Modules.



Fig.5 : Prototype of the first variant with two layers based on different patterns.

Furthermore, this is not the only geometric dependency existing between the two layers. The distance between the arches of one layer is determined by the other layer's pattern. The two

layers are tuned in a way that leads towards the desired superposition of stronger and weaker zones. At the bearings, those zones are superposed by one-directional displacement. Along the summit, a two-directional displacement can be identified. The only area where the superposition does not work in an optimal way is where the diagonal elements of the one layer are on top of a weaker zone of the other layer. The actual connection between the layers is established by additional continuous horizontal elements perpendicular to the span. By connecting the two layers, the separate arches become part of the interconnected layer. One continuous entity is created and the desired continuity is established. In this case study, the continuous pattern was chosen for the exterior layer in order to render visible its continuity towards the outside.

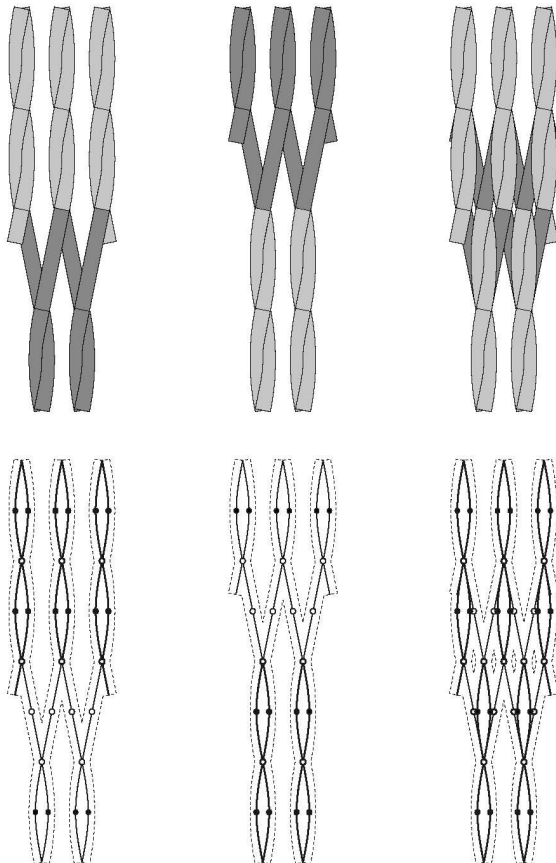


Fig. 6: The upper row shows the patterns of the two symmetrical layers, as well as their superimposition. Below, the center lines are indicated. Stronger zones are marked with a filled dot, weaker zones with a hollow one.



Fig. 7: Prototype of the second variant with interlaced layers.

However, it would be equally possible to invert the layers and place the series of arches on the outside of the barrel vault instead. It can be concluded that, thanks to an overall successful superposition of stronger and weaker zones, a relatively good structural strength is achieved. Depending on the angle of the sun, direct and indirect light transmission through the structure are possible.

### 3.2 'Interlaced Layers'

In contrast to the previous case study, this one not only sets out to use the same principle for both layers, but employs two layers with a completely identical configuration for building up the double-layered structure (see fig. 6 & 7). This is made possible by the asymmetric section of the configuration used, which in turn derives from the pattern that was implemented. The pattern developed here is based on the minimum pattern necessary to create a regularly interconnected structure with one entire Textile Module on each bearing and a zone of transitional elements in the center.

In order to create an asymmetric section, the elements are extended on one side of the structure to form an additional Textile Module. On one side of the structure there is a sequence of two Textile Modules, after which the intermerged elements continue in a diagonal array, forming a V-like shape, and then merge again into one Textile Module at the other bearing of the layer.

As for the case of the differentiated patterns structure, the span of the interlaced layer structure equals four Textile Modules. In this instance this parameter is a consequence of the two rules implemented in the design of the pattern: having entire Textile Modules at the bearings and the obligate creation of an asymmetric section. As in the differentiated patterns case study, the design aim was to have the interlaced elements merging towards the bearings of the structure. But this time the goal was to accept only elements merged into one entire Textile Module.

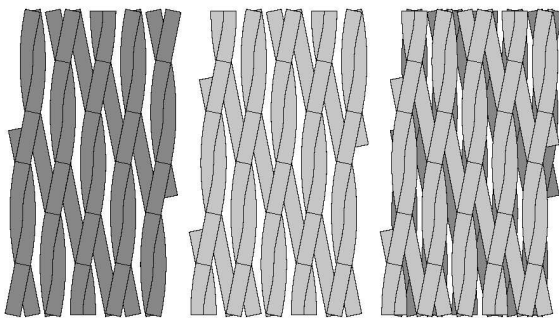
While the pattern of the second layer is point symmetric to the original layer, the second layer is not exactly identical to the first one. This is done to avoid generating zones with only one layer and to

assure a double layered design all over the structure. It is also the reason why it's difficult to achieve a structure with a globally rectangular plan. The half with two Textile Modules in a row is always on the exterior, the other half of the layer on the interior.

This case study essentially deals with the concept of interlacing layers. As implemented the concept is geometrically interesting, however there are some problems regarding the resulting structural capacities of the edifice as a whole. This is partly due to the exact superposition of stronger and weaker zones: strong superposed with strong, weak superposed with weak.

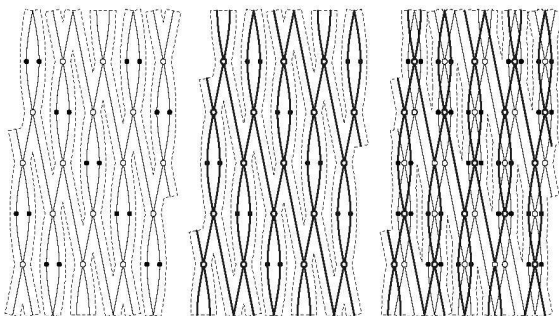
Another less desirable aspect of such an interlaced layer structure is the fact that, due to the intersection and due to the symmetrical and identical build-up of the layers, a linear zone with almost no structural height is created at the structure's zenith. Globally, the structure acts similarly to a three hinged arch.

This particular study presents an exception in the total series of structural variants explored: in all the other solutions examined, there are two different layers with two different radii. The length of the Textile Modules on the exterior layer is systematically bigger than the one on the interior layer.



In this variant, the radius changes within the layer, which is achieved by varying the length of the involved modules.

A further interesting point is the fact that the strategy applied here is a logical advancement of a fundamental principle inherent to the Textile Module. The two planks that constitute the Textile Module are also point symmetric. In such a unit, the plank which is on the exterior at the one extremity becomes the interior plank at the other extremity. This principle of layer inversion is pushed to the next level with the proposal of interlaced layers - one layer is not only one plank, but rather a continuous fabric.



### 3.3 'Doubled Continuity'

Among the several solutions and patterns developed from the examination of single-layered Timberfabric, one in particular served as the starting point for the current phase of exploration of the double-layered approach introduced here. The particularity of the single-layered pattern in question is due to the way in which its composite elements are merged, which leads towards a continuous construct.

The elements forming a single Textile Module are repeated in a diagonal plane. Those diagonals form a V-like shape, and then the elements merge again into Textile Module configurations. As already mentioned, this same principle was also applied in one of the layers in the study on differentiated layers. The only difference in the single-layered case study is that the arms of the V-like shape are unequal. It is this asymmetry which leads to a construct in which the Textile Modules are shifted and a diagonal pattern is created (see fig. 8 & 9).

In the doubled continuity case study, the concept is to create a second layer, based on the same pattern as in the single-layered case, but superimposed with rotational displacement by half a module, relative to the original layer. The span as well as the width of

Fig. 8: The upper row shows the patterns of the interior and the exterior layer, as well as the superimposition of the two. Below, the center lines are indicated. Stronger zones are marked with a filled dot, weaker zones with a hollow one.



Fig. 9: Prototype of the third variant.

the structure presented here are imposed by the constraint of having one complete diagonal array of Textile Modules on the interior layer. This diagonal array consists of five Textile Modules, while the resulting span of the structure equates to three Textile Modules.

A rather dense structure results from the strategy applied and the predefined pattern specifications. Despite the fairly simple logic of its repeating pattern it has a visually complex and puzzling appearance.

### 3.4 ‘Twisted Superimposition’

The approach applied in this case is to use the same pattern on both layers. The make-up used is relatively simple. Each layer consists of a sequence of independent ‘interbraided’ arches. The arches of the interior layer equate to a length of three Textile Modules and lie perpendicular to the borderlines of the structure. The exterior layer is equally composed of a sequence of ‘braided’ arches, again with an arch-length of three Textile Modules. However, this layer’s arches are built up quite differently from the first. Each arch starts with half a Textile Module, followed by two complete ones and ending with a half module again (see fig. 10 & 11).

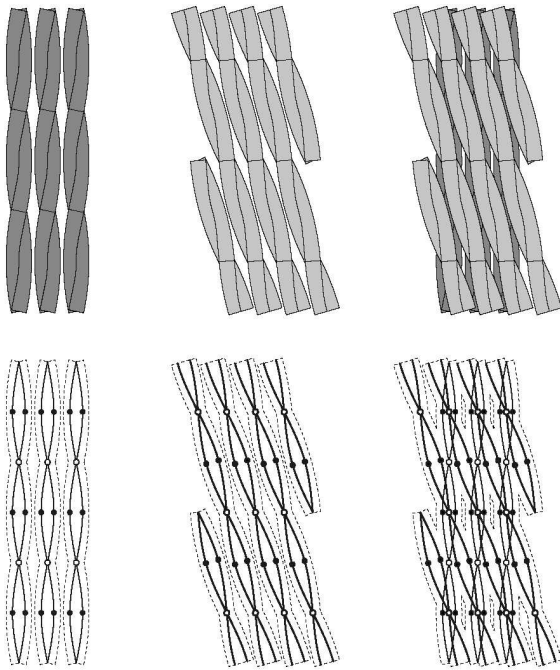


Fig. 10: The upper row shows the patterns of the interior and the exterior layer, as well as the superimposition of the two. Below, the center lines are indicated. Stronger zones are marked with a filled dot, weaker zones with a hollow one.

This approach results in a shifted pattern on the exterior layer and offers the possibility to connect weaker and stronger zones between layers rather than merely within each layer thus increasing overall structural performance. The major difference in comparison to the interior layer is that the exterior layer’s arches are not perpendicular to the borderline. The solution proposed by this study is very similar to the structure that was developed in the first double-layered prototype [1].

This approach succeeds in improving the connectivity of the separate arches by the simple means of rotating the span direction of the exterior layer relative to the interior layer. In the original double-layered prototype, always one arch of one layer was connected to two arches of the other layer. In the solution employing rotation, one arch of the exterior layer can be connected to five arches of the interior layer. In this way, an improved connectivity and continuity is achieved. As in the other examples, with exception of the interlaced layers solution, the sequence of the layers is convertible.

This version is considered for further development. A bigger prototype will be built and its structural capacity and behavior will be tested in a comprehensive manner.

## 4. Conclusion

The solutions presented here have different vastly qualities in terms of light transmission and structural rigidity. Two of the four solutions have a span-length of four Textile Modules. In comparison to those with a span-length of only three modules, the former are structurally less advantageous: they have the same structural height, but a larger span.

While the span parameter can't be changed as it results from the pre-defined pattern specifications, a



Fig. 11: Prototype of the fourth variant. The exterior layer is rotated around a central, vertical axis.

possible solution to investigate could be to increase the distance between layers and thereby the ratio of span to structural height. For further general improvement of double-layered structures, the tactic of adding a third layer is a feasible option that could be considered. Another could be to increase the thickness of the stripes within the interbraided arches by doubling the planks or panels used.

## **5. References**

- [1] HUDERT, M., WEINAND, Y., “Structural Timber Fabric: Applying Textile Principles on Building Scale“, *Structures and Architecture*, vol. CD, 2010
- [2] Timber Project, Espace Archizoom, EPFL, February 26<sup>th</sup> to May 30<sup>th</sup> 2010