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Experimental and numerical study on structural behavior of a single timber Textile Module

M. Sistaninia, M. Hudert, L. Humbert *, Y. Weinand

IBOIS Laboratory for Timber Construction, Ecole Polytechnique Fédérale de Lausanne (EPFL), CH-1015 Lausanne, Switzerland

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ABSTRACT

The present work investigates an innovative class of timber structure with potential applications in roofing, facade and bridge construction, called Timberfabric. The development of Timberfabric structures originates from the approach of harnessing the structural, modular and qualities of textiles in timber construction (Weinand and Hudert, 2010) [9]. Timberfabric structures are comprised of repetitive arrangements of one or more structural unit cells called Textile Modules. When properly designed, one obtains a modular and lightweight structure with interesting and unusual geometrical and structural qualities.

This paper focuses on the single timber Textile Module. Based on the finite element (FE) method, a reliable procedure is proposed for modeling the overall assembly process of the Textile Module. For comparison, Textile Module prototypes are constructed at two different scales (large and intermediate scales) with different assembly conditions. The proposed geometrically nonlinear FE model allows evaluation of the stresses that are induced during the construction process and which may affect the structural integrity of the module. In particular, the risk of failure during assembly is identified using the anisotropic Tsai-Hill criterion.

The structural behavior of the timber Textile Module is then investigated through bending tests using the constructed prototypes. During the loading procedure, the vertical deflections are measured at different locations on the prototype surface by means of external displacement transducers. Using the FE model, the corresponding deformed shapes are simulated by applying the bending loads on the prestressed Textile Module. Experimental displacements and FE predictions are thus compared and found to be in good agreement.

1. Introduction

Wood is a versatile construction material that is abundant in many regions of the world. Moreover, this is a renewable resource that can be processed and assembled in energy efficient ways. Recent studies [1,2] indicate that the use of timber as construction material results in buildings with a better environmental performance in comparison to conventional materials. With regard to present-day concerns over globally increasing energy consumption and simultaneously decreasing resources wood holds a distinct advantage over other construction materials such as concrete or steel. This, in turn, should increase the interest of the research community in expanding the range of applications of timber structures.

Examples of modern but already well-established timber architectural forms include folded plate structures [3,4], lattice structures (e.g. timber lattice roof for the Mannheim Bundesgartenschau) [4,5] and Multi-reciprocal frame structures [6,7]. Such forms present clear advantages over more traditional flat-surfaced roofing structures, increasing the efficiency of the structure, reducing its weight and enforcing load carrying capacity.

Recently, a new type of timber structures, called Timberfabric, with particular structural properties emanating from the principle of weaving techniques has been developed at IBOIS [8,9]. Its development has been driven by the aim of incorporating specific textile qualities such as modularity and the mutual support of textile fabrics' constituent elements in timber construction. Timberfabric structures have a broad potential for architectural applications due to their versatility, adaptability and their qualities, which are directly linked to their structural make-up. They are based on repetition of a structural unit cell, the Textile Module, which is depicted in Fig. 1a, and which results from bringing together textile assembly principles with timber components. The double-layered Timberfabric structure shown in Fig. 1b represents only one of many possible configurations of Textile Modules.

* Corresponding author. Tel.: +41 216 932398; fax: +41 216 932394.
E-mail addresses: masoud.sistaninia@epfl.ch (M. Sistaninia), markus.hudert@epfl.ch (M. Hudert), laurent.humbert@epfl.ch (L. Humbert), yves.weinand@epfl.ch (Y. Weinand).

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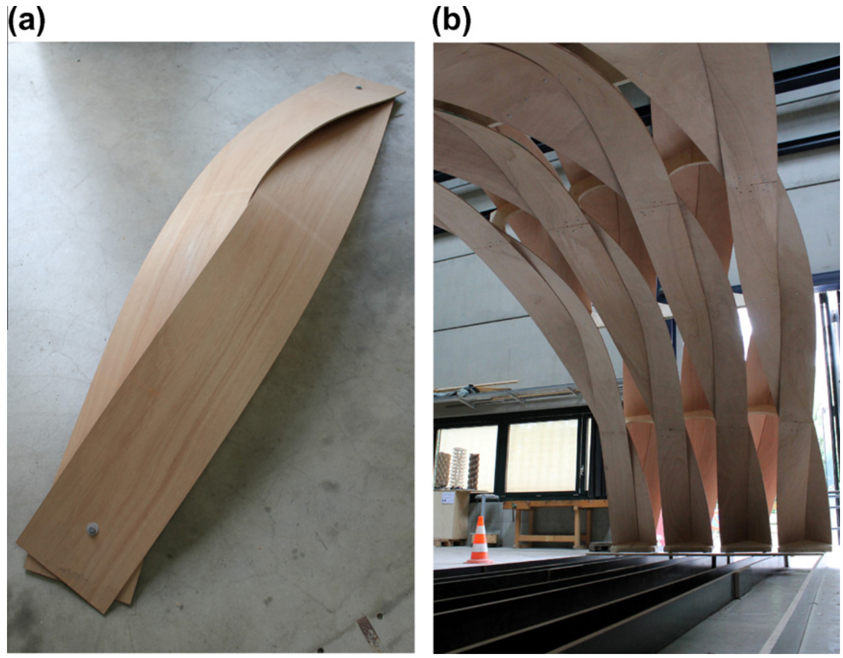

Fig. 1. (a) Single Textile Module. (b) Double-layered Timberfabric structure.

The single Textile Module presented in Fig. 1a provides a structural shape of particular interest for this study. Briefly, it consists of two mutually supporting thin panels that become curved during the assembly process as illustrated in Fig. 2. Consequently, construction (or residual) stresses are generated during the fabrication of the module and their amplitude typically depends on the constitutive material, the size of panels as well as the assembly conditions. The use of poor quality material or inappropriately dimensioned panels or a combination of both may even cause the Textile Module's premature failure during the assembly process. The construction stresses can be evaluated by means of a finite element (FE) model that takes into account the different fabrication stages (Fig. 2).

This paper focuses on the fabrication process and structural behavior of a representative single Textile Module in a bending load configuration. The proposed approach is both experimental and numerical. It involves the fabrication of two prototypes at two different scales (intermediate and large scale) with different assembly conditions, as discussed in the first part of Section 2.

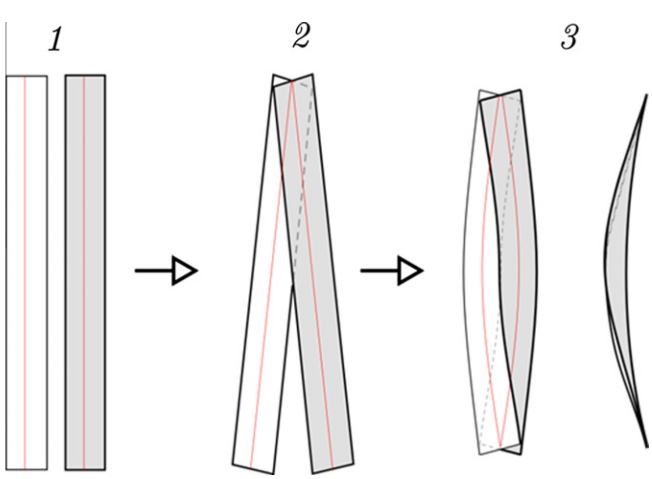

Fig. 2. Design principle for the Textile Module.

The second part of the section is devoted to the bending test setup and required measurement equipment.

Despite the numerous finite element (FE) models already available for braided textile composites [10–14], the numerical study of the timber Textile Module requires special attention as its analysis is complicated by the particular geometry and assembly conditions encountered. Because of the large deflections and rotations undergone by the module during the fabrication stages (Fig. 2), a geometrically non-linear FE model that aims to accurately reproduce the geometrical shape of the Textile Module is developed in Section 3. It is anticipated that this model should permit a representative evaluation of the construction stresses involved in fabrication. In Section 4, vertical displacements measured at several locations of the prototype surface during the bending tests are compared to the finite element predictions. Finally, the structural behavior of the Textile Module is discussed.

2. Experimental investigations

2.1. Materials and specimens

For this study, two Textile Modules have been constructed: one is formed of two GFP laminated wood panels of length $l = 12.320$ m and width $w = 0.770$ m and the other is formed of two TeboPly™ Okoumé plywood panels of $l = 2.34$ m and width $w = 0.24$ m. The GFP and Okoumé panels used to fabricate the Textile Modules are respectively supplied by the companies Schilliger Holz AG (Switzerland) and Thebault (France). As schematically depicted in Fig. 3, the panels consist of symmetric orthotropic laminates, with the three-ply [0/90/0] GFP and four-ply $[0/90]_s$ Okoumé having thickness t of 33 mm and 6.3 mm respectively. As customary, plywood is produced from rotary cut veneers that are bonded with an adhesive (synthetic) resin under high pressure conditions. In each case, the uppermost (face) and lowermost (back) veneers are of equal thickness with the same grain direction along the longitudinal axis (L-axis) of the laminate. As depicted in Fig. 3a, for the three-ply configuration, the symmetry plane passes through the center of the core ply of 13 mm thick and its grain is directed along the transversal axis (T-axis) of the laminate. For the four-ply layup,