LOW-CARBON COMPOSITE FLOOR

DESIGN OF A NEW COMPOSITE SLAB MADE OF CROSS-LAMINATED-TIMBER AND RAW EARTH FOR MASS TIMBER STRUCTURES

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The growing interest in mass timber construction is driven by the need to reduce building's carbon footprint, but wood panels such as CLT face challenges in terms of acoustic insulation and vibration behaviour. The use of raw earth is being considered in this type of floors to compensate for its weaknesses and improve its mechanical performance. This thesis focuses on the development of a CLT-raw earth composite slab, with the aim of reducing the amount of wood used and promoting the use of a low-carbon material such as raw earth.

Key words:
Mass Timber Strucutre; Composite Slab; Cross-laminated-timber (CLT); Raw Earth; Gamma-Method

0 – CONTEXT

These days, the interest in mass timber construction is growing steadily. This is driven by the objective of reducing building's carbon footprint. "Mass timber" meets these challenges with new engineered wood products (EWPs) such as cross-laminated-timber panels (CLT) and glue-laminated-timber elements (GLT), a.k.a. glulam. Unfortunately, the relatively lightweight of the CLT floors, compared with their concrete equivalents, makes them the Achille's heel of mass timber constructions in terms of serviceability requirements such as acoustic insulation and vibration behaviour. As a matter of fact, design offices are required to add dead-load mass like gravel or sand to reach these requirements.

In this framework, another material is locally and widely available and could compensate for CLT's weaknesses: raw earth. Its use is sustainable, low cost and it can provide thermic or acoustic mass and fire safety in mass timber buildings. Despite all these advantages and its potential for use, excavated earth from the construction of the foundations is generally and nevertheless considered like a construction site's waste.

1 – CLT STATE OF THE ART

Cross-laminated-timber is a structural panel product which was originally developed in Austria and entered the European market in 1990s. These panels are used as wall structure, floor and roof slabs for small housing or high-rise buildings up to 18 storeys (i.e. the Mjøstårnet by Voll Arkitekter in Norway). The fabrication of a CLT panel results from the bonding of layers of parallel wood boards stacked crosswise, each layer of boards is usually oriented perpendicular to adjacent layers and glued on the wide faces of each board (see Fig. 1). In general, it is done in a symmetric way so that the outer layers have the same orientation. The resulting standard panels are from 3,50m wide to 16,50m long. The majority of commercially available CLTs are made of an odd number of layers (usually 3, 5 or 7) and are entirely manufactured at present from softwoods. The use of hardwoods in CLT, or more generally in EWPs, is indeed limited due to the slower growth rate of hardwood.

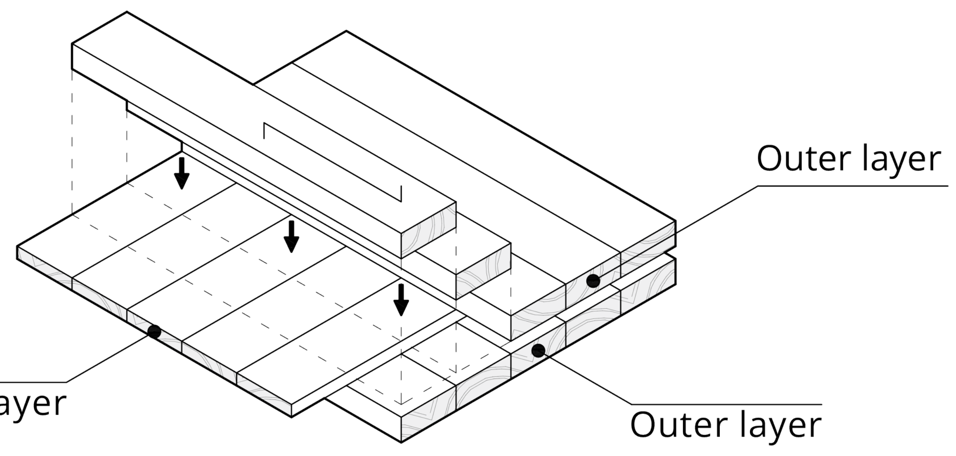

Figure 1 – Fabrication process of a cross-laminated-timber (CLT) 3-ply panel © E. MARY

Due to its orthogonal make-up, CLT has greater dimensional stability than the constituent solid timber and has the ability to withstand bi-axial loading. In contrast with glulam, which is a uni-directional structural element, CLT can be used as panel subjected to out-of-plane bending, such as floors and roofs. In that case, it behaves like a composite material due to the higher shear flexibility of the cross-layers. The cross-layers tends to decrease the effective bending stiffness of the CLT sections, and therefore, have both ultimate limit state (ULS) and serviceability limit state (SLS) implications in terms of failure governed by the rolling shear strength of the cross-layers and deflection due to significant shear deformation of the cross-layers.

2 – RAW EARTH STATE OF THE ART

For thousands of years, earth has been used as a building material because it was nearby and abundant. This material consists of a compacted mixture of moist clay and sand, depending on the local available resources. Today in Belgium, 37 million tonnes of soil are excavated every year on construction sites, of which 16 million tonnes are unused and disposed of in landfill sites or quarries. In addition to this huge potential for use, the use of raw earth could significantly reduce the carbon footprint of the construction sector by not requiring any fossil fuels for its manufacture.

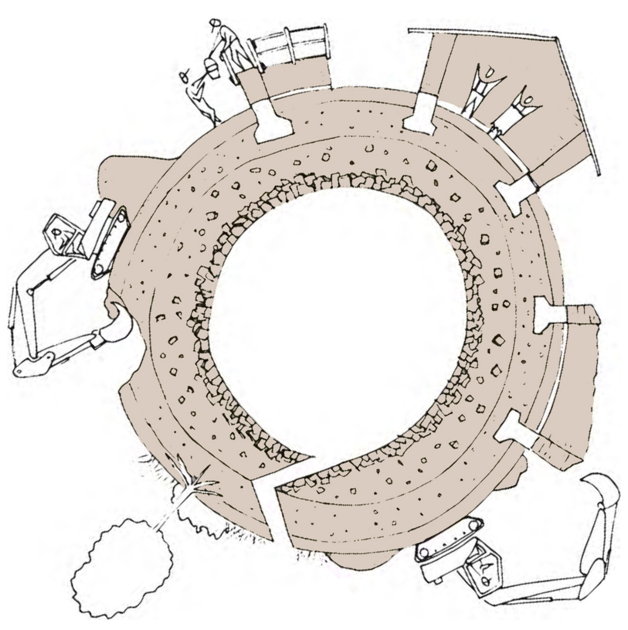

Figure 2 – Cradle-to-cradle design and circularity of earth material © BC materials (Léém Guide

The most commonly used techniques for using raw earth are: pisé (rammed earth), poured earth, bauge, adobe, compressed blocks, cob and plaster. Some of these techniques are non-structural work, but others can be used in structure because they have sufficient mechanical properties due to their manufacturing process or composition. The load-bearing walls of low-rise buildings (up to 2 storeys) can actually be made of raw earth blocks or rammed earth, as long as the carried loads are not too significant.

3 – COMPOSITE PROPOSITION

The perspective of creating a new composite slab made of cross-laminated-timber (CLT) and raw earth is considered to reduce the amount of wood used and add value to another low-carbon material. Following some initial calculations with gamma-method (considering gamma between the two layers =0,80), it is possible to reduce the thickness of a CLT floor from 150mm (see Fig. 3) to 100mm (see Fig. 4) by making it work together with 80mm raw earth.

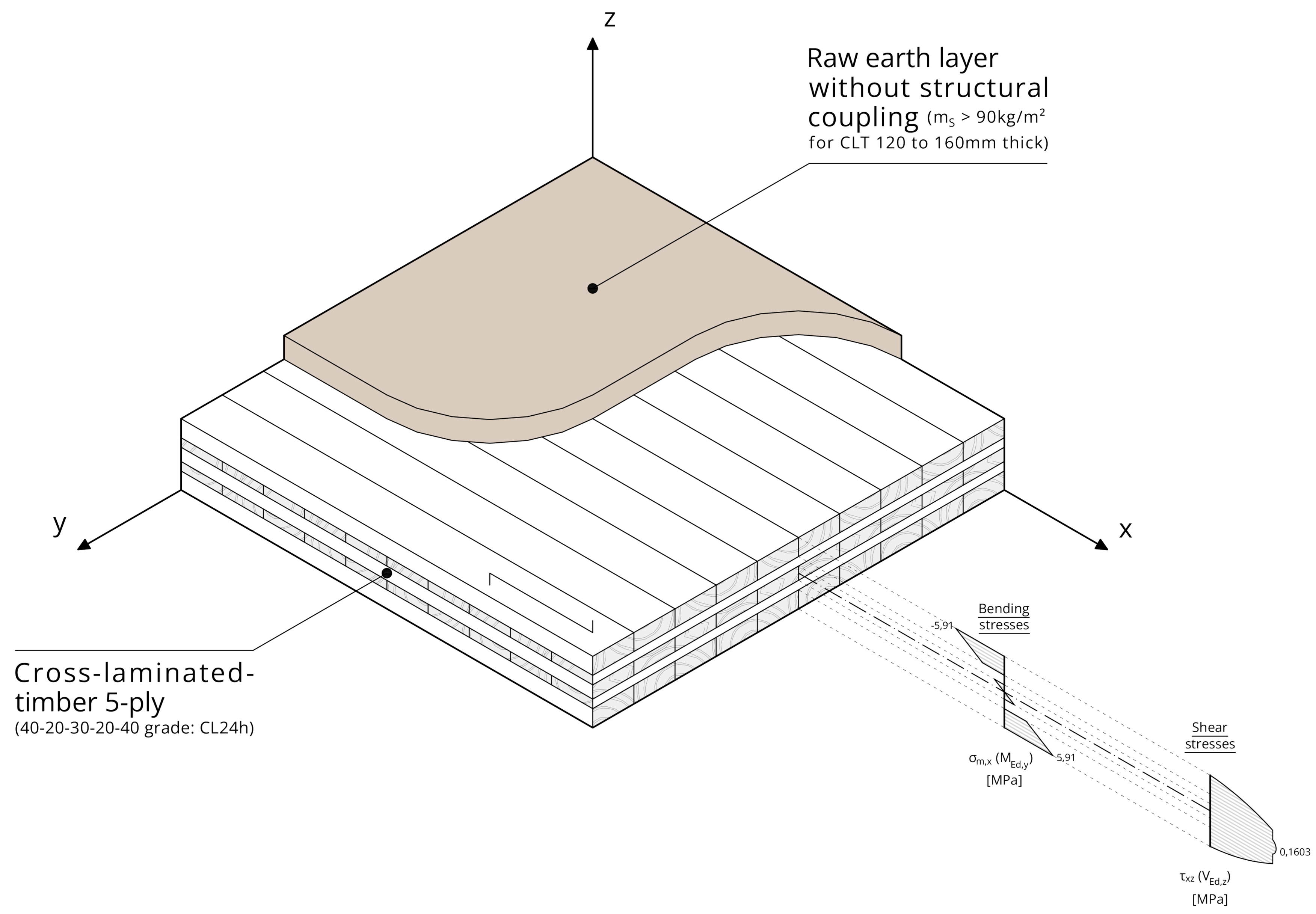

Figure 3 – Cross-laminated-timber (CLT) 5-ply under out-of-plane bending due to typical dwelling loads (span of 4,50m) © E. MARY

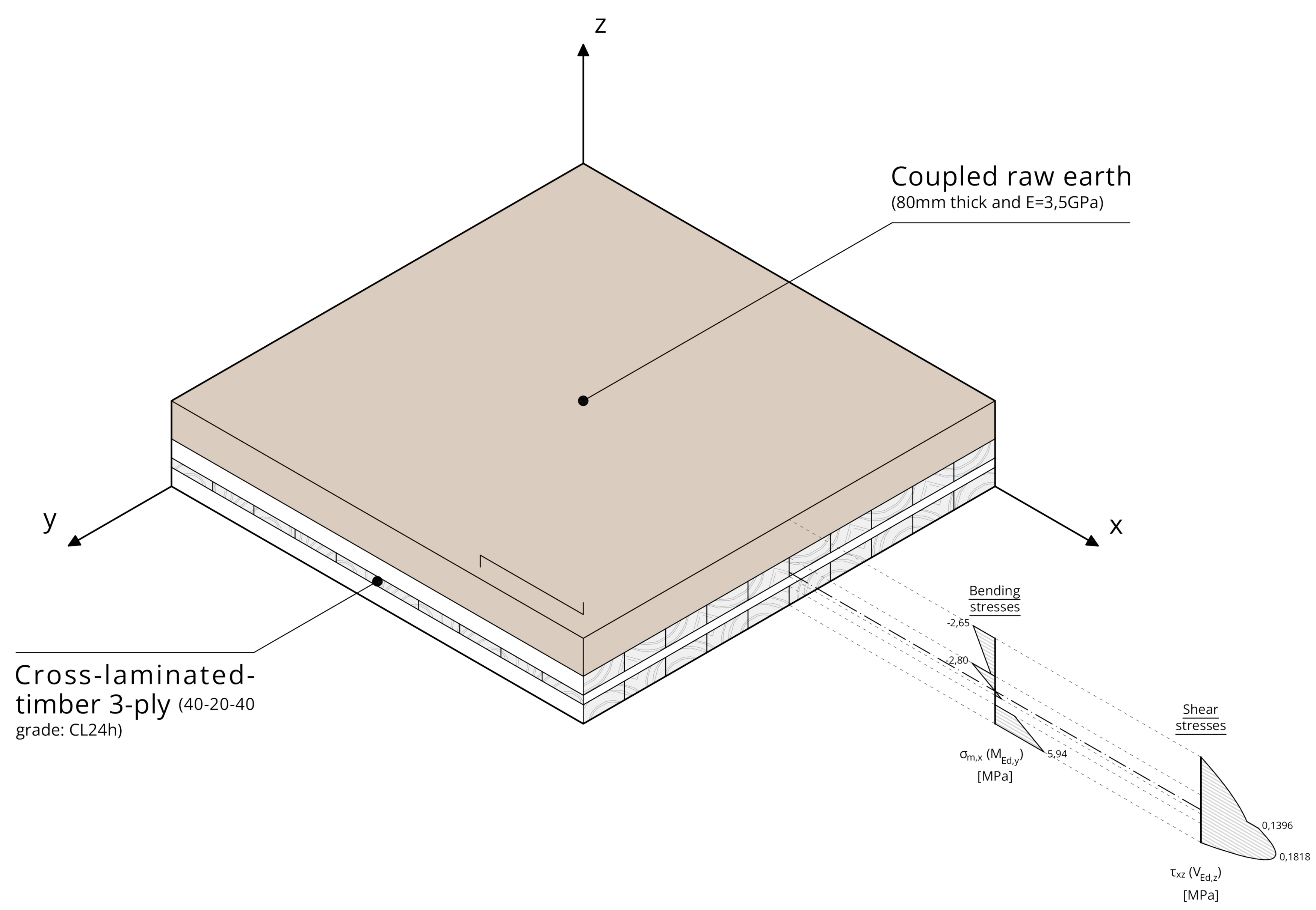

Figure 4 – CLT-raw earth composite slab under out-of-plane bending due to typical dwelling loads (span of 4,50m) © E. MARY

4 – MECHANICAL CONNECTION

One of the main challenges for this composite slab is the connection between the CLT panel and the raw earth layer. The connection stiffness has indeed an impact on the stresses distribution of the composite element. The greater the stiffness of the connectors, the greater the bending stiffness of the floor. For standard timber-concrete-composite (TCC) slabs, the usual connections are made using steel fasteners: screws or perforated plates glued to timber (see Fig. 5 (1) and (2)). The intention for this thesis would be to favour wooden connectors and not to use steel fasteners.

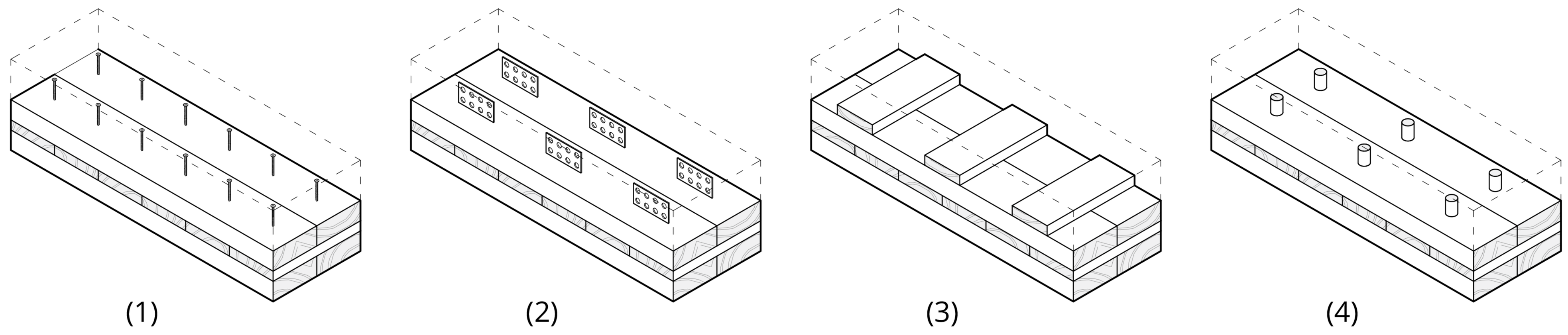

Figure 5 – Most commonly used connections: (1) screws; (2) steel plates glued to timber; (3) transversal glued boards; (4) timber dowels © E. MARY

5 – PERSPECTIVES / OUTLOOK

With this knowledge, the aim of this thesis is to study the mechanical behaviour of a low-carbon CLT-raw earth composite floor, with a view to improve its acoustic, vibratory and mechanical performance. First of all, the way in which the raw earth is laid on the CLT panel must be designed taking into account the constraints associated with its implementation on site. Similarly, the raw earth manufacturing recipe must be optimised to obtain sufficient mechanical properties. Next, the mechanical connections between the two layers must be studied and experimentally tested in the lab to find out the connection stiffness of the connectors.