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EVALUATING MOISTURE BEHAVIOUR IN CROSS LAMINATED TIMBER USING TIME-RESOLVED COMPUTED TOMOGRAPHY SCANNING AFTER WEATHER PROTECTION FAILURE

Tommy VIKBERG
RISE - Research Institutes of Sweden
Laboratorgränd 2, 931 77 Skellefteå, Sweden
Tel: 0046 10 516 50 00, E-mail: tommy.vikberg@ri.se

Frank SCHLEICHER
RISE - Research Institutes of Sweden
Laboratorgränd 2, 931 77 Skellefteå, Sweden
E-mail: frank.schleicher@ri.se

Irina MARTYNYUK
RISE - Research Institutes of Sweden
Laboratorgränd 2, 931 77 Skellefteå, Sweden
E-mail: irina.martynyuk@ri.se

Lars HANSSON
Luleå University of Technology, Wood Science and Engineering
Forskargatan 1, 931 87 Skellefteå, Sweden
E-mail: lars.hansson@ltu.se
Norwegian University of Science and Technology,
Faculty of Engineering, Department of Ocean Operations and Civil Engineering, Ålesund, Norway
E-mail: laha@ntnu.no

Olof BROMAN
Luleå University of Technology, Wood Science and Engineering
Forskargatan 1, 931 87 Skellefteå, Sweden
E-mail: olov.broman@ltu.se

Karin SANDBERG
RISE - Research Institutes of Sweden
Laboratorgränd 2, 931 77 Skellefteå, Sweden
E-mail: karin.sandberg@ri.se

Abstract:

Cross-laminated timber (CLT) is increasingly used in sustainable construction but is sensitive to moisture, which can compromise durability and promote microbial growth. Damage to temporary weather protection during construction can lead to unintended moisture exposure. In such cases, it is important to understand how the material may have been affected. While X-ray computed tomography (CT) is not suitable for field application, it offers a detailed means of studying internal moisture behaviour and contributes to a better understanding of moisture-related risks in CLT following barrier failure.

This study uses CT to investigate how moisture distributes and changes within CLT after protective covering damage. Eight CLT specimens from Scots pine were subjected to controlled wetting and drying cycles. Time-resolved CT scanning, combined with image processing techniques, was used to capture internal moisture variation with high spatial resolution. The method enabled detailed observation of both absorption and drying, revealing transport patterns between layers and interfaces.

The study demonstrates that CT effectively reveals both moisture spread and slow drying in CLT following barrier failure.

Key words: *CT, x-ray, CLT, wood, construction.*

INTRODUCTION

Sweden's construction and real estate sector accounts for about one fifth of Sweden's total climate impact (Boverket, 2020). In order to reduce the CO2 emissions of buildings, it is necessary to find building materials that have a lower climate impact. Even when the house structure itself is made of wood, concrete, which in the production phase emits a significant amount of CO2, is commonly used as the foundation material. Therefore, alternatives are being sought, both for insulation materials and foundations and there are already some completed buildings with more or less sustainable foundations depending on the material use and mix, where concrete has been partially or completely replaced by other materials such as CLT, glass foam or expanded polystyrene. Especially CLT as an organic material can be exposed to mold growth or rot over time if construction errors cause high moisture content in the wood. Since the material in the CLT is renewable and the timber itself can act as a carbon sink if used in applications with long service life, it offers significant environmental benefits compared to traditional materials, provided that moisture control and proper detailing are ensured. Comparisons between, for example, concrete foundations and CLT foundations for apartment buildings show possible savings of 2/3 of the CO2 emissions over a lifespan of 100 years (Hultqvist and Ziegenfeldt 2023).

In foundations with CLT, a semipermeable moisture barrier is usually used on the surface to avoid moisture damage during transport and the construction process itself. Although calculations show that it should work (Baric and Johansson 2022), there is a lack of both long-term experience and long-term tests that show safe function during the service life.

The construction process for a house takes approximately seven days until the roof is installed and the danger of standing water on the house foundation has thus been averted. During the installation period, personnel move around the construction site where negligence and ignorance can lead to both major and minor damage to the sealing membranes. If damage occurs that is not repaired, the material can become damp in the event of precipitation. CT has been widely used as a research tool to investigate water in wood (Beaulieu and Dutilleul 2019; Couceiro et al. 2020; Vikberg and Hansson 2024). With a CLT exposed to free water, some extra concerns arise since the water can travel in joints between single boards building up the CLT (Brandner et al. 2016) and the actual soaking can take place far from where the water enters the CLT. In order to understand if the CT is a suitable tool for doing such an investigation, this work focused on developing a methodology for investigation the water in wooden constructions.

OBJECTIVE

The main objective of this work is to develop a methodology for detailed investigation of water distribution in wooden constructions after exposure to free water. In the long term, the aim is to improve the understanding of how large the affected areas may become and how long a subsequent drying period may need to be if a weather-protection failure occurs at a construction site.

MATERIAL, METHOD, EQUIPMENT

In order to evaluate whether CT scanning is a suitable tool for this type of investigation, a methodology for studying water distribution in wooden constructions was developed. Eight CLT specimens with different types of moisture-barrier failures were examined.

In this work, eight specimens of CLT with dimensions 420 × 210 × 80 mm^3 were utilized. The CLT consisted of three layers of Scots pine. After the specimens were covered with a moisture barrier on five sides, a plastic pipe section was attached with silicone to the upper side. In the area of the plastic pipe, the moisture barrier was damaged in four different ways, with two replicates of each damage type. The four types of damage were:

- Small holes made with the tip of a knife, corresponding to small scratches in the barrier caused by dropping tools or simiilar.
- Large opening in the barrier, i.e. a ”X” made with knife.
- Screw to the centre of the CLT, corresponding to when a temporary support needs to be attached to the CLT.
- Screw through the entire CLT such as above, simple with a longer screw.

The four differnt failures of the barrier is shown in Fig.1.

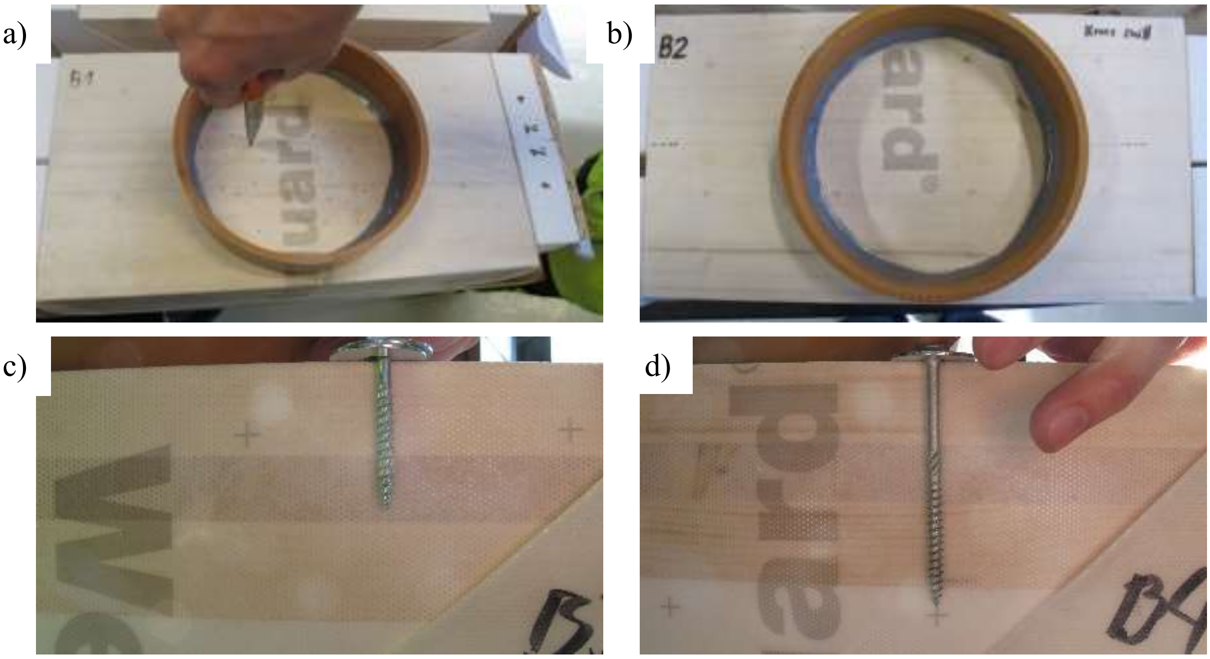


Fig. 1.
The four different types of barrier failure, a) small scratches, b) large opening in the barrier, c) screws to the mid lamella of the CLT, d) screws through the entire CLT.

To improve the efficiency in the handling and scanning, four specimens were placed on one support, individually separated by expanded polystyrene to get a low density area between each specimen making the separation in the stack of images easier, see Fig. 2.

Fig. 2.
Four specimens on one support prior to the attachment of the barrier and water containers.

The specimens were scanned using an industrial CT scanner (Microtec Mito, Microtec Bressanone) adapted for research at Luleå University of Technology in Skellefteå, Sweden. The scans produced reconstructed 3D image volumes in 16-bit grey-scale TIFF format, with a spatial resolution of 0.3 mm in all three orthogonal directions, resulting in cubic voxels of 0.3 × 0.3 × 0.3 mm³.

Repeated scans were performed at different stages of the wetting and drying cycles. The scanning took place at:

- Day 0, prior to the wetting.
- Day 5, after 5 days of water imerssion in container.
- Day 10, after 10 days of water in container.
- Day 15, after 5 days of drying.
- Day 25, after 15 days of drying.
- Day 45, after 35 days of drying.

To enable direct voxel-wise comparison between time steps, the image volumes of each CLT specimen were spatially registered to align the same physical regions of the material. Non-rigid registration, performed using the open-source SimpleElastix library (Klein et al. 2010), ensured accurate alignment and made it possible to compute reliable difference images between scans.

The analysis was performed using the free 3D slicer software (version 5.6.2) in which the first step was to subtract the initial picture from the subsequent ones, resulting in files showcasing just the density difference. To get rid of single voxels showing large density difference, a filtering which removed all the areas smaller than 3 × 3 × 3 voxels was applied. Finally, some artefacts origin from the plastic pipe, which worked as a container for the free water in between the scanning of the wetting cycle, were manually erased.

RESULTS AND DISCUSSION

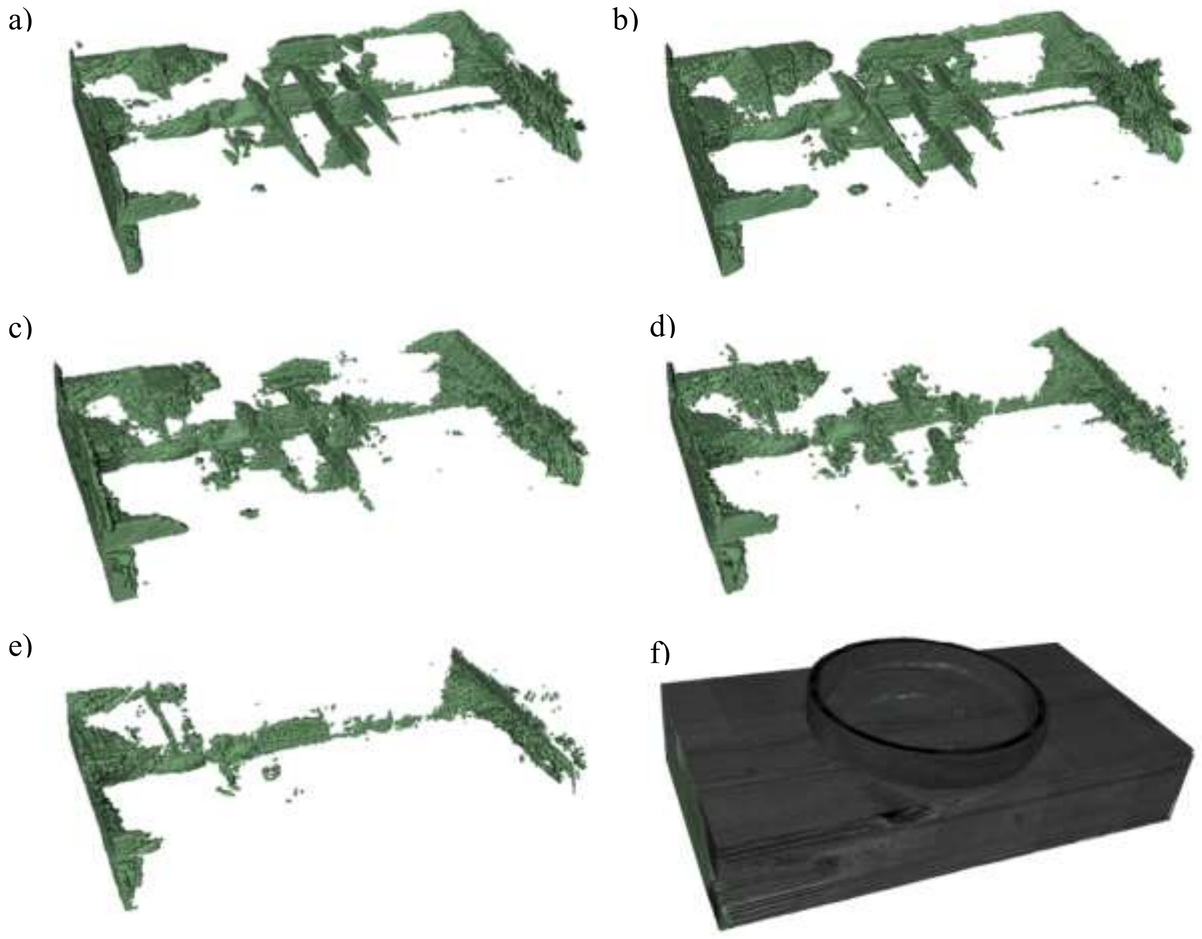
Experimental setup

When subtracting the images from the different scans, some single voxels with large values appeared. This was caused both by difficulties in aligning the specimens in the scanner before each scan and by achieving perfect voxel-wise registration. The problem would likely have been smaller if it had been possible to keep the specimens in the scanner throughout the entire test. Due to the risk of water leakage and the cost of occupying the scanner for the full period, this was not possible. A more rigid support with mechanical end positions, holding the specimens during scanning, would increase the possibility of achieving smaller lateral positioning errors in subsequent scans.

The plastic pipes attached to the test specimens, functioning as containers for the free water, also caused some artefacts in the images. Although these artefacts could be removed during the image analysis, it would have been preferable to use a water container with lower density to reduce artefact formation in the first place.

Water spread

Due to the small number of tested specimens, the risk of drawing broad conclusions is clear. One example of an examined specimen is shown in Fig. 3.



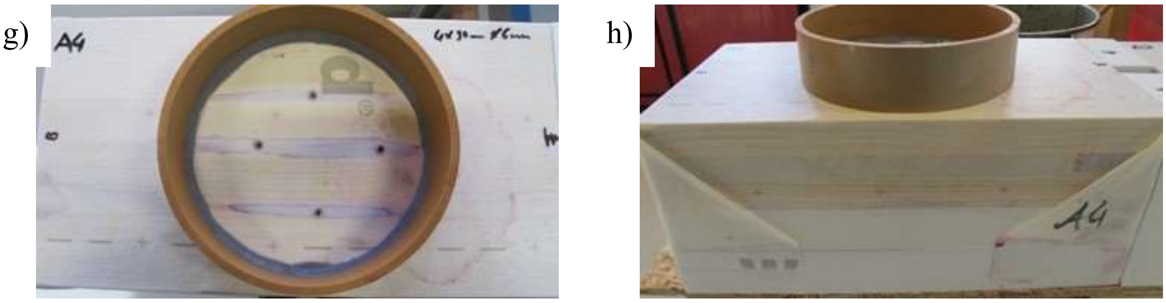


Fig. 3.
One of the specimens where the barrier was damaged by four screws. a) water after five days of wetting, b) water after 10 days of wetting, c) remaining water after five days of drying, d) water after 15 days of drying, e) water after 35 days of drying, f) CT image showing the wood structure and water container, g) specimen seen from above, h) specimen seen from side.

From Fig. 3, it is clear that the water entered the CLT through the screw holes and spread mainly along the grain direction in the solid wood. It can also be seen-although more clearly when rotating and magnifying the images-that water spread between the short edges of adjacent boards in the CLT. It should be noted that in this particular CLT, the short edges of the boards were not glued together.

Finally, a large amount of water was transported to the ends of the specimen, where it accumulated. To increase relevance when mimicking real conditions, it would be useful to elongate the specimens in one direction from the damage location. This would make it possible to examine water spread for damages occurring both close to a CLT edge and far from the edge, using a single specimen but analysing two directions.

These observations directly address the stated objectives by demonstrating both the extent of the water-affected areas and the slow drying behaviour over several weeks.

CONCLUSIONS

This work developed a CT-based methodology for detailed investigation of water distribution in CLT exposed to free water. The combination of repeated scanning, image registration and voxel-wise comparison enabled reliable identification of wetting and drying patterns, although very small wetting events may be partly lost and the limited specimen size restricts full-scale representativeness.

The results showed that the extent of water uptake depends strongly on the type of membrane failure. Large openings and through-screws caused rapid and extensive moisture transport, often reaching lamella interfaces and, in several cases, the panel ends. Smaller damages yielded more localized wetting.

Drying was slow. Even after 35 days, several specimens retained internal moisture, especially along screw channels and lamella interfaces. This indicates that CLT can hold free water for several weeks after exposure.

Overall, the method proved effective, and the findings provide valuable insight into both the potential size of moisture-affected regions and the drying duration following weather-protection failures.

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