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Moisture monitoring throughout the construction and occupancy of mass timber buildings

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Abstract:
While wood has been used as a building material for millennia, "mass timber" buildings have only been realized within the past few years within North America. Mass timber refers to a class of wood composites that include glue-laminated timber (glulam), structural composite lumber, and cross laminated timber (CLT). These composites allow multi-story residential and non-residential buildings to be constructed more efficiently than traditional light-framed wood systems. While there are a host of environmental and other benefits to building with mass timber, these buildings are different from steel or concrete buildings as the physical and mechanical properties of wood change with its moisture content. Wood-moisture interactions can lead to difficulties in the utilization of wood such as dimensional instability, cracking, microbial attack, and fastener corrosion. Understanding the amount of moisture and range of moisture fluctuations that could be expected in North American mass timber buildings is necessary for more informed design of mass timber buildings.
This paper presents preliminary findings from an ongoing research program instrumenting CLT buildings to measure wood moisture content. An overview of the research program is presented along with data from first year of moisture monitoring in an 8-story building in Portland, Oregon. This project measures the wood moisture content throughout the construction cycle, including the fabrication, shipping, staging, and erection of the panels. These preliminary field measurements can help characterize moisture changes in CLT during construction and guide the construction of future CLT buildings.

Keywords:
Cross laminated timber (CLT), wood, moisture monitoring, construction

1. Introduction

"Mass timber" buildings made of large timber products such as glue-laminated timber (glulam) and cross laminated timber (CLT) have recently been introduced in Canada and the United States as a way to sequester carbon and achieve taller buildings than are possible with traditional wood systems [1, 2]. Because the timber members in mass timber buildings are much thicker than traditional dimensioned lumber used in "stick frame" construction, they are more fire resistant, but at the same time they pose a challenge in moisture control of the building as they take longer to dry if they get wet [3, 4].

While there have been laboratory and modelling studies of moisture movement in CLT [5, 6], CLT behavior cannot be fully understood without gathering data from real buildings [7]. Data collected on real buildings can be used to validate design assumptions used. Because CLT can take a long time to dry out if it gets wet, it's important to understand what moisture exposures the CLT experiences on the jobsite, what the starting moisture content of the CLT panels are when the building is finished, and how quickly the CLT reaches an equilibrium with its environment. This paper describes a portion of a large study to obtain moisture monitoring data in mass timber buildings across several different climate zones in the US. The goal is to understand the wood moisture content from the factory to occupancy of the building. The focus of this paper is on the challenges of instrumenting and moisture monitoring during the fabrication of the CLT panels through the building occupancy.

2. Methods

Overall, the approach for moisture monitoring involves sensors installed at the CLT production facility, and additional sensors on the jobsite at different construction stages. This paper focuses on the sensor installation in the first building, an 8-story building in Portland, OR. The monitoring project utilizes small, pin type moisture meters manufactured by Omnisense LLC (Models no. S-2, and S-16). The meters calculate wood moisture content by measuring the electrical conductance between two pins embedded in the wood [8, 9].

The installed sensors in the building are located in five primary assemblies: (1) glulam columns near the wood/concrete foundation interface (2) CLT- sensor installed at the top with pins measuring at the half depth and full depth (3) CLT- sensor installed at the top with pins measuring at each lamination within the CLT (4) CLT- sensors installed at the top with pins measuring the top lamination (used only on the roof) (5) sensors installed in fire-retardant-treated (FRT) stud walls to measure the moisture content of the secondary

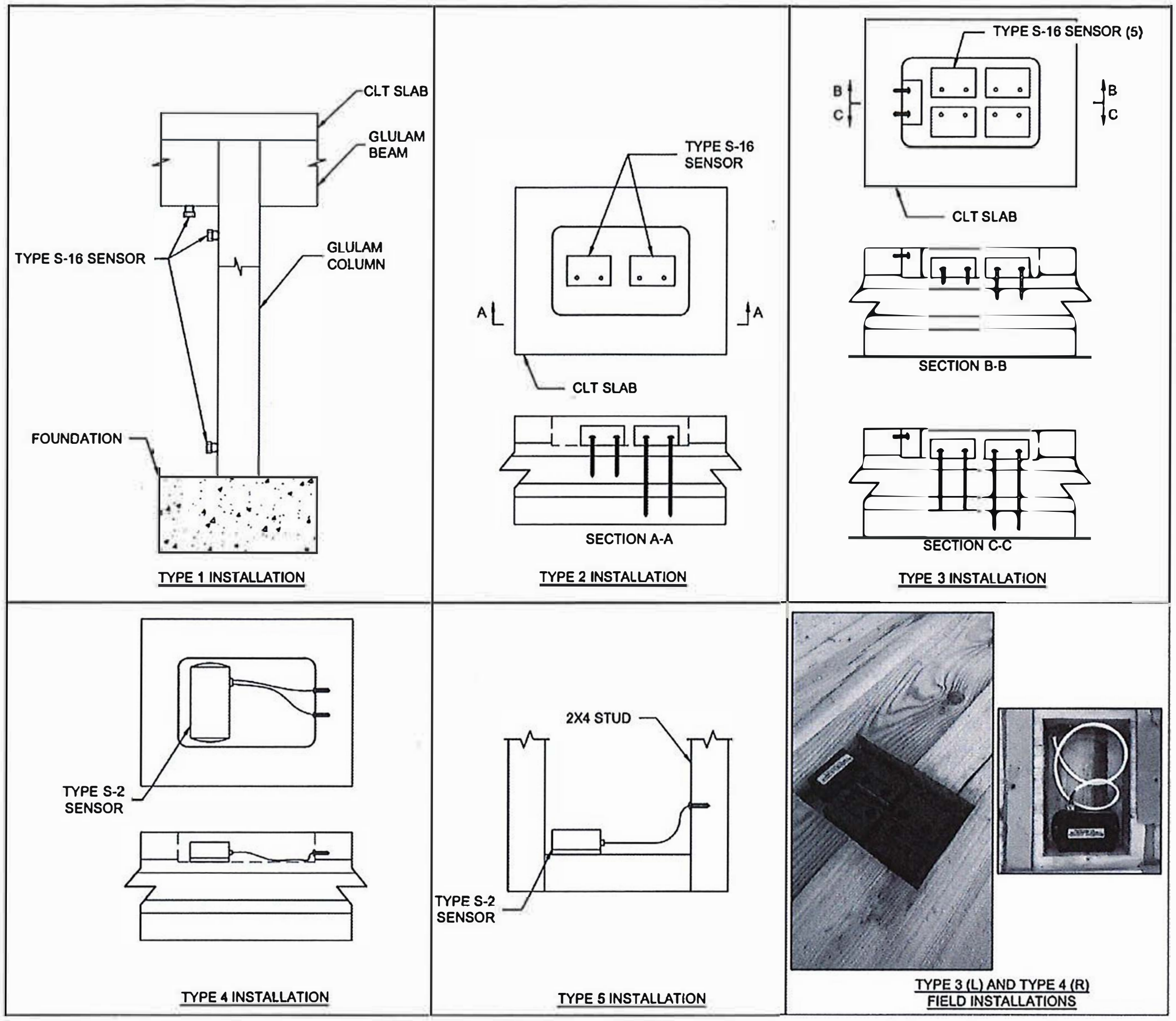

Figure 1 : Sensor installation details

structure. Figure 1 shows the various measurement configurations. Because the building owner preferred the sensors to be hidden from view, sensors were installed on the top side of the CLT panels. This required notching out small areas to place the sensors. Overall, eighty three sensors were installed throughout the building.

Twenty of the sensors were installed at the Structurlam factory located in Penticton, British Columbia, Canada on November 18-20,2016. Four panels were installed with five, type S-16 sensors (type 3 configuration). The panels chosen for production monitoring were selected on a basis of availability and accessibility within Structurlam's production cycle. Sensors were installed in the panels to record data during storage at Structurlam and through shipping and arrival at the building site.

The remaining 63 sensors were installed in two stages as building construction progressed on site during the building's construction.

The first set of sensors were deployed upon the completed framing of the fourth floor on January 6–8 of 2017 and included all sensors on the fourth floor and below. At the same time, a wireless gateway was installed to retrieve and transmit the data from the sensors. However, in the days following the January implementation trip the project site was subjected to adverse weather conditions including a rare blizzard and frequent precipitation. During this time, the building's framing was fully exposed to environmental conditions without a building enclosure. This direct exposure to liquid water damaged many of the sensors. Even though sensors installed in recesses in the top layer of the CLT were covered with flashing and were sealed with tape after installation to protect them from liquid water, this system was ineffective and many of the CLT integrated sensors on the site were damaged by precipitation.

The second set of sensors were installed on February 10–13 of 2017 upon the completed framing of the

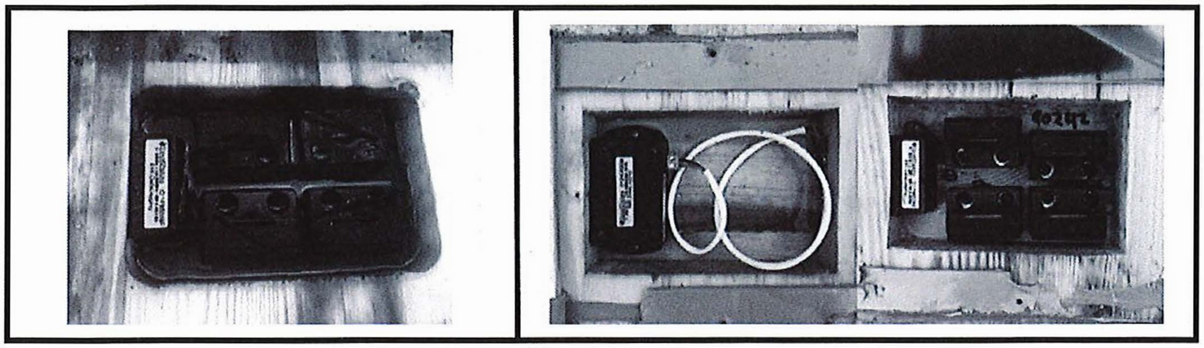

Figure 2 : Water damaged sensors from the first (left) and second (right) installations.

structural system up to and including the roof. In addition, damaged sensors installed on the prior implementation trip were removed and replaced. All sensors placed in recesses on the top of the panel were covered with flashing and sealed with foam gasketing and silicone caulk.

At the time the sensors were installed, it was expected that the roofing membrane would be installed immediately after. However, heavy precipitation followed the sensor installation before membrane application. Due to concerns with drying ability of the rooftop CLT panels, the installation of the water impermeable membrane on the top side of the CLT panels was delayed. During this period, several of the recesses containing sensors became waterlogged and the sensors were damaged. Figure 2 shows pictures of water damaged sensors on the site

3. Results and discussion

The goal of this paper was to describe the approach for sensor installation, and share lessons learned for future moisture monitoring of mass timber buildings under construction. At this point, the two major findings are that (1) CLT panels remain dry in the factory and throughout the shipping process and (2) without robust sensors that can withstand adverse environmental conditions, it is extremely difficult to collect data throughout the construction cycle before the building envelope is finished.

Figure 3 shows the wood moisture content during the manufacturing and shipping stages of the construction process. The sensors were installed on November 20th, 2017 in panels that would be placed on the fourth floor. The panels were erected on January 5th, 2017. Note that wood moisture content remains between 10% and 15% MC throughout the fabrication, shipping, and initial construction. There is a large spike in the moisture content readings in the middle of January, due to a precipitation event during construction where the sensors were exposed to liquid water causing the sensors to short out. Thus, Figure 3 shows no post-construction data since the sensors stop working. Because the moisture content is based upon the measured resistance, bridging (shorting) of the moisture meter pins by liquid water results in a high effective moisture content reading. These high moisture contents, in all five layers, were likely caused by a liquid water current path at the moisture meter pins. The liquid water also caused the circuit board to short which damaged the sensor.

Figure 3 also highlights the difficulties of trying to perform moisture monitoring during construction before the building envelope is finished. Of the 83 sensors installed, 35 stopped working because of water damage. The sensors are not waterproof and there is a high likelihood of the sensors getting wet during construction. Furthermore, since the sensors were placed within recesses on the top sides of panels, water managed to wick into these recesses and damage the sensors despite the waterproofing methods employed.

Figure 4 shows data from the glulam columns on the first floor near the concrete footing. Similar to the CLT panels (Figure 3), the data show that the moisture content of the columns were high during construction. However, because these sensors were installed on a vertical face of the wood, they were not exposed to water ponding and were able continuously transmit data throughout the construction cycle. It can be seen that glulam columns dried out quickly after construction and have been maintaining a steady moisture content slightly above 15% MC.

4. Lessons learned

Based on the results from this study, we recommend the following in future monitoring projects:

1. Sensors should be protected by placing them on the bottom side of the panel to create a built-in "roof" for the sensors and prevent ponding of water in the sensor recesses.
2. Sensors should be placed in waterproof boxes with only wires running out to the moisture meter pins. However, even with an improved approach for protecting sensors from water, it is unlikely that all of the installed sensors will survive the construction phase of the project and continue to work throughout the occupancy phase.

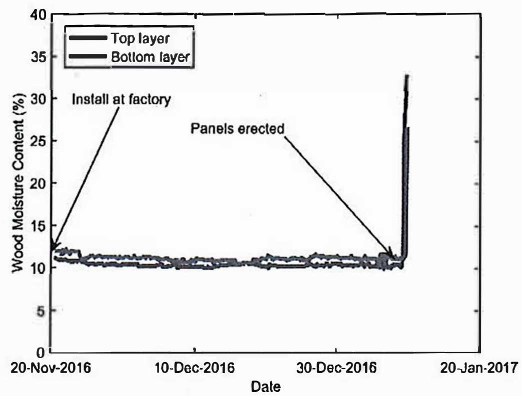

Figure 3: Wood moisture content during fabrication, shipping, and installation.

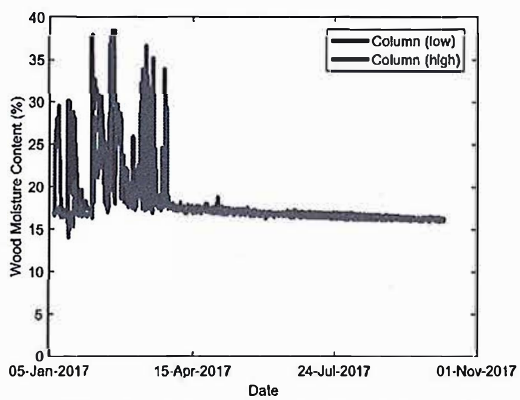

Figure 4: Wood moisture content of the glulam columns on the first floor. "

5. Conclusions and outlook

The goal of this project is to collect real-world data on the hygrothermal performance of mass timber buildings over several years. Currently, the sensors have been installed and data was collected during the construction phase. Based on sensors readings CLT panels remain dry during the fabrication and shipping phases. Although a complete understanding of the moisture behavior of the building throughout occupancy is not yet available, this paper lays out valuable lessons about how difficult it is to install moisture monitoring equipment during the construction phase, which has inspired designs for more durable instrumentation approaches.

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References

1. *CLT Handbook.* 2013, Pointe Claire: FPInnovations.
2. Jakes, J.E., et al., *Not Just Lumber—Using Wood in the Sustainable Future of Materials, Chemicals, and Fuels.* JOM, 2016. **68**(9): p. 2395-2404.
3. White, R.H., *Analytical methods for determining fire resistance of timber members.* The SFPE handbook of fire protection engineering. 2nd ed. Quincy, MA: National Fire Protection Association, 1995.
4. Glass, S.V. and S.L. Zelinka, *Moisture Relations and Physical Properties of Wood*, in *Wood Handbook. Wood as an Engineering Material.*, R.J. Ross, Editor. 2010, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.
5. McLung, R., et al., *Hygrothermal performance of cross laminated timber wall assemblies with built in moisture: field measurements and simulations.* 2013, Elsevier.
6. Lepage, R., *Moisture Response of Wall Assemblies of Cross Laminated Timber Construction in Cold Canadian Climates* 2012, University of Waterloo: Waterloo.
7. Wang, J., C. Ni, and G. Mustapha, *Monitoring of Vertical Movement in a Four-Story Wood-Frame Building in Coastal British Columbia.* Journal of Testing and Evaluation, 2013. **41**(4): p. 611-618.
8. James, W.L., *Electric Moisture Meters For Wood. U.S. Forest Service Research Note FPL-08.* 1963, Madison, WI: US Forest Service Forest Products Laboratory. 24.
9. James, W.L., *Electric Moisture Meters For Wood. Forest Products Laboratory General Technical Report FPL-GTR-6.* 1988, Madison, WI: US Forest Service Forest Products Laboratory. 17.