CLT Research: Available and Accessible to North American Building Designers

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In 2010, cross laminated timber (CLT) took US designers by storm when architect Andrew Waugh toured the US sharing the amazing success of what was, at that time, the tallest modern timber structure in the world. A nine-story building constructed almost entirely of CLT seemed out of reach for designers in the US; yet here we are five years later with approved codes and standards inclusive of CLT construction up to six stories prescriptively and perhaps more using the performance path. Cross laminated timber and other mass timber technologies have captured the interest of designers, industry and governments alike. The result of all this interest is the need for lots of research and the need has not gone unanswered.

An interesting aspect of CLT research to date is not only that there has been so much in such a short period of time but also that it has been uncharacteristically well organized and distributed; not always the norm in the world of research. The motivation for such a swift and organized effort stems from a perfect storm of factors surrounding this innovative structural system:

- Market need: Designers are looking for a low-carbon building material to address drastic reduction goals for atmospheric carbon emissions.
- Available resources: The North American public forest inventories are increasing in age and density, leading to increased potential for fire and disease. CLT and other mass timber products offer high value markets for low-value small diameter logs yielded from forest restoration projects.
- Social/economic motivation: Rural economies that rely on the forest products industry have been in steady decline. High-value products such as CLT provide opportunities to stimulate job growth in non-urban communities.

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In 2013, FPInnovations and the Binational Softwood Lumber Council in association with the USDA Forest Products Laboratory, American Wood Council, APA – The Engineered Wood Association and WoodWorks published the US Edition of the *CLT Handbook* (Karacabeyli and Douglas 2013), making relevant European and North American research accessible to US designers. By deciphering important results, offering conclusions, and identifying where further study was needed, that document has provided an important foundation for the research that has taken place since and is yet to come.

Several sources of funding, including the Softwood Lumber Board, Binational Softwood Lumber Council, Natural Resources Canada, the USDA Wood Innovation Grant program and the Canadian NEWBuildS Network, are enabling research efforts to move forward for many new wood building systems, including CLT. These programs have the benefit of being well-coordinated and also having an outreach component. This prevents research institutions across North America from being islands of knowledge, allowing each research project to build upon the others and offering an opportunity for early input from the manufacturing and design industries. For example, the NEWBuildS program has a single steering committee reviewing all of the funding proposals from over 13 participating research institutions. Their website provides access to abstracts and papers on all CLT-themed research in a single location, making it easy to determine what's being done without insider knowledge about which universities are working on what. Another site, the Wood Education and Resource Center hosted by the US Forest Service, contains similar information for USDA grant funded projects. Further improving access to research, the wood industry -- funded by the Binational Softwood Lumber Council and Forestry Innovations Investment -- is pursuing a single database to house information on completed and in-progress research on CLT and other mass timber systems. The databased will be made available via the rethink Wood website (www.rethinkwood.com).

In addition to widespread accessibility, CLT research has also been largely application based. Organizations like WoodWorks that are focused on assisting designers with non-residential and multi-residential projects are providing a mechanism for identifying the needs of architects and engineers and putting them at the forefront of research discussions. Structural and fire summits were held in November 2014 in association with WoodWorks' *Toward Taller Wood Buildings Symposium* in Chicago, serving as a kind of research charrette for this purpose. Bridging the gap between data and design has been a strength of the organization, which has helped support the rapid growth of CLT manufacturing and the greater mass timber industry. The purpose of this article is to highlight research efforts recently completed and underway that address pressing questions related to the design and construction of CLT, thus allowing continued pursuit of this product as a mainstream building system.

Since the *CLT Handbook's* release, a code definition for CLT has been established through the code cycle process and now appears in the 2015 *International Building Code* (IBC). The definition recognizes the *APA/ ANSI PRG 320 Standard for Performance-Rated Cross-Laminated Timber* (ANSI/APA 2012), and specifically calls out opportunities for its use in prescriptive Type IV construction. The American Wood Council also recently published the *2015 National Design Specification® (NDS®) for Wood Construction* with specific design standards for CLT (AWC 2015). While research and the Handbook played a role in these achievements, the conclusions presented in the Handbook and subsequent inquiries from the design community highlight the need for further study, most notably in the areas of fire performance and seismic/structural analysis.

Fire Performance

Fire performance, and specifically exposed fire resistance, may be one of the most asked about areas in terms of additional research information—but, in reality, suffers more from misperception than lack of research data. The predictability of wood's char rate has been well established for decades and has also been recognized for years in US building codes and standards. However, the use of existing code provisions has not been commonplace in modern commercial construction; therefore, jurisdictional comfortability with an expanded use of those provisions for the purpose of CLT design has presented a challenge. The 2015 NDS includes a char calculation procedure to provide calculated fire resistance of up to two hours. It expands on the design examples in the fire chapter of the US CLT Handbook by allowing for laminations of varying thicknesses. Further study and additional full-scale panel tests continue to be done, not necessarily to prove legitimacy of the CLT char methodology but to support expansion of its applicability. Areas of expansion include new assembly configurations (in pursuit at the Advanced Composite Lab and the University of Maine), exploring performance under non-standard fires and developing performance prediction tools (as was done at Carleton University under the NEWBuildS program).

The Fire Research Team at the USDA Forest Products Laboratory is studying the fire resistance properties of CLT panels in order to improve their marketability for low to midrise construction. The goal is to find a panel layup that maximizes the hourly fire rating so structural panels can be used in a larger variety of situations. Recent studies on 25 CLT specimens have investigated how features such as the grade of wood, layout of individual boards, adhesives and protective membranes can be optimized to reduce the charring rate and increase the hourly rating of the panel. This research is being performed in conjunction with Virginia Tech, Clemson University and North Carolina State University.

It is commonly asked why there are not Underwriters Laboratories (UL) or equivalent tested assemblies available for CLT and this area is often suggested for research. The truth is that the calculated method offers more flexibility to designers than a series of UL assemblies and provides more precision with regard to the panel thickness needed to accommodate fire-resistive requirements. When structural strength and fire resistance are so intertwined, a prescriptive method for determining fire resistance cannot offer material efficiency. A comparison of the ASTM E 119 fire tested CLT performance and the predicted performance using the calculated method demonstrates the reliability of char calculations for CLT. Such a comparison can be done by independent designers but is also shown in graphical form with tests done prior to 2013 in the fire chapter of the US Edition of the *CLT Handbook* (Karacabeyli and Douglas 2013).

The impressive ability of CLT to meet two and three hours of fire resistance with and without gypsum protection seems to be overshadowed by concerns about its combustibility. The increase of wood volume raises necessary questions about the additional potential for structural contribution to combustion and what it means for fire safety. Full-scale fire tests completed by FPInnovations and funded by Natural Resources Canada and others are intended to help address this issue. In association with a 13-story mass timber demonstration project (12 stories of CLT over one story of concrete) in Quebec, the provincial government there funded full-scale CLT fire tests to prove CLT's equivalence to 2-hour-rated non-combustible construction.

- One series of full-scale compartment tests compared the performance of light-gauge steel, light-frame wood and CLT. Tests included a three-story encapsulated CLT apartment simulation that ran for three hours. Details of this study are described in a previous WDF article (Dagenais 2015). Results of the apartment simulation show the effectiveness of encapsulation in significantly delaying CLT's potential contribution to fire growth and proved that the structure can withstand complete burnout. The summary study went so far as to state, "Results show that, with encapsulation, the three test apartments constructed using wood structural elements provided the level of fire performance that meets the NBC intent statement assigned to the noncombustible construction requirement in limiting the involvement of the structural elements in fire and in limiting the contribution of the structural elements to the growth and spread of fire." (Su and Lougheed 2014, p.105).
- Another test focused on a 25.5-ft CLT stair/elevator shaft (exposed on the inside face with two layers of gypsum protection on the fire side) and studied the smoke propagation and leakage as well as its structural stability as a fire exit. The test ran for two hours and showed no sign of smoke or heat penetration into the shaft.

One area highlighted by the Handbook as needing more study was detailing for penetrations and concealed spaces. Research recently completed by FPInnovations and funded by Natural Resources Canada/The Canadian Forest Service evaluated the ability of selected fire stops and sealing joints in CLT assemblies, both for panel joints and around through-penetrations to prevent the passage of hot gasses and limit heat transfer. Results showed that products commercially available for use in light-frame and concrete construction are also feasible for CLT applications. (Dagenais 2014)

Structural and Seismic Performance

There has been a proliferation of industry and academic research initiatives to build out the body of knowledge on CLT structural performance in US applications.

Some have pertained to standards and testing methods suitable to North America, such as the investigation of testing protocols for evaluation of in-plane shear strength of CLT panels (Gagnon et al. 2014). These and other efforts have led to the new *Acceptance Criteria For Cross -Laminated Timber Panels For Use As Components In Floor and Roof Decks* (AC455) from the ICC Evaluation Services. This product evaluation standard is generally compatible with the ANSI/APA PRG 320 qualification requirements with a notable addition of testing procedures for evaluating the in-plane strength of CLT panels. Having acceptance criteria for CLT panels allows manufacturers to pursue directed testing culminating in an Evaluation Service Report (ESR). ESR reports are helpful in gaining jurisdictional approval for new materials, further assisting designers. Current North American CLT manufacturers are promising ESRs in the near future.

Research into connection technology for North American CLT has included static and cyclical testing of self-tapping screws for CLT-to-CLT and CLT-to-wood beams performed at the University of British Columbia in Vancouver, Canada (Hossain 2015 and Ashtari 2014). In addition to connection behavior, Ashtari et al. looked at the behavior of a horizontal CLT floor system as a diaphragm of a lateral force-resisting system.

Using CLT components in lateral (wind or seismic) force-resisting systems is an area of considerable ongoing research. A much anticipated project is the *Development of Seismic Performance Factors for Cross Laminated Timber* with principal investigator John van de Lindt of Colorado State University. This project will follow the Federal Emergency Management Agency (FEMA) P-695 process, which is currently underway, to rigorously quantify seismic performance factors (R, Ω_o and C_d) for a type of CLT shear wall system for use following seismic design procedures of ASCE 7. This comprehensive study was preceded by a site- and building-specific FEMA P-695-like study to estimate whether a seismic Response Modification Factor of R = 4.5 met the performance objectives of the candidate design (Pei 2013). To date, CLT shear wall systems for seismic resistance have been designed using conservative seismic performance factors or using advanced performance-based seismic design procedures. The completion of this research will be a significant step toward easier design of CLT shear wall systems for seismic resistance and eventual inclusion of CLT in the seismic structural design standards used throughout the US.

Another research project evaluating CLT walls for seismic resistance is a Network for Earthquake Engineering Simulation (NEES)/National Science Foundation (NSF) project investigating seismic-resistant tall wood buildings for the Pacific Northwest (Pei 2014a). This multiuniversity project is executing an inclusive process to develop seismic performance goals, as well as a variety of potential high-performance/low-damage seismic force-resisting systems. Since the 2014 publication on this project, the research team has progressed to running a series of experimental tests of CLT rocking walls at Washington State University. Additional research is being performed on the design of CLT rocking walls at Clemson (Gu et al 2014) and the University of Alabama.

For those wanting to know more about the history of CLT seismic research, the 2014 *Journal of Structural Engineering* forum article entitled *Cross-Laminated Timber for Seismic Regions: Progress and Challenges for Research and Implementation* is a very good resource (Pei 2014b).

Additional Research

In addition to expanding knowledge of CLT as it is currently manufactured and used, other research is exploring different ways to manufacture CLT by using different source material, for example, such as southern pine (Hindman and Bouldin, 2014) and hybrid poplar (Kramer et al., 2013), or the inclusion of voids within the panels (Montgomery et al. 2014). These new opportunities are intended to allow for greater utilization of lower-value small diameter timber stocks that are available across the country.

The U.S. Tall Wood Building Prize Competition, sponsored by the Softwood Lumber Board, USDA and Binational Softwood Lumber Council, is also providing support for and helping drive research into practical applications of tall wood buildings across the U.S.

WoodWorks is working to expand military, public, and private markets for wood construction by studying the blast performance of CLT wall systems with funding from a USDA Wood Innovation Grant. Karagozian & Case, an internationally recognized protective design consultant, with support from the Advanced Composites Lab at the University of Maine and several other research and government institutions, is collaborating with WoodWorks to test the dynamic performance of the material and propose a design methodology based on the results of this testing.

Prioritizing the research needs for CLT was the focus of a recent Mass Timber Workshop hosted by the USDA Forest Products Laboratory. With a large diversified attendance of designers, researchers, and industry, outcomes are expected to influence upcoming funding allocations and help to ensure that the future of CLT research meets market needs.

CONCLUSION

As low carbon alternatives to other building materials, mass timber products are poised to revolutionize the landscape of the built environment. They're also helping to bolster rural economies, because stronger markets for wood products provide an incentive for public and private landowners to invest in the long-term sustainability of North American forests.

With tremendous interest in the potential of CLT in particular, prompt attention has been given to its inclusion in building codes and standards, with the awareness that a great deal of research is still underway. In addition to the research described in this paper, the depth and breadth of research on CLT is spreading to embrace other mass timber systems, including the development of mechanically-laminated products such as dowel- and nail-laminated timber, and the expanded use of glue-laminated timber.

WEB RESOURCES

http://www.na.fs.fed.us/werc/

http://newbuildscanada.ca/

http://www.bcfii.ca/tools-resources/market-research/

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