Introduction to Cross Laminated Timber

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ABSTRACT

Cross-laminated timber (CLT), a new generation of engineered wood product developed initially in Europe, has been gaining popularity in residential and non-residential applications in several countries. Numerous impressive low- and mid-rise buildings built around the world using CLT showcase the many advantages that this product can offer to the construction sector. This article provides basic information on the various attributes of CLT as a product and as structural system in general, and examples of buildings made of CLT panels. A road map for codes and standards implementation of CLT in North America is included, along with an indication of some of the obstacles that can be expected.

BRIEF HISTORY

Cross laminated timber (CLT) is a relatively new building system of interest in North American construction which is helping to define a new class of timber products known as massive timber. It is a potentially cost-competitive wood-based solution that complements the existing light frame and heavy timber options, and is a suitable candidate for some applications which currently use concrete, masonry and steel. CLT is an innovative wood product that was introduced in the early 1990s in Austria and Germany and has been gaining popularity in residential and non-residential applications in Europe. There are currently over one hundred CLT projects in Europe.

In the mid-1990s, Austria undertook an industry-academia joint research effort that resulted in the development of modern CLT [1]. After several slow years, construction in CLT increased significantly in the early 2000s, partially driven by the green building movement but also due to better efficiencies, product approvals, and improved marketing and distribution channels. Another important factor has been the perception that CLT, like masonry and concrete, is a heavy construction system which is typical in multi-story residential construction in many European countries.

The use of CLT panels in buildings has increased over the last few years in Europe. Hundreds of impressive buildings and other types of structures built around the world using CLT show the many advantages this product can offer to the construction sector. The European experience shows that CLT construction can be competitive, particularly in mid-rise and high-rise buildings. Easy handling during construction and a high level of prefabrication facilitate rapid project completion. This is a key advantage, especially in mid-rise construction (e.g. 5 to 8 storys). Good thermal insulation, good sound insulation and good performance under fire are added benefits that come as a result of the massive wood structure.

DEVELOPMENT OF CLT IN NORTH AMERICA

While this product is well-established in Europe, work on the implementation of CLT products and systems has just begun in Canada and the United States. The use of CLT in North America is gaining interest in both the construction and wood industries. At this time, there are four North American manufacturers currently producing CLT and several others are in the process of product and manufacturing assessment or have already started pilot production. Under the Transformative Technologies Program of Natural Resources Canada, FPInnovations launched a multi-disciplinary research program on CLT in 2005. Based on these studies and the knowledge gained from the European experience, FPInnovations prepared a peer-reviewed *CLT Handbook* [1]. More recently, a harmonized North American CLT product standard, *Standard for Performance Rated CLT* (ANSI/APA PRG 320) was developed by the ANSI/APA CLT Standard Committee and published in December 2011 [2].

The driving force behind the development of CLT in North America is the need to provide alternative wood-based products and systems to architects and engineers.

In Canada, adoption of the 2005 and 2010 editions of the National Building Code of Canada (NBCC), which are objective-based codes, helped to eliminate the bias against wood inherent in previous prescriptive codes (1995 and earlier). The new format recognizes both "Acceptable Solutions" and "Alternative Solutions" which encourage the use of innovative materials, products and systems [3]. Similarly, in the US there are performance-

Figure 1. CLT Panel Configuration

based building codes that state an expected level of performance, and there are provisions in the prescriptive-based building codes that allow the use of alternate methods and materials.

DEFINITION OF CROSS-LAMINATED TIMBER (CLT)

CLT panels consist of several layers of structural lumber boards stacked crosswise (typically at 90 degrees) and glued together on their wide faces and, sometimes, on the narrow faces as well. A cross-section of a CLT element has at least three glued layers of boards placed in orthogonally alternating orientation to the neighboring layers. In special configurations, consecutive layers may be placed in the same direction, giving a double layer (e.g. double longitudinal layers at the outer faces and additional double layers at the core of the panel) to obtain specific structural capacities. CLT products are usually fabricated with three to seven layers and even more in some cases. Figure 1 includes a diagram and photograph of a CLT panel configuration while Figure 2 is a diagram of possible CLT panel cross-sections. Figure 3 is a diagram of a 5-layer CLT panel including both cross-sectional views.

Thickness of individual lumber pieces may vary from 16 mm to 51 mm (5/8 inch to 2.0 inch) and width may vary from about 60 mm to 240 mm (2.4 inch to 9.5 inch). Boards are fingerjointed using structural adhesive. Lumber is visually-graded or machine stress-rated and is kiln dried. Panel sizes vary by manufacturer; typical widths are 0.6 m (2.0 ft), 1.2 m (4.0 ft), and 3 m (9.8 ft) (could be up to 4~5 m (13.0 ~ 16.5 ft) in particular cases) while length can be up to 18 m (60 ft) and the thickness can be up to 508 mm (20 inches). Transportation regulations may impose limitations to CLT panel size. Lumber in the outer layers of CLT panels used as walls are normally oriented parallel to vertical loads to maximize the wall resistance. Likewise, for floor and roof systems, the outer layers run parallel to the major span direction.

KEY ADVANTAGES OF CROSS-LAMINATING

Cross-laminated timber used for prefabricated wall and floor panels offers many advantages. The cross-laminating process provides improved dimensional stability to the product which allows for prefabrication of wide and long floor slabs and single story long walls. Additionally, cross-laminating provides relatively high in-plane and out-of-plane strength and stiffness properties in both directions, giving these panels a two-way action capability similar to a reinforced concrete slab. The 'reinforcement' effect provided by the cross lamination in CLT also considerably increases the splitting resistance of CLT for certain types of connection systems.

Figure 4 is a diagram illustrating the primary difference between CLT and glulam products. Figure 5a is a diagram of a floor built with four individual CLT panels acting mostly in one direction, while Figure 5b is a diagram of the same floor, this time built with one CLT panel only acting most likely in two directions (i.e. two-way action).

MANUFACTURING PROCESS

A typical manufacturing process of CLT includes the following steps: lumber selection, lumber grouping and planing, adhesive application, panel lay-up and pressing, product cutting, marking and packaging. The key to a successful CLT manufacturing process is consistency in the lumber quality and control of the parameters that impact the quality of the adhesive bond. Stringent in-plant quality control tests are required to ensure that the final CLT products will fit for the intended applications.

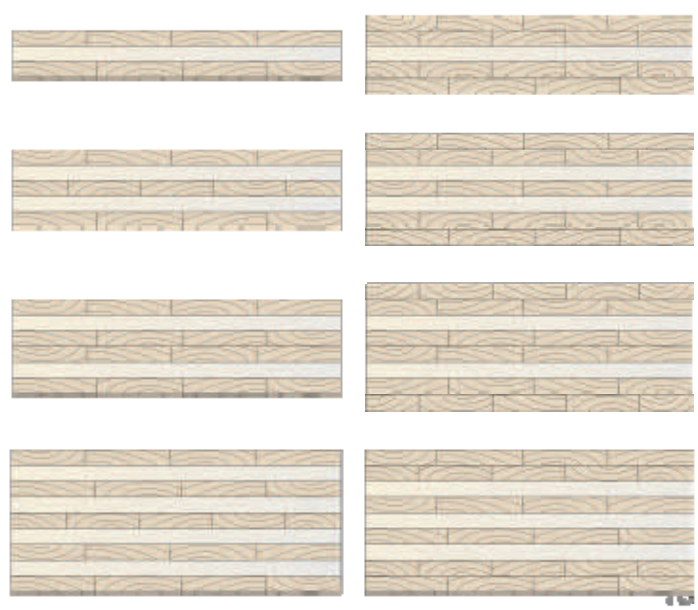


Figure 2. Examples of CLT Panel Cross-Sections

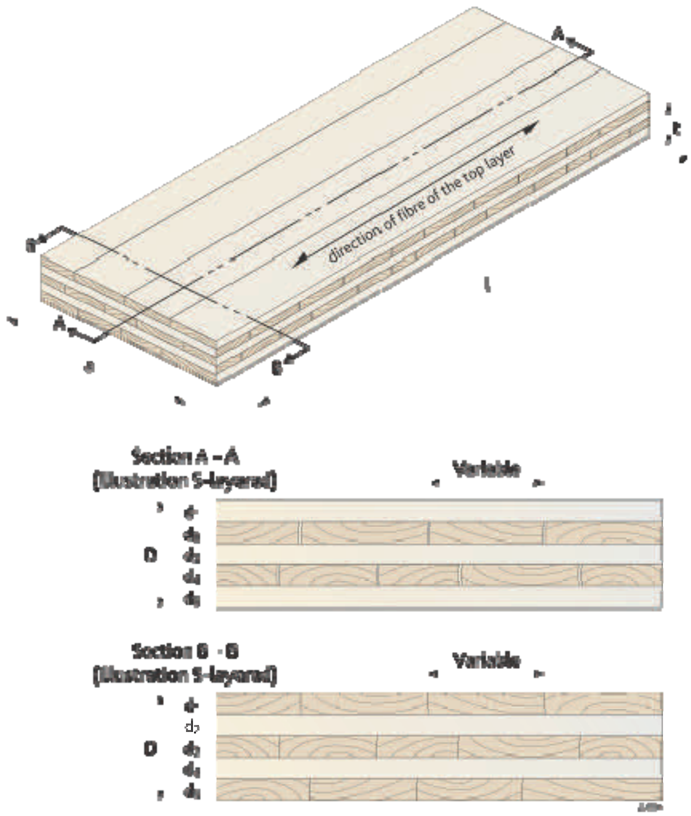


Figure 3. Example of CLT Panel Cross-sections and Direction of Fibers of the Top Layers

Typically, lumber must be kiln dried to a moisture content of 12% ± 3%. Proper moisture content prevents dimensional variations and surface cracking. Lumber can be procured dried or further drying may be needed at the factory. Trimming and finger-jointing (FJ) are used to obtain the desired lengths and quality of lumber. Panel FJ is feasible too, but not recommended. Panel sizes vary by manufacturer.

The assembly process time varies from 15 minutes to 1 hour depending on equipment and adhesive. Adhesive is the second input in CLT. Adhesives used in North America must meet the same requirements as those used in glued-laminated timber manufacturing and include qualified polyurethane, melamine and phenolic-based adhesives. Both face and edge gluing can be used. Once adhesive is applied, the assembly is pressed using hydraulic (more common) or vacuum presses and compressed air depending on panel thickness and adhesive used. The assembled panels are planed or sanded for a smooth surface at the end of the process. Panels are cut to size and openings are made for windows, doors and service channels, connections and ducts using Computer Numerically Controlled (CNC) routers which allow for high precision. For quality control purposes, compliance with product requirements prescribed in the product standard are typically checked at the factory (e.g., bending strength, shear strength, delamination).

STRUCTURAL DESIGN AND SERVICEABILITY CONSIDERATIONS OF CLT

CLT panels are typically used as load-carrying plate elements in structural systems such as walls, floors and roofs. For floor and roof CLT elements, key critical characteristics that must be taken into account are the following:

- In-plane and out-of-plane bending strength, shear strength, and stiffness
- Short-term and long-term behaviour:
  - ◊ Instantaneous deflection
  - ◊ Long-term strength for permanent loading
  - ◊ Long-term deflection (creep deformation)
- Vibration performance of floors
- Compression perpendicular to grain issues (bearing)
- Fire performance
- Acoustic performance
- Durability

For wall elements, the load-bearing capacity is critical and should be verified together with the in-plane and out-of-plane shear and bending strength. In addition, fire and acoustic performance along with the durability of the system are key characteristics that must be taken into account at the design stage. The following sections provide a brief summary of the key design and performance attributes of CLT panels and assemblies.

Methods for Designing CLT Structural Systems

Generally, different design methods have been adopted in Europe for the determination of basic mechanical properties of CLT. Some of these methods are experimental in nature while others are analytical. For floor elements, experimental evaluation involves determination of flexural properties by testing full-size panels or sections of panels with a specific span-to-depth ratio. The problem with the experimental approach is that every time the lay-up, type of material, or any other manufacturing parameters change, more testing is needed to evaluate the bending and shear properties of such new product configurations.

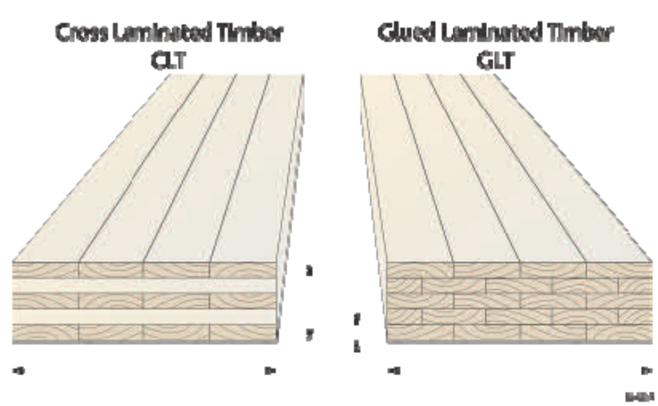
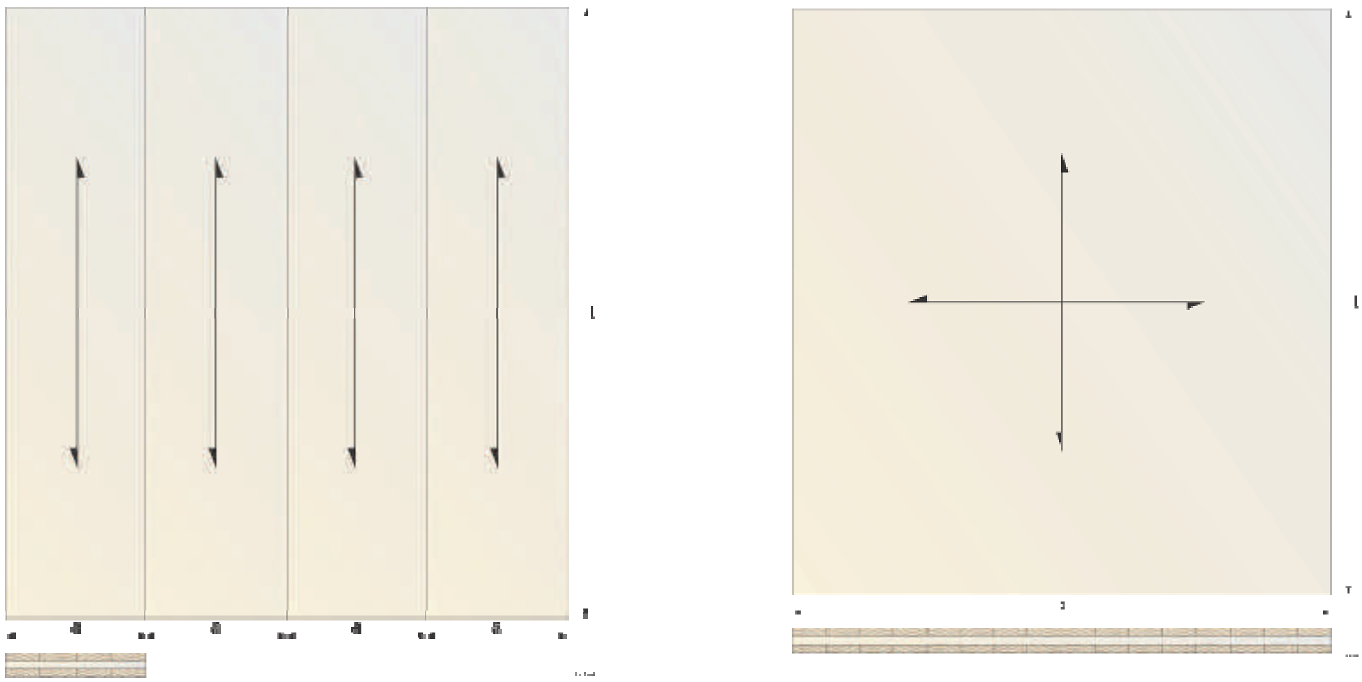


Figure 4. CLT Panel vs. Glulam



(a) (b)

Figure 5. (a) Floor Assembly Made of Four 3-ply CLT Panels Acting in One Direction and (b) Floor Assembly Made of One 3-ply CLT Panel Acting in Both Directions. Distance "a" May Reach 4 m

The analytical approach, once verified with the test data, offers a more general and less costly alternative. An analytical approach generally predicts strength and stiffness properties of CLT panels based on the input material properties of the laminate boards that make up the CLT panel. Proposed methods by Europeans are described in detail in FPInnovations CLT Handbook [1]. The shear analogy method has been adopted by ANSI PRG 320 for determining the bending and shear strength and stiffness of various lay-ups [2].

Seismic Performance of CLT Buildings

Based on the literature review of research work conducted around the world and results from a series of quasi-static tests on CLT regular and tall wall panels conducted at FPInnovations, CLT wall panels can be used as an effective lateral load resisting system [4]. Results from small and large scale shake table seismic tests on two CLT buildings in Japan by the Trees and Timber Institute of Italy (IVALSA) in 2009 demonstrated that CLT structures perform quite well when subjected to seismic forces (Figure 6a). FPInnovations shearwall tests to date have also shown that the CLT wall panels demonstrated adequate seismic performance when nails or slender screws are used with steel brackets to connect the walls to the floors below (this ensures a ductile failure in the connection instead of a brittle failure in the panel). The use of hold-downs with nails on each end of the walls tends to further improve seismic performance. Use of diagonally placed long screws to connect CLT walls to the floor below is not recommended in high seismic zones due to lower ductility and brittle failure mechanisms. Use of half-lapped joints in longer walls can be an effective solution not only to reduce the wall stiffness and thus reduce the seismic input load, but also to improve wall ductility. Timber rivets in smaller groups with custom made brackets were found to be effective connectors for CLT wall panels due to their potentially high ductility. Further research in this field is needed to clarify the use of timber rivets in CLT and to verify performance of CLT walls with alternative types of connection systems (e.g. bearing types). A 2-story CLT assembly has also been tested recently at FPInnovations and analysis of results is underway (Figure 6b).

CLT buildings are a platform type of structural system and tend to be less susceptible to develop soft story mechanisms than many other structural systems of the same type. Since the nonlinear behaviour (and the potential damage) is localized in the hold-down and bracket connection areas only, the panels, that are also the vertical load carrying elements, are virtually left intact in place, even after failure of the connections. In addition, all CLT walls in a story contribute to the lateral and gravity resistance, thus providing a degree of redundancy and a system sharing effect.

Preliminary evaluation of the force modification factors (R-factors) for the seismic design of structures according to the National Building Code of Canada (NBCC) was also performed. Based on the experimental and analytical research conducted in Europe and at FPInnovations, a comparison of CLT performance relative to existing sys-

(a) (b)

Figure 6. (a) Seven-story CLT house tested at E-Defense Laboratory in Miki as a part of the SOFIE Project, (b) CLT test assembly at FPInnovations.

tems in NBCC, and evaluation of CLT performance with light-frame seismic equivalency criteria given in ICC-ES Acceptance Criteria AC 130, conservative force modification factors (R-factors) for the seismic design of CLT structures in Canada of $R_d = 2.0$ and $R_o = 1.5$ are proposed.

Connections in CLT Assemblies

Connections in timber construction, including those built with CLT, play an important role in maintaining the integrity of the timber structure and in providing strength, stiffness, stability and ductility. Consequently, connections require the thorough attention of the designers.

Traditional and innovative connection systems have been used in CLT assemblies in Europe and North America. Common types of connections in CLT assemblies include: panel to panel (in floors, walls and roofs), wall to foundation, wall to wall intersections and wall to floor/roof. Basic panel to panel connections can be established through single or double exterior splines made with engineered wood products, single or double interior splines, or half-lapped joints (Figure 7). Metal brackets, hold-downs, and plates are used to transfer forces at the wall to floor/roof interfaces and in wall to wall intersections. Innovative types of connection systems can also be used which lead to enhanced performance or quicker assembly [1].

Researchers in Europe have developed design procedures for traditional connections in CLT, including dowels, wood screws, and nails which are commonly used in Europe for designing CLT assemblies. Empirical expressions were developed for the calculation of characteristic embedment properties of each type of fastener (i.e., dowels, screws, nails), depending on the location with respect to the plane of the panel (perpendicular to or on edge). Those expressions were verified and results seem to correspond well with predictions [5,6]. Yield mode equations were adopted for the design using CLT fastener embedment strength equations. Empirical equations have also been developed for the calculation of the withdrawal resistance of the various types of fasteners in CLT based on hundreds of tests. Based on limited exploratory validation tests conducted at FPInnovations using self-tapping screws on European CLT, the proposed embedment equations seem to provide reasonable predictions of both the lateral and withdrawal capacity based on the Canadian timber design provisions [7]. More work is needed, however, to validate the proposed equations using North American made CLT and different types of fasteners.

Due to the reinforcing effect of cross lamination in CLT, it is speculated that current minimum geometric requirements given in CSA O86-09 [8] and the *National Design Specification for Wood Construction* (NDS) [9] for dowels, screws and nails in solid timber or glulam could be applicable to CLT. However, designers need to be cautious about this as further verification is required, considering the specific features of individual panel types. Brittle failure modes also need to be taken into account which have not been investigated yet.

Duration of Load and Creep Behavior

Duration of load is defined as the duration of stress or the time during which a load acts on a member [10]. Creep is defined as the time-dependent increase of deformation of the test material under a constant load [11].

Given the nature of CLT, with orthogonal arrangement of layers and either mechanically fastened with nails or wood dowels or bonded with structural adhesive, CLT is more prone to time-dependent deformations under load (creep) than other engineered wood products such as glued-laminated timber. Therefore, special attention is needed to the duration of load and creep behaviour of such products. Testing is underway at FPInnovations to develop duration of load factors for CLT.

Figure 7. Examples of Types of Connections Typically Used to Establish Panel to Panel and Wall to Floor Connections in CLT Assemblies

Vibration Performance of Floors

Laboratory and field tests on CLT floor assemblies indicate that the vibration behaviour of CLT floors is different from lightweight wood joist floors and heavy concrete slab floors. Traditional lightweight wood joist floors usually have a mass around 20 kg/m^2 and a fundamental natural frequency above 15 Hz. Heavy concrete slab floors, typically have a mass above 200 kg/m^2 and fundamental natural frequency below 9 Hz. Based on test results, CLT floors were found to have mass varying from approximately, 30 kg/m^2 to 150 kg/m^2, and a fundamental natural frequency above 9 Hz. Due to these special properties, the existing standard vibration controlled design methods used in Canada for lightweight and heavy floors may not be applicable to CLT floors. CLT manufacturers recommend using uniform distribution load (UDL) deflection method for CLT floor control vibrations by limiting the static deflections of the CLT panels under a UDL. Using this approach, avoiding excessive vibrations in CLT floors relies mostly on the engineer's judgment.

A new design method for CLT floor vibrations has been developed. Originally developed by FPInnovations for wood joist floors and modified for CLT floors, the new model is based on CLT floor test data and field floor vibration tests at FPInnovations. The new design method uses a 1 kN static deflection and fundamental natural frequency as design parameters and the predicted CLT floor vibration performance agreed with the subjective ratings of floor vibration performance. An impact study of the proposed design methodology to determine vibration controlled maximum spans of CLT floors concluded that the new method is promising.

Fire Performance of Cross-Laminated Timber Assemblies

CLT panels have the potential to provide good fire resistance, often comparable to typical massive assemblies of non-combustible construction. This is due to the inherent nature of thick timber members to slowly char at a predictable rate, allowing massive wood systems to maintain significant structural capacity for extended durations when exposed to fire.

In order to facilitate the acceptance of future code provisions for the design of CLT panels with regard to fire resistance, a one-year research project was launched at FPInnovations in April 2010. The main objective of the project was to develop and validate a generic calculation procedure to calculate the fire resistance ratings of CLT wall and floor assemblies. A series of full-scale fire resistance experiments have been completed to allow a comparison between the fire resistance measured during a standard fire resistance test and that calculated using the proposed procedure. Parallel research activities on fire resistance of CLT are also taking place at several research institutes such as Carleton University in Canada and Oregon State University and FPL in the US. A simple but conservative design procedure is presented in the *CLT Handbook* and current fire tests at FPInnovations will be used to validate the proposed calculation method.

In the US, the fire resistance of exposed wood members can be calculated using the fire design provisions from Chapter 16 of the NDS [9]. These provisions are permitted for calculating up to 2-hr structural fire resistance of wood members exposed to a standard ASTM E 119 fire exposure. NDS Chapter 16 is specifically referenced in the International Building Code (IBC) under Chapter 8 [12].

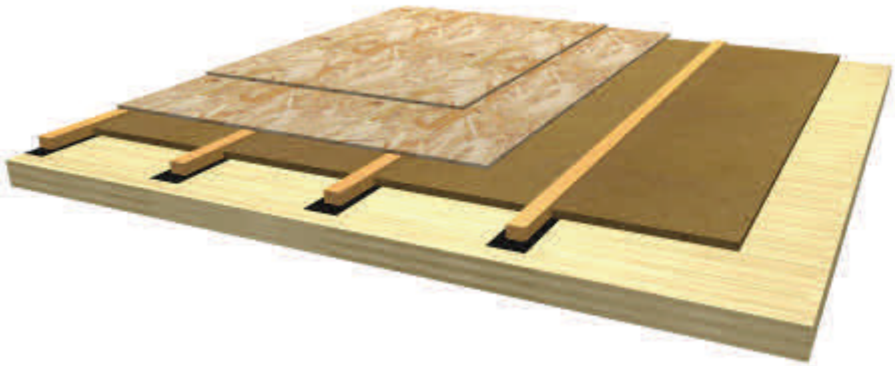


Figure 8 CLT Floor Sound-Insulated on the Top

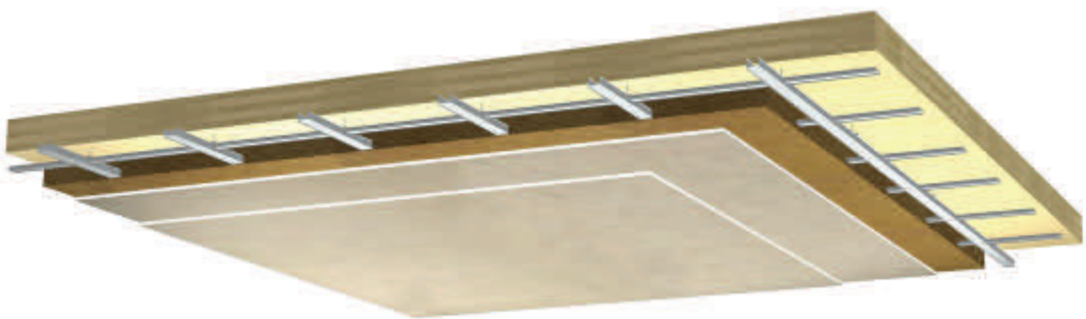


Figure 9 CLT Floor Sound-Insulated Underneath the Floor/Ceiling

Acoustic Performance of Cross-Laminated Timber Assemblies

Adequate levels of noise/sound control in multi-family buildings are mandatory requirements of most building codes in the world. In many jurisdictions, these requirements are as strictly enforced as those for structural sufficiency and fire safety. Much effort has been spent on evaluation of sound transmission class (STC) and impact sound insulation class (IIC) of floor and wall assemblies and on studying flanking transmission in light frame multi-family dwellings in Canada. However, limited work has been done on the acoustic performance of CLT systems.

CLT panels offer good acoustic performance for sound transmission between walls and floors. In Europe, additional sound insulation materials and designs that results in floor systems with enhanced sound transmission class (STC) and impact sound insulation class (IIC) ratings are required. Based on recent testing conducted in Europe and in Canada, CLT floor and wall assemblies made of CLT elements could perform well acoustically in residential and non-residential buildings. More details about proposed floor and wall designs to meet current minimum code requirements are detailed in the *CLT Handbook* [1]. Figures 8 and 9 are diagrams of proposed insulation techniques to enhance STC and IIC.

Building Enclosure Design of CLT Construction

The design of CLT panels for building enclosure in North America requires considerable effort to ensure their long-term durability, particularly in areas with high moisture loads such as coastal regions. Like other wood products, the key to CLT durability is to keep it dry. Once moisture gets into the panel, there is a potential for slow drying due to the thickness of the product.

CLT is not intended to be exposed to the exterior environment and the panels should be protected from rain and high relative humidity levels with a properly designed building envelope. Like other wood construction types, the use of basic design elements such as overhangs and the integration of drained and ventilated rain screen walls will effectively prevent rain penetration into building assemblies. In addition, appropriate design and application of insulation materials, air and vapor control strategies, as well as ground moisture control measures are needed. Such measures will ensure that the panels will be kept warm and dry, help prevent moisture from being trapped and accumulated within the panels during the service life, and ensure the energy efficiency of CLT building enclosures.

Since CLT has been used for prefabrication in Europe for over a decade, much attention has been paid to protecting the CLT panels from getting wet during transportation and construction. One way of controlling wetting during transport of CLT elements is to use closed containers. As for assembly, Europeans have adopted several methods for controlling moisture during construction. Delivering CLT panels for on-time assembly to minimize construction time is one strategy. Another method successfully implemented in Europe involves the construction of a temporary roofing system to protect against rain and snow during construction. Other methods involve building the actual roof system on ground first, then jacking it up

Figure 10 Eight-Story Building Under Construction Protected by a Tent

as the building is built beneath it from the ground up. Figure 10 is a photograph of a system of tents used in Sweden during the construction of an 8-story CLT building.

In terms of thermal insulation efficiency of CLT, the natural thermal resistance of wood adds value to CLT assemblies. Precise manufacturing and dimensional stability permits tight tolerances with better energy efficiency and improved insulation of windows, doors and cladding. Furthermore, boards within the CLT wall can be edge-glued to improve thermal efficiency by reducing potential air flow through the wall system. Dimensional stability will also ensure air tightness over time due to reduced potential shrinkage of CLT.

ENVIRONMENTAL PERFORMANCE OF CROSS-LAMINATED TIMBER

The environmental footprint of CLT is frequently discussed as potentially beneficial when compared to functionally equivalent concrete systems. Inherent to that discussion is an assumption that the comparative environmental profile of CLT will be lower, based on the generic life cycle analysis (LCA) profiles of wood and concrete. In particular, CLT (because it is made of wood), is assumed to have a small carbon footprint, due to relatively low embodied greenhouse gas emissions in wood versus concrete, and due to the carbon storage capacity of wood products.

CLT is also manufactured using mostly small diameter timber; most Canadian and European CLT panels are made of spruce. The process is energy efficient and environmentally responsible, as prefabricated panels virtually eliminate jobsite waste. In addition, the more common adhesives used for panel construction in North America are formaldehyde free.

Existing environmental comparisons between wood and concrete buildings generally focus on light wood framing using lumber, whereas CLT is a massive structural system involving at least three times more wood material, and added processing and auxiliary materials such as adhesives similar to any engineered (composite) wood products. Using existing LCA data on Canadian glulam as a proxy, the footprint of the material itself compared to the materials in reinforced concrete, and of the material in a mid-rise building compared to concrete were examined. Modified glulam LCA data were used to approximate an LCA for a CLT floor section and compare it to a functionally equivalent concrete floor section. In all these cases, it is estimated that the CLT will substantially outperform concrete in every environmental metric addressed by LCA.

CODES AND STANDARDS ROAD MAP FOR CLT

Implementation of CLT in the regulatory systems in Canada and the United States requires a multi-level strategy that includes development of a product standard, a material design standard, and adoption of these standards in the building codes. Energy and green building codes are also important aspects of regulatory systems and need to be included in the future as well.

Considering the importance of implementing CLT in the various codes and standards in North America to facilitate the acceptance of the product and the system, a North American Advisory Committee on CLT was formed to advance the implementation of CLT technology. The Advisory Committee formed a Research/Standards Subcommittee. A considerable amount of work is being conducted in the areas of Research and Standards for CLT. The Subcommittee includes experts working in these areas so that the activities can be streamlined. The following CLT Codes and Standards Road Map has been developed.

CLT Codes and Standards Road Map

Product Standard Level

The first level of standardization needed is a product standard. There are four “efforts” underway: a) European Draft; b) FPInnovations drafts; c) APA/ANSI PRG 320 Standard; d) ISO Working Draft. Although presented as separate tracks, FPInnovations and APA coordinated the development of the initial contents of APA and FPInnovations draft CLT standards. Since then, FPInnovations passed the FPInnovations CLT Plant Qualification and Product Standards to the ANSI-accredited APA Committee to facilitate the development of a single North American product standard that could be used as a basis for an ISO standard to harmonize North American and European standards. The North American CLT product standard was published in December 2011 and is proposed to be included in the US Edition of the CLT Handbook. The ISO Task Group under ISO Technical Committee on Timber Structures (ISO TC 165) met in September, 2010 and approved the New Work Item Proposal for the development of an ISO Standard for CLT. Subsequently, the ISO Task Group prepared the Working Draft of an international CLT product standard which was discussed at the last meeting of ISO TC 165 in September 2011.

Material Design Standard Level (CSA O86 in Canada and NDS in USA)

The second level of standardization needed is the material design standard. The Canadian Wood Council (CWC) has initiated the process of inclusion of CLT in the Canadian Standards Association (CSA) O86 *Engineered Design in Wood* standard [8] in Canada and the American Wood Council (AWC) has taken similar steps to incorporate CLT into the *National Design Specification for Wood Construction* (NDS) [9] in the US. CSA's process in Canada and AWC's process in the US will each take about 2-3 years. Design provisions in these design standards are developed and approved with the understanding that such products meet and are evaluated in accordance with a product standard. Consequently, a key step is referencing the product standard in the design standards.

Building Code Level (NBCC in Canada and IBC in USA)

The third level of standardization needed is the building code adoption. It is unlikely that the CLT system will receive broad public acceptance until the product standard is referenced in a design standard, and the design standard is referenced in the building codes. Until that happens, individual projects will need a design professional's intervention to document the suitability and obtain approval of the product on a jurisdiction-by-jurisdiction basis. The CCMC in Canada and the various evaluation services in the US may provide some temporary relief, but the CLT buildings will still need to be approved by the local authority having jurisdiction (AHJ).

From a timing standpoint, changes to the 2015 National Building Code of Canada (NBCC) and the 2015 International Building Code (IBC) must be submitted to CCFBC and ICC, respectively, by 2012. In Canada, discussions between the National Research Council (NRC) and CWC about implementation in the NBCC have already begun. In the US, APA's new product standard, ANSI/APA PRG 320, was recently recommended for approval by the ICC Structural Committee for inclusion in the 2015 IBC. In addition, a CLT chapter may be included in the next version of the NDS or an NDS CLT Supplement may be developed; AWC committees are currently studying both options. In the event that the implementation in US does not occur in the 2015 code cycle, the next version would likely be published in 2018.

Meanwhile, FPInnovations published the Canadian edition of the CLT Handbook that provides technical information to assist a) CWC in their code proposals, and b) design and construction community in their designs. A US version is under development and scheduled to be completed in December 2012 and will be available on line for free download.

Primary Code Obstacles – Seismic and Fire Protection Design

The biggest code obstacles in implementing CLT in North America are the seismic design and fire protection design requirements. Seismic design issues are expected to require significant effort both in the US and Canada and a joint effort would be the most logical avenue for implementation of CLT systems in NBCC and IBC. The biggest information gap in Canada and the US is the development of the seismic Response Modification Factor (R) for CLT systems. There is an effort by the Applied Technology Council (ATC) to develop a procedure for the development of R values, and the Subcommittee will discuss the use of ATC procedures to develop seismic factors for CLT systems. Work planned under a USFPL research program will be instrumental in the development of these factors.

The work that AWC has done to add large wood member fire design provisions to NDS Chapter 16 and to get those NDS provisions directly referenced in the IBC should help to address many fire design issues. However, some limited amount of verification fire testing will be necessary in the US. The implementation of similar provisions in the Canadian Design standard, CSA O86 is underway. Many building applications require non-combustible construction in Canadian and US building codes. Determination of what changes are necessary to address these limitations and types of construction in the NBCC and IBC are still being reviewed; however, it would be reasonable to assume that changes will be needed in the next editions of NBCC and IBC. A testing program on CLT floor and wall assemblies conducted recently by FPInnovations in Canada will also support the current efforts to demonstrate the performance of CLT assemblies exposed to fire.

Other Considerations

FPInnovations and their research collaborators published a *CLT Handbook* (Canadian Edition) that includes structural (including seismic) and fire design, vibration characteristics, sound transmission, and building envelope and environmental performance of CLT. The *CLT Handbook* was welcomed by the Canadian design and construction community who are using this peer-reviewed reference publication in their early designs.

Early adopters will likely use CLT products manufactured to a product standard along with peer-reviewed technical information, such as *CLT Handbook*, in designs. This approach will require an engineer to accept responsibility for the design and the local building code official to approve the building system on a project by-project basis.

The above process can be somewhat facilitated by engaging the evaluation services (such as CCMC, ICC-ES, NTA, IAMPO-ES) who can issue an Evaluation Report for proprietary CLT. Code approval of CLT is permitted under the alternative methods and material provisions in the building codes which allows for a new product to be approved by the AHJ. While code officials do not necessarily need to accept the evaluation reports, many do. This approach is how most new products, such as I-joists and SCL, have been brought into the marketplace. A US Edition of the *CLT Handbook* being developed this summer will facilitate the adoption of CLT in US. The technical information in the handbook will also assist in the development of code submissions in the building codes.

CROSS-LAMINATED TIMBER IN CONSTRUCTION

CLT panels have been used to build hundreds of structures across Europe and, more recently, in North America. While most CLT projects have been designed as residential construction; there are many examples of non-residential applications. In many cases, CLT has been used in combination with other wood based products such as glulam or with other construction materials such as concrete or steel to form hybrid building systems.

CONCLUSIONS

Cross-laminated Timber (CLT) being a new generation of engineered wood product, provides a great potential for use in Canada and the US in both residential and non-residential construction applications. The superior attributes of the CLT panels and assemblies such as good fire and seismic resistance, excellent sound and thermal insulation properties combined with ease of fabrication, quick assembly, and many environmental advantages makes CLT a preferred choice by designers and clients in some types of construction.

Some challenges are still present in terms of code acceptance. There is a need to continue and support research and development activities in North America and adopt a codes and standards road map to ensure a wide acceptance of the CLT product and systems. The recent development of the ANSI/APA PRG 320 standard will help facilitate the approval of the product in material standards and building codes across North America and, potentially, overseas.

ACKNOWLEDGEMENTS

The authors would like to express their special thanks to Natural Resources Canada (NRCan) for their financial contribution to studies conducted at FPInnovations in support of the introduction of Cross-laminated Timber product in Canada.

Thanks are also extended to FPInnovations industry members, NRCan (Canadian Forest Service), the Provinces of British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, Québec, Nova Scotia, New Brunswick, Newfoundland and Labrador, and the Yukon Territory for their continuing guidance and financial support.

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