



## Cross Laminated Timber

Taking wood buildings to the next level

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FPIInnovations | By Layne Evans

**C**ross laminated timber (CLT) is an engineered wood building system designed to complement light- and heavy-timber framing options. Part of a new product category known as massive (or “mass”) timber, it is made from several layers of lumber board, stacked crosswise (usually at 90 degree angles) and glued together on their wide faces. This cross lamination provides dimensional stability, strength and rigidity, which is what makes CLT a viable alternative to concrete, masonry and steel in many applications. It can be used for an entire building, as both the lateral and vertical load resisting system, or for select elements such as the roof, floors or walls.

CLT has been popular in Europe for more than 20 years, with extensive research and a documented track record supporting its widespread use. Internationally, it has propelled wood

construction to new heights, the most recent example of which is the Forté, a 10-story CLT apartment building in Australia.<sup>1</sup> It offers the structural simplicity needed for cost-effective projects, as well as benefits such as design versatility, rapid installation, reduced waste, lighter weight (compared to concrete), and energy efficiency.

In North America, CLT is relatively new but quickly gaining momentum. Last year, the American National Standards Association approved ANSI/APA PRG 320-2012 *Standard for Performance-Rated Cross-Laminated Timber*, a product standard that details manufacturing and performance requirements for qualification and quality assurance. Thanks to recently approved code changes, CLT is also scheduled to be included in the 2015 *International Building Code* (IBC). In the meantime, a handful of innovative designers have already built

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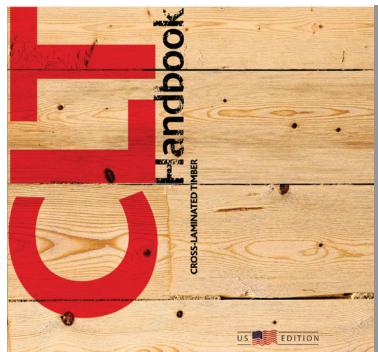
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#### Learning Objectives

After reading this article, you should be able to:

1. Describe the characteristics of cross laminated timber (CLT) and its use in a range of building types.
2. Discuss the advantages of cross laminated timber over other building materials in terms of speed and efficiency of construction, design flexibility, environmental performance and other factors.
3. Use technical guidance available in the U.S. Cross-laminated Timber Handbook related to key issues such as structural design, connectors, vibration, and fire resistance.
4. Recognize how U.S. CLT buildings can be approved under current building codes and how this will change under the 2015 *International Building Code*.
5. Examine the use of CLT in three innovative but very different building projects in the U.S., Canada and Australia.

To receive credit, you are required to read the entire article and pass the test. Go to [www.awc.org](http://www.awc.org) for complete text and to take the test for free.



## U.S. CLT HANDBOOK

The U.S. CLT Handbook is a peer reviewed technical resource developed by research organization FPInnovations in cooperation with the American Wood Council, USDA Forest Products Laboratory, APA, U.S. WoodWorks and a team of more than 40 national and international experts. It includes detailed information that can be used for the design and construction of CLT systems under the “alternate design” path (or similar concept) that is typical in building codes. It can be downloaded free of charge from the website [www.masstimber.com](http://www.masstimber.com), and hard copies can be obtained from the American Wood Council ([www.awc.org](http://www.awc.org)).

CLT structures in the U.S. and Canada, having had them approved under their local building code as an alternative building system. In the IBC, the applicable section is 104.1.1, which states that “An alternative material, design or method of construction shall be approved where the building official finds that the proposed design is satisfactory and complies with the intent of the provisions of the code.”

This course will consider the characteristics of CLT that make it not only a viable option, but an ideal choice for many building types. Based on the *U.S. Cross-laminated Timber Handbook*<sup>2</sup> it will focus on technical information necessary to engineers considering the

*Photo courtesy of Karakusevic Carson Architects*



**CLT's relative light weight made it ideal for the five- and eight-story Bridport House, located over a large storm sewer in London's Hackney Borough.**

use of CLT in a project, such as structural design, connections and fire performance, as well as resources available to those seeking additional detail. Through examples of existing buildings in North America and around the world, it will also illustrate the design flexibility and adaptability of this unique wood product.

### Why CLT?

Designers choose wood for a variety of reasons—including aesthetics, cost effectiveness and environmental performance—many of which are the same for CLT. However, CLT also builds on these advantages with several of its own. This section provides a high-level overview of these benefits, and is followed by a closer look at issues of particular importance to structural engineers.

### Speed and efficiency of installation.

CLT panels are manufactured for specific applications. They are prefabricated, complete with pre-cut openings for doors, windows, stairs, service channels and ducts, and shipped directly from the manufacturer to the job site, where they can be quickly and efficiently lifted into place. This can shave months off the construction schedule. Many manufacturers ship panels with pre-installed lifting straps; contractors then use cranes to lift panels into place. Because panels are designed for specific end-use applications, they are often delivered and erected using a “just-in-time” construction method, making CLT ideal for projects with limited on-site storage capacity.

When Bridport House (see image) in London was constructed in 2011, it was the largest contemporary timber-built apartment block in the world. The CLT construction was completed in 12 weeks, by four skilled laborers and one supervisor.<sup>3</sup>

**Design flexibility.** CLT can be used for an entire building or any combination of wall, floor/ceiling and roof applications. Its light weight and other characteristics make it highly adaptable to different types of projects, designs and site conditions like soft soils or tight proximity to neighboring buildings. CLT elements can also be combined with other building materials, enabling flexibility in design, style and finish architecture. When field modifications are needed, one of the advantages of CLT over materials such as precast concrete is that changes can be made on site with simple tools, pending approval by the engineer of record.

Three examples of CLT's design

*Photo courtesy of Martin Tessler, courtesy of Perkins+Will*



**Designers of the five-story Earth Sciences Building at the University of British Columbia used CLT for the roof and exterior canopies.**

*Photo courtesy of Lend Lease*



**In addition to its structural characteristics, CLT's aesthetic benefits are highlighted in Forté suites with exposed balcony ceilings and interior walls.**

flexibility are discussed in case studies later in this course:

- The Crossroads, a 52,000-square-foot client and staff reception area owned by the Promega Corporation, is part of a 300,000-square-foot Good Manufacturing Practices (GMP) facility, which is a highly regulated and specialized building used for manufacturing medical device products. The Crossroads has a fairly complex footprint, forming a sinuous S-curve which wraps around one corner of the larger facility. The design team chose to use wood for the two-story, open area. Structurally, they were challenged to use a material that would perform well for the long-span deck needed to cover the curved roof. CLT provided the solution.
- The Earth Sciences Building (ESB) at the University of British Columbia is comprised of two five-story wings—a laboratory wing made from conventional reinforced concrete and the North Wing, a new LEED Gold building with offices and lecture halls, which utilizes wood as the main structural element. The North Wing features an innovative combination of mass timber systems, including CLT roof and exterior canopies, composite laminated strand lumber/concrete floors, and glued laminated timber (glulam) heavy timber braced frames. The two wings are connected by an atrium, also made from solid wood panel and glulam post-and-beam construction.
- Forté (see cover image) is the first CLT building in Australia and currently the world's tallest timber apartment building.<sup>4</sup> The walls and floors form a honeycomb-like load-bearing frame, with floor spans reaching up to 19 feet (6 meters) and providing a repetitive load path for vertical and lateral resistance. Lend Lease, which was both the developer and project architect, cites a number of reasons for choosing CLT, including the ability to manufacture materials to precise tolerances off site and fast installation. Installing 10 stories of CLT took five skilled laborers just 10 weeks—which Lend Lease estimates is a 30 percent savings over the same structure in concrete.

**Cost competitiveness.** Light wood-frame construction is still the most economical wood system for low-rise projects. However, CLT is competitive when compared to other materials in a variety of building types. In a 2010 study by FPInnovations, researchers compared the cost of CLT versus certain concrete,

*Photo courtesy of IVALSA*



**Tested in Japan on the world's largest shake table, this CLT building survived 14 consecutive seismic events with almost no damage.**

masonry and steel building types. Even without accounting for the advantages of faster construction time and lower foundation costs (because of CLT's light weight), CLT was found to be cost competitive for mid-rise residential and non-residential, low-rise educational, low-rise commercial, and one-story industrial buildings.<sup>5</sup> CLT is particularly cost effective in large, regularly shaped structures and in situations where fabrication is repetitive.

Manufacturers work closely with the design team to develop estimates based on factors such as the thickness, grade and size of the panels, size of the job (large jobs tend to cost less per square foot as tooling, set-up and delivery costs are distributed), number of openings needed, type of fasteners, and other project-specific factors.

**Fire protection.** CLT's thick cross-section provides valuable fire resistance because panels char slowly. Once formed, char protects the wood from further

degradation. In addition, CLT offers increased compartmentalization if used for interior walls. Fire protection is covered in more detail later in this course.

#### **Seismic performance.**

Because of their dimensional stability and rigidity, CLT panels create an effective lateral load resisting system. Since it is a system of multiple, small connectors, CLT also offers good ductile behavior and energy dissipation. Researchers have conducted extensive seismic testing on CLT and found panels to perform exceptionally well with no residual deformation, particularly in multi-story applications.

In Japan, for example, a seven-story CLT building was tested on the world's largest shake table. Even when subjected to severe earthquake simulation (magnitude of 7.2 and acceleration of 0.8 to 1.2 g), the structure showed no residual deformation after

the test. The maximum inter-story drift was 1.5 inches and the maximum lateral deformation at the top of the building was just 11.3 inches. The building survived 14 consecutive seismic events with almost no damage—which, in addition to demonstrating the safety of CLT buildings, illustrates their promise in the context of “resilient” design. A growing trend within the sustainability movement, resilient design places an emphasis on making efficient use of resources while creating buildings that last because they are less vulnerable to events such as earthquakes.

**Thermal performance and energy efficiency.** Thermal conductivity is a measure of the rate of heat flow through one unit of thickness of a material subjected to a temperature gradient. The thermal conductivity of common structural wood is much less than the conductivity of metals with which wood is often mated in construction. It is about two to four times that of common

## CASE STUDY

### EARTH SCIENCES BUILDING, UNIVERSITY OF BRITISH COLUMBIA

Owner: University of British Columbia  
Location: Vancouver, BC (Canada)  
Architect: Perkins+Will Canada  
Engineer: Equilibrium Consulting  
Completed: 2012

Under one roof, the University of British Columbia's new Earth Sciences Building combines five stories, four science departments, and two distinct structural systems. The South Wing is a conventional reinforced concrete laboratory building. The North Wing, which consists of academic teaching and research spaces, lecture halls and offices, uses wood as the primary structural material, as does the connecting atrium.

With its innovative combination of materials, the ESB exemplifies not only the design flexibility inherent to CLT, but its value as a complement to other materials. CLT is featured in the roof and generous exterior canopy structure surrounding the building. The structure is supported by glulam columns and beams, and floors are made from an innovative composite of laminated strand lumber and concrete.

One of the largest applications of CLT to date, the North Wing also demonstrated CLT's advantages in terms of speed of construction. According to the manufacturer, roof panels were placed on the building at a rate of one every 15 minutes.

insulating material. For example, the conductivity of structural softwood lumber at 12 percent moisture content is in the range of 0.7 to 1.0 Btu·in/(h·ft<sup>2</sup>·°F) compared with 1,500 for aluminum, 310 for steel, 6 for concrete, 7 for glass, 5 for plaster, and 0.25 for mineral wool.<sup>6</sup>

Since CLT is a solid wood panel, it also provides thermal mass. But the key measures of CLT's thermal performance are U-value (coefficient of heat transfer) and R-value (insulating ability). Both are related to panel thickness. Thicker



*Photo by KK Law, courtesy of naturallywood.com*

The panels span between glulam post and beam frames, which run across the building width on a 21-foot (6.4-meter) grid. The panels were simply secured to the glulam beams using self-tapping lag screws, which made for fast and reliable installation. The new generation of self-tapping screws commonly used in solid wood construction was originally developed in Europe, but examples are now readily available in North America from a number of suppliers and in a variety of types and sizes.

In addition to being technically innovative, the use of mass timber products supported the environmental goals of the University and design team. "The project boasts a low embodied energy profile and sequesters carbon dioxide, thereby mitigating the impact of climate change," says Jana Foit, ESB's Project Architect and Higher Education Practice Leader of Perkins+Will's Vancouver office.

panels have lower U-values; they are better insulators and therefore require less insulation.

The commonly used R-value for wood is 1.25 per inch of thickness. So a 7-inch-thick CLT panel would have an R-value of 8.75. Softwood in general has about one-third the thermal insulating ability of a comparable thickness of fiberglass batt insulation, but about 10 times that of concrete and masonry, and 400 times that of solid steel.<sup>7</sup>

In addition, since CLT panels can be manufactured using Computer Numeric

Control (CNC) equipment to precise tolerances, panel joints fit more tightly, resulting in better energy efficiency for the structure. Because the panels are solid, there is little potential for airflow through the system. As a result, an extremely tight building envelope can be achieved.

#### Environmental performance.

Manufactured using wood from sustainably managed forests, CLT provides a number of environmental benefits in addition to energy efficiency.

Wood grows naturally and is renewable. Life cycle assessment (LCA) studies also show that wood outperforms steel and concrete in terms of embodied energy, air pollution and water pollution, and LCA studies are underway on CLT specifically. Wood also has a lighter carbon footprint because wood products continue to store carbon absorbed by the trees while growing, and wood manufacturing requires less energy and results in less greenhouse gas emissions.<sup>8</sup>

Carbon storage is an important attribute of wood structural components, which typically stay in place over long periods. With CLT, the stored carbon mass of the wood is significant. For example, calculations done for The Crossroads estimated the total potential carbon benefit of the wood used just in the CLT portion of the building at 692 metric tons of CO<sub>2</sub> (equivalent), which compares to keeping 132 cars of the road for a year, or providing total energy to operate a home for 59 years.

Depending on the manufacturer and other factors, the wood used in North American CLT products may be a factor in LEED certification or other green building rating systems, for example when the wood comes from certified forests or from forests killed by mountain pine beetles.

**Resource efficiency.** CLT contributes to efficient use of the resource in several ways. One of the advantages of CLT is that it can make use of smaller-dimension material that might not otherwise be used in structural applications. Also, since CLT panels are manufactured specifically for each project, there is almost no job site waste, and manufacturers can re-use any fabrication scraps for stairs and other architectural elements, or as biofuel.

Photo courtesy of U.S. WoodWorks

## UBC Earth Sciences Building

**V** Volume of wood used:  
573,360 board feet (equivalent)

**T** U.S. and Canadian forests grow  
this much wood in:  
4 minutes

**C** Carbon stored in the wood:  
1,005 metric tons of CO<sub>2</sub>

**G** Avoided greenhouse gas emissions:  
1,168 metric tons of CO<sub>2</sub>

**✓** TOTAL POTENTIAL CARBON BENEFIT:  
2,173 metric tons of CO<sub>2</sub>

EQUIVALENT TO:

Source: US EPA  
**EPA** 415 cars off the road for a year

**H** Energy to operate a home for 185 years

**Estimated carbon benefits of the Earth Sciences Building. Estimated by the Wood Carbon Calculator for Buildings ([www.woodworks.org](http://www.woodworks.org)), based on research by Sarthre, R. and J. O'Connor, 2010, A Synthesis of Research on Wood Products and Greenhouse Gas Impacts, FPInnovations. Note: CO<sub>2</sub> on this chart refers to CO<sub>2</sub> equivalent.**

In terms of overall resource use, the distinction between light-frame and “heavy” construction is important. CLT was developed not as a replacement for light-frame construction, but as a low-carbon alternative to “heavy” construction materials such as concrete and steel in building applications where light-frame construction is less appropriate—in taller buildings, certainly, but also others, such as an industrial warehouse with 40-foot walls that need to withstand the impacts of heavy machinery, or a Class A office building where few partition walls and minimal floor vibrations are desired.

## WILL CLT LEAD TO FOREST RESOURCE DEPLETION?

Extensive research has been done to ensure that CLT will not create a challenge to the sustainability of North American forests. The basic question was asked: if designers begin to replace construction materials typically used in commercial buildings with mass timber products such as CLT, will we create an unsustainable trend leading to forest resource depletion? Based on analysis of market projections and forest growth-removal ratios, the answer

A CLT building may require more total wood than a light-frame building, but when compared to steel or concrete in applications where all three are potentially applicable, advantages such as renewability, carbon off-sets, low embodied energy and operational energy efficiency make CLT an environmentally preferable choice.

### CLT BASICS

As recently as 2011, CLT panels had to be shipped from manufacturers in Europe, but there are now a number of manufacturers and distributors working in North America.<sup>12</sup>

CLT manufacturers typically work closely with the project design team, offering technical support and material efficiency advice throughout the process. An engineer of record (EOR) is required for a CLT project. However, the CLT manufacturer often acts similarly to a truss or component manufacturer in that they have staff engineers and technicians that provide shop drawings and calculations to meet the EOR's specifications. On most projects, there is continuing interaction and support from the manufacturer to optimize the CLT system.

Panel sizes vary by manufacturer; typical widths are 2 feet (0.6 meters), 4 feet (1.2 meters), 8 feet (2.4 meters) and 10 feet (3 meters). Length can be up to 60 feet (18 meters) or more, and the thickness can be up to 20 inches (50.8 centimeters), though the current maximum available in North America is 16 inches (40.6 centimeters). Transportation is most likely the variable that will limit the CLT panel size, not the manufacturing capabilities.

North American manufacturers use formaldehyde-free interior/exterior

is no. Stringent sustainable forest management practices in the U.S. and Canada restrict harvesting levels, while maintaining other forest values such as biodiversity and wildlife habitat.<sup>9</sup> In the U.S., less than 2 percent of the standing tree inventory is harvested each year while net tree growth is close to 3 percent.<sup>10</sup> In Canada, less than 0.2 percent of the forest resource is harvested annually and all forests on public land must be successfully regenerated.<sup>11</sup>

Photo by Martin Tessler, courtesy of Perkins+Will

## EARTH SCIENCES BUILDING

The expansive 12,378-square-foot (1,150-square-meter) canopy of the Earth Sciences Building appears as a pristinely flat timber plate which emerges from the building and cantilevers past a glulam colonnade, giving the appearance that the entire canopy is made from a single, giant piece of CLT. The illusion is achieved by locating all supporting beams on top and hanging the panels from the underside with self-tapping screws, effectively creating an upside-down structure. The 32-square-foot (3-square-meter) double cantilever corners are strategically reinforced with hidden steel elements located on top or in the panel joints.



polyurethane (PUR) structural adhesives with exceptional moisture performance. Adhesives must be qualified in accordance with ANSI/APA PRG 320 for bonding strength, moisture durability, elevated temperature performance, and heat durability. Boards are face-glued and then pressed, planed or sanded into panels. Using CNC precision machinery, the panels can be custom fabricated to create openings, compound angles and unique features requiring complex geometry to meet specific end-use applications.

Manufacturers in North America may use different species or mixes of species in their CLT products. Typical species are discussed in the ANSI/APA PRG-320 standard.

In general, however, designers don't select a particular species, but instead specify the required performance based on the application (floor, wall, roof, etc.)

## CASE STUDY

### THE CROSSROADS

**Owner:** Promega Corporation

**Location:** Madison, WI

**Architects:** Uihlein/Wilson Architects, Inc. / EwingCole

**Engineer:** EwingCole

Environmental Consulting: Archemy Consulting

**CLT Engineer:** Equilibrium Consulting Inc.

**Completed:** 2013

The project team for The Crossroads evaluated several types of structural systems during the initial design phase. "There was no particular assumption in terms of what the structural material needed to be," says David Rousseau from Archemy Consulting, design consultant for Promega. "I think we may have even initially assumed it would be a steel structure since that's what we were using for the GMP portion of the project."

Cross laminated timber came up because it's an innovative material and the team knew it wanted to create a unique space, but it also served the design in key ways. "Together with glulam, it was a natural fit for the warm aesthetic we wanted to create," says Rousseau. "Plus, we wanted to have a high quality, exposed roof deck with long spans and minimum on-site construction complexity. CLT met the criteria."

Photo by Uihlein/Wilson Architects



View from Southwest



Aitor Sanchez-Prado, structural engineer and

principal for EwingCole, said, "CLT provided us

with a solution that met all of our architectural and engineering goals. Architecturally speaking, our decision to use CLT for the roof of The Crossroads allowed us to leave the interior ceiling surfaces exposed, which certainly enhanced the glulam beam and column superstructure. From an engineering point of view, the CLT panels gave us the ability to increase deck spans while supporting heavily loaded areas due to snow drifts. In addition, the CLT panels allowed us to design an overhang of three feet while maintaining a slim profile."

and request the appropriate grade of CLT. There are two routes manufacturers can take to achieve a specific stress grade—prescriptive and performance. "Layup" is the term for the arrangement of the timbers that make up a CLT panel. With the prescriptive route, a lamination size, species and grade-specific layup combination has been tested and is known to have certain structural design properties. With the performance route, any alternative layup can be used if it is proven by the manufacturer to qualify as meeting the CLT grade requirements. This approach is taken with other engineered wood products such as wood structural panels. With either route, the grade of the CLT will be third-party certified ensuring the stated design values.

CLT panels are usually manufactured with an odd number of layers, which creates a direction of greater strength for a specific application (floor, roof or wall). Although panels have strength capacity in both directions like a plate element, the direction parallel to the grain of the outside laminations is typically the stronger axis (i.e., major strength direction). Exact lamination thickness

and number of layers varies by application and manufacturer.<sup>13</sup>

CLT's dimensional stability is rooted in its manufacture and is the result of two basic factors:

- The lumber itself has an average moisture content (MC) of about 12%, which is relatively dry. Dryer lumber means less overall shrinkage when the lumber acclimates to the service

Photo courtesy of FPInnovations



condition. Also, because smaller-dimension lumber can be used, the moisture content tends to be consistent throughout the product.

- The nature of cross lamination is also a major contributor. Wood expands and contracts five to ten times more tangential to the grain than parallel to the grain. The alternating orientation of layers in CLT has the effect of restricting

overall expansion and contraction of the panel in both directions.

The exact weight of CLT is dependent on the density of the species used and thickness of the panel (for values, see the *National Design Specification® (NDS®) for Wood Construction*), but may be estimated at about 35–36 pounds per cubic foot. Manufacturers provide detailed information for their product offerings.

Structural design is discussed in the next section, but in general there are a number of simple details that can be used to establish roof/wall, wall/floor, and inter-story connections in CLT assemblies, to connect CLT panels to other wood-based elements, or to connect CLT panels to concrete or steel for a hybrid assembly. The type of hardware depends on the assemblies to be connected, on the panel configuration, and on the type of structural system used in the building. Some of the more common lateral load transfer connectors include metal ‘L’ brackets for shear or traditional strap hold-downs used for overturning.

Proprietary self-tapping screws or a variety of commodity nails can be used to connect panels in plane or at intersections. Ease of installation along with high lateral and withdrawal capacity make self-tapping screws especially popular because they can take combined axial and lateral loads.

CNC technology is also driving the development of new and innovative fastening systems. For example, glued-in rods can be used for connections under high longitudinal and transverse loads, and epoxied shear connectors can be used to create composite floors with structural concrete over CLT.

Detailed guidelines on how to design structural elements using CLT are included in the *U.S. CLT Handbook*.

### **CLT and Mechanical/Electrical/Plumbing**

When the CLT is exposed on the interior, these are some of the ways MEP is being addressed:

- ▶ Fur out a wainscoting on the lower half of the wall to accommodate electrical outlets and plumbing pipes.
- ▶ Run the conduit, pipes and chases on the face of the CLT and use them as exposed architectural elements.
- ▶ Add stick-framed partition walls on the interior of the structure to

accommodate MEP.

- ▶ Create a drop ceiling to conceal the MEP.
- ▶ Gap the CLT panels to accommodate plumbing and mechanical and add a thin faux panel on the face.
- ▶ Create a non-structural built-up floor on top of the CLT floor deck to accommodate plumbing and mechanical, similar to the approach with heavy timber.

When the CLT is covered, there are two basic approaches:

- ▶ Rout and bore the panel to take the electrical conduit, plumbing pipes and mechanical chases. This can be done on site with traditional carpentry tools or in the factory using CNC technology, but the latter would require more coordination and would increase the cost of the product.
- ▶ Fur the wall out to accommodate MEP. This is likely to be the more common method in North America based on building practices and need to satisfy sound insulation requirements.

Local MEP codes may have an impact on the options available. In addition, note that “concealed spaces” are not allowed in Type IV (heavy timber) construction, which is where CLT is being added under the IBC.

### **STRUCTURAL DESIGN CONSIDERATIONS**

CLT panels are typically used as load-carrying plate elements in structural systems such as walls, floors and roofs. Lumber in the outer layers of CLT panels used as walls are normally oriented up and down, parallel to gravity loads, to maximize the wall’s vertical load capacity. Likewise, for floor and roof systems, the outer layers run parallel to the longer span direction.

For floor and roof CLT elements, key characteristics that must be taken into account are the following:

- ▶ Out-of-plane bending strength, shear strength, and stiffness
- ▶ Short-term and long-term behavior:
  - Instantaneous deflection
  - Long-term deflection (creep deformation)
  - Long-term strength for permanent loading
- ▶ Vibration performance of floors
- ▶ Compression perpendicular to grain issues (bearing)
- ▶ Fire performance
- ▶ Sound insulation
- ▶ Exposure to elements

For wall elements, key characteristics that must be taken into account at the design stage include:

- ▶ Load-bearing capacity (critical criterion)
- ▶ Out-of-plane shear and bending strength
- ▶ Fire performance
- ▶ Sound insulation
- ▶ Exposure to elements

The *U.S. CLT Handbook* discusses these and many other issues such as proposed analytical design methods, research and conclusions about lateral design of CLT buildings, enclosure design, environmental performance, etc. This section on structural considerations will focus on two key areas: connections and floor vibration. The following section will summarize important information about fire resistance.

### **Connections and Construction of CLT Structures**

Connections in timber construction, including those built with CLT, play

## **CLT AND THE INTERNATIONAL BUILDING CODE**

In the next version of the IBC, recently approved changes are scheduled to streamline the acceptance of CLT buildings. The 2015 IBC will recognize CLT products when they are manufactured according to the product standard. In addition, CLT walls and floors will be permitted in all types of combustible construction, including Type IV buildings. Type IV wall provisions require the exterior side (only) of exterior CLT walls to be protected by fire retardant treated wood sheathing, gypsum sheathing, or a noncombustible material; however, there are other requirements for the exterior wall, floors, roof, etc. Floors are required to be 4-inch (10.16-centimeter) nominal minimum thickness and roofs a minimum of 3-inch (7.16-centimeter) nominal. While this code change will not go into effect officially until the 2015 IBC is adopted by a jurisdiction, the information could be used to simplify an alternative methods argument under current codes. For more information, see the American Wood Council website at [www.awc.org](http://www.awc.org).

## CASE STUDY

### FORTÉ

**Owner:** Lend Lease

**Location:** Melbourne, Australia

**Architect:** Lend Lease Design

**Engineer:** Lend Lease Design and the Robert Bird Group

**Completion:** 2012

Numbers tell a powerful story when it comes to Forté. It's Australia's first CLT building and the first 10-story CLT building anywhere. Research and development was a three year process, followed by a year of design and 10 months of construction from site preparation to completed building.

Although Lend Lease cites benefits such as speed of installation and lightweight materials (a particular advantage given the site's poor soil conditions), the three-year investment in R&D had more to do with the company's desire to demonstrate that sustainability can be cost effective in a large commercial development.

*Photo by Lend Lease*



Forté is the first residential building in Australia to achieve a '5 Star Green Star As Built' rating, which is similar to LEED Platinum. "The construction industry is one of the worst in the world for polluting," says Daryl Patterson, Head of Operational Excellence and Development for Lend Lease. "If we want to do

something about this, we have to challenge the materials we're building with. Among other things, we need to place a greater focus on embodied carbon in addition to operational energy efficiency."

As it turned out, the use of CLT helped Lend Lease achieve its objective of "as close to a net zero carbon building as possible." Between the carbon sequestered in the wood itself and the greenhouse gas emissions avoided by not using steel or concrete, Forté kept approximately 1,450 metric tons of carbon dioxide (equivalent) out of the atmosphere. It also set the stage for additional carbon savings in future CLT developments.<sup>14</sup>

## CLT AND ENVIRONMENTAL PRODUCT DECLARATIONS

Environmental Product Declarations (EPDs) are a means of presenting environmental information in a standardized way, independently verified by a third party. A common part of decision making elsewhere in the world, they are relatively new to the U.S., produced mainly by large manufacturers or industries committed to being leaders in environmental performance, and used by a relatively small number of design practitioners with the same objective.

Governed by international standards (ISO 14025, ISO 21930 and others), EPDs are based on life cycle assessment, which is a rigorous study of inputs and outputs over a product's lifetime and the associated environmental impacts of those flows to and from nature.

EPDs are currently available for two CLT products manufactured in North America.<sup>15</sup> Prepared by research organization FPInnovations, both consider all aspects of production from cradle to gate—i.e., from the extraction of raw materials through final production of the CLT. They provide life cycle data on primary energy use as well as impact categories such as global warming potential, smog potential and ozone depletion potential. In terms of carbon footprint, the EPDs conclude that both products have a negative carbon balance leaving the mill gate, which means the amount of carbon sequestered in the wood (absorbed from the

atmosphere while the trees were growing) is greater than their cradle to gate carbon emissions.

Increasing interest in EPDs reflects a growing demand for sustainability in every aspect of a building's design, construction and operation, and the recognition that this cannot be evaluated without transparent, verifiable data. Their growing use will allow designers to compare products in the same category in a much more transparent and meaningful way than is otherwise possible.

The information contained in EPDs is quantifiable and verifiable—but it is not the final word, by any means. EPDs are complementary to other third-party independent certifications such Energy Star labels and forest certification programs (for example, Forest Stewardship Council, Sustainable Forestry Initiative, and Programme for the Endorsement of Forest Certification). EPDs remain only one of many reporting mechanisms, and product certification continues to serve important functions. Products have other impacts besides those covered by EPDs, involving human and social values such as fair practices, biodiversity, and many others.

In the case of wood products, for instance, sustainably managing forests with future generations in mind, conserving biodiversity, and protecting other values related to forests have great worth and complement the parameters measured in an EPD. Together, EPDs and forest certification provide a more complete picture of the environmental attributes of a forest product.

an important role in maintaining the integrity of the timber structure and in providing strength, stiffness, stability and ductility. Consequently, they require thorough attention of the designers.

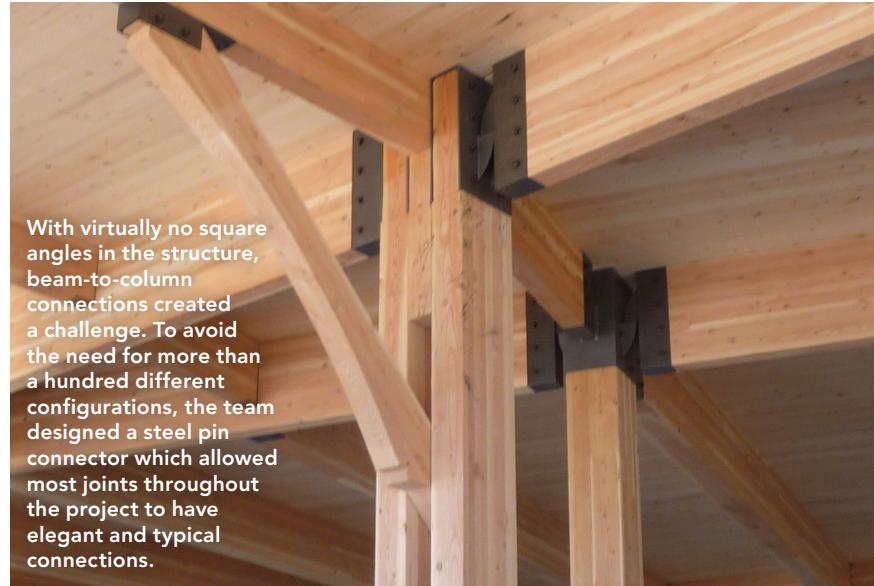
Traditional and innovative connection systems have been used in CLT assemblies in Europe and North America. Common types of connections in CLT assemblies include: in-plane panel-to-panel (floors, walls and roofs), out-of-plane panel intersections, and panel-to-foundation. Basic panel-to-panel connection can be established through single or double exterior splines made with engineered wood products, single or double interior splines, or half-lapped joints. 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.

Mechanical fasteners may be dowel-type (e.g., nails, screws, glulam rivets, dowels, bolts) or bearing-type (e.g., split rings, shear plates).

CLT connections should adhere to the NDS just like other wood connections. The NDS has specific provisions for commodity fasteners, which can be found in Appendix K - L. It does not yet include information on how to apply its dowel bearing equations regarding grain direction to CLT. However, the existing NDS design provisions can be applied with some modification, assuming that the CLT dowel bearing strength is based on the species-specific gravity of the ply in the shear-plane and the loading direction relative to the grain angle of the ply in the shear-plane. A reduction in effective thickness is also taken for the plies running perpendicular-to-grain if the ply in the shear-plane is parallel-to-grain.

Self-tapping screws will likely be the most common connector used in CLT construction. These are proprietary connectors and design values and requirements would be specified by the manufacturer. The manufacturer will be responsible for providing lateral and withdrawal connection values and any information needed to explain how to apply provisions of the NDS (e.g., dowel bearing strength adjustments, dowel bending strengths of the self-tapping screws, and specific application of the NDS yield equations).

*Photo courtesy of Uihlein/Wilson Architects*



Design values for proprietary fasteners and information on their approved use are available in Evaluation Reports or the manufacturer's literature.

Researchers in Europe have developed design procedures for traditional connections in CLT. These include dowels, wood screws, and nails, which are commonly used in Europe for designing CLT assemblies. Empirically-based equations 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 equations were verified with testing and results seem to correspond well with calculated predictions.<sup>16</sup>

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.<sup>17</sup> 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

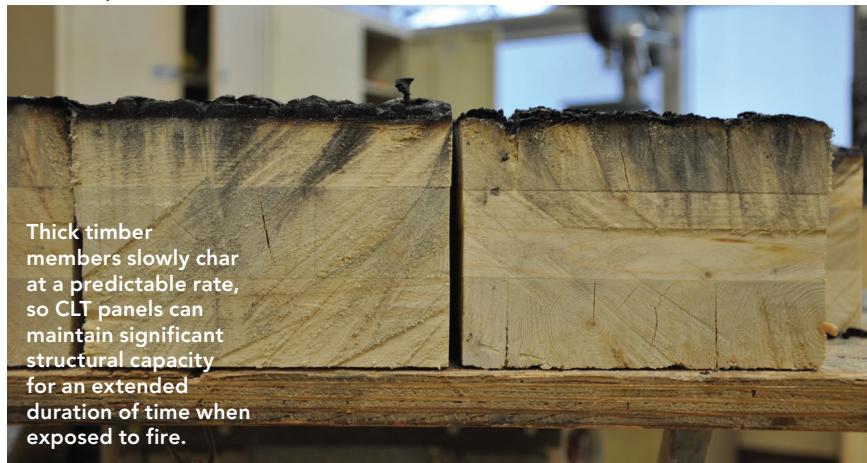
that current minimum geometric requirements given in the NDS for dowels, screws and nails in solid timber or glulam could be applicable to CLT. However, designers need to be cautious about this as further verification is needed, considering the specific features of individual panel types. Brittle failure modes, which have not yet been investigated, also need to be taken into account.

The Connections chapter in the U.S. *CLT Handbook* is mainly focused on connecting CLT to CLT. However, since all buildings are considered to be mixed construction to a certain extent, the scope covers hybrid construction, where traditional wood-based systems (e.g., light frame, glulam, etc.) or materials such as concrete or steel are mixed with CLT to resist vertical and lateral loads.

### Vibration Performance of Floors

Studies at FPInnovations found that bare CLT floor systems differ from traditional lightweight wood joisted floors with typical mass around 4 pounds per square foot (20 kilograms per square meter) and fundamental natural frequency above 15 Hz, and heavy concrete slab floors with a mass above 40 pounds per square foot (200 kilograms per square meter) and fundamental natural frequency below 9 Hz. Based on FPInnovations' test results, bare CLT floors were found to have mass varying from approximately 6 pounds per square foot (30 kilograms per square meter) to 30 pounds per square foot (150 kilograms per square meter), and a fundamental natural frequency above 9 Hz. Due

Photo courtesy of FPInnovations



to these special properties, the standard vibration controlled design methods for lightweight and heavy floors may not be applicable for CLT bare floors.

Some CLT manufacturers have recommended that deflection under a uniformly distributed load (UDL) be used to control floor vibration. Using

this approach, the success in avoiding excessive vibrations in CLT floors relies mostly on the designer's judgment. Besides, static deflection criteria can only be used as an indirect control method because they ignore the influence of mass characteristics of the floors. Therefore, a new design methodology is needed to determine the vibration controlled spans for CLT floors. A proposed design methodology for controlling vibrations of CLT floors under normal walking is given in Chapter 7 of the U.S. *CLT Handbook*.

### CLT AND FIRE RESISTANCE

Structural integrity and fire containment capability of building assemblies can be assessed by conducting full-scale fire-resistance tests in accordance with ASTM E119 standard test methods. Fire resistance is defined as the ability of a

## CLT AND CURRENT CODES

While CLT has been used in Europe for years, it is still relatively new to North America. Fortunately, U.S. building codes are flexible enough to accommodate new materials. Promega's design team for The Crossroads earned local building department approval by using ANSI/APA PRG 320-2011 standard. The design team discussed the standard with building officials early in the process, and submitted engineering information under the 'alternate designs' section of the IBC.

"The building was designed per the 2009 IBC with State of Wisconsin amendments," says structural engineer Aitor Sanchez-Prado. "The basic criteria for the project consisted of minimum roof snow loads of 30 psf with a maximum snow drift load of 132 psf. The structure was designed for basic wind speeds of 90 mph and seismic design category B. These loads, together with diaphragm chord and tie forces, set the design criteria that the custom-made CLT panels were required to meet."

In the Earth Sciences Building, under the prescribed fire safety requirements for the British Columbia Building Code (BCBC), having the academic wing built entirely of heavy timber or wood-frame construction was not permitted. In order to allow for the use of wood as the main structural element, a fire hazard assessment was carried out and documented in a Building Code Alternative Solution, which was peer-reviewed as part of the building permit approval process.

The assessment essentially looked at how the wood construction might perform in fire. The Earth Sciences Building was designed with an automatic sprinkler system, and a fire retardant coating was applied where necessary to alter the surface burning characteristics of the wood interior

finishes to more closely meet the standard required in a non-combustible building. Further, taking advantage of the highly compartmentalized nature of the wing, a fire risk analysis was presented to show that the risk of fire growth and spread would inherently be limited by the many separate, individual offices and rooms. To address concerns, the wood structure was engineered to account for the charring of the wood members for the required fire-resistance period so that the resistance provided by the reduced cross section (unburned portion) of the wood members would continue to resist the gravity loads expected during the fire.

A key component in the fire safety design of the heavy timber element, which is traditionally not explicitly addressed by the building code, was the fire performance of the steel connections. The minimum fire resistive properties of steel connectors were considered critical since the loss of the load-bearing capacity of the structure at the early stage of a fire would be significant if the steel connectors failed. To ensure the connectors would continue to transfer loads in the heavy timber wood-frame system during a fully-developed fire, concealed connections were specified. Where there were other exposed steel elements that were part of the wood structure's load path, appropriate 'passive' fire protection, in the form of an intumescent coating, was also specified.

ICC-ES has not yet published any reports for CLT products or their connections; however, there are several APA Product Reports (e.g., PR-L306) that provide third-party testing and may be accepted under IBC Section 104.11.1. Moreover, the research and testing data provided in the U.S. *CLT Handbook* can also be provided as an alternate means approach under that section. At least one manufacturer to date also has testing data available on a series of CLT connectors.

material or their assemblies to prevent or retard the passage of excessive heat, hot gases or flames under conditions of fire. A fire-resistance rating is defined as the period of time a building element, component or assembly maintains the ability to confine a fire (separating function), and/or continues to perform a given structural function. More specifically, a standard fire-resistance test entails three failure/acceptance criteria:

- ▶ Structural resistance: the assembly must support the applied load for the duration of the test.
- ▶ Integrity: the assembly must prevent the passage of flame or gases hot enough to ignite a cotton pad.
- ▶ Insulation: the assembly must prevent the temperature rise on the unexposed surface from being greater than 325°F (180°C) at any location, or an average of 250°F (140°C) measured at a number of locations, above the initial temperature.

The time at which the assembly can no longer satisfy any one of these three criteria defines its fire-resistance rating.

AWC conducted a successful ASTM E119 fire resistance test on a CLT wall at NGC Testing Services in Buffalo, NY. The wall, consisting of a 5-ply CLT (approximately 6-7/8 inches thick), was covered on each side with a single layer of 5/8-inch Type X gypsum wallboard. The wall was loaded to the maximum load attainable by the NGC Testing Service equipment. The 10×10 foot test specimen lasted three hours, five minutes, and 57 seconds (03:05:57)—well beyond the two-hour goal.<sup>18</sup>

Industry has taken an analytical approach to CLT, rather than the route of prescriptive fire-rated assemblies. This is because CLT assemblies, and in particular floors, will most likely never be loaded to their full design capacities, but instead be designed based on serviceability (vibration and/or deflection). Therefore, it would be overdesigning to evaluate based on a prescriptive fire-rated assembly. This also allows more flexibility in wall and floor assembly designs. The approach taken was to test CLT under different load ratios, including full design loads, in order to validate the proposed calculation method(s). Fire resistance calculation methods will be included in the next version of the NDS and are explained in Chapter 8 of the U.S. *CLT Handbook*.

Results of full-scale fire tests show that

CLT panels have the potential to provide excellent fire resistance comparable to the typical Type IV exterior wall assemblies of non-combustible construction. Due to the inherent nature of thick timber members to slowly char at a predictable rate, CLT panels can maintain significant structural capacity for an extended duration of time when exposed to fire.

Adhesives can also have an effect on fire performance, but standards exist to prevent that from playing a significant role in the overall product performance and to ensure appropriate adhesive performance under heat and fire. The ANSI/APA product standard established for CLT requires that, in the U.S., adhesives used in the manufacturing of CLT shall meet similar requirements as structural glued laminated timber used in dry service conditions (the equilibrium moisture content of wood is less than 16 percent). Also, adhesives shall be evaluated for heat performance.

The fire resistance calculation methodology outlined in Chapter 8 also accounts for altered performance characteristics of a laminated product like CLT. In addition to the fire-resistance calculation method of CLT assemblies, this chapter provides requirements related to fire safety in buildings, namely with regard to the types of construction prescribed in the IBC, fire-resistance requirements, connection detailing, interior finishes, through-penetrations and exterior walls.

## PROVEN PERFORMANCE, NEW OPPORTUNITY

CLT's strength, structural performance and cost-competitiveness are expanding opportunities for the use of wood in a wider range of buildings. Available in North America and increasingly accepted under building codes, it provides a flexible, sustainable and efficient alternative to concrete and steel for many applications. ■

## ENDNOTES

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The reThink Wood initiative is a coalition of interests representing North America's wood products industry and related stakeholders. The coalition shares a passion for wood and the forests it comes from. Innovative new technologies and building systems have enabled longer wood spans, taller walls, and higher buildings, and continue to expand the possibilities for wood use in construction. [www.rethinkwood.com](http://www.rethinkwood.com)



AMERICAN WOOD COUNCIL

American Wood Council is the leading developer of engineering data, technology, and standards on structural wood products in the U.S. These tools are used widely by design professionals, building officials, and manufacturers of traditional and engineered wood products to ensure the safe and efficient design and use of wood structural components. [www.awc.org](http://www.awc.org)



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