Cross-Laminated Timber: A Primer

Pablo Crespell and Sylvain Gagnon

Introduction

Cross-laminated timber (CLT) is a novel building system of interest in North American construction. It is a cost-competitive wood-based solution that complements the existing light- and heavy-frame options, and is a suitable substitute for some applications that currently use concrete, masonry, and steel.

This publication is mostly based on European experience. Application of European results to North America is preliminary until validated for local species and technologies. This primer is not intended for promotional use but rather it is a compilation of the knowledge gathered on CLT to date.

Product Description

CLT is a multi-layer wooden panel made of lumber. Each layer of boards is placed crosswise to the adjacent layers for increased rigidity and stability. The panel can have three to seven layers or more, normally in odd numbers, symmetrical around the mid layer. The solid wood building system consists of ready-to-use building components that are assembled to form complete frameworks. Dimensional lumber is the main input material. It is possible to use low grade for the interior layers and higher grades for the outside and it can be pre-dressed (planed) or dressed at the factory once the panel is assembled. While softwoods dominate, it is feasible to manufacture CLT using hardwoods like poplar or even hybrid panels (e.g., structural composite lumber products).

Manufacturing

Lumber Drying

The boards must be kiln-dried to a moisture content of 12% ± 2% depending on target location. Proper moisture content prevents dimensional variations and surface cracking. Lumber can be procured dried or further drying may be needed at the factory.

Finger Jointing (FJ)

Trimming and finger jointing are used to obtain the desired lengths and quality of lumber. Panel FJ is feasible too.

Panel Assembly

Panel sizes vary by manufacturer. Typical widths are 2', 4', and 9.7' (up to 13') while length can be up to 78' (FJ), and thickness can be up to 1.5'. The outer layers of panels used as walls normally orient boards with the grain direction parallel to vertical loads to maximize resistance. Likewise, for floor and roof systems, the exterior layers run parallel to the span direction. Final width is obtained by joining panels together. Transportation regulations may impose size limitations. The assembly process can take from 15 minutes to one hour depending on equipment and adhesive.

Panel Assembly Options

Besides gluing, nails or wooden dowels can be used to attach the layers. The middle layer can be lumber or composite materials.

Gluing

Glue is the second input in CLT. Interior/exterior polyurethane adhesives are normally used (formaldehyde- and solvent-free) although MUF and PRF may be used as well. Face and edge gluing can be used. FPInnovations has tested several Canadian species and glues.

Press

The right pressure and homogeneity are critical. Hydraulic presses dominate, however the use of vacuum and compressed air presses is also possible, depending on panel thickness and adhesive used. Vertical and horizontal pressing are applied.

Planer and Sander

The assembled panels are planed or sanded for a smooth surface.

CNC Router

CNC routers allow high precision. Panels are cut to size; openings are made for windows, doors, and service channels, connections, and ducts.

Quality Control

Compliance with product requirements prescribed in the product standard must be checked at the factory (e.g., bending strength, shear strength, delamination).

Carpentry Room and Finishing

Installation of insulation and drilling for openings may take place at the factory.

Mechanical Properties and Serviceability

Different methods have been adopted for the determination of basic mechanical properties of CLT in Europe. Some of these methods are analytical in nature while others are experimental. 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 layout, type of material, or any of the manufacturing parameters change, testing is needed to evaluate the bending properties of such products.

In Europe, mechanical properties are provided by each manufacturer on a proprietary basis. In the case of CLT panel products, there is no European standard to date. The approval process includes preparation of a European Technical Approval Guideline that contains specific characteristics/requirements of the product as well as test procedures for evaluating the product prior to submission to the European Organization for Technical Approvals (ETA). The ETA allows manufacturers to place CE marking (Conformité Européenne) on their products.

Assemblies

Configuration

Assembly configurations are project-dependent. Below is an example from the Limnologen building in Växjö, Sweden (see Figure 1):

Exterior wall: 3-ply CLT, exterior insulation (4" - 8"), facade (e.g., 3/16" stucco), 1x or 2x gypsum board on furring, optional 4" internal insulation.

Separation walls: 2 x 3-ply CLT, insulation, gypsum on furring on both sides

Partition walls: 3-ply CLT, gypsum on both sides. Wood or metal stud partitions are quite common and economical. Some load bearing reinforcement may be needed.

Floors: 3- to 7-ply CLT, insulation (e.g., mineral wool), suspended ceiling, and underlayment. T-shaped Glulam beams can also be used together with thinner panels (e.g., 3-ply floor Limnologen). Cassette floors are also feasible when long and clear spans are needed.

LIMNOLOGEN

Building Type	Residential: 1+7 stories (last as duplex)
Location/Year	(4 buildings) Växjö, Sweden/2008
Cost	320M SEK ($53M) 255 - 330 $/ft^2
Floor Area	115,000 ft^2 (10,700 m^2)
Volume CLT	4,800 m^3 (169,000 ft^3)
Yield Factor	1.47 ft^3/ft^2
Shell Construction Time	4 days per floor (1,027 SF/day) (not including tent adjustments)
Lessons	Tension rods (48/building) were chosen to resist wind lift-up. Load-transferring connectors between walls were not needed. Floor heating system is cumbersome Construction speed highly dependent on crew's experience.

Figure 1. Limnologen building in Sweden constructed with CLT.

Roof: 3- to 5-ply CLT, covering, insulation. It may include Glulam beams or metal joists.

Utilities

Electrical, HVAC, and water distribution are typically placed in the suspended ceiling space or in cavities above the panels. Sound and fire insulation are important factors when deciding how to run distribution lines.

Connections

Common types of connections in CLT assemblies include:

Wall-to-foundation
Wall-to-wall (straight)
Wall-to-wall (junction)
Floor-to-floor
Wall-to-floor
Wall-to-roof

The basic panel-to-panel connection can be established through half-lapped, single or double splines made with engineered-wood products. Metal brackets (see Figure 2), hold-downs, and plates are used to transfer forces. Innovative types of connection systems can also be used, including mechanical and carpentry connection systems.

Two major mechanical fasteners are used for connecting CLT panels and assemblies:

Dowel-type fasteners:

- Nails
- Screws (traditional and proprietary self-tapping)
- Glulam rivets
- Dowels
- Bolts

Figure 2. Metal bracket fastener system.

Bearing-type fasteners:

- Split rings
- Shear plates

Innovative connection systems such as glued-in rods and other types of proprietary connection systems have shown good potential for use in CLT assemblies. The European Yield Model design philosophy has been adopted for the design of dowel-type fasteners in CLT.

The embedment properties of such fasteners in CLT panels, however, need to be established as they are directly linked to the density of the wood that goes into the panel, type of fastener, CLT panel layup, and other panel-specific features (e.g., glued or unglued edges).

Capacity of non-traditional fasteners in CLT can also be established through testing, where design values can be derived following a well-established procedure in Canada, the United States, and Europe.

Features

Environmental Performance

CLT likely has better characteristics than functionally equivalent concrete and steel systems in several aspects of environmental performance. European marketing literature on CLT often refers to the renewability of wood, recyclability, recoverability, carbon storage, etc. CLT's cited positive environmental attributes have also been identified as key advantages for CLT in North America.

Fire Performance

CLT assemblies can inherently have excellent fire resistance due to the thick cross-sections, which, when exposed to fire, char at a slow and predictable rate.

CLT construction typically has fewer concealed spaces within wall and floor assemblies, which also can reduce the risk of fire spread.

Charring rate experiments conducted in Switzerland found that the adhesive used in the manufacturing of CLT panels can have a significant impact on the charring rate. This was because the protective char layer that forms and insulates the unburned wood from fire, fell off in layers when some polyurethane adhesives were used. When CLT panels with more traditional adhesives were used, the charring rate was found to be the same as that assumed for solid timber and Glulam members.

The issues of edge-glue vs. face-glue, performance of adhesives in high temperatures, strategies for repair and re-use after the fire, connections, effect of active protection systems (e.g., sprinklers), fire design of exposed CLT in ceilings, quantification of fire loads, use of fire-retardant laminations or sheet metal in exterior wall applications have been raised.

Demonstration tests were conducted by the Trees and Timber Research Institute of Italy (IVALSA) on a three-story CLT building. Fire room was protected by gypsum board, and room contents (and later the CLT wall panels) burned for one hour without fire spread to adjacent rooms or floors.

Acoustical Performance

It is possible to exceed code requirements for floors and walls. The acoustical performance of CLT has been rated as:

Sound class B and A in Europe
Exterior walls: Rw = 47 to 52 dB (3-3/8" panel + 6" insulation) (min. 43)
Partition walls: Rw = 65 to 75 dB (min. 50)
Ceilings: up to Lnw = 40 dB (max. 53)
Units conversion: STC~Rw; IIC~ 110-Lnw

Vibrations

The low damping ratio (about 1% critical damping ratio) is one of the weaknesses of CLT floors. Damping, to a large extent, is affected by the degree of integration of the floor to the surrounding structural parts, especially by the addition of partitions. Any measures for increasing the damping ratio through CLT product design and CLT floor construction details will make CLT floor systems more cost-effective and better positioned to compete with concrete slabs. Elevators can be detailed in such a way that their operation does not create perceptible vibrations.

Thermal Performance

European sources often suggest that CLT provides thermal mass for a building, which can be associated with heating and cooling energy reductions. CLT has the same fundamental thermal properties as the wood from which it is made. In terms of heat capacity and thermal resistance, wood is average among building materials. Values for CLT are improved simply through the virtue of its thickness. Good air tightness may be achieved. Foam tape is normally used at the joints for this purpose. Edge-gluing of the boards also helps.

Seismic Performance

Three- and seven-story full-scale CLT buildings were tested by IVALSA in Japan on the largest shaking table in the world. The buildings performed remarkably well even when subjected to severe earthquake motion like that of the devastating Kobe earthquake (magnitude of 7.2 and accelerations of 0.8 to 1.2 g).

In the case of the seven-story building, there was no residual deformation at the end of the test. The maximum inter-story drift was 1.5" (1.3%), while the maximum lateral deformation at the top of the building was only 11-1/4". The CLT buildings showed ductile behavior and good energy dissipation. Such behavior was mainly influenced by the mechanical connections used.

CLT as a Building System

Versatile

CLT's versatility as a building system is a feature that architects and engineers may find appealing. CLT's versatility comes from the fact that panels can be used for all assemblies just by varying the thickness. Furthermore, long spans are possible to achieve:

Spans up to 24.6' with no beams or columns (e.g., 9" 7-ply floor)

Cassette floors allow longer spans (e.g., 2x3-ply CLT slabs with Glulam beams in the middle). Cassette is also suitable for cantilever applications.

The span can go up to 65.6' if "folded" structural CLT systems are used.

Longer spans require Glulam columns or beams and trusses.

Floors can be put directly on columns without carrying beams because of the effective potential of spreading point loads.

Feasibility for High-Rise Construction

There is ongoing work in Europe aimed at targeting high-rise construction:

TRADA worked out a 12-story building example (118')

IVALSA designed a 15-story CLT/steel building

Waugh Thistleton simulated a 25-story CLT/concrete building.

Construction Features

CLT has all the advantages of prefabricated buildings plus some distinctive features given its massive nature and structural makeup.

Rapid Construction Time

Fast construction is probably one of the main attributes of CLT. Outputs from 1,000 to 8,000 ft^2/day can be achieved with small crews and little equipment. Crews of two, four, or eight carpenters plus one or two mobile crane operators are typically employed in Europe. Some advantages include lower capital cost, faster project turnaround, and potential insurance benefits due to fast and safe erection. Being wood-based, follow-on contractors come in quicker and finish faster.

Precise

European marketing literature and research done on existing buildings suggest that CLT features high-dimensional stability:

Perpendicular: 0.04" to 0.08" tolerance for the panels (0.002 in/ft per percent of wood's equilibrium moisture content; 10 to14% equilibrium moisture for 35 to 65% relative humidity),

Parallel: negligible change.

This stability plus the use of CNC routers allow pre-installed windows and/or cladding. Pre-installed piping, electrical, insulation, and HVAC are also possible. These installations can be placed in the cavity between the plasterboard and the CLT panels.

Building Code Issues

Current limitations to wood construction are a major obstacle for CLT in North America. Limitations to story height and floor areas will have to be revisited in light of the properties of CLT as a building system. Therefore, changes to the building codes and the development of proper standards and design values will be crucial to allow market penetration.

Conclusion

Because CLT is made of wood it possesses a number of positive environmental characteristics common to all wood products. These include carbon storage, less manufacturing greenhouse gas emissions than non-wood materials, and an overall lighter environmental footprint than non-wood materials, according to life cycle assessment studies.

CLT buildings can perform quite adequately in terms of sound performance as well as in their resistance to earthquakes and fire. Since it is prefabricated, the system is precise and provides a construction process characterized by: faster completion, increased safety, less demand for skilled workers on site, less disruption to the community, and less waste.

It is a flexible building system, allowing for long spans and it can be used in all assemblies (e.g., floors, walls, or roofs). Also, a high degree of finishing preinstalled off site is possible. Its ability to be used as a panelized and or modular system makes it ideally suited for additions to existing buildings. It can be used jointly with any other material, such as light wood-frame, heavy timbers.

Pablo Crespell and Sylvain Gagnon are scientists with FPInnovations. They can be reached via e-mail at Pablo.crespell@fpinnovations.ca and Sylvain.Gagnon@fpinnovations.ca

This article was developed from an online document, complete with citations, available on the FPInnovations website. Reprinted with permission. The authors also developed a more comprehensive CLT Handbook, which is available as well.

First U.S. non-residential project

The first U.S. non-residential CLT project was recently constructed in Gastonia, N.C. A 75'-tall bell tower for the Meyers Memorial United Methodist Church was constructed entirely of CLT imported from Austria.

Photo credit: Bruce Lindsey, WoodWorks