Guest Column

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Is North America Ready For Wood High-Rises?

By Lisa Podesto, P.E.

There has been a lot of talk lately about buildings that are 8, 10, even 20 stories tall and built entirely of wood – cross laminated timber (CLT) to be precise, which is sometimes referred to as "plywood on steroids." In Europe, CLT has been steadily gaining popularity over the past decade, due in part to a strong push by governments to lower the carbon footprint of buildings, and it's now making inroads in North America. However, while the potential for high-rise wood buildings has been widely reported in the design media, it has also been the focus of debate in online forums frequented by structural engineers – who may love a good story of technological advancement, but approach anything new with a degree of skepticism (rightfully so).

This article has been written for the skeptics. In addition to the reasons one might consider using CLT, it examines its structural applications and some of the design considerations related to its use. It seeks to answer the question – Does cross laminated timber have the potential to change the North American building landscape?

First, what is CLT?

Conceived in Switzerland in the early 1990s and further developed in Austria, CLT is an engineered "mass timber" building system that complements light- and heavy-timber framing options in the arsenal of wood-based building solutions. Its prefabrication and ease of installation have drawn comparisons to concrete tilt-up. However, it can be used as a carbon-friendly alternative to concrete, masonry and steel in a wide range of building applications.

CLT is made from layers of dimensional lumber, each stacked at right angles to the adjacent layers and glued to form solid elements. Boards are kiln dried, prior to lamination, to a moisture content of 12% +/- 2%, which adds to their dimensional stability.

Manufactured to custom sizes, panels have an odd number of layers (three, five, seven or nine). In North America, they're available in configurations up to 12⅜ inches thick, 10 feet wide and 64 feet long. The length is usually limited by transportation restrictions.

By varying the number of layers as well as the lumber species, grade and thickness, CLT panels can be used in any assembly type (e.g., walls, floors, roofs, elevator shafts, stairways). As with plywood, the primary direction of the load-bearing capacity typically corresponds to the grain orientation of the outer layers. For example, panels developed for use in walls are oriented so the grain of the outer layers will be parallel to vertical loads while in panels used for floor and roof systems, the exterior grain is oriented to run parallel to the span direction.

The Stadthaus building (UK) includes eight stories of CLT over one story of concrete. Courtesy of Waugh Thistleton Architects.

Once the layers are pressed, panels are planed or sanded, and CNC routers are used to cut the required openings for windows, doors, MEP systems, etc. The addition of insulation and exterior cladding may also take place in the factory, and the completed panels are shipped to the job site ready to be erected into place.

Because panels are prefabricated and a high degree of finishing can be done off site, CLT buildings are relatively quick to erect, requiring only a small crane to lift the panels into place and lightweight power tools for on-site assembly. Construction is safer because there are few hazards on the jobsite, and there is considerably less noise and waste than with buildings made of other materials.

The Rise of CLT

CLT began gaining popularity as a structural building system in the early 2000s – most notably in Austria, Germany, Norway, Sweden, Switzerland, and the United Kingdom. The tallest CLT structure to date is the Stadthaus building in London's east end, which includes eight stories of CLT over one story of concrete. It is also gaining popularity for educational buildings such as the 102,000-square-foot Norwich Open Academy, also in the UK.

A 78-foot bell tower at Myers Memorial United Methodist Church in Gastonia, NC was the first non-residential CLT structure in North America and a two-story commercial building has since been built in Whitefish, Montana. In Canada, the University of British Columbia is building a 20,300-square-foot Bioenergy Research + Demonstration Project with CLT walls and roof construction, and several other buildings are in development. So far,

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there are three CLT manufacturers in North America, a company making nail-laminated CLT, and several CLT distributors, but the supplier landscape is changing quickly and several other companies are developing plans to enter the market.

Structural Properties

CLT systems offer a number of attractive structural characteristics, including:

- High dimensional stability and static strength in all directions
- High axial load capacity for walls due to large bearing area of the solid panels
- High shear strength to resist lateral loads coupled with good ductility
- Wall systems that are rigid around openings, requiring fewer hold-downs
- Failure modes that are ductile and occur at connections
- Negligible settlement effects (e.g., 0.78 inches for one building with seven stories of CLT over one story of concrete after one year)
- Low probability of in-plane buckling
- Great span-to-depth ratio for floor panels, which allows shallow floors
- Lack of susceptibility to soft-story failures

CLT also offers effective and even superior performance with regard to life safety and other priorities reflected in building codes.

Fire Resistance

Although it may seem counter-intuitive, CLT buildings can be designed to perform extremely well when exposed to fire. Because the panels are thick and solid, they char at a slow and predictable rate. Once formed, this char protects the wood from further degradation, helping to maintain the building's structural integrity and reducing its fuel contribution to the fire, which in turn lessens the fire's heat and flame propagation. When used in Type IV construction, CLT assemblies also tend to have fewer concealed spaces, which reduces a fire's ability to spread undetected.

A full-scale model of a seven-story building tested on the world's largest shake table. Courtesy of Italian National Institute of Timber Trees (IVALSA).

To generate additional information for North American building designers, FPInnovations and the Canadian Wood Council have undertaken a study on the fire design of CLT systems. Researchers are considering the impact of edge-glued versus face-glued systems, performance of various adhesives, use of fire retardant treated members and other factors. Equations have also been developed to help designers determine the required thickness of a CLT system in order to accommodate structural requirements in addition to the fire rating.

Seismic Performance

To evaluate the seismic performance of CLT buildings, full-scale models of three- and seven-story structures were tested by the Trees and Timber Research Institute of Italy (IVALSA) on the world's largest shake table in Miki, Japan. The buildings performed extremely well even when subjected to motions comparable to the devastating 1995 Kobe earthquake, which had a magnitude of 7.2 and accelerations of 0.8 to 1.2 g.

At the end of the test, for example, the seven-story building had no residual deformation. The maximum inter-story drift was 1.57 inches and the maximum lateral deformation at the top of the building was 11.3 inches. Both buildings showed good ductile behavior and energy dissipation, which can be attributed primarily to their mechanical connections.

As with other building types, CLT structures can be designed to withstand earthquakes by adhering to capacity design principles, which are based on how the structure will sustain large deformations when subjected to severe seismic motion. For wood structures in general, this means designing so that failure is intended to occur in the connections. For a CLT structure, it is recommended that non-linear deformations and energy dissipation occur in the brackets that connect wall and floor panels and, if used, hold-down connections and vertical step joints.

In addition to performing well during a seismic event, structural repairs after an earthquake would be relatively easy and cost effective for a CLT building as failure is localized at the connections. New connections could be added inches from where the failure occurred using simple hand-held power tools.

The 78-foot bell tower at Myers Memorial United Methodist Church in Gastonia, N.C. Courtesy of Kevin Meechan, WoodWorks.

Acoustic Performance

Like other wood products, CLT offers acoustical advantages when used for floor and wall systems. When used in conjunction with insulation and gypsum board or resilient channels, it is possible for a CLT building to exceed code requirements related to the acoustical performance of floors and walls.

Thermal Efficiency

Although properties vary based on thickness of the panels, wood's natural thermal resistance adds value to CLT assemblies. Insulation and cladding options are similar to a variety of concrete systems; however, the CLT itself has an R-value of about R-1.2/inch or R-4.2 for a panel that is 3½ inches thick, so less insulation is required to meet the desired level of thermal efficiency.

Precise manufacturing and dimensional stability result in tight tolerances with better energy efficiency (thanks to an airtight structure) and improved installation of doors, windows, utilities and cladding. Boards within the CLT panel's laminations can be edge-glued to further improve thermal efficiency by further reducing air flow.

It has been observed that the potential for creep shortening due to compression under load is negligible for the walls and 0.02 inches for the floors. Likewise, the potential for moisture expansion is negligible for the walls and 0.07 inches for the floors, resulting in maximum settlement of less than 1 inch for eight stories of CLT.

The 102,000-square-foot Norwich Open Academy utilized 123,000 cubic feet of CLT. Courtesy of KLH Massivholz GmbH.

Connections

One of the advantages of CLT structures is that they are built with strong yet simple connection systems. However, the building's structural performance and therefore success is dependent to a large degree on the efficient design and fabrication of those connections.

Panel-to-panel connections can be created with half-lapped, single or double splines made with engineered wood products. Metal "L" brackets, hold-downs and plates are used to transfer forces from walls to floors and foundations, and proprietary systems and innovative carpentry can also be used. In terms of fasteners, long self-tapping screws are most commonly recommended by CLT manufacturers; however, traditional dowel-type fasteners such as wood screws, nails, lag screws, rivets, bolts and dowels can also effectively connect the panel elements. Bearing-type fasters such as split rings and shear plates have also shown potential (though their use is likely to be limited to applications involving high loads), as have several innovative systems including epoxied-in rods and proprietary products.

When detailing connection systems for a CLT structure, engineers must consider strength and stiffness as well as other performance requirements such as fire protection, sound transmission, air tightness, durability and vibration. Shrinkage and swelling due to seasonal fluctuations in environmental conditions and the differential movement between CLT and other materials (if applicable) must likewise be taken into account.

North American Standards

Since CLT assembly configurations are customized by project, so too are the mechanical properties of the completed panels and assemblies. In Europe, mechanical properties are provided by each manufacturer and there is no European standard to date. Instead, European manufacturers are operating on a proprietary basis using European Technical Approval (ETA) reports.

In North America, an American National Standard, PRG320: *Standard for Performance Rated Cross –Laminated Timber*, which covers manufacturing, qualification, and quality assurance requirements has been approved and is available on the APA – The Engineered Wood Product Association's website (**www.apawood.org**). The American Wood Council (**www.awc.org**) and FPInnovations (**www.fpinnovations.ca**) have also established a committee to begin developing a design standard for CLT.

Cost Competitiveness

To convince developers of the Stadthaus that CLT would save money, Waugh presented concepts for two almost identical structures, one designed in wood and the other in concrete. Not only was the CLT building estimated to cost 15% less per square foot, it was projected to weigh four times less – which lowered transportation costs, allowed a 70% smaller foundation and eliminated the need for a tower crane during construction.

In a recent study by FPInnovations, researchers examined 17 building types to determine which North American market segments offer the greatest opportunity from a cost perspective. While reduced construction time (typically 25-30%) was not taken into account, the cost of a CLT structure was found to be most competitive in the following categories:

- Mid-rise residential – 15% less
- Mid-rise non-residential – 15 to 50% less
- Low-rise educational – 15 to 50% less
- Low-rise commercial – 25% less
- One-story industrial – 10% less

Environmental Benefits

A large part of the attraction to CLT is wood's low carbon footprint. In addition to being the only major building material that's renewable and sustainable, wood grows naturally, using solar energy, and doesn't require large amounts of fossil fuels to manufacture. As trees grow, they absorb carbon dioxide (CO_2) from the atmosphere and release oxygen (O_2), and wood products continue to store carbon (C) over their lifetimes – longer if the wood is reclaimed and repurposed at the end of the product's original service life.

Although projected cost savings convinced developers of the Stadthaus to use CLT, local building authorities were impressed by the carbon savings. Waugh estimates that the CLT design saved the equivalent of about 300 metric tons of carbon compared to the concrete design – which is the amount the building is projected to emit over 21 years of operation.

CLT also makes use of small diameter timber harvested from sustainably managed forests, contributing to efficient use of the resource. The manufacturing process is energy efficient. And prefabricated panels all but eliminate jobsite waste.

CLT in North America

The idea that advancements in wood technology, systems and products are expanding the possibilities for wood construction is nothing new. The first industrial plywood was produced in the U.S. in the early 1900s, giving the construction industry a high-strength sheet material that could be used in many applications. The principle of bonding together cut or refashioned pieces of wood to form composite materials has since been used to create a variety other structural products – including oriented strand board, laminated veneer lumber, glued laminated timber, I-Joists, and now CLT. Each has created new, innovative opportunities to use wood.

Building on the Stadthaus experience, the Timber Research and Development Association (TRADA) published a design example for a 12-story CLT building, while IVALSA has designed a 15-story CLT and steel building, and Waugh Thistleton Architects has simulated a 25-story CLT and concrete hybrid. Closer to home, the author of a pending study says it will confirm the feasibility of a 20-story wood building in British Columbia.

The difference is one of degree. The structural performance of CLT makes it feasible in applications where wood has never before been an option – at a time when governments and the design community are seeking innovative ways to lower the carbon footprint of buildings. How high we'll end up going is anyone's guess, but we can safely say that CLT has the potential to significantly change the North American building landscape. APA is producing Product Reports which serve as an aid to building officials and design professionals to determine conformance with codes and standards similar to an ES Report.▪

Reference

Cross Laminated Timber: A Primer, edited by Pablo Crespell and Sylvain Gagnon, FPInnovations, 2010; CLT Handbook, FPInnovations, 2010; **www.forintek.ca**