

Mass Timber in North America

Expanding the possibilities of wood building design

Sponsored by reThink Wood



Albina Yard

Location: Portland, Oregon
Architect: LEVER Architecture
Structural Engineer: KPFF Consulting Engineers
Developer: reworks

Photo courtesy of LEVER Architecture

It's been a while since a major category of building materials inspired the kind of widespread enthusiasm currently being shown for mass timber. Around the world, designers are leveraging the strength, stability, and design flexibility of products such as cross-laminated timber (CLT) to push beyond wood's perceived boundaries, achieving building heights and spans that would have once required concrete, steel, or masonry for structural support.

For many, it's the combination of aesthetics, structural performance, and opportunity for innovation that have proven irresistible. But mass timber also offers a host of other advantages:

Lighter carbon footprint: Mass timber products allow the use of a renewable and sustainable resource as an alternative to more fossil fuel-intensive materials. Designers of 'tall wood' buildings have been especially focused on the reduced carbon footprint achieved by using wood, which aligns with the goals of Architecture 2030. Reducing carbon is also a priority for many public buildings and schools.

Construction efficiency: Mass timber construction is fast, and speed correlates to revenue, whether the project is an office, school, student residence, condominium, or hotel. Bernhard Gafner of structural engineering firm Fast + Epp, says that, in his firm's experience, a mass timber project is approximately 25 percent faster to construct than a similar project in concrete. Noting the advantages for urban infill sites in particular, he says it also offers 90 percent less construction traffic (trucks delivering materials) and requires 75 percent fewer workers on the active deck, making for a much quieter job site.

The fact that mass timber weighs less than other materials also has a number of potential benefits, including smaller foundation requirements and lower forces for seismic resistance. Discussing the new Design Building at the University of Massachusetts, for example, structural engineer Robert Malczyk of Equilibrium Consulting, says, "The seismic force is proportionate to the weight of the building.

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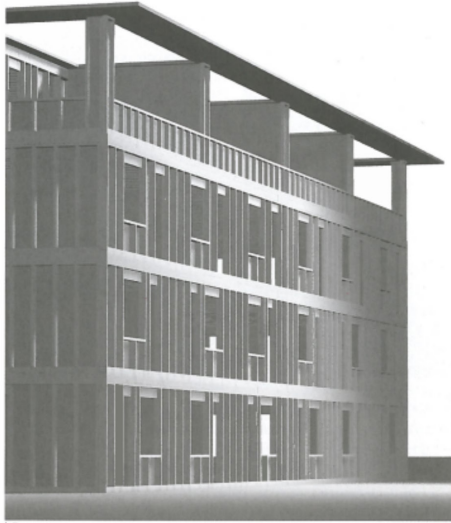
1. Examine the trend toward mass timber buildings in the context of carbon footprint, construction efficiency, fire and life safety, occupant well-being, and other potential advantages.
2. Identify a range of mass timber products available to North American building designers.
3. Discuss research and resources related to the structural performance and fire/life safety of mass timber products.
4. Based on examples of mass timber buildings either built or under construction, describe how all-wood and hybrid systems are expanding the options for wood design.

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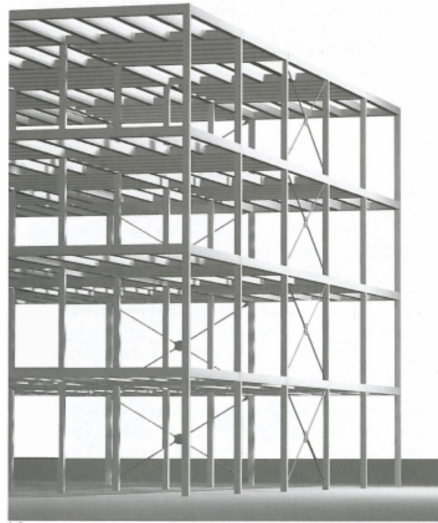
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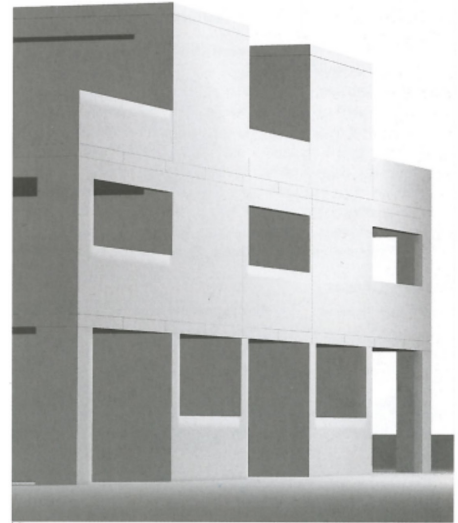
LIGHT WOOD-FRAME



POST + BEAM



MASS TIMBER



Mass timber systems are a complement to light wood-frame and post-and-beam construction.

If this building were designed in concrete, which was considered, the weight would be six times more than the mass timber design.”

Fire and life safety: Structurally, mass timber offers the kind of proven performance—including fire protection and seismic resistance—that allows its use in larger buildings. It also expands the options for exposed wood structure in smaller projects.

Occupant well-being: An increasing number of studies focused on wood’s biophilic aspects have linked the use of exposed wood in buildings with improved occupant health and well-being.^{1,2}

This course is intended for architects and engineers seeking current information on mass timber, including products, research related to structural performance and life safety, and available resources. It answers common questions regarding strength, fire protection, and durability, and highlights examples of mass timber buildings in different occupancy groups to illustrate both design trends and the extent to which mass timber has captured the imagination of North American building designers.

WHAT IS MASS TIMBER?

Mass timber is a category of framing styles typically characterized by the use of large solid wood panels for wall, floor, and roof construction. It also includes innovative forms of sculptural buildings, and non-building structures formed from solid

wood panel or framing systems of six feet or more in width or depth. Products in the mass timber family include:

Cross-Laminated Timber (CLT)

CLT consists of layers of dimension lumber (typically three, five, or seven) oriented at right angles to one another and then glued to form structural panels with exceptional strength, dimensional stability, and rigidity.

Panels are particularly cost effective for multistory and large building applications. Some designers view CLT as both a stand-alone system and product that can be used together with other wood products; it can also be used in hybrid and composite applications. CLT is well-suited to floors, walls, and roofs, and may be left exposed on the interior for aesthetics. Because of the cross-lamination, CLT also offers two-way span capabilities.

CLT can be manufactured in custom dimensions, with panel sizes varying by manufacturer. There are several CLT suppliers in North America, with more anticipated. The species of wood used depends on the manufacturing plant location.

The 2015 International Building Code (IBC) and 2015 International Residential Code recognize CLT products manufactured according to the ANSI/APA PRG-320: Standard for Performance Rated Cross-Laminated Timber. Under the 2015 IBC, CLT at the required size is specifically stated for prescribed use in Type IV buildings. However, CLT can be used in all types of combustible construction—i.e.,

wherever combustible framing or heavy timber materials are allowed. The National Design Specification® (NDS®) for Wood Construction is referenced throughout the IBC as the standard for structural wood design, including CLT. The 2012 IBC does not explicitly recognize CLT, but the 2015 IBC provisions for CLT can be a basis for its use under alternative method provisions.

For more information on CLT, the *U.S. CLT Handbook* is available as a free download at www.rethinkwood.com.

Nail-Laminated Timber (NLT or Nail-lam)

NLT is created from individual dimension lumber members (2-by-4, 2-by-6, 2-by-8, etc.), stacked on edge, and fastened with nails or screws to create a larger structural element.

NLT is far from new—it’s been used for more than a century—but is undergoing a resurgence as part of the modern mass timber movement. Commonly used in floors, decks, and roofs, it offers the potential for a variety of textured appearances in exposed applications, and wood structural panels can be added to provide a structural diaphragm. NLT has also been used to create elevator and stair shafts in midrise wood-frame buildings.

NLT naturally lends itself to the creation of unique roof forms. Because panels are comprised of individual boards spanning in a single direction, both singly curved and freeform panels can be created by slightly offsetting and rotating each board relative to

Photo courtesy of LEVER Architecture

the others. This allows the complex geometry of curved roof and canopy structures to be realised with a simple system.

Advantages of NLT include the ability to use locally available wood species and the fact that specialized equipment generally isn't necessary. An NLT system can be created via good on-site carpentry, though some suppliers do offer prefabrication, and this can have benefits depending on the scale and complexity of the project. Prefabricated NLT panels typically come in sizes up to 10 feet wide and 60 feet long, with wood sheathing preinstalled. When detailing NLT systems, designers need to account for moisture movement.

The IBC recognises NLT and provides guidance for structural and fire design. No product-specific ANSI standard is required, as the structural design of each element is covered by the NDS and applicable grading rules. NLT can be used in all types of combustible construction.

Glued-Laminated Timber (glulam)

Glulam is composed of individual wood laminations (dimension lumber), selected and positioned based on their performance characteristics, and then bonded together with durable, moisture-resistant adhesives. The grain of all laminations runs parallel with the length of the member.

Glulam has excellent strength and stiffness properties, and is available in a range of appearance grades for structural or architectural applications. While typically used as beams and columns, designers can use glulam in the plank orientation for floor or roof decking. With careful specification and design that considers the flatwise structural properties (see APA reference below), deep glulam sections can be placed flatwise as decking similar to NLT. With the flexibility of glulam manufacturing, glulam 'panels' can be used to create complex curvature and unique geometry. When used in such innovative floor and roof panel configurations, glulam is seen as an extension of the mass timber product family and sometimes referred to as GLT.

The IBC recognizes glulam products manufactured in conformance with ANSI Standard A190.1-2012: Standard for Wood Products—Structural Glued Laminated Timber. For more information, consult the *Glulam Product Guide* available at www.apawood.org/glulam.

Dowel-Laminated Timber (DLT)

Dowel-laminated timber panels are a next-generation mass timber product commonly used in Europe. Panels are made from softwood lumber boards (2-by-4, 2-by-6,



ALBINA YARD & FRAMEWORK

Location: Portland, Oregon
Architect: LEVER Architecture
Structural Engineer: KPFF Consulting Engineers
Design Assist + Build (Framework): StructureCraft
Developer (Albina Yard): reworks

The four-story, 16,000-square-foot Albina Yard is noteworthy for being the first commercial building in the United States to use domestically fabricated CLT as a structural element. A Type III project designed under the 2014 Oregon Structural Specialty Code, it is also interesting as a precursor to another LEVER-designed office project—Framework, the 12-story winner of the U.S. Tall Wood Building Prize Competition.

"We were very interested in exploring a mass timber/CLT project on a smaller scale prior to building the larger high-rise project, so it was a very fortunate coincidence," says Design Principal Thomas Robinson. Asked about lessons learned, he emphasized the need for early collaboration between architectural, structural, mechanical, and installation. "Each discipline had a role to play; input and problem solving needed to happen together. As the building was essentially prefabricated off-site, the coordination and problem solving that often occurs in the field needed to be accounted for beforehand. After we were off the ground-floor slab, Albina Yard was built to a 1/8-inch tolerance, and it went together perfectly."

Currently in design, Framework will consist of ground-floor retail, five levels of office space, five levels of housing, and a rooftop community space. It is expected to include CLT floor panels as well as a new system of post-tensioned rocking wall panels.

Developed for use in high seismic regions, rocking mass timber shear walls were tested by the Network for Earthquake Engineering (NEES) as part of its CLT Planning Project. Seismic activity was simulated by cyclic loading that pushed and pulled the top of a 16-by-4-foot CLT panel with an embedded vertical pretensioned rod into a rocking motion. The wall was able to reach 18 inches of displacement, while maintaining its ability to self-center back to a vertical position.

Framework, which is scheduled for completion in 2018, is expected to be the first application of a rocking mass timber shear wall system in the United States.

Photo courtesy of StructureCraft



Pictured is a dowel-laminated timber panel with an acoustic profile integrated into the exposed surface.

2-by-8, etc.) stacked like the boards of NLT and friction-fit together with dowels. Typically made from hardwood lumber, the dowels hold each board side-by-side, similar to how nails work in an NLT panel, and the friction fit lends some dimensional stability to the panel.

There isn't a prescriptive code path for the use of DLT under the current IBC, and the NDS doesn't provide published design values or equations for calculating capacities of wood dowel joints. To calculate capacities, the Timber Framers Guild provides some information. However, because nothing is referenced in the code, the use of DLT would require approval by the Authority Having Jurisdiction on a case-by-case basis.

Among the advantages of DLT, acoustic strips can be integrated directly into the bottom surface of a panel. This can help a designer achieve acoustic objectives, while keeping the wood exposed and allowing for a wide variety of surface finishes.

With growing interest in DLT, continued product innovation is likely, along with increased availability to U.S. building designers.

Structural Composite Lumber (SCL)

SCL is a family of wood products created by layering dried and graded wood veneers, strands, or flakes with moisture-resistant adhesive into blocks of material, which are subsequently re-sawn into specified sizes. Two SCL products—laminated veneer lumber (LVL) and laminated strand lumber (LSL)—are relevant to the mass timber category, as they can be manufactured as panels in sizes up to 8 feet wide, with varying thicknesses and lengths, depending on the product and manufacturer. Parallel strand lumber (PSL) columns are also commonly used in conjunction with other mass timber products.

The manufacture of SCL is standardized. However, while SCL is included in the NDS, design values are provided by the manufacturers. International Code Council Evaluation Service (ICC-ES) evaluation reports and APA product reports are available to assist with structural design capacities and specifications.

Wood-Concrete Composites

Mass timber systems vary widely, and hybrids are an option for wood high-rises, very long spans, or other project-specific requirements. No material is perfect for every job, and it's important for designers to choose a combination of materials that effectively meets the performance objectives.

At a product level, most of the panels described above can be made into a wood-concrete composite by applying a concrete topping in such a way that the two materials act as one.

One example is the University of Massachusetts Design Building described later in this course (see Schools), which includes CLT/concrete composite floors. According to architect Tom Chung of Leers Weinzapfel Associates, the team relied on the CLT panels for the building load requirements. However, the composite action between the CLT and concrete provided extreme stiffness and minimal deflection which, along with an insulation layer between the materials, provided good acoustic separation between floors.

WHEN IS MASS TIMBER APPROPRIATE?

Because of its strength and dimensional stability, mass timber offers a low-carbon alternative to steel, concrete, and masonry for many applications. A complement to other wood framing systems, it can be used on its own, in conjunction with other wood systems such as post-and-beam, or in hybrid structures with steel or concrete. Mass timber is not necessarily a good substitute for light wood-frame construction, only because dimension lumber framing offers such a compelling combination of performance and cost where permitted by code. For this reason, building types where designers typically default to forms of construction other than light wood-frame—including offices, public/institutional buildings, schools, and taller mixed-use occupancies—may offer greater appeal for mass timber than low-rise commercial or residential buildings, though examples of the latter do exist.

"We're seeing a lot of interest in mass timber for midrise buildings such as hotels

and high-end offices that would have typically used concrete or steel," said Lucas Epp of StructureCraft, a specialty timber engineering and construction company known for innovative wood structures. "In addition to the warmth of exposed wood, people are discovering that it's a viable option for creating high-performing and cost-competitive structures."

Thomas Robinson, whose firm is designing three mass timber projects in addition to Albina Yard and Framework, sees particular potential in multifamily housing and other building types that lend themselves to modular prefabrication. "The time spent upfront designing and perfecting a building system can be leveraged in projects where you have repeatable elements," he says.

Office/Mixed-Use

For office environments, the aesthetic of mass timber can be a particular draw, resulting in higher rents and longer-term tenants.

The Radiator in Portland, Oregon—a five-story, Type IIIA project completed in 2015—is part of a surge of mass timber offices in the Pacific Northwest. Designed by PATH Architecture for the Kaiser Group, gravity loads for the 36,000-square-foot structure are handled through a system of glulam beams and columns, while a mass timber deck with wood structural panels creates the structural floor diaphragm, and dimension lumber walls sheathed with wood structural panels provide shear capacity. Beams, columns, and the underside of the floor decking are all left exposed, contributing to the interior's contemporary industrial character.

Further expanding the possibilities, the seven-story, 220,000-square-foot T3 building in Minneapolis, Minnesota, includes a mix of glulam columns and beams, NLT floors, and a concrete core. Architect Michael Green, a long-time advocate of using wood to reduce the carbon footprint of buildings, calls the Type IV project "a game changer for the commercial building industry and a milestone for mass timber construction in the United States." In addition to its carbon benefits, Green cites the ability of modern wood products to bring warmth and beauty to the interior, while promoting a healthy indoor environment.

Demonstrating some of the efficiencies associated with mass timber, the wood structure of T3 took an average of nine days to erect per 30,000-square-foot floor. More than 100 truckloads of glulam and NLT panels arrived as they were needed at the project site, with steel connections preinstalled, allowing the structural components to be assembled quickly. The

Photo courtesy of StructureCraft



Designed by MGA, the seven-story T3 building in Minneapolis, Minnesota, includes glulam columns and beams, and NLT floors.

project team estimates that it is 30 percent lighter than a comparable steel design and 60 percent lighter than post-tension concrete.

Public and Institutional

Reasons to use mass timber in public and institutional buildings are similar to those for offices and schools, including carbon footprint, and wood's biophilic effects. The aesthetic possibilities are also exciting to many designers.

In the United States, examples include Chicago Horizon, a Type IV public pavilion designed by Ultramoderne for the Chicago Architecture Biennial. Elegantly crafted, this award-winning structure includes a CLT roof supported on 13 glulam columns distributed in a radial pattern to address lateral loads and uplift. The pavilion represents the first use of exposed CLT in the city of Chicago, providing local precedent for the approval and use of mass timber for government and public assembly applications. In addition, the two-way slab roof is the first

of its kind, suggesting new opportunities for open-layout buildings made from CLT. The planned long-term use of the building as a commercial vendor and public assembly space is a significant and sustainable departure from the typical design exhibition model of temporary installations.

With a growing body of research supporting the positive impacts of wood on occupant well-being, there is also a trend toward the use of mass timber in healing environments.

Schools

Mass timber has a number of characteristics that make it attractive for schools and universities—from the ability to construct an entire project over the summer while students are off campus, to the potential efficiencies of replicable modular designs, a lighter carbon footprint, and the positive impacts of exposed wood on student well-being.

MASS TIMBER: AN EFFICIENT SOLUTION

In addition to the structural, aesthetic, and environmental advantages, mass timber can be an efficient and practical solution to design challenges.

With prefabricated panels, mass timber construction is fast—approximately 25 percent faster than concrete, according to Bernhard Gafner of Fast + Epp, based on his firm's experience. Gafner says it also results in 90 percent less construction traffic and 75 percent fewer workers on the active deck, making it well-suited to urban infill sites.

Because mass timber is lighter than steel and concrete, it can be a good solution for sites where poor soil is an issue.

There is also a trend toward the integration of services into prefabricated elements, such as panels and trusses. The fact that the labor is done off-site means greater quality control and a less hectic job site.

Image courtesy of Michael Green Architecture

**T3**

Location: Minneapolis, Minnesota
Design Architect: Michael Green Architecture
Architect of Record: DLR Group
Structural Consultant: MKA
Design Assist + Build: StructureCraft

For a 14,000-square-foot addition to Common Ground High School in New Haven, Connecticut, for example, Gray Organschi Architecture and engineering partner Bensonwood chose a combination of CLT and glulam. CLT panels provide the tension surface (and final ceiling finish) in a system of prefabricated stressed skin assemblies that span the upper classrooms and circulation spaces. Vertical CLT panels form bearing and shear walls throughout the building, while glulam rafters and heavy timber trusses span a large ground-floor multipurpose space. A treated glulam bridge deck on laminated timber piers provides access from the upper campus.

Discussing some of the advantages of mass timber, Design Principal Alan Organschi says, “CLT and glulam can serve as both primary structure and finished interior surface at the same time. This creates efficiencies in deploying trades and sequencing construction, which has very real monetary implications. As the construction industry, accustomed to building institutional buildings like schools using conventional wall, roof, and floor assemblies, gains more experience with these versatile new timber products, greater production economies will accrue and more of timber’s potential benefits—light weight, high strength, workability, etc.—will be captured.”

Organschi also stressed construction speed. Assisted only by a mobile crane, a five-person assembly crew installed the entire primary structure and enclosure in just four weeks.

Regarding the impact of wood on students and teachers, he adds, “It’s well-known that, as a hygroscopic material (cellular plant structure), wood surfaces serve as moisture buffers, moderating swings in interior humidity and thereby improving air quality. It’s worth mentioning that during the first few weeks the new building was being used, a teacher commented to me that people were remarking on the freshness of the air in the classrooms. Anecdotal, I know, but it squares with the scientific predictions of health benefits of using wood (especially unfinished wood) in building interiors.”

Common Ground High School is Type VB Construction, fully sprinklered, and was designed under the 2005 Connecticut State Building Code.

Another example, the Design Building at the University of Massachusetts – Amherst (UMass), features an exposed glulam post-and-beam structure, CLT decking and shear walls, CLT/concrete floors (rigidly connected by glued-in steel fasteners), and a ‘zipper truss’ roof spanning a two-story-high common space.

One challenging aspect of this project was that it started as a steel design. Keen to make the building a showcase for sustainability, the university made the decision to use wood part way through the design process.

Noting that he may have made different choices had he started with wood, architect

Tom Chung of Leers Weinzapfel Associates said, “Generally, mass timber doesn’t have to radically change the design concepts we already use; we can accomplish what we are already familiar with in steel and concrete. Steel post-and-beam can be done as glulam post-and-beam. Concrete/masonry shafts can be done in CLT. Steel/concrete floors can be CLT/concrete floors. A steel deck roof can be a CLT roof. Steel braces can be glulam braces. For the UMass project, we went step by step, asked ourselves what the precedents were and how we could go about maximizing the use of timber.

“If the project started out in wood and the primary objective was to design the most efficient mass timber building, then the shape and massing may have been more along the lines of a conventional ‘box,’ which is the shape of most of the mass timber structures built so far. But since there were other important design objectives, the UMass building has unique angles and cantilevers that required steel in addition to wood. Our goal was to use the most appropriate materials to meet the structural objectives at hand.”

Chung also said that educating code officials is an important part of the process. The UMass project team was in constant communication with a Massachusetts state building inspector and, because the building represented a new type of construction, also

Photo courtesy of David Sundberg

went before the Massachusetts state board of appeals for official approval. The project was approved after the team was able to demonstrate its performance capabilities as well as the long history of mass timber structures in Europe and Canada.

Scheduled for completion in 2017, the UMass project is a combination of Type IV and IIB Construction.

Multifamily and Hospitality

In the United States, a recent example of a multi-story mass timber building is a four-story CLT hotel, Candlewood Suites at Redstone Arsenal, an Army base near Huntsville, Alabama. Developed and designed by Lendlease, the hotel is part of the Privatization of Army Lodging (PAL) program, created to provide quality private-sector lodging for soldiers and their guests. Compared to typical PAL hotel of 54,891 square feet, Lendlease says the new 62,688-square-foot CLT hotel was erected in 37 percent less time, with a 44 percent reduction in structural person hours. In terms of structural performance, the hotel's location on a military base meant it also had to meet Anti-Terrorism and Force Protection standards.

Another project at the preconstruction stage is a 70,000-square-foot hotel/condominium complex in Austin, Texas. Known as a leader in sustainable design, architecture firm Lake|Flato was interested in whether mass timber could meet both structural and environmental objectives for a multistory building. The project includes five buildings, three of which use mass timber construction, with a combination of NLT, glulam, and prefabricated wood-frame walls.

Tall Wood

While most of this course focuses on structures that can be built under current U.S. building codes, a discussion of mass timber is incomplete without reference to wood high-rises. Many examples exist worldwide, illustrating the potential of mass timber to bring environmental and other advantages to higher-density projects. A recent reThink Wood infographic (www.rethinkwood.com) highlights 17 tall wood buildings built in the past five years, including:

- Treet – Norway – 14 stories, 2014
- Trafalgar Place – United Kingdom – 10 stories, 2015
- Forté – Australia – 10 stories, 2012
- Banyan Wharf – United Kingdom – 10 stories, 2015

Closer to home, architect Michael Green foreshadowed his work on the T3 project with the 96-foot-tall Wood Innovation and Design Centre in British Columbia, Canada.



Common Ground High School

Location: New Haven, Connecticut
Architect: Gray Organschi Architecture
Timber Engineer: Bensonwood

Completed in 2014, it is made from an innovative combination of glulam post-and-beam construction and built-up CLT floor panels. It includes six stories, plus a penthouse and mezzanine.

An 18-story student residence—one of the tallest mass timber buildings in the world—is also under construction at the University of British Columbia (UBC). The structure, Brock Commons, is a hybrid system comprised of CLT floor slabs, glulam columns, steel connectors, and concrete cores. Scheduled for completion in 2017, it has been designed to achieve LEED Gold certification.

UBC is a strong proponent of utilizing wood for its carbon benefits, and Brock Commons is just the latest of several mass timber buildings on its campuses.

In the United States, a number of tall wood buildings are in design, including the winners of the U.S. Tall Wood Building Prize Competition. Established by the U.S. Department of Agriculture (USDA), Softwood Lumber Board (SLB), and Binational Softwood Lumber Council (BSLC), the competition was the first step in a process to showcase the safe application, practicality, and sustainability of tall wood structures (minimum 80 feet in height) using mass timber, composite wood technologies, and innovative building techniques. It was created to provide scientific and technical support for the design and construction of tall wood buildings, and the winners received a combined \$3 million in funding to further develop their projects.

Photo courtesy of naturally:wood

Brock Commons**Location:** University of British Columbia, Vancouver, Canada**Architect:** Acton Ostry Architects**Structural Engineer:** Fast + Epp

In the Pacific Northwest, the developer/architect team responsible for The Radiator has also designed an eight-story (85-foot-high) residential building known as Carbon 12. The building includes a heavy timber gravity frame, CLT floors, and CLT core walls. The building is expected to break ground in late 2016.

Given that wood buildings over six stories are not currently within the prescriptive height limits of the IBC, designers of taller projects must follow an alternative means process in consultation with the Authority Having Jurisdiction over appeal of the building project. However, the ICC Board of Directors recently approved the formation of a Tall Wood Ad Hoc Committee. Comprised of stakeholders, code officials, and other interested parties, the committee will study tall wood construction, and their findings may contribute to code changes for the 2021 IBC.

STRUCTURAL PERFORMANCE AND LIFE SAFETY

There are a number of factors propelling the increased use of mass timber by North American building designers, most notably the precedent of mass timber structures elsewhere in the world, and the abundance of research demonstrating its safety and structural performance.

Because glulam and SCL have a long history in the market, a great deal of research and design data is available for these products. As such, this section focuses on recent research related to CLT and the viability of tall wood buildings.

In 2012, for example, the American Wood Council sponsored an ASTM E119 fire endurance test on CLT. A 5-ply CLT specimen ($6\frac{7}{8}$ inches thick) was covered on each side with a single layer of $\frac{5}{8}$ -inch Type X gypsum wallboard loaded to the maximum load attainable by the test equipment. It was then exposed to

a standard fire that reached over 1,800 degrees Fahrenheit in the first 90 minutes of exposure. While only seeking a 2-hour rating as required by building code provisions, the test specimen lasted 3 hours 6 minutes. This test, along with a series of CLT wall and floor tests conducted by FPInnovations, was used to substantiate the performance of CLT, leading to its recognition in the 2015 IBC.

Until a few years ago, CLT research centered largely on European-made products and design requirements of the European market, which is where most of the projects were being built. However, there has been a proliferation of recent studies and data specific to North America. Research is being supported by a variety of organizations, including the SLB, BSLC, USDA Wood Innovation Grant program, Natural Resources Canada, FPInnovations, and the Canadian NEWBuildS Network, as well as designers such as Arup.

The following sections on fire performance and structural/seismic performance are excerpted from the paper “CLT Research: Available and Accessible to North American Building Designers”³³ published in *Wood Design Focus* magazine. For a complete list of research references, download the paper at: www.woodworks.org/wp-content/uploads/CLT-Research_Podesto_Breneman.pdf.

Fire Testing

Fire performance, and specifically exposed fire resistance, may be one of the most asked about areas in terms of additional research information—but, in reality, suffers more from misperception than lack of research data.

The predictability of wood’s char rate has been well-established for decades and has also been recognized for years in U.S. building codes and standards. However, the use of existing code provisions has not been commonplace in modern commercial construction; therefore, jurisdictional comfortability with an expanded use of those provisions for the purpose of CLT design has presented a challenge.

The 2015 NDS includes a char calculation procedure to provide calculated fire resistance of up to two hours. It expands

RESEARCH LIBRARY WWW.RETHINKWOOD.COM

For current mass timber research in the United States and worldwide, including CLT and tall wood buildings, the reThink Wood website includes a library of studies, categorized by topic area and updated regularly.

on the design examples in the fire chapter of the *U.S. CLT Handbook* by allowing for laminations of varying thicknesses. Further study and additional full-scale panel tests continue to be done, not necessarily to prove legitimacy of the CLT char methodology, but to support expansion of its applicability. Areas of expansion include new assembly configurations (in pursuit at the Advanced Composite Lab and the University of Maine), exploring performance under nonstandard fires and developing performance prediction tools.

It is commonly asked why there are not Underwriters Laboratories (UL) or equivalent tested assemblies available for CLT, and this area is often suggested for research. The truth is that the calculated method offers more flexibility to designers than a series of UL assemblies and provides more precision with regard to the panel

thickness needed to accommodate fire-resistive requirements. When structural strength and fire resistance are so intertwined, a prescriptive method for determining fire resistance cannot offer material efficiency.

A comparison of the ASTM E 119 fire-tested CLT performance and the predicted performance using the calculated method demonstrates the reliability of char calculations for CLT. Such a comparison can be done by independent designers but is also shown in graphical form with tests done prior to 2013 in the fire chapter of the *U.S. CLT Handbook* (Karacabeyli and Douglas 2013).

The impressive ability of CLT to meet two and three hours of fire resistance with and without gypsum protection seems to be overshadowed by concerns about its combustibility. The increase of wood volume raises necessary questions about the additional potential for structural



Design Building, University of Massachusetts (UMass)
Location: Amherst, Massachusetts
Architect: Leers Weinzapfel Associates
Structural Engineer: Equilibrium Consulting

Photo courtesy of Alexander Schreyer, UMass

contribution to combustion and what it means for fire safety. Full-scale fire tests completed by FPInnovations and funded by Natural Resources Canada and others are intended to help address this issue. In association with a 13-story mass timber demonstration project (12 stories of CLT over one story of concrete) in Quebec, the provincial government there funded full-scale CLT fire tests to prove CLT's equivalence to 2-hour-rated noncombustible construction.

One series of full-scale compartment tests compared the performance of light-gauge steel, light-frame wood, and CLT. Tests included a three-story encapsulated CLT apartment simulation that ran for three hours. Results of the apartment simulation show the effectiveness of encapsulation in significantly delaying CLT's potential contribution to fire growth and proved that the structure can withstand complete burnout.

Another test focused on a 25½-foot CLT stair/elevator shaft (exposed on the inside face with two layers of gypsum protection on the fire side) and studied the smoke propagation and leakage as well as its structural stability as a fire exit. The test ran for 2 hours and showed no sign of smoke or heat penetration into the shaft.

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

Structural and Seismic Testing

There has been a proliferation of industry and academic research initiatives to build out the body of knowledge on CLT structural performance in U.S. applications. Some have pertained to standards and testing methods suitable to North America, such as the investigation of testing protocols for evaluation of in-plane shear strength of CLT panels (Gagnon et al. 2014). These and other efforts have led to the new "Acceptance Criteria For Cross-Laminated Timber Panels for Use as Components in Floor and Roof Decks" (AC455) from the ICC Evaluation Service. This product evaluation standard is generally compatible with the ANSI/APA PRG 320 qualification requirements with a

notable addition of testing procedures for evaluating the in-plane strength of CLT panels. Having acceptance criteria for CLT panels allows manufacturers to pursue directed testing culminating in an ICC-ES evaluation report. Evaluation reports are helpful in gaining jurisdictional approval for new materials, further assisting designers. Current North American CLT manufacturers are promising evaluation reports in the near future.

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

Using CLT components in lateral (wind or seismic) force-resisting systems is an area of considerable ongoing research. A much-anticipated project is the Development of Seismic Performance Factors for Cross Laminated Timber with principal investigator John van de Lindt of Colorado State University. This project will

follow the Federal Emergency Management Agency (FEMA) P-695 process, which is currently underway, to rigorously quantify seismic performance factors (R , Ω_0 , and C_d) for a type of CLT shear wall system for use following seismic design procedures of ASCE 7. This comprehensive study was preceded by a site- and building-specific FEMA P-695-like study to estimate whether a seismic response modification factor of $R = 4.5$ met the performance objectives of the candidate design (Pei 2013).

To date, CLT shear wall systems for seismic resistance have been designed using conservative seismic performance factors or using advanced performance-based seismic design procedures. The completion of this research will be a significant step toward easier design of CLT shear wall systems for seismic resistance and eventual inclusion of CLT in the seismic structural design standards used throughout the United States.

Another research project evaluating CLT walls for seismic resistance is a Network for Earthquake Engineering Simulation (NEES)/National Science Foundation (NSF) project investigating seismic-resistant tall wood buildings for the Pacific Northwest (Pei 2014a). This multi-university project is executing an inclusive process to develop

DESIGN GUIDANCE AND RESOURCES

There are many resources available to architects and engineers designing mass timber projects.

- For general information, the reThink Wood website (www.rethinkwood.com) offers an expanding library of materials on mass timber products, research, building examples, and developments related to tall wood buildings.
- The National Design Specification (NDS) for Wood Construction (www.awc.org) is the IBC-referenced design standard for lumber, glulam, SCL, and CLT, including fire design, fasteners and connections, etc. A mass timber building in the United States cannot be designed without the NDS.
- The *U.S. CLT Handbook* (www.rethinkwood.com) includes detailed technical information on the use of CLT. It should be used in conjunction with information provided by manufacturers since most CLT currently available in North America is proprietary (i.e., lay-ups aren't standard across suppliers).
- APA Product Reports (www.apawood.org/product-reports) signify a product's compliance with relevant provisions of the model building codes. The L-Series covers products manufactured from lumber, veneer, or other wood base, such as glulam and structural composite lumber (SCL).

For one-on-one support (at no cost), technical experts at WoodWorks are available to provide free project assistance related to nonresidential and multifamily buildings in the United States, including those using mass timber. Designers have the option of contacting an expert in their region (www.woodworks.org/project-assistance) or emailing help@woodworks.org.

seismic performance goals, as well as a variety of potential high-performance/low-damage seismic force-resisting systems. Since the 2014 publication on this project, the research team has progressed to running a series of experimental tests of CLT rocking walls at Washington State University. Additional research is being performed on the design of CLT rocking walls at Clemson (Gu et al 2014) and the University of Alabama.

The first full-scale application of CLT rocking walls is expected to be on the Framework building in Portland, Oregon, which will use the 12-story-high rocking walls as a self-centering seismic lateral force-resisting system. Full-scale testing is currently underway at Oregon State University and Portland State University.

For more information on CLT research, another good source is the paper “An Overview of CLT Research and Implementation in North America”⁴ developed for the 2016 World Conference on Timber Engineering.

The Research Behind Tall Wood

While some of the CLT research noted above has implications for tall wood buildings, numerous studies have also focused specifically on the feasibility of wood high-rises.

One recent example, “Mass Timber High-Rise Design Research: Museum Tower in Los Angeles Reimagined in Mass Timber,”⁵ demonstrates the design of a code-compliant, high-rise mass timber apartment tower in Los Angeles. Using the existing reinforced concrete Museum Tower Apartment building as a basis, the study demonstrates architectural, structural, and fire performance improvements and trade-offs of the mass timber design compared to a reinforced concrete design.

Another report, the “Survey of International Tall Wood Buildings,”⁶ offers a look at ten international tall wood buildings, and presents common lessons learned from the experiences of key stakeholders, including the developer/owner, design team, Authorities Having Jurisdiction, and construction team.

To stay abreast of research related to mass timber, including CLT and tall wood buildings, the reThink Wood website (www.rethinkwood.com) includes a library of studies, categorized by topic area and updated regularly.

CONCLUSION

Over the next decade, as researchers continue to provide information specific

to North American products and building codes, many are predicting a dramatic increase in mass timber construction, similar to the increase seen in Europe over the past 10 years.

“Mass timber structures have been built in North America for more than 100 years,” says Epp, citing the nine-story Butler Building in Minneapolis, Minnesota, built in 1908 and still in use. “They’ve proven to be inherently durable, and research is providing the information on fire protection, acoustics, etc., that will make it easier to design mass timber buildings in the United States using next-generation products. With the advantages offered by these materials—performance, construction speed, carbon footprint, opportunity for innovation, beauty—the interest we’re seeing within the design community can only increase, especially as uptake from developers continues to lend credence to the cost competitiveness of these structures.”

END NOTES

¹“Wood as a Restorative Material in Healthcare Environments.” FPInnovations. 2015. <https://fpinnovations.ca/media/publications/Documents/health-report.pdf>

²“Wood and Human Health.” FPInnovations. 2012. <https://fpinnovations.ca/media/publications/Pages/default.aspx>

³Podesto, Lisa and Scott Breneman. “CLT Research: Available and Accessible to North American Building Designers.” *Wood Design Focus*. V.26, N.1. www.woodworks.org/wp-content/uploads/CLT-Research_Podesto_Breneman.pdf

⁴Shilling, Pei and D. Rammer, M. Popovski, T. Williamson, P. Line, J. van de Lindt. “An Overview of CLT Research and Implementation in North America.” 2016 World Conference on Timber Engineering.

⁵Timmers, Matthew and Andrew Tsay Jacobs, Bevan Jones, James O’Neill. “Mass Timber High-Rise Design Research: Museum Tower in Los Angeles Reimagined in Mass Timber.” 2015 Structural Engineers Association of California Convention Proceedings. <http://www.woodworks.org/wp-content/uploads/Mass-Timber-Highrise-Design-Research.pdf>

⁶“Summary Report: Survey of Tall Wood Buildings.” Forestry Innovation Investment. Binational Softwood Lumber Council. 2014. <http://www.rethinkwood.com/webform/get-summary-report>