MASS TIMBER/CLT & WASHINGTON BUILDING CODES: A TECHNICAL PRIMER
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MASS TIMBER AND WASHINGTON STATE
CLT and other engineered wood building systems, collectively referred to as “Mass Timber,” have been used in European architecture for over twenty years. Mass Timber is now gaining traction in North America, notably in the construction of tall buildings. Mass Timber components are comprised of large panelized elements that are quick to fabricate and install on site. This technological advancement modernizes design and construction to deliver a high quality building in a relatively short amount of time. Our region’s strengths in forestry, digital fabrication, technology, and design position Washington State for unique opportunities to produce and integrate Mass Timber in the built environment.

This document is a guide for those interested in learning more about Mass Timber: its applications, ongoing testing for safety and integrity, and future possibilities for its expanded use.
CURRENT APPLICATIONS

MASS TIMBER AND THE BUILDING CODE

Mass Timber elements, including Cross-laminated timber (CLT), are allowed outright for certain applications in the 2015 International Building Code (IBC), which has been adopted by Washington State. The material can be used prescriptively in buildings up to 6-stories for offices and 5-stories for residential.

For taller buildings and select uses in shorter buildings, CLT used as a seismic lateral load resisting system is limited. In these instances, a code alternative and more involved design approach called performance-based design (in lieu of pre-approved prescriptive design) is required to gain approvals from the Authority Having Jurisdiction (AHJ). This pathway for design is typically not favored due to extra time, cost, and related perceived or real risks.

The future may offer more application options. The International Code Council (ICC), the organization that writes the International Building Code (IBC), is rapidly advancing testing that can collectively serve to support building code developments to expand the prescriptive use of Mass Timber.

CURRENT (2015) INTERNATIONAL BUILDING CODE HEIGHT LIMITS FOR WOOD STRUCTURES:

- 85 feet tall to the roof line of building is the cap for combustible (wood construction) buildings.
- 75 feet to the top occupied floor is the line that delineates when a building is high-rise. These two requirements are in effect in alignment, assuming the top floor of a building is 10 feet tall.

MASS TIMBER FOR HIGH RISE BUILDINGS

While the 2015 IBC limits the use of wood structure at 85 feet and 5 or 6 stories for office and residential, numerous Mass Timber buildings, from 8-18 stories, are materializing around the world – particularly in Canada, Australia, and Europe. Others are planned to attain even greater heights, such as the future 24-story HOHO building in Vienna, Austria.

In the Pacific Northwest, the 8-story Carbon 12 pushes beyond the code-defined number of stories for multi-family residential construction in wood by 3-stories, yet stays under the 85 feet height limit for wood. The building uses a Glued-laminated timber (GLT) post and beam structure with CLT floors, and features a CLT roof, with a code-compliant steel braced frame lateral system; the building was permitted for construction following a code alternate process led by the Oregon State building department. Despite exceeding the code-allowance, a fire and life safety strategy with sprinkler protection and exposed timber framing was deemed acceptable due to Mass Timber’s inherent fire protection and ability to form a char layer during a fire event.¹

At 174 feet tall, the 18-story Brock Commons building in Vancouver, British Columbia is currently the tallest Mass Timber building in the world. This student housing building employs hybrid materials, featuring Glued-laminated timber (GLT) columns with CLT floors, and cast-in-place reinforced concrete shear walls. The concrete shear walls are local only to

¹ This building was still under the 85ft height limit, and therefore within the combustible construction height limit of the code; non-compliance was in reference to the number of stories being 8 instead of the code limit of 5. The project went through a code-alternate pathway at the Oregon State Building Department level.

Read about Carbon 12 design approval here: http://www.nextportland.com/2016/01/27/carbon12-approved/

the stair and elevator cores and serve as the lateral force resisting system, in addition to protecting the exit stairs; the balance of the floor plate is supported by Mass Timber structure. Brock Commons underwent an extensive peer review process and testing to gain approvals for the fire and life safety strategy. As the building significantly exceeds the National Building Code height limit of 6-stories, sprinkler protection with encapsulated Mass Timber was deemed acceptable where most of the timber components are protected with multiple layers of gypsum wall board. This approach is intended to prevent timber from burning and contributing to the fuel load in the event of a fire.

**MASS TIMBER AS A LOAD BEARING (GRAVITY) SYSTEM**

Mass Timber elements are strong, and when used as walls or columns, can support exceptionally large gravity forces imposed by upper levels. A 5-ply CLT wall, for example, can support over 10 times the weight as a traditional 2x6 stud framed wall. For this reason, Mass Timber is especially applicable in high-rise, as well as larger educational and institutional buildings. Accordingly, Mass Timber has been used in recent years to build at heights that currently exceed the IBC allowances.

Hybrid solutions can also be applied where the gravity load carrying system is Mass Timber, and lateral framing consists of conventional systems, such as ductile concrete shear walls or steel brace frames. Examples of this hybrid approach include Brock Commons, Seattle’s Bullitt Center, and the Mountain Equipment Company corporate headquarters, located in Vancouver, B.C.

**MASS TIMBER AS FLOOR AND ROOF DIAPHRAGMS**

Floor and roof diaphragms serve to transfer lateral wind and seismic forces to vertical force resisting systems, like shear walls. In turn, these transfer forces to the building’s foundations. Traditionally, plywood sheathing or reinforced concrete acts as diaphragms in buildings, but CLT can also accomplish this and serve as the primary lateral structure. By way of example, Carbon 12 utilizes CLT as floor and roof diaphragms. LEVER Architecture’s Albina Yard project in Portland uses CLT floor panels as the diaphragm, supported on glulam beam framing. The project’s lateral system consists of plywood sheathed stud framed shear walls, with most of the shear walls located around a core. Washington State University’s PACCAR Environmental Technology Building uses CLT for its roof diaphragm. Guidance is available for design professionals interested in using CLT as diaphragms.

**MASS TIMBER IS HIGH PERFORMANCE**

Wood is a natural insulator due to its low thermal conductivity. Wood is an attractive structural material for use in high-performance buildings, creating more comfortable interior environments and reducing emissions due to lower heating and cooling demands. Around the world, the majority of passive house or net-zero buildings (capable of using no net electricity or producing more electricity than they consume) are constructed using wood. Wood also has the natural ability to moderate interior humidity fluctuations throughout the year, contributing to a healthy interior environment. Mass Timber construction thus provides a path for meeting or exceeding the performance requirements in the Washington State Energy Code.

**CURRENT AND FUTURE RESEARCH**

As Mass Timber, notably CLT, emerges in the U.S., there are three primary areas of perceived performance concerns that challenge its widespread use: structural performance, fire performance, and occupant comfort issues, such as floor vibration and acoustic performance. Given its safe usage internationally, there are efforts underway to leverage and build upon proven technologies through research and testing to meet market and industry performance objectives in the United States. The following summarizes current and future research and testing, aimed at establishing the performance of CLT in the U.S.

**STRUCTURAL PERFORMANCE**

Mass Timber is proven for use in gravity systems (e.g. floors, beams, columns, load-bearing walls) in low-, mid- and high-rise building applications. However, use for lateral systems, particularly in high-seismic areas such as Western Washington, requires additional research and testing to establish the necessary seismic design parameters for implementation in the building code. The formal process for defining the seismic design parameters is directed by FEMA P695. This testing intends to validate numerical models and building code based design methods for CLT floor diaphragms and shear walls. After the full design methodology is developed and testing completed, it will be reviewed by the Building Seismic Safety Council and the ASCE Seismic Loads Sub-Committee. Once approved, CLT will be included in ASCE 7 and designers will be able to use it as part of a normal design process without the added requirements and risks of following alternative means and methods procedures.

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CLT shear wall testing is led by Dr. John W Van de Lindt out of Colorado State University, funded by the USDA Forest Products Laboratory. Results are estimated to be published for public comment in 2018.

In addition to testing and research on CLT lateral resisting systems, one major area of focus is the standardization and performance of connections of Mass Timber components (e.g. beam-to-column, floor-to-column, floor-to-wall, floor-to-beam, etc.) and specifically, their performance when subject to seismic-related motion.

In the Pacific Northwest, the code-allowed use of CLT varies between British Columbia, Oregon, and Washington. In Canada, comprehensive design provisions for CLT buildings were proposed in 2014 by the CSA-O86 Technical Committee, a division of the Canadian Wood Council, and are now utilized in the 2015 National Building Code of Canada (NBC). Oregon has adopted a Statewide Alternative Method provision that allows the use of CLT and defines it as a seismic force resisting system in low-rise applications. The 2015 National Design Specifications for Wood (NDS) provide some provisions for the use of CLT. However, Washington has not yet defined CLT as a seismic force resisting system, as in Canada and Oregon.

To confirm that buildings meet the life safety and collapse prevention objectives of the IBC, all buildings in high seismic zones must have a seismic force resisting systems capable of withstanding and dissipating energy imposed by earthquake shaking. While CLT and other Mass Timber components are strong and stiff when used as shear wall systems, they have yet to be approved for use in seismic force resisting systems, as defined in the IBC. Despite the current gap in code preapproved technical documentation, preliminary seismic testing for CLT has been conducted around the world, demonstrating that a CLT system can be utilized effectively as a lateral force resisting system.

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4 The following SOFIE Project studies included full scale shake table tests on 3- and 7-story buildings: Ceccotti and Follesa, 2006; Ceccotti, 2008; Dujic and Zarnic, 2006; Dujic et al., 2008; Popovski et al., 2010


Watch testing here: https://www.youtube.com/watch?v=To8KRyVhyeo

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Seismic Design Category Map from ICC International Residential Code (IRC 2015). Forces are measured as percentage of gravity. Images courtesy: Dr. J. Daniel Dolan

For a more detailed map of seismic design categories: https://www.dnr.wa.gov/programs-and-services/geology/geologic-hazards/geologic-hazard-maps#seismic-design-categories

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In spite of these barriers, several projects in Washington State have successfully obtained building code approval for use of CLT as shear walls to manage seismic forces. In 2016, the Washington State Legislature appropriated capital funding to install modular classroom demonstration projects in five school districts; CLT was integrated as part of each building’s seismic force resisting system. CLTHouse, a 2-story home in Seattle designed by atelierjones, utilizes a seismic system of CLT floor and roof diaphragms, as well as CLT shear walls.5

Mass Timber rocking shear walls are an emerging solution for lateral stability in tall and mid-rise buildings. Rocking shear walls create a system to effectively dissipate seismic forces while reducing or eliminating the potential for damage to the building’s superstructure, also minimizing permanent displacements after an earthquake. CLT, used as a rocking shear walls system, utilizes post-tensioned steel tendons and energy-dissipating fuses to manage seismic forces. CLT panels are spanned continuously between floors, supported at grade, off the building foundation. Mass Timber rocking shear walls have already been used extensively in New Zealand, and the technology is being adopted in Oregon-based projects, including the Framework building, Oregon State University’s 4-story Forest Science Complex (currently under construction), and proposed Mass Timber parking garage project in Springfield. Rocking wall systems are generally suited for office, education, and parking garage structures where open floor plates with isolated locations for shear walls are a programmatic requirement.

In July 2017, the National Science Foundation funded a preliminary 2-story CLT rocking shear wall test at University of California San Diego. After four separate shake table tests, there was no significant damage detected in the 2-story, 22-foot tall

CLT shake table testing in Japan: https://www.youtube.com/watch?v=X7AZVO6q3c
FPInnovations testing in British Columbia: https://www.youtube.com/watch?v=_GKOi3vUFIA

5 Key to making these projects possible is the CLT Handbook, an authoritative manual on CLT design. Suitable for designers seeking approval from local jurisdictions, this manual provides a conservative value for using the material as a seismic force resisting system.

structure. Published results are expected in early to mid-2018. This testing also assisted in validating the systems and methodology for future testing on a larger structure. By 2020, a research team including Washington State University and University of Washington will test a 10-story CLT rocking wall structure on the nation’s largest shake-table to simulate earthquake conditions and verify performance of Mass Timber in seismic regions.

FIRE PERFORMANCE

Heavy Timber is a type of construction that, along with other factors, requires a minimum thickness to attain fire resistance. This construction type has been allowed by building codes since their inception, and 7–9 story buildings are commonly found in older U.S. and Canadian cities such as Chicago, Seattle, Vancouver, Montreal, and New York. Heavy Timber construction has demonstrated a strong reputation for fire resistance when compared with steel or unprotected light-frame wood construction.

Modern Mass Timber offers similar benefits. It features better inherent fire resistance than other traditional structural materials, such as light-framed wood or metal studs and joists, due to its considerable size, depth and ability to self-protect. There is a growing body of evidence demonstrating that wood with large cross-sectional dimensions (larger than 5 inches), such as that in Mass Timber, has considerable inherent fire resistance. Improved performance is possible through a char layer that develops on the exposed surfaces of Mass Timber during a fire. This char layer burns at a slow and predictable rate, and self-insulates the inner core of the wood section to retain load carrying capacity during exposure to fire. The predictability and

- 2017 ICC Tall Wood Buildings Ad Hoc Committee Fire Tests
  The US Forest Service, Forest Products Laboratory and the American Wood Council have, in 2017, completed 5 full-scale fire tests. These tests measured the performance of protected and exposed CLT and Glued-laminated timber surfaces under the real fire dynamics of an apartment unit fire. Tests were performed under varied conditions including no sprinklers, full sprinklers, and simulated sprinkler malfunction. Read a summary of results here: http://www.awc.org/pdf/codes-standards/fire/WCTE-2018_Fire-Tests.pdf

- Osborne and Dagenais, “Preliminary CLT Fire Resistance Testing Report,” FPInnovations, 2012. Performance testing of loaded CLT floor and wall assemblies, including protected and unprotected assemblies, indicated that the greater the depth of the CLT section (3, 5 or 7 layers), the greater the fire resistance. Gypsum board protection was also shown to increase the fire resistance time.

- McGregor, “Contribution of Cross Laminated Timber Panels to Room Fires,” Carleton University, 2013. 5 fire tests were carried out using propane and furniture fires with CLT panels in protected and unprotected configurations. Results indicated that with gypsum board protection of CLT, there was no contribution of the CLT to the room fire or any influence. Unprotected CLT panels did contribute to the fire load and increased fire growth rates and energy release rates.

- Aguanno, “Fire Resistance Tests on Cross-Laminated Timber Floor Panels: An Experimental and Numerical Analysis”, Carleton University, 2013. A series of 8 medium-scale fire tests using standardized and nonstandardized fires was performed to evaluate the performance of CLT floors. The experiments demonstrate that CLT panel constructions can be designed to possess a fire-resistance that complies with building code requirements.

- Osborne and Dagenais, “Full-scale Mass Timber Shaft Demonstration Fire,” FPInnovations, 2015. A large-scale fire test to validate the fire safety performance of CLT stair/ elevator shaft as an alternative solution. Test indicated a 2- and 3-hour fire-resistance could be achieved in floor and wall assemblies, respectively.

- Glulam Connection Fire Tests: The Softwood Lumber Board, Arup, MyTiCon and DR Johnson have completed 3 full-scale fire tests for glulam beam to column connectors that meet a minimum of 1-hour fire resistance rating (FRR) and as much as a 90 minute FRR.

Read more here: https://www.rethinkwood.com/Glulam-Fire-Testing-Report


longevity of Mass Timber during fires makes the material, in many ways, safer than some non-combustible materials. Concrete is shown to exhibit spalling; steel framing thermally expands and significantly weakens with temperature to cause structural damage and potential collapse.

In 2012, the American Wood Council demonstrated that a 5-layer CLT wall panel, loaded with 87,000 pounds, protected with only a single layer of gypsum wall board on each side, could last over 3 hours in a standardized fire test.  

Recent tests, completed by the Oregon CLT manufacturer DR Johnson, showed that a 5-layer CLT loaded floor panel with no protection could last over 2-hours. This successful testing demonstrated the tested floor assembly meets the IBC requirements for a “2-hour rated floor assembly.” These results enabled approval of the 12-story mixed-use Framework project in Portland, Oregon. Currently, a 2-hour calculated fire resistance is already allowed in the National Design Specifications for Wood.

Other examples of fire-resistant Mass Timber buildings are already complete in the U.S. Bullitt Center is a 6-story Heavy Timber office building in Seattle. The upper four floors of the building consist of exposed Glue-laminated timber (GLT) columns and beams and solid Nail-laminated timber (NLT) floors above a 2-story concrete podium. The T3 building in Minneapolis is a 7-story Heavy Timber office building, constructed over a 1-story concrete podium that utilizes a similar exposed structural system of Glue-laminated timber columns and beams, and NLT floors.

Recent research includes testing related to the Framework building, funded through a grant from the USDA, Softwood Lumber Board, and Binational Soft Wood Lumber Council as part of the 2014 U.S. Tall Wood Building Prize Competition. A two-hour fire rating was validated through testing for a glulam beam-to-glulam column connection, as well as CLT floor and wall panels and their connections. Tests like these serve to demonstrate Mass Timber’s predictable performance and justify its safe use within current code limits.

**OCCUPANT COMFORT**

Acoustic and vibration control of any system is associated with the comfort level of the occupants and users of the space. While the evaluation of comfort is largely subjective, designers are responsible for understanding and ensuring reasonable serviceability is achieved. The way floors and walls respond to acoustic and floor vibration (i.e. footfall) depend on their inherent properties, such as mass, stiffness, and capacity to absorb energy (i.e. damping). Mass Timber is heavier and stiffer than conventional light-wood frame construction and much lighter than solid concrete. This means Mass Timber floor and wall assemblies require their own set of unique design solutions to confirm vibration and acoustic performance criteria are met.

With increased usage of Mass Timber in North America, new and innovative floor and wall assemblies are continually being developed and tested. For example, the federally funded National Research Council (NRC) laboratory in Canada published a report in August 2016 that details 13 different CLT floor assemblies and 5 different GLT floor assemblies that were successfully tested for air-borne and structure-borne sound transmission, according to ASTM E90-09 and ASTM E492-09 (acoustic testing requirements referenced in the IBC for airborne and impact sound transmission), respectively. In addition, impact and sound

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9 ULI Bullitt Case Study: https://casestudies.uli.org/bullitt-center/
10 Testing is complete and is expected to become publicly available when building construction commences.
11 See more about testing here: https://www.youtube.com/watch?v=iWzohThkOg
testing performed for the Framework building, successfully validated that the proposed floor assembly meets the serviceability requirement for the project.

Finished structures have been shown to perform favorably, as well. The Candlewood Suites at Redstone Arsenal, serves as an example of successful testing. The structure was completed in 2015 by architect/developer Lendlease. Assemblies were tested for acoustic performance, and it was found that these “produced a Sound Transmission Class (STC) rating substantially greater than required by code” (p6).

**FUTURE CODE DEVELOPMENTS FOR TALL WOOD BUILDINGS**

There is strong interest in using Mass Timber for taller buildings despite the restrictive height allowances currently in the IBC. To explore the potential for high-rise Mass Timber buildings, in 2015 the American Wood Council (AWC) submitted a request to the ICC Board of Directors to study tall wood buildings and develop prescriptive code language for adoption in the future IBC. Code changes are intended to provide design professionals a prescriptive path for the safe design and approval of such buildings. In early 2016, the ICC Board of Directors appointed members to its newly created Tall Wood Building Ad Hoc Committee (TWBC). The committee includes a cross-section of the U.S. building industry, including architects, structural and fire engineers, wood, concrete and steel representatives, code officials, and fire officials. Since then, the TWBC has created specific work groups to address the issues of tall wood buildings, including Definitions and Standards, Fire, Structural, and Codes and Standards groups. Working over an 18-month period, the Committee’s goal is to issue complete model code language that will revise the relevant IBC Code sections to recognize Mass Timber, its structural and fire characteristics, as well as outline new, modernized height & areas limits, for the new structural system.

As part of the work, the TWBC has established three general construction categories for tall Mass Timber buildings: one in which the Mass Timber is fully protected by noncombustible protection (i.e. gypsum board); a second in which the protection is permitted to be partially omitted to expose a certain amount of wood; a third in which the Mass Timber for the whole structure is permitted to be exposed. Based on this understanding, the TWBC proposed three new building construction types: Type IV-A, Type IV-B and Type IV-C, and assigned reasonable and conservative heights and building area maximums to them based on

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professional judgement and expert consultation. All construction types require fully compliant sprinkler systems and exiting requirements. The existing Type IV construction found in the current building code will also remain, renamed Type IV-HT.

As this document details, existing building codes allow for Mass Timber construction in a certain building types. The ICC TWBC has developed and submitted code language for future prescriptive design of tall wood buildings.

As of January 2018, these three new types were proposed, with voting and approvals taking place throughout 2018. If adopted, this language would be made available to jurisdictions as early as 2021 in the IBC update. Additionally, these provisions can be adopted immediately through a code alternative approach upon approval from the authority having jurisdiction.

### PROPOSED & EXISTING BUILDING TYPES
ICC Tall Wood Building Ad Hoc Committee (2016 to 2017)

- **Type IV**
  - T3, Minneapolis MN
  - 6-Story Wood over 1 Story Concrete
  - <85ft, Exposed Wood
  - 1hr Fire-Resistant Rating

- **Type IVC**
  - Carbon 12, Portland OR
  - 8-Story Wood over 1 Story Concrete
  - <85ft, Exposed Wood
  - 2hr Fire-Resistant Rating

- **Type IVB**
  - Origine, Quebec CA
  - 12-Story Wood
  - >85ft, Partially Encapsulated
  - 2hr Fire-Resistant Rating

- **Type IVA**
  - Brock Commons, Vancouver BC
  - 18-Story Wood/Concrete Hybrid
  - >85ft, Fully Encapsulated
  - 3hr Fire-Resistant Rating

Photos: KATERRA

- IV is Heavy Timber (HT) in which the exterior wall are of noncombustible materials and the interior elements are of solid or laminated wood without concealed spaces.

- IV-C is similar to existing heavy timber (HT) that the height in feet and number of stories is based upon the existing Type IV-HT values of 85 feet tall, with an increase to 9 stories maximum, depending on occupancy.

- Type IV-B is equivalent to existing IBC Type I-B for height: 180 feet tall or 12-story maximum, depending on occupancy. Type IV-B allows up to 20-40 percent of the Mass Timber elements to be exposed.

- Type IV-A has a higher fire safety standard with full protection (encapsulation) of the timber elements. Due to the enhanced passive fire protection, proposed height allowances for Type IV-B would be increased to potentially

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13 ICC Tall Wood Building Ad Hoc Committee news and documents are found here: [https://www.iccsafe.org/codes-tech-support/cs/icc-ad-hoc-committee-on-tall-woodbuildings/](https://www.iccsafe.org/codes-tech-support/cs/icc-ad-hoc-committee-on-tall-woodbuildings/)