Tall Wood Structures: Current Trends and Related Code and Standards Changes-DES600

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Description

Cross-laminated timber (CLT) has been in use worldwide for over 15 years, but most notably in Europe. Building with CLT has increased in popularity for many reasons including: just-in-time fabrication and job site delivery, speed and efficiency in construction, reduced job site noise and on-site labor force, substitution of high embodied materials with a renewable resource that sequesters carbon, and creating a living or work space that has the aesthetics of exposed wood.

The recent introduction of CLT in the 2015 National Design Specification® for Wood Construction (NDS®) and the 2015 International Building Code has opened up an exciting new chapter in wood construction. The use of CLT alone or in combination with other mass timber elements, such as glued-laminated timber (GLT), nail-laminated timber (NLT), or structural composite lumber (SCL), is becoming more common in buildings complying with the current code. There is also an effort underway by the International Code Council (ICC) to recognize the use of mass timber elements in taller, combustible construction through the work of the ICC Tall Wood Ad Hoc Committee. This presentation will provide an introduction to CLT including relevant design standards and code references. Examples of various mass timber buildings around the world will be provided and potential future code provisions relating to mass timber will also be discussed.

Learning Objectives

At the end of this program, participants will be better able to

1. Define cross-laminated timber
2. Identify code and standard updates relevant to CLT and other mass timber elements
3. Recognize notable mass timber structures around the world
4. Understand how wood performs in fire conditions
5. Comprehend current tall wood building code developments and resources
Polling Question

1. What is your profession?
   a) Architect/Building Designer
   b) Engineer
   c) Code Official
   d) Builder/Product Manufacturer
   e) Other

Climate Change

Carbon Footprint – Climate Change

Natural or Anthropogenic? (human activity)

Solar Radiation

Greenhouse Gases:
- Water vapor
- Carbon dioxide
- Methane
- Ozone
Climate Change

Stradthaus – 24 Murray Grove
London infill project
29 flats
4x less weight than concrete
~1/2 construction time of precast concrete
(saved 22 weeks 30%)
Saves 300 metric tons of CO2
21 years of building energy usage

THE CASE FOR Tall Wood BUILDINGS How Mass Timber Offers a Safe, Economical, and Environmentally Friendly Alternative for Tall Buildings Structures FEBRUARY 22, 2012 PREPARED BY: mgb ARCHITECTURE + DESIGN; Equilibrium Consulting; LMDG Ltd; BTY Group

Heavy Timber Type IV

602.4 Type IV.
Type IV construction (Heavy Timber, HT) is that type of construction in which the exterior walls are of noncombustible materials and the interior building elements are of solid or laminated wood without concealed spaces. The details of Type IV construction shall comply with the provisions of this section and Section 2004.1. Exterior walls complying with Section 602.4.1 or 602.4.2 shall be permitted. Minimum solid sawn nominal Cross laminated timber (CLT) dimensions used in this section are actual dimensions.
Heavy Timber Type IV

602.4.3 Columns. Wood columns shall be a dimension where support 8 inches (203 mm) nominal or superimposed and or required.

602.4.4 Floor framing. Wood beams and girders mm) nominal in width arc timber arches, which spri nominal in any dimension inches (203 mm) nominal.

602.4.5 Roof framing. Wood-frame or glued-lam do not support floor loads less than 8 inches (203 mm) nominal in depth for the top of walls or walls ab loads, shall have member mm) nominal in depth. Sp:

602.4.6 Floors. Floors shall be without concealed spaces. Wood flo or 602.4.6.2.

602.4.6.1 Sawn or glued-laminated plank floors. Sawn or glued-laminated plank floors shall be one c

[BS] CROSS-LAMINATED TIMBER. A prefabrications layers of solid-sawn lumber or structural composite bonded with structural adhesive to form a solid wo:

[BS] STRUCTURAL COMPOSITE LUMBER. Structure together with exterior adhesives. Examples of struc:

Laminated strand lumber (LSL). A composite of wood along the length of the member, where the least dimension 6 less and their average lengths not less than 150 lam

Laminated veneer lumber (VSL). A composite of wood oriented along the length of the member, where the ve less.

Oriented strand lumber (OSL). A composite of wood the length of the member, where the least dimension c less and their average lengths not less than 75 times c elements.

Parallel strand lumber (PSL). A composite of wood s the length of the member where the least dimension of and their average lengths not (less than 300 times the l

[BS] STRUCTURAL GLUED-LAMINATED TIMBER. planks, comprised of assemblies of specially selected or laminations is approximately parallel longitudinally and

2304.8.3 Mechanically laminated decking. Mechanically laminated decking shall compl

2304.9.3.1 General. Mechanically laminated decking consists of f to the adjacent pieces and to the supports.

2304.9.3.2 Nailing. The length of nails connecting laminations at
Structural Composite Lumber (SCL)

- **PSL**
  - parallel strand lumber

- **LSL**
  - laminated strand lumber

- **LVL**
  - laminated veneer lumber

- **OSL**
  - oriented strand lumber

Nail Laminated Timber (NLT)

Photo provided by Structurecraft

Photo provided by Truss Joist

Photo provided by Weyerhaeuser

Photo provided by Wood Solutions

Photo courtesy of Structurecraft
Warner Drive – Culver City, CA

- Nail-Laminated Timber – 2x12 vertical mechanically-connected w/nails
- NDS principles of mechanics

Nail-Laminated Timber

(g) Mechanically Laminated Floors and Decks. A laminated lumber floor or deck built up of wood members set on edge, when meeting the following requirements, may be designed as a solid floor or roof deck of the same thickness, and continuous spans may be designed on the basis of the full cross section using the simple span moment coefficient. Laminations shall be driven up and spaced closely together with a row of nails near each edge at spaced intervals and staggered vertically. Nail spacing in each row shall not exceed eighteen inches (18") for twelve-by-eight-inch (2" x 8") nominal width and be proportional for other plank widths. Nail length shall be not less than two and one-half times the net thickness of each lamination. A single span deck shall have all laminations full length. A continuous deck of two spans shall have not more than every fourth lamination spaced within quarter points adjoining supports. A continuous deck of more than two spans shall have not more than every third lamination spaced within quarter points adjoining supports. Joints shall be closely butted over supports or staggered across the deck but within the adjoining quarter spans. No lamination shall be spaced more than twice in any span.
Nail-Laminated Timber

- **2304.8.3 Mechanically laminated decking.**
- **2304.8.3.1 General.**
- **2304.8.3.2 Nailing.**
- **2304.8.3.3 Controlled random pattern.**

Nail length \( t_{\text{min}} = 2.5 \times t_{\text{lamination}} \)

Nail spacing
- \( < 30” \text{ o.c.} \) * 48” span
- \( < 18” \text{ o.c.} \) > 48” span

*nail placement alternates between top and bottom

---

**Nail-Laminated Timber**

- **Nail length \( t_{\text{min}} = 2.5 \times t_{\text{lamination}} \)**
- **Nail spacing**
  - \( < 30” \text{ o.c.} \) * 48” span
  - \( < 18” \text{ o.c.} \) > 48” span

*nail placement alternates between top and bottom*
Nail-Laminated Timber

• Clay Creative
  • Portland, Oregon
  • Mixed-Use
  • 72,000 SF
  • 6 Story (5 over 1 plus 1 level partial below grade parking)

Developer: Killian Pacific
Architect: Mackenzie
Structural Engineer: Kramer Gehlen & Associates
Completion: 2016
Nail-Laminated Timber

• The Hudson
  • Vancouver, WA
  • Mixed-Use
  • 45,000 SF
  • 3 story

Developer: Killian Pacific
Architect: Mackenzie
Completion: 2016
Nail-Laminated Timber

General Contractor: Companion
Location: Surrey, British Columbia, Canada
Design Assist, Fabrication and Installation: StructureCraft
Completion: 2013

Nail-Laminated Timber

Resource: StructureCraft
Nail-Laminated Timber

Glued-laminated Timber (GLT)
Glued-laminated Timber

• **One North**
  - Portland, Oregon
  - Mixed Use
  - East Bldg. 43,000 SF
  - West Bldg. 43,000 SF

Development Team: Karuna Properties II, LLC; Nels Gabbert, LLC; Kaiser Group Inc.; Owen Gabbert, LLC
Contractor: R&H Construction
Architect: Holst Architecture
Structural Engineer: Froelich Consulting Engineers
Completion: 2016
Glued-laminated Timber

- **Synergia Complex**
  - Saint-Hyacinthe, Quebec
  - Office Building
  - 13,000 SF
  - 6 Story
  - Estimated completion Spring 2017

Glued-laminated Timber

Owner: Robin Group
Architect: Lemay
Completion: 2016
Glued-laminated Timber

Single Grade Layup

- Same lumber grade and species used throughout
- Primarily for use in axially loaded members, such as columns and truss chords
Cross-laminated Timber (CLT)

Photo provided by FPInnovations

Mass Timber Concept - History of CLT

- 1985 1st CLT patent - France
- 1993 1st CLT projects - Switzerland and Germany
- 1995-1996 Improved press technology
- 1998 1st multi-story res building - Austria
- Early 2000’s
  - CLT use (Europe) increased significantly
  - Green building movement driven
  - Better efficiencies, product approvals, improved marketing and distribution channels
- Over 500 CLT buildings in England
- Recent - US and Canadian use of CLT
CLT vs. GLT

Cross Laminated Timber

Thick Orthotropic Plate

Graphics provided by WoodWorks

Glued Laminated Timber

Beam-like member

Graphics provided by APA

CLT Production

Photos provided by Structurlam
Lamstock Lifting Crane

CLT Press and Glue

Photos Courtesy of Structurlam
CLT Press and Glue

Photos Courtesy of Structurlam

CNC Technology

Photos Courtesy of Structurlam
CNC Technology

Photos Courtesy of Structurlam

Ready to ship

Slide Courtesy of Structurlam
Other Innovations

- Dowel Laminated Timber
- Wood-Concrete Composites

Photos courtesy of StructureCraft

Dowel Laminated Timber

Photos courtesy of StructureCraft
Wood-Concrete Composites

Wood (LSL) - Concrete composite panels (4” conc., 1” insulation, over 3-1/2” LSL)

Wood-Concrete Composites
Polling Question

2. What are some of the wood products commonly used for mass timber construction?
   a) Sawn lumber
   b) Glued-laminated timber
   c) Engineered Rim Board
   d) Cross-laminated timber
   e) a., b., and d.

Historical Tall Wood
Historical Tall Wood

Former Marine Corps Air Station Tustin, 1942
U.S. Naval Air Station Hangar B, now Tillamook Air Museum, Tillamook, Oregon, 1942

Kelly, Douglas and Co. Warehouse; Vancouver, BC (c. 1905)

Leckie Building, Vancouver, BC (c. 1908)

The Purse Building, Dallas, TX, (c. 1905)
Butler Brothers Building – Minneapolis - 1906

Historic Wood Heights and Areas

1920 - 1999
- 3-stories
- 40 ft height
- 6,000 ft²

1999 - 2015
- 5-stories
- 70 ft height
- 13,200 ft²

2015 – 2018
- 6-stories
- 85 ft height
- 20,500 ft²
2000 IBC vs 1999 BOCA NBC

Table II
Code Comparison - Area Increases

<table>
<thead>
<tr>
<th>Feature</th>
<th>IBC</th>
<th>BOCA NBC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum open space for increase credit</td>
<td>20 ft</td>
<td>30 ft</td>
</tr>
<tr>
<td>Basis of open space increase credit</td>
<td>same</td>
<td></td>
</tr>
<tr>
<td>Maximum possible area increase with total open perimeter of at least 20 feet in width</td>
<td>50 percent</td>
<td>no increase permitted (30 ft minimum width required for open perimeter)</td>
</tr>
<tr>
<td>Maximum possible area increase with total open perimeter of at least 30 feet in width</td>
<td>75 percent</td>
<td>150 percent</td>
</tr>
<tr>
<td>Automatic sprinkler system increase credit</td>
<td>300% increase for one-story buildings, 200% increase for multi-story buildings</td>
<td>200% increase for one and two-story buildings, 100% increase for buildings three or more stories</td>
</tr>
<tr>
<td>Additional area limits for multi-story buildings</td>
<td>Aggregate floor area limited to not more than three times the single-story allowable area, basements excluded</td>
<td>Percent reduction applied to single story area, based on construction type and number of stories, per Table 506-4</td>
</tr>
</tbody>
</table>

Mass Timber per Current Code
Mass Timber – US

Fire House
Multnomah County, Oregon

Owner: Multnomah County Rural Fire Protection District 10, Oregon
Architect: Hennebery Eddy Architects, Inc
Photo by Josh Parbee

Mass Timber – US

Elementary School, Franklin, West Virginia

Source: LignaTerra
Mass Timber – US

Private Army Hotel
Redstone Arsenal Huntsville, AL

Four stories 58,000 sq ft
Architect: Lend Lease

Mass Timber – US

Mixed retail/office space
Minneapolis, Minnesota

- T3 Project
- 7 Stories
  - [https://vimeo.com/162500838](https://vimeo.com/162500838)
Mass Timber per Alternate Means

Tall Wood

US Projects

• **Framework**
  • Portland, Oregon
    • 12 Story
    • Street-level retail, office, workforce housing and community space
    • U.S. Tall Wood Building Prize Competition winner *

* Sponsored by the U.S. Department of Agriculture, the Softwood Lumber Board and the Binational Softwood Lumber Council

http://www.nextportland.com/2016/07/21/framework-dz1/

* Photo provided by Next Portland
US Projects

Carbon 12
• Portland, Oregon
• 8 Stories
• Residential tower
http://www.nextportland.com/2015/05/14/carbon12/

Canadian Projects

The Arbora
• Québec, Canada
• 8 Stories
• 434 Residential condo, townhouse and rental units
The Arbora

[Images of construction site]
The Arbora
Canadian Projects

The Wood Innovation and Design Centre
- Prince George, British Columbia, Canada
- 8 Stories
- Office and education space

Canadian Projects

Brock Commons
- Vancouver, British Columbia, Canada
- 18 Stories
- Mixed use student housing
UBC - Brock Commons

• Brock Commons Videos
  - https://www.youtube.com/watch?v=zB5H1ZVZk-c&t=2s
  - https://www.youtube.com/watch?v=GHtdnY_gnmE
  - https://www.youtube.com/watch?v=rYwI6wHcRvc
Tall Wood Worldwide

Tall Wood Worldwide

Source: reTHINK WOOD

International Projects

Bridport House

- Hackney, London, England
- 7 Stories
- Residential
International Projects

**LCT One**
- Dornbirn, Austria
- 8 Stories
- Business office

**Cenni di Camiamento**
- Milan, Italy
- 9 Stories
- Commercial and residential

**International Projects**

**Treet**
- Bergen, Norway
- 14 Stories
- Luxury apartments
International Projects

• **Baobab**
  • Paris, France
  • 35 Stories
  • Mixed Use
  • Réinventer Paris competition entry

Polling Question

3. **What is the tallest wood building in the United States?**
   a) Framework
   b) Carbon 12
   c) T3
   d) Brock Commons
   e) Treet
Building Codes

Governing Codes for Wood Design

2015 IBC references in 2015 NDS
2015 NDS

- Webinar on 2015 NDS available on AWC website

Chapter 10 – Cross-Laminated Timber

10.1 General

10.1.1 Application

10.1.2 Definition

Cross-Laminated Timber (CLT) – a prefabricated engineered wood product consisting of at least three layers of solid-sawn lumber or structural composite lumber where the adjacent layers are cross-oriented and bonded with structural adhesive to form a solid wood element.

10.1.3 Standard Dimensions

10.1.4 Specification

All required reference design values shall be specified in accordance with standard dimensions.
Chapter 10 – Cross-Laminated Timber

Single or multiple surface layers

1, 2, 3, 4 transverse layers

Laminations: 5/8”-2” sawn lumber or SCL
Panel thickness: 20” max
In-Service MC: 16%

Chapter 12 – Dowel-type Fasteners

- Chapter 12 has been updated to accommodate differences in CLT connection design
GLT and CLT Adhesives

CLT Handbook

- Additional information on issues not yet covered in NDS or IBC
  - Energy
  - Sound
  - Vibration
  - Enclosures
  - Handling
Seismic Design Options

- **ASCE 7 Minimum Design Loads for Buildings and Other Structures**
- **Response Modification Coefficient, R**
  - CLT not recognized system in ASCE 7 Table 12.2-1
- **Options**
  - Performance-based design procedure per ASCE
  - Demonstrating equivalence to an existing ASCE system
  - ASCE 7-10, FEMA P695, and FEMA P795 Quantification of Building Seismic Performance Factors; Component Equivalency Methodology

Current Research

- **Colorado State University**
  - CLT shear wall testing (P695) to determine seismic R factor
- **Colorado School of Mines**
  - NEES project on rocking CLT shear wall
- **Arup**
  - Heavy timber buckling-restrained braced frame system
- **Oregon State University**
  - CLT diaphragm testing
Seismic Design Options

- Horizontal diaphragm example
  - Wood structural panels over CLT
  - Acceptable under current codes

http://structurlam.com/

Methods for Determining Fire Resistance (IBC 703)

- Seven methods to determine fire resistance:
  - Tested fire assembly (ASTM E119 or UL 263)
  - Fire resistance designs documented in approved sources
  - Prescriptive assemblies using of fire-resistance-rated designs in Section 721
  - Calculation of fire resistance per Section 722
  - Engineering analysis based on a comparison of building element, component or assembly designs that have been tested
  - Alternative protection methods per Section 104.11
  - Fire-resistance designs certified by an approved agency
Heavy Timber Fire Resistance Rating

HT vs. Fire Resistance Rating

• **Type IV Construction**
  - Structural framing: prescribed min. sizes  The wood structural elements are assumed to have inherent fire-resistance due to their required minimum dimensions (no fire-resistance rating is required except for exterior walls).

• **III and V Construction**
  - Prescribed fire-resistance requirements
NDS Chapter 16 – Fire (ASD)

- Fire resistance up to two hours
  - Columns
  - Beams
  - Tension Members
  - ASD only
- Products
  - Lumber
  - Glulam
  - SCL
  - decking
  - CLT - NEW

NDS Chapter 16 – Fire (ASD)

Technical Report No. 10
- Background on NDS provisions
- Design examples
- Updated with CLT

Free download www.awc.org
NDS Chapter 16 – Calculated Resistance

- Fire resistance of exposed wood members may be calculated using the provisions of NDS Chapter 16
# Fire Performance

![Diagram showing fire exposure, heated zone, char layer, and cross-section used for calculating capacity.]

# Fire Design of Exposed Wood Members

## Allowable Stress Design

### Table 16.2.2 Adjustment Factors for Fire Design

<table>
<thead>
<tr>
<th>Member Type</th>
<th>ASD</th>
<th>Design Stress to Allowable Stress Factor</th>
<th>Shear Factor</th>
<th>Volume Factor</th>
<th>Fatigue Factor</th>
<th>Ducksback Factor</th>
<th>Column Stability Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bending Strength</td>
<td>1.00</td>
<td>2.85</td>
<td>C_p</td>
<td>C_r</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beam Buckling Strength</td>
<td>1.00</td>
<td>2.03</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>1.00</td>
<td>2.85</td>
<td>C_p</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compressive Strength</td>
<td>1.00</td>
<td>2.58</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Column Buckling Strength</td>
<td>1.00</td>
<td>2.03</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. See 4.3, 5.3, 6.3, and 10.3 for applicability of adjustment factors for specific products.
2. Factor shall be based on initial cross-section dimensions.
3. Factor shall be based on reduced cross-section dimensions.
Fire Design of Exposed Wood Members

**New Cross-laminated Timber-Effective Char Depth**

$$a_{char} = 1.2 \left[ n_{lam} h_{lam} + \beta_n \left( t - \left( n_{lam} t_{gl} \right) \right)^{0.813} \right]$$

$$t_{gl} = \left( \frac{h_{lam}}{\beta_n} \right)^{-1.23}$$

- $t_{gl}$ = time for char front to reach glued interface (hr.)
- $h_{lam}$ = lamination thickness (in.)
- $n_{lam}$ = number of laminations charred (rounded to lowest integer)
- $t$ = exposure time (hr.)

Fire-Resistance of Exposed Wood

- **16.3 Wood Connections**
  - Where fire endurance is required, connectors and fasteners shall be protected from fire exposure
  - Wood
  - Fire-rated gypsum board
Fire Test

American Wood Council
ASTM E119 Fire Endurance Test
• 5-Ply CLT (approx. 7” thick)
• 5/8” Type X GWB each side
• Sought 2 hour rating
• RESULTS: 3 hours 6 minutes

Polling Question

4. HT construction requires fire resistance calculations for determine the duration of fire resistance in hours?
   a) True
   b) False
Residential Fire Load Demonstration

CLT and NLT: September 3, 2015

Residential Fire Load Demonstration
ICC Tall Wood Ad Hoc

- October - December 2015
  - ICC Board approves formation of the TWAH
- January 2016
  - ICC advertises call for committee
  - Over 60 applications received
- April 2016
  - ICC appoints committee

ICC News Release

Per Immediate Release
January 7, 2016
www.icc-es.org
1-888-ICC-SAFE (455-7233), ext. 5217
iccnews@icc-es.org

ICC Accepting Applications for Ad Hoc Committee on Tall Wood Buildings

The International Code Council (ICC) Board of Directors has established an ad hoc committee to explore the building science of tall wood buildings. Tall wood is a term used in the industry to identify wood construction which utilizes Cross Laminated Timber (CLT) in buildings of heights greater than six stories. ICC buildings with heights varying from seven to 15 stories are in the planned stages in Minneapolis, Portland, and New York City.

ICC Tall Wood Ad Hoc

- First meeting July 2016 in Chicago
- 83 Issues identified (many overlapping)
- Subcommittees established
  - Allowable height and area
  - Fire
  - Structural
  - Definitions
- Second meeting November 2016 in Seattle
  - UBC – Brock Commons presentations
  - Committee Reports
AWC Proposals

- Existing Type IV construction to remain
- New categories for CLT/Mass Timber
  - Examples based on Use Groups R1 and R2
  - Type IV C - 9 Stories meeting existing code requirements for HT except with 2-hour fire performance
  - Type IV B - 12 Stories meeting existing code requirements (except for non-combustibility) of Type IB construction
  - Type IV A - 20 Stories meeting existing code requirements (except for non-combustibility) of Type IA construction
  - Additional enhancements above current code requirements can be considered for each category

ICC TWAH Next Steps

- TWAH to remain through 2021 Code Development process
  - Code provisions for all items (except structural) submitted November 2017
  - Remaining provisions by November 2018
- ICC Code Development process information
COC Benefits

- No cost to qualifying participants:
  Code Officials   Inspectors   Plans Examiners
- Free electronic AWC technical publication
- Discounted publications
- One free *WoodWorks* access per department
- *WoodPost* bi-weekly e-newsletter
- Free Online Tools and updates
- Free continuing education
- ICC Preferred Provider
- National Council of Structural Engineers Association
- American Institute of Architects

American Wood Council

AWC is committed to ensuring a resilient, safe, and sustainable built environment.
Questions?

• This concludes The American Institute of Architects Continuing Education Systems Course

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