Research to help push the limit for use of massive timber in Canada

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The concept of ‘tall’ wood buildings is not new!

• A 2012 survey conducted by FPInnovations has revealed that there are low- and mid-rise timber buildings built prior to building code era:
  – 125 in Toronto
  – At least 37 of these buildings are 5-8 storeys (up to 22 ft /storey)
  – Built between 1859– 1933
Appearance of these buildings – brick, timber posts & beams

Source: FPInnovations
Some structural details from inside

Post & Beam with wood planks

Joisted floor with wood decking on secondary floor beams

A report on this study, including a similar survey in Vancouver will be published by FPInnovations

Source: FPInnovations
The introduction of modern building codes (NBCC 1941) placed a limit on building height for different construction........
# 1941 edition of NBCC

## Table 3 - Maximum Building Heights for Combustible Construction (1941)

<table>
<thead>
<tr>
<th>Occupancy Group</th>
<th>Division</th>
<th>Description</th>
<th>Type 2 Heavy Timber</th>
<th>Type 3 Masonry &amp; Frame</th>
<th>Type 4 Wood Frame</th>
<th>Type 5 Unprotected Metal or Fire- Retardant Treated Wood</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>Theatres</td>
<td>3 (45-feet)</td>
<td>2 (35-feet)</td>
<td>1 (35-feet)</td>
<td>1 (35-Feet)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Auditoriums, Community halls</td>
<td>4 (55-feet)</td>
<td>3 (45-feet)</td>
<td>1 (35-feet)</td>
<td>1 (not specified)</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>Asylums, Jails</td>
<td>NP</td>
<td>NP</td>
<td>NP</td>
<td>NP</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Child Shelters, Hospitals</td>
<td>3 (45-feet)</td>
<td>2 (35-feet)</td>
<td>1 (35-feet)</td>
<td>1 (not specified)</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Dry Cleaning Plants using explosive solvents</td>
<td>NP</td>
<td>NP</td>
<td>NP</td>
<td>NP</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>High Hazard Industrial</td>
<td>3 (45-feet)</td>
<td>2 (35-feet)</td>
<td>1 (25-feet)</td>
<td>1 (not specified)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Medium Hazard Industrial</td>
<td>4 (55-feet)</td>
<td>3 (45-feet)</td>
<td>2 (35-feet)</td>
<td>1 (not specified)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Office buildings</td>
<td>Not Specified (75-feet)</td>
<td>4 (55-feet)</td>
<td>2 (35-feet)</td>
<td>1 (not specified)</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Low Hazard Industrial</td>
<td>Not Specified (75-feet)</td>
<td>4 (55-feet)</td>
<td>2 (35-feet)</td>
<td>1 (not specified)</td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>Convents and Dormitories</td>
<td>4 (55-feet)</td>
<td>3 (45-feet)</td>
<td>1 (35-feet)</td>
<td>1 (not specified)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Apartments and Hotels</td>
<td>4 (55-feet)</td>
<td>3 (45-feet)</td>
<td>2 (35-feet)</td>
<td>1 (not specified)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>one- and two-family dwellings</td>
<td>4 (55-feet)</td>
<td>3 (45-feet)</td>
<td>3 (40-feet)</td>
<td>1 (not specified)</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Private barns &amp; Garages</td>
<td>Not Specified (55-feet)</td>
<td>Not Specified (45-feet)</td>
<td>Not Specified (20-feet)</td>
<td>Not Specified (45-feet)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Towers, Water tanks, etc.</td>
<td>Unlimited</td>
<td>Unlimited</td>
<td>Unlimited</td>
<td>Unlimited</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Stands &amp; Stadiums</td>
<td>Not Specified (55-feet)</td>
<td>Not Specified (45-feet)</td>
<td>Not Specified (35-feet)</td>
<td>Not Specified (45-feet)</td>
</tr>
</tbody>
</table>

Source: Michael Kruszelnicki
1953 Edition of NBCC

- Concept of combustible vs non-combustible construction
- No differentiation between heavy and light wood frame
- Benefit of sprinklers was allowed
- Building height limits (ft) were removed
- Max storey limit is now 4

Table 4 - Maximum Building Height for Combustible Construction by Occupancy Group

<table>
<thead>
<tr>
<th>Group</th>
<th>Building Height Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non-Sprinklered</td>
</tr>
<tr>
<td>A1</td>
<td>NP</td>
</tr>
<tr>
<td>A2</td>
<td>2</td>
</tr>
<tr>
<td>A3</td>
<td>1</td>
</tr>
<tr>
<td>A4</td>
<td>NP</td>
</tr>
<tr>
<td>B1</td>
<td>NP</td>
</tr>
<tr>
<td>B2</td>
<td>NP</td>
</tr>
<tr>
<td>C</td>
<td>3</td>
</tr>
<tr>
<td>D</td>
<td>3</td>
</tr>
<tr>
<td>E</td>
<td>3</td>
</tr>
<tr>
<td>F1</td>
<td>1</td>
</tr>
<tr>
<td>F2</td>
<td>3</td>
</tr>
<tr>
<td>F3</td>
<td>4</td>
</tr>
</tbody>
</table>

Source: Kruszelnicki
Building height limits for wood buildings in selected countries

- Norway (No limit)
- UK (No limit)
- Austria (22m)
- Switzerland (6 storeys)
- Germany (18m)
- Canada (4 storeys)
- Finland (4 storeys)
- Russia (3 storeys)

Performance-based design approach
the timber buildings in Canada (plus many others) provide some degree of confidence that tall wood buildings are capable of meeting the multiple objectives of modern building codes. ......... but research is needed.
Presentation outline

- Research led by industry
- Research led by government
- Research led by FPInnovations
- Research led by universities

Funding & implementation

Government agencies and labs

Sci & Eng capacity & HQP development

Universities

Needs & Opportunities

Industry

Implementation & deployment
Government-led Research

Research program at NRC Construction Portfolio: Tall wood buildings (2013 - )
- Recently approved by NRC
Industry-led Research

Project: Wood and Wood-Hybrid Mid-rise Buildings (2012-2014)
- Research to support proposed change on storey limit for combustible construction in NBCC
- Fire and acoustic performance, with check on building envelope
- Focus on light wood frame and CLT
FPInnovations-led research

Advanced Building Systems Program (Ongoing)
- Innovative building systems e.g. CLT and heavy timber
- Fire, structural, durability and serviceability performance, and sustainability design
Advanced Building Systems Research Program

- Goal is to
  - maintain existing markets and
  - expand wood use in new applications
- Deployment mechanism - uptake of innovative wood solutions by the design and construction community

Existing Market

New Market
Building Systems – Focus is on tall and large buildings

Wood Building Systems

- Light Frame
- Post & Beam
- CLT
- Hybrid
Paradigm shift in introducing innovative wood building systems

R&D

BC Contracts

NRCan Programs

FPInnovations
Universities
NRC

Quebec Contracts

NSERC

Package Technical Solutions for Adoption

Early Adoption

Code Implementation

Concordia Handbook

National Building Code of Canada
Highlights Impact of 2012-13 – Relevant to tall wood buildings

- **Codes & Standards**
  - **CWC/NRC/FPI Mid-Rise Project**
    - NBCC code changes for combustible construction 4- to 6-storeys
  - **Support and/or evaluation of “Alternative” Solutions in BC and QC**
    - Assisted with the regulatory acceptance of several mid-rise buildings
  - **Fire Performance of CLT assemblies**
    - FPI/NRC test report used by AWC & APA to support implementation in US

- **Packaged Technical Tools**
  - **US CLT Handbook**
2013-14 Planned Activities – Hybrid Structures

- Hybrid Wood-Concrete Buildings
  - Prefabricated wood-concrete slabs
  - Podium structures (wood on concrete)

- Hybrid Steel-Wood Buildings
2013-14 Planned Activities - Fire performance

- CWC/NRC/FPI Mid-Rise Project
  - Address critical fire code-related issues & implementation of wood use in mid-rise (NBCC 2015) & potentially in tall buildings

- Performance-based Design Tools for tall and large wood buildings (e.g., Fire Risk Index) to replace prescriptive approach

Source: BC Government
2013/2014 Planned Activities - Sustainability

- LCA for emerging wood and hybrid systems and bio-products
2013-14 Planned Activities – Building Envelope

Energy Efficient Building Enclosure Design Guidelines
For Wood-Frame Multi-Unit Residential Buildings in Marine to Cold Climate Zones

CREE System - Austria

FFTT Concept - Canada
Holistic approach to building system research

Multi-disciplinary approach is required to ensure that:
- Required performance issues mandated by building code are addressed
- Solution developed to address one performance issue does not adversely affect others

Sustainable design

- Structural
- Fire
- Energy
- Durability
- Serviceability
University-led Research
NEWBuildS

• Network on Engineered Wood-based Building Systems
• 5-year research program (2010-2015) to increase use of wood in mid-rise construction
• Alignment with FPInnovations’ Advanced Building Systems research program
• A collaborative effort between universities and FPInnovations, CWC, NRC and industry
Network Statistics

- 25 professors from 13 universities
- 17 scientists from FPInnovations
- 2 scientists from NRC
- 37 projects
- 70 graduate students and PDF’s
Research program

Basket 1
Consolidation of market

Basket 2
Innovative building solutions

Projects

Light wood frame buildings
Address the gaps going from low to mid-rise buildings (BC in 2009, National 2015??)

Heavy timber construction
CLT or combining wood with other materials (hybrid) in an innovative way
Selected NEWBuildS Projects

• Potentially contributing to design and construction of tall wood buildings:
  – Structural performance
  – Seismic response
  – Fire resistance
  – Building envelope durability
  – Treatment for second-line of defense
Structural performance – CLT sub-systems (3 projects)

- In-plane stiffness and strength of CLT diaphragms (T1-7-C3)

Diaphragm flexibility affects building drift and load distribution to walls.
Structural performance – CLT sub-systems

• In-plane stiffness and strength of CLT diaphragms (T1-7-C3)

• Stability of CLT wall panels under gravity loading (T1-9-C1)

Thin CLT wall panel may lead to buckling failure – problem more acute for taller buildings
Structural performance – CLT sub-systems

- In-plane stiffness and strength of CLT diaphragms (T1-7-C3)
- Stability of CLT wall panels under gravity loading (T1-9-C1)
- Force transfer around openings in walls subjected to in-plane loading (T1-8-C1)

How to design and how does opening affect in-plane behaviour?
Structural performance – CLT connections

• Connections in CLT construction (T1-11-C1)

  – Contribution to the development of CLT connection design values in CSA O86
  – Embedment, lateral and withdrawal strength for selected fasteners
Seismic response – CLT buildings

- Seismic response of mid-rise CLT buildings (T1-5-C1)
  - To develop 3-d modelling approach (non-linear) to predict seismic response of CLT buildings
  - Adoption of structural reliability concept
Seismic response – Self-centering and energy dissipation

• Innovative post-tensioned CLT walls (T1-10-C1)

– To explore the adoption of the self-centering/damage fuse concept to CLT wall construction to resist seismic load

Source: Deierlein et al 2005
Implemented by researchers from Univ. of Canterbury, NZ

Marlborough Institute of Technology, Nelson, NZ - 3-storey structure, completed in December 2010

Source: nzwood.co.nz
Seismic response – System seismic force modification factor for hybrid structure (2 projects)

Sub-system 1

Sub-system 2

3-d non-linear dynamic analysis - Drift and collapse assessment
Seismic response – System seismic force modification factor for hybrid structures (2 projects)

- Steel-frame multi-material tall hybrid systems (T2-3-C4)
  - Development of connection details

Structural steel frame with wood panels as in-fill walls
Seismic response – Natural period of wood buildings

- Lateral drift and natural period of mid-rise wood and hybrid buildings (T2-5-C2)
- Field measurement and modelling

Applicability to wood buildings?
Fire Resistance – CLT assemblies

- Fire behaviour of cross laminated timber panels (T3-3-C7, Carleton & NRC)
  – Thesis project 1
- Understanding contribution of CLT panels to room fire
Room test details

<table>
<thead>
<tr>
<th>Test #</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protected</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Fire load</td>
<td>Propane</td>
<td>Furniture</td>
<td>Propane</td>
<td>Furniture</td>
<td>Furniture</td>
</tr>
<tr>
<td>Joint sealed</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Smoke detector</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Sprinkler indication</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

Room dimensions: 3.5m x 4.5m x 2.5m
CLT panels are 3-ply 105mm thick
Test 1 – active burning

- 42 min at 1100°C
- 47 min at 850°C
- 54 min at 675°C
Fire Resistance – CLT assemblies

- Fire behaviour of cross laminated timber panels (T3-3-C7)
  - Thesis project 2
    - Model to predict load-carrying capacity of CLT floor under fire
    - Data contributed to development of charring-rate design method currently being considered for CSA O86
Research approach – Mid- and full-scale test facilities

NRC Full-Scale Fire Testing Floor Furnace Under UDL
- 4.7m x 3.6m specimen

Carleton University Mid-Scale Fire Testing Floor Furnace under 4-point load
- 4.7m x 1.0m specimen
Research approach – test program

<table>
<thead>
<tr>
<th># of Plies in CLT</th>
<th>Type X Gypsum</th>
<th>Fire</th>
<th>Model Prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>-</td>
<td>CAN/ULC</td>
<td>67 min</td>
</tr>
<tr>
<td>3</td>
<td>1x 5/8”</td>
<td>CAN/ULC</td>
<td>96 min</td>
</tr>
<tr>
<td>3</td>
<td>2x 1/2”</td>
<td>CAN/ULC</td>
<td>116 min</td>
</tr>
<tr>
<td>3</td>
<td>2x 1/2”</td>
<td>Non-Std*</td>
<td>83 min</td>
</tr>
<tr>
<td>5</td>
<td>-</td>
<td>CAN/ULC</td>
<td>104 min</td>
</tr>
<tr>
<td>5</td>
<td>-</td>
<td>Non-Std</td>
<td>111 min</td>
</tr>
<tr>
<td>5</td>
<td>1x 5/8”</td>
<td>CAN/ULC</td>
<td>130 min</td>
</tr>
<tr>
<td>5</td>
<td>1x 5/8”</td>
<td>Non-Std</td>
<td>98 min</td>
</tr>
</tbody>
</table>

* Non-standard fire load from room test in project 1
Fire Resistance - Fire Risk Model Development

• Fire Risk Analysis (T3-1-C8)

- Fire Risk Model (CUrisk) to calculate probability of specific fire scenarios and their consequences

- Model can be used for
  • evaluating alternative solution
  • supporting new fire provisions
Case study

- 6 storeys, floor height 3 meters
- 6 apartments each floor

Source: Li 2012
Case study – Storey and Apartments

• For each storey
  ➢ 2 stairway shafts, 5.5 x 3m
  ➢ 2 elevator shafts
  ➢ 1 corridor, 24 by 1.5 m
  ➢ 2 public zones

• For each Apartment
  ➢ 8 x 8 m, 5 Rooms
  ➢ Living room (12), Master Bedroom (15), Small Bedroom (14), Bathroom (13), Kitchen (11)
  ➢ 2 Windows, 1.5 x 1.5m each
  ➢ 5 Doors, 0.9 x 2.0m each

Source: Li 2012
Case study - Fire in a room

2nd Floor
Living Rm (11)
Medium fire
Max HRR = 6MW

Fire Origin Room (11) at 2nd Floor
- No Fire Protection
- with Sprinklers
- with Fire Department
- with Sprinklers and Fire Depart.

Source: Li 2012
Long-term goal – Shift in design philosophy

• Current building code requirements are prescriptive

• Move towards performance-based approach
  – rely on fire modelling tool such as CUrisk
  – Fire Safety Index – take into account contribution from various fire fighting measures
Building Envelope Durability – Characterizing key moisture source

- Characterizing wind-driven rain load on mid-rise buildings (T4-6-C10)
  - Focus on effectiveness of overhang
Research approach

- Characterizing wind-driven rain pattern with and without overhang
  - Field measurement – 3 buildings across the country
  - Computational Fluid Dynamic model accounting for overhang sizes, building geometry, rain droplet size, wind speed, etc
Building Envelope Durability – Hygrothermal performance of CLT wall construction

- Developing durable building envelope assemblies for CLT construction (T4-5-C10)
  - Development of construction details for moisture management through CLT wall
    - Long-term hygrothermal test
    - Hygrothermal modelling
  - Drying performance of CLT
Research approach

• CLT wall panels with different details - hygrothermal performance over 12 months

Interior of wall before drywall installation - 16

U. of Waterloo BEGhut Test Facility
Research approach

• Modelling to supplement field testing – effects of climate, wall permeance, etc
Second-line of defense - Durability

- Borate pretreatment to protect building envelope components from decay and mould (T4-4-C11)
- Use of boron rods, which release treatment chemical when a certain moisture level is reached
Research approach

- Diffusion of chemical through wood in different directions
- Strategic application of boron rods on CLT – locations in product and in building assemblies
Second-line of defense - Fire

- Intumescent coating to protect engineered wood products (T4-3-C11)

  - To identify effective intumescent coating products, focusing on long-term durability and method of evaluating effectiveness of products

  Volume expands by 50-200 times to insulate substrate from heat source
Research approach

- Evaluation of 4 commercial coating products
  - Thermal (TGA and DSC) and flammability (flame spread and cone calorimeter) test

![Graph showing flame spread versus basis weight for different coatings]

- Two-foot tunnel test
Few comments on future research needs
Future research needs –
1. Construction management

- Reduced construction cost
- Protection from fire and moisture during construction

Is this overkill?
Future research needs – 1. Construction management

A Modular High-Rise

The developer of Atlantic Yards in Brooklyn is exploring plans to build what would be the tallest prefabricated steel structure in the world, a 34-story apartment building. The “modules” could be built in a factory and bolted together on-site, as in this hypothetical section:

- Each module has its own steel frame, providing structural integrity for the building.
- After delivery by truck, individual modules are put into place by crane.
- Modules may include bathrooms and kitchens.

Modular construction – capitalizing on wood’s attributes
Future research needs –

2. Minimizing perpendicular to grain movement

- Relatively large movement due to low transverse modulus and shrinkage/swelling
- Movement cumulative with height
- Could swelling be an issue?
Future research needs –
2. Minimizing perpendicular to grain movement
- Innovative detailing is required
Future research needs –
3. Whole building vibration –
occupant discomfort

Probability Distribution of Frequencies for Wind and Earthquakes

- Human sensitive range – 1 - 3 Hz
- Normal Buildings
- High Rise Buildings

(adapted from Augusti et al., 1984)
Future research needs – 4. Connection

- Making strong and stiff wood connection is always a challenge
- Connection design likely dictates maximum height of wood building from a structural standpoint
- New connection systems are desirable
Thank you and Questions?

More information on projects can be found at www.NEWBuildsSCanada.ca