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

Y. H. Chui
University of New Brunswick

Scientific Director
NSERC Strategic Network on Innovative Wood Products and Building Systems
(NEWBuildS)

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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

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Appearance of these buildings – brick, timber posts & beams

Source : FPInnovations

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Some structural details from inside

Post & Beam with wood planks

Joisted floor with wood decking on secondary floor beams

Source : FPInnovations

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

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The introduction of modern building codes (NBCC 1941) placed a limit on building height for different construction………

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1941 edition of NBCC

Source : Michael Kruszelnicki

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

Occupancy Group	Division	Description	Maximum Permissible Building Height for Construction Type *Height in Storeys (Height in Feet)*			
			Type 2 Heavy Timber	Type 3 Masonry & Frame	Type 4 Wood Frame	Type 5 Unprotected metal or Fire-Retardant Treated Wood
A	1	Theatres	3 (45-feet)	2 (35-feet)	1 (35-feet)	1 (35-Feet)
	2	Auditoriums, Community halls	4 (55-feet)	3 (45-feet)	1 (35-feet)	1 (not specified)
B	1	Asylums, Jails	NP	NP	NP	NP
	2	Child Shelters, Hospitals	3 (45-feet)	2 (35-feet)	1 (35-feet)	1 (not specified)
C	1	Dry Cleaning Plants using explosive solvents	NP	NP	NP	NP
	2	High Hazard Industrial	3 (45-feet)	2 (35-feet)	1 (25-feet)	1 (not specified)
	3	Medium Hazard Industrial	4 (55-feet)	3 (45-feet)	2 (35-feet)	1 (not specified)
		Office buildings	Not Specified (75-feet)	4 (55-feet)	2 (35-feet)	1 (not specified)
	4	Low Hazard Industrial	Not Specified (75-feet)	4 (55-feet)	2 (35-feet)	1 (not specified)
D	1	Convents and Dormitories	4 (55-feet)	3 (45-feet)	1 (35-feet)	1 (not specified)
	2	Apartments and Hotels	4 (55-feet)	3 (45-feet)	2 (35-feet)	1 (not specified)
	3	one- and two-family dwellings	4 (55-feet)	3 (45-feet)	3 (40-feet)	1 (not specified)
E	1	Private barns & Garages	Not Specified (55-feet)	Not Specified (45-feet)	Not Specified (20-feet)	Not Specified (45-feet)
	2	Towers, Water tanks, etc.	unlimited	unlimited	unlimited	unlimited
	3	Stands & Stadiums	Not Specified (55-feet)	Not Specified (45-feet)	Not Specified (35-feet)	Not Specified (45-feet)

1953 Edition of NBCC

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

Group	Building Height Limit	
	Non-Sprinklered	Sprinklered
A1	NP	1
A2	2	2
A3	1	1
A4	NP	NP
B1	NP	NP
B2	NP	2
C	3	4
D	3	4
E	3	4
F1	1	2
F2	3	4
F3	4	4

Source : Kruszelnicki

- 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

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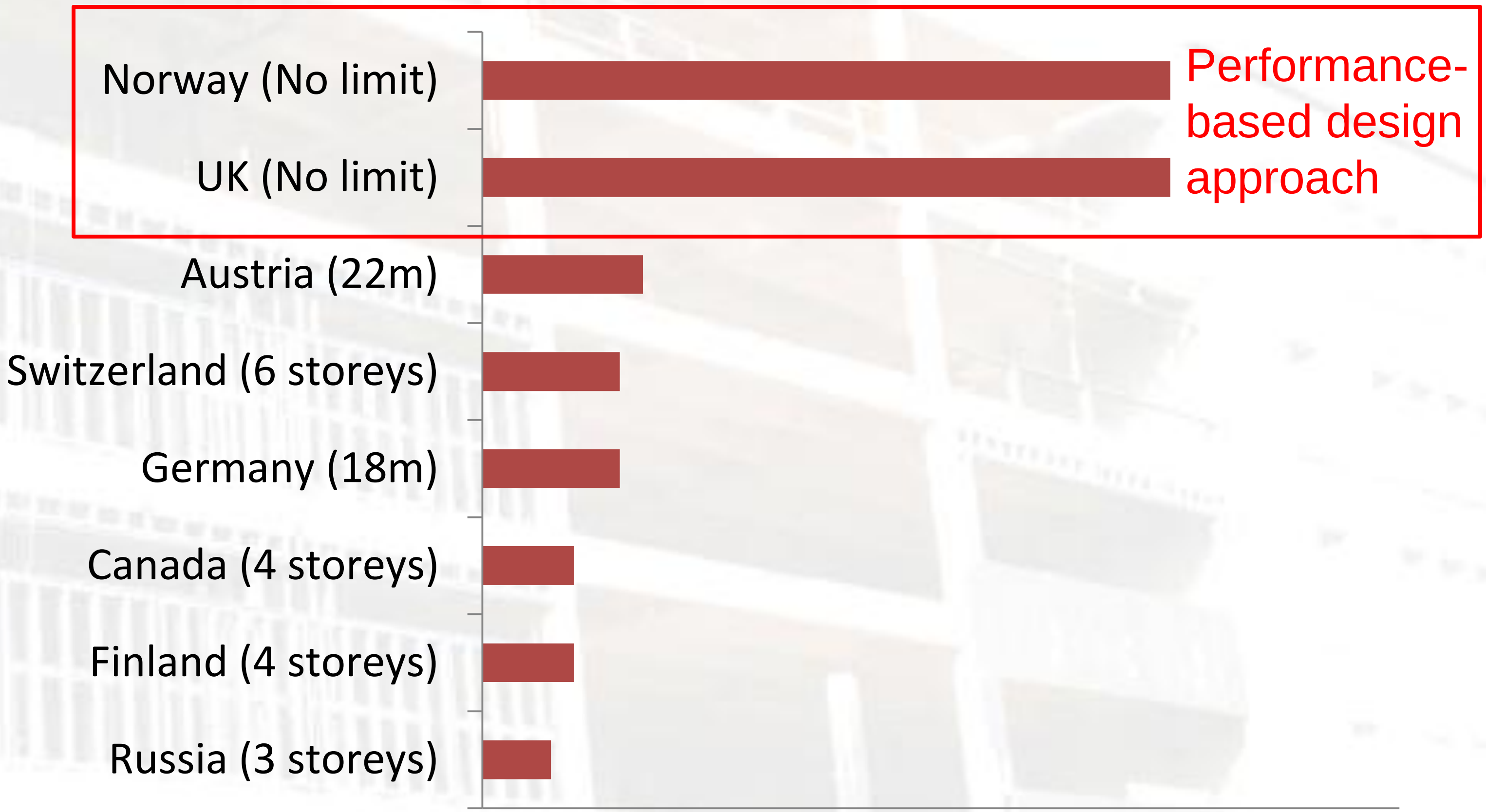
Building height limits for wood buildings in selected countries



………… 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.

10-Storey hotel building in Oakland, USA (1903)

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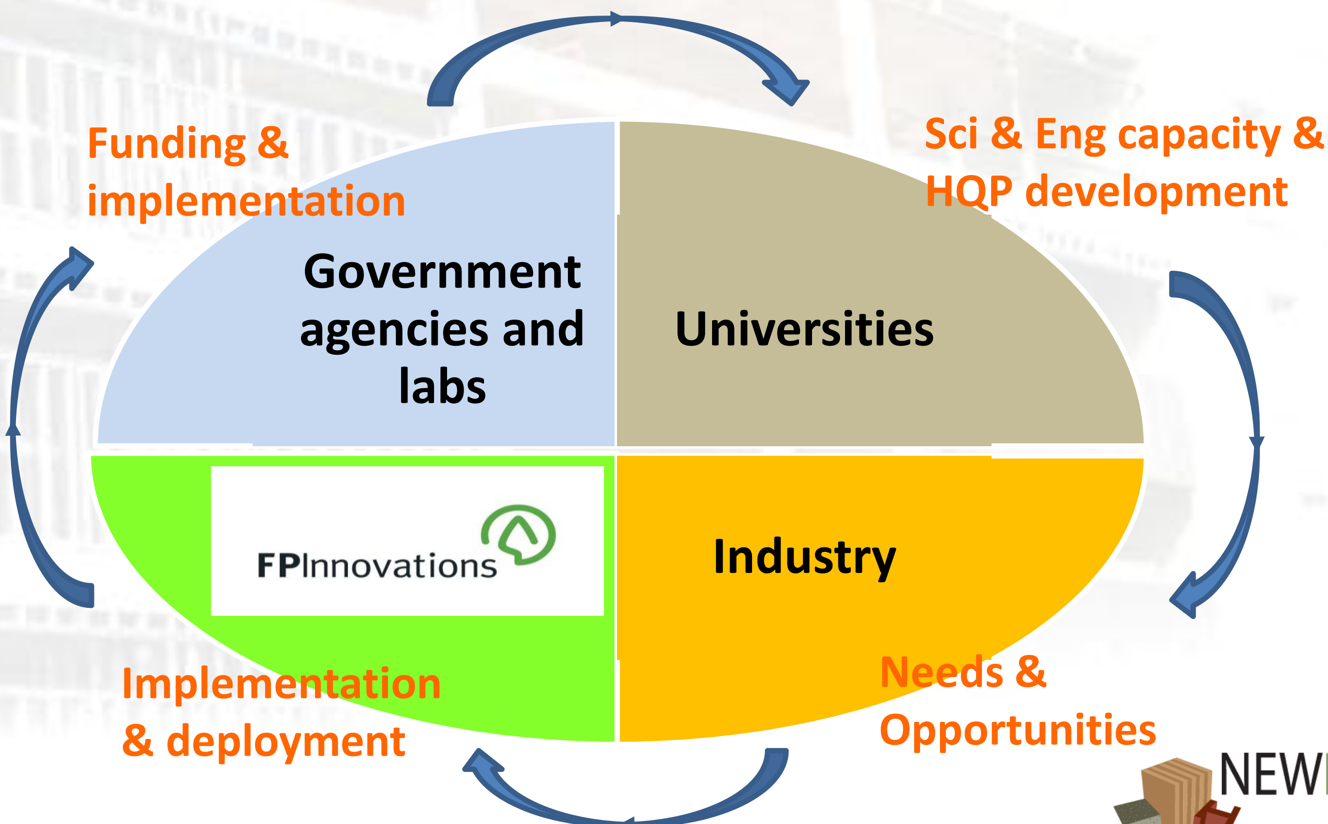
Presentation outline

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



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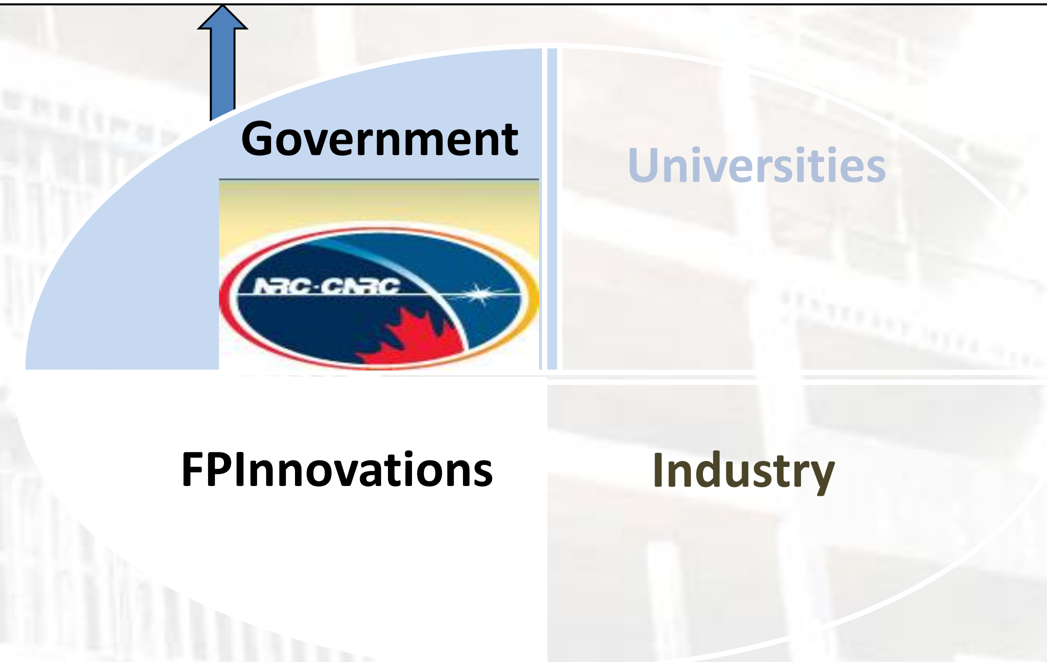
Government-led Research

Research program at NRC Construction Portfolio : Tall wood buildings (2013 -)

- Recently approved by NRC



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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

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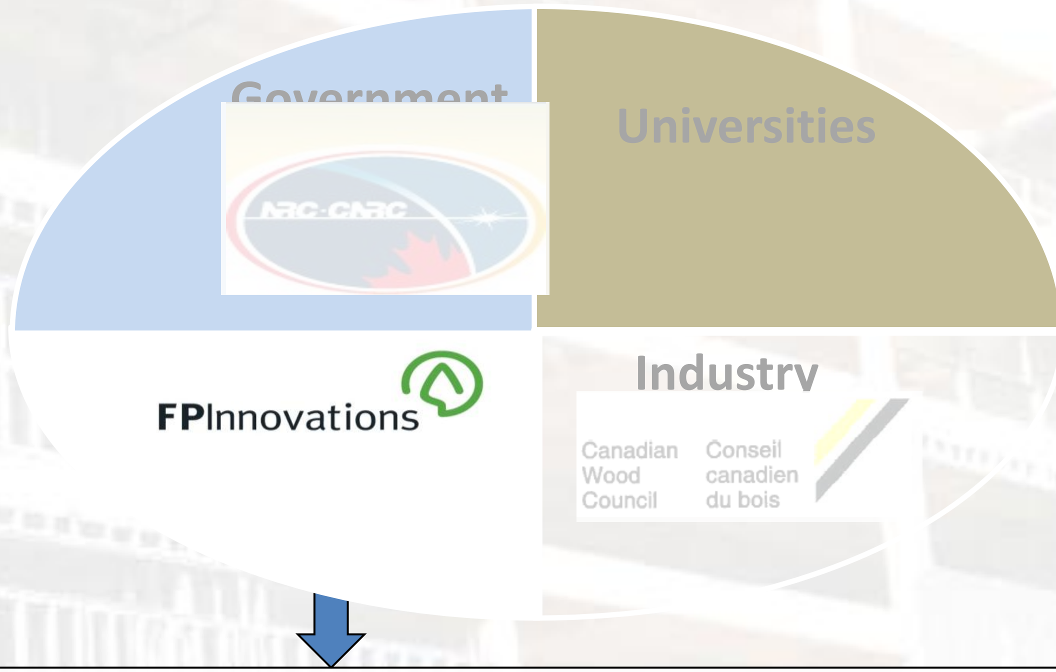
FPInnovations-led research



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

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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

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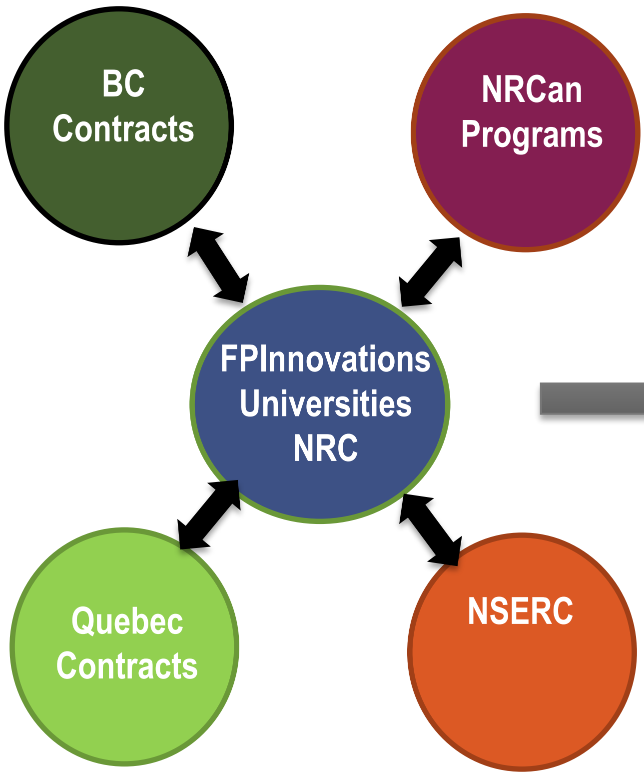
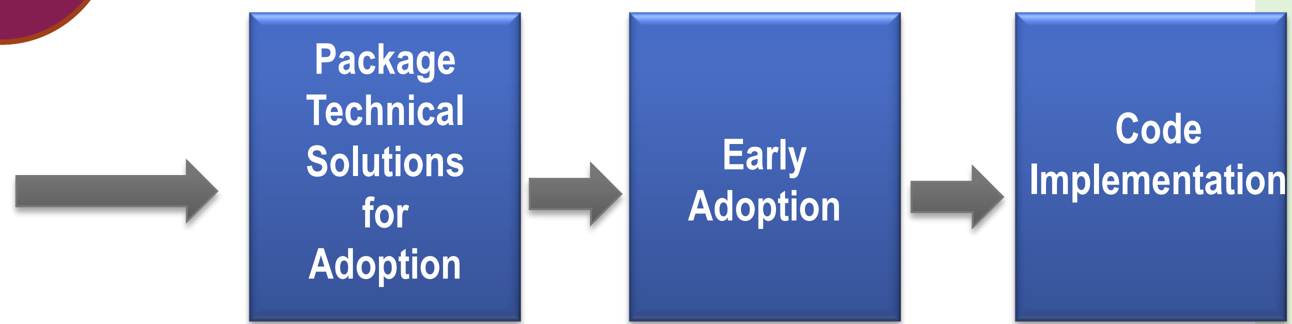
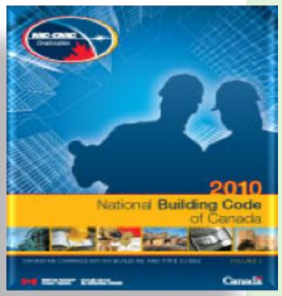
Paradigm shift in introducing innovative wood building systems

R&D







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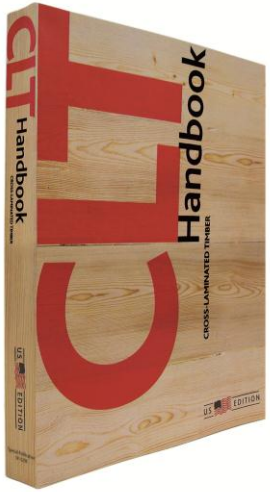
Highlights Impact of 2012-13 – Relevant to tall wood buildings

- **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**



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2013-14 Planned Activities – Hybrid Structures

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

- **Hybrid Steel-Wood Buildings**

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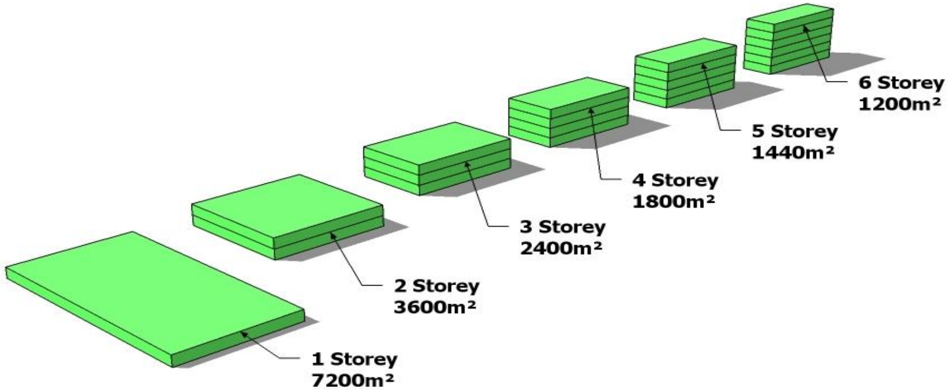
2013-14 Planned Activities - Fire performance

- 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

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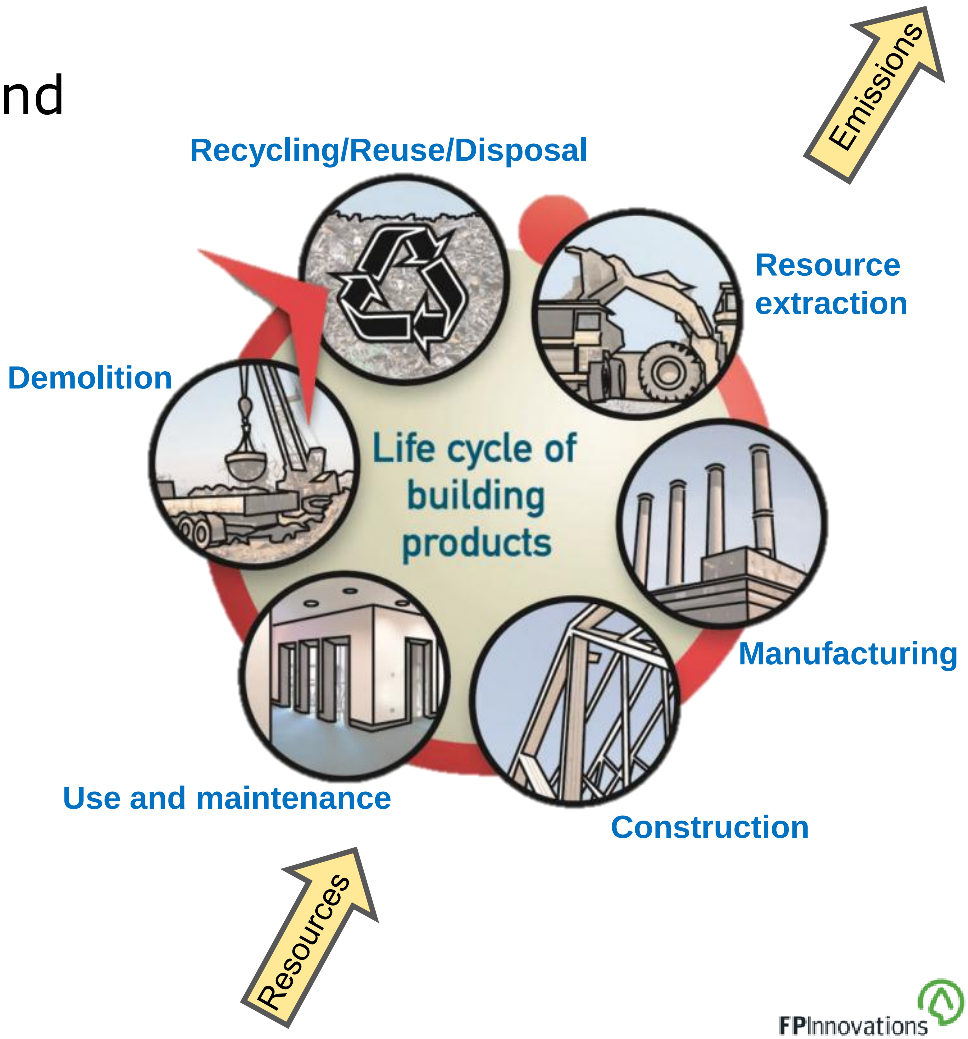
2013/2014 Planned Activities - Sustainability

- LCA for emerging wood and hybrid systems and bio-products



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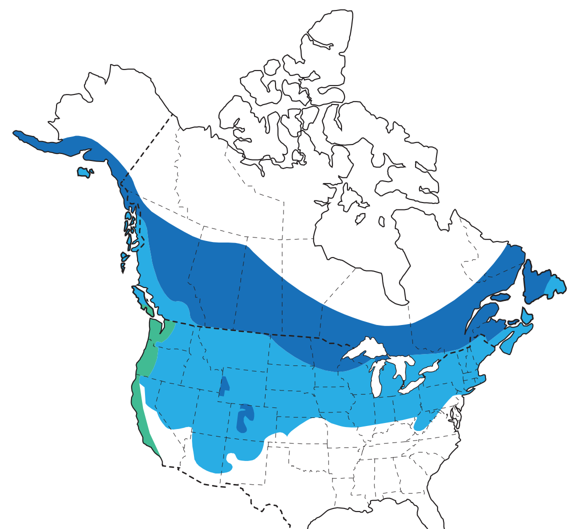
2013-14 Planned Activities – Building Envelope

Energy Efficient Building Enclosure Design Guidelines

For Wood-Frame Multi-Unit Residential Buildings in Marine to Cold Climate Zones



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Development of a Technical Guide for Tall Wood Buildings – To be completed in 2013

CREE System - Austria

FFTT Concept - Canada

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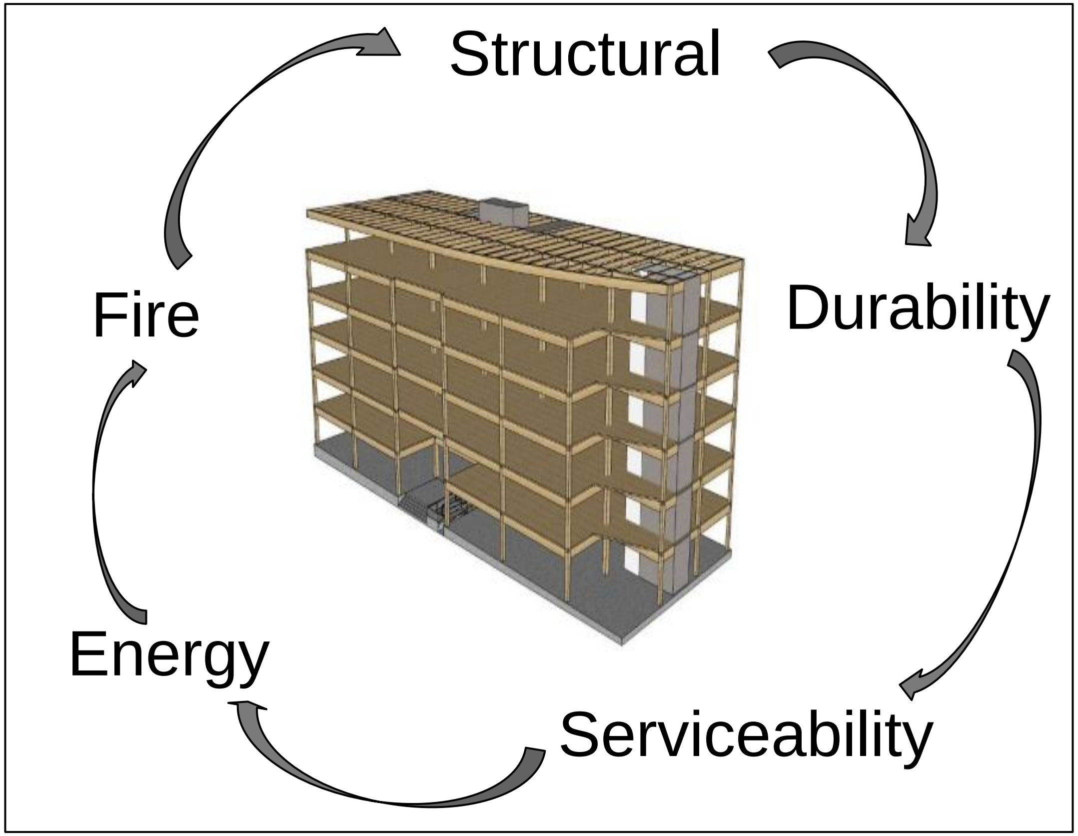
Holistic approach to building system research

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



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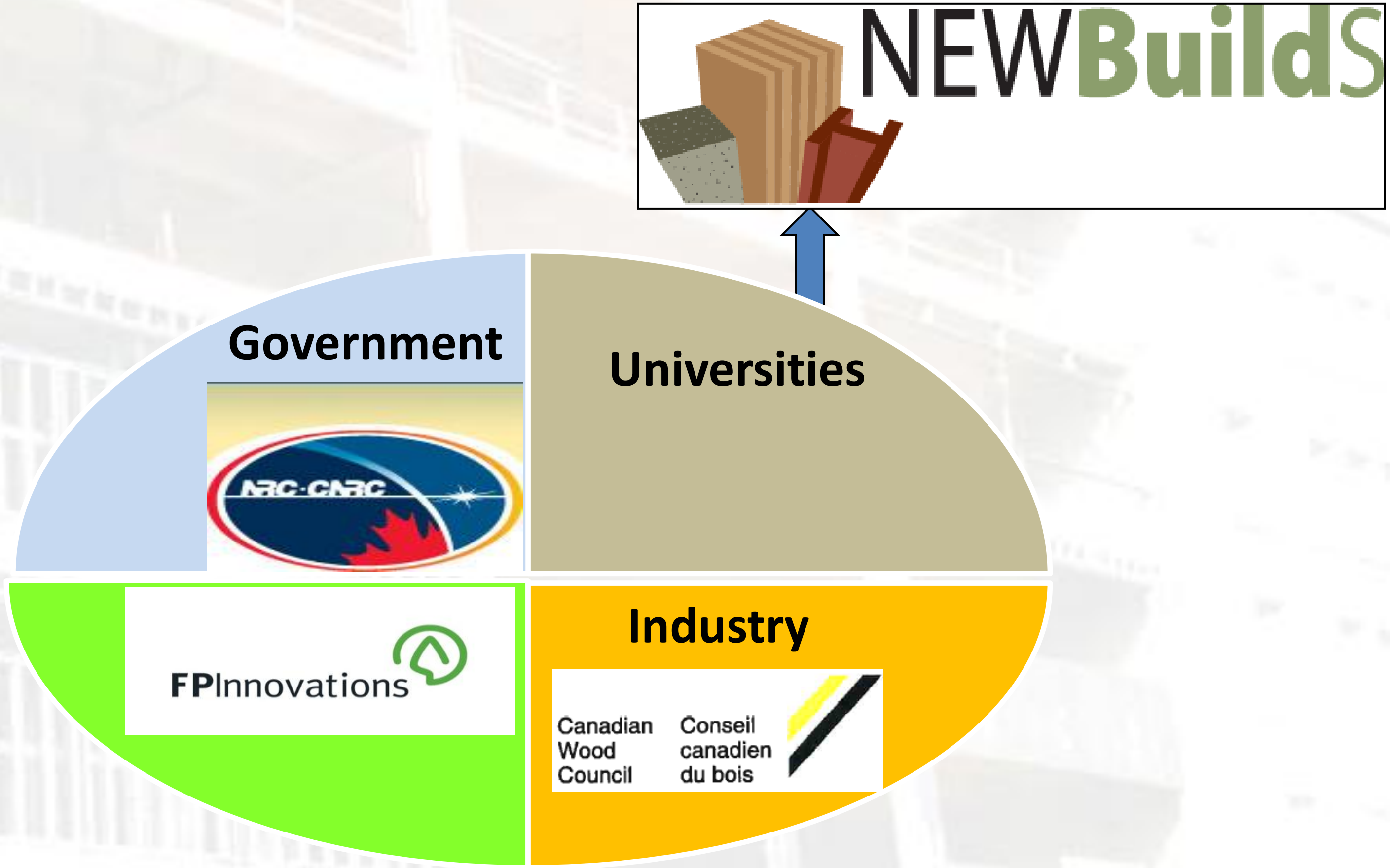
University-led Research



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- **N**etwork on **E**ngineered **W**ood-based **Build**ing **S**ystems
- 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

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Network Statistics

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

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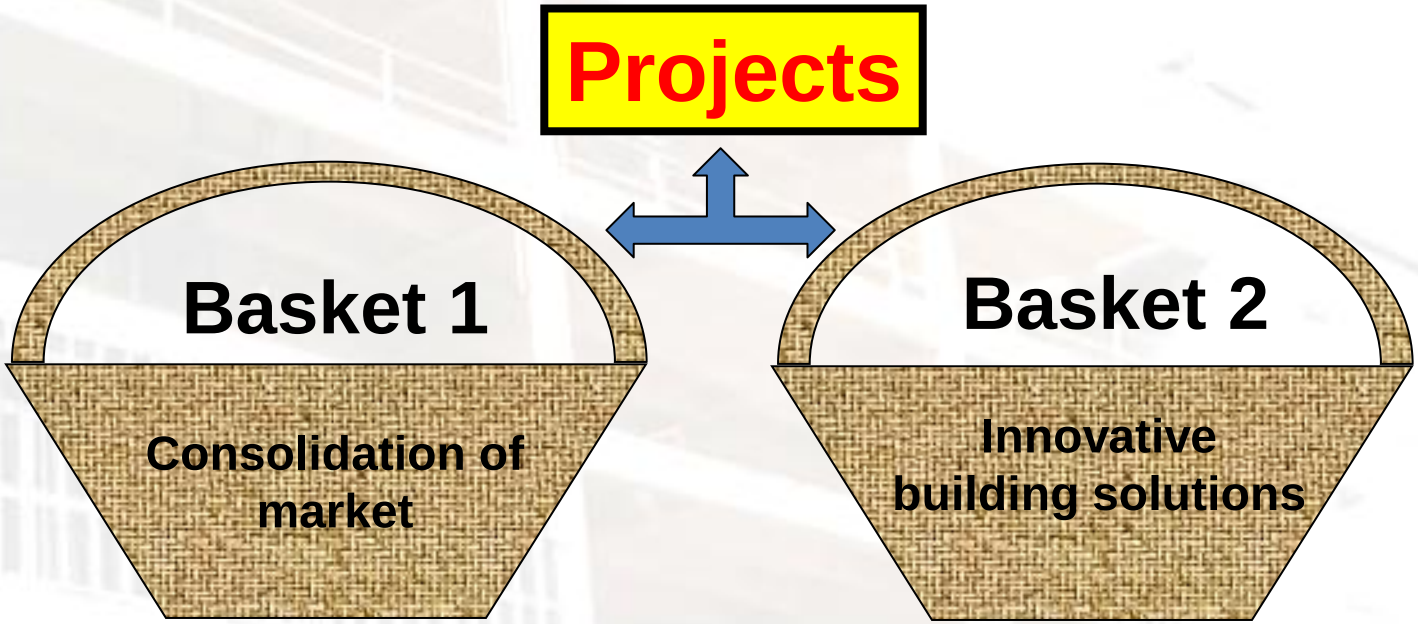
Research program



Light wood frame buildings

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

Heavy timber construction

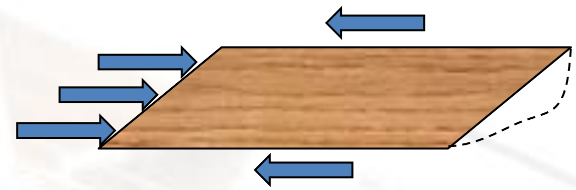
CLT or combining wood with other materials (hybrid) in an innovative way

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

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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

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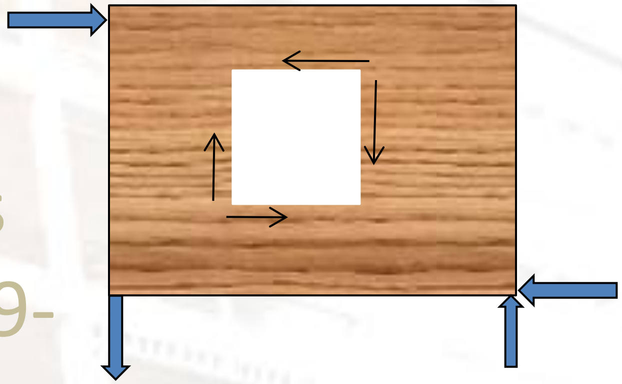
Structural performance – CLT sub-systems

- 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

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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

SOFIE 7-storey CLT building test

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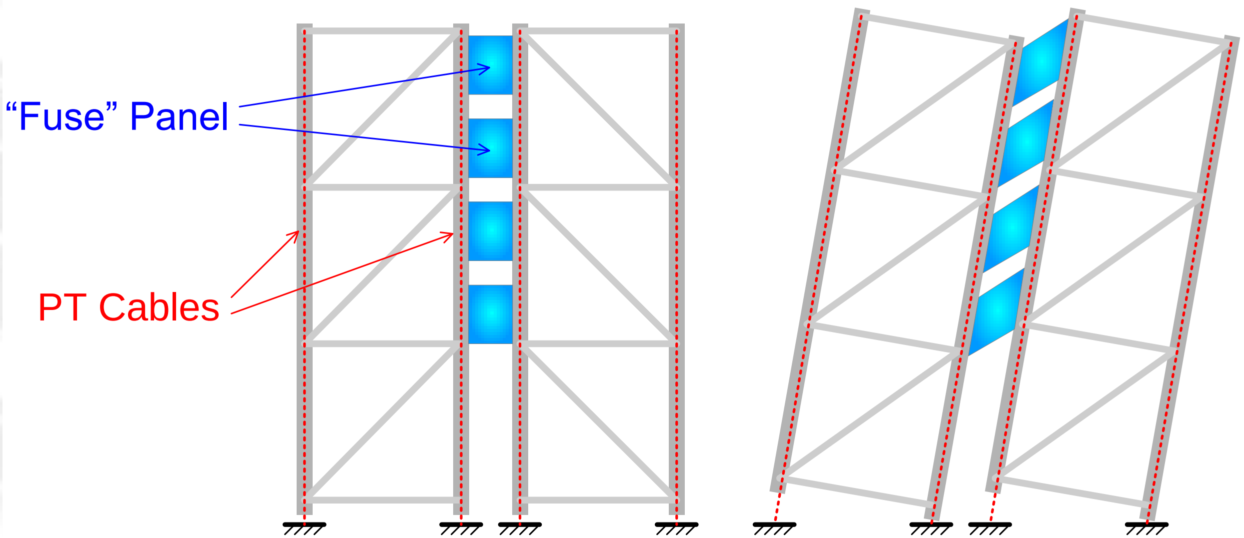
Seismic response – Self-centering and energy dissipation

- 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



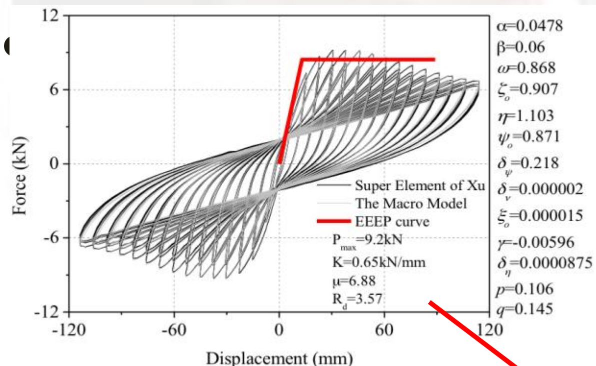
Source : Deierlein et al 2005

Implemented by researchers from Univ. of Canterbury, NZ

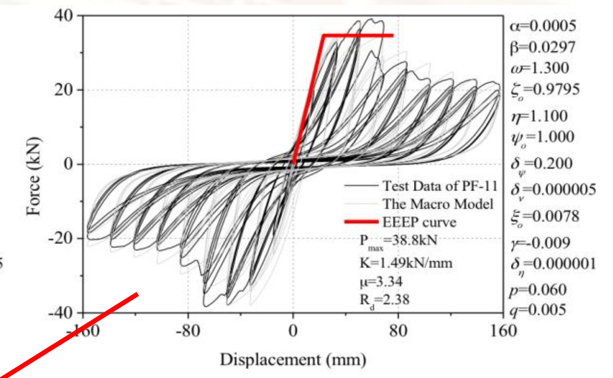
Marlborough Institute of Technology, Nelson, NZ
- 3-storey structure, completed in December 2010

Source : nzwood.co.nz

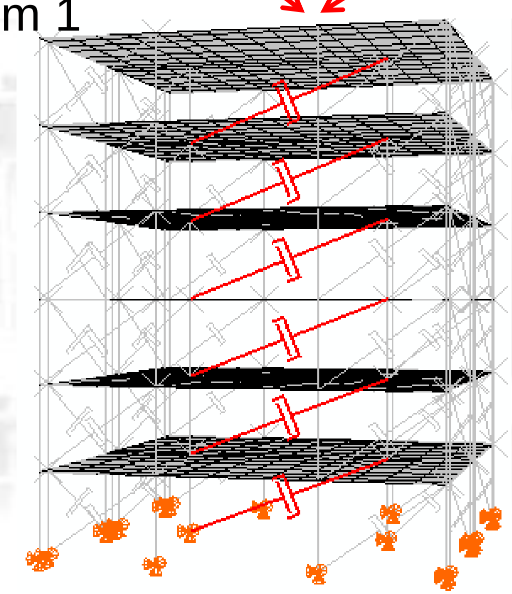
Seismic response – System seismic force modification factor for hybrid structure (2 projects)



Sub-system 1



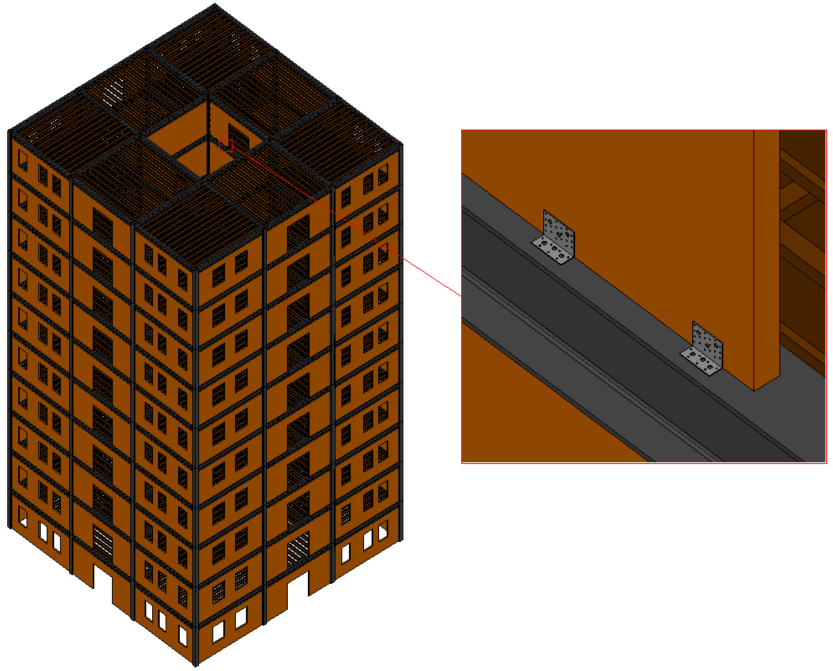
Sub-system 2



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

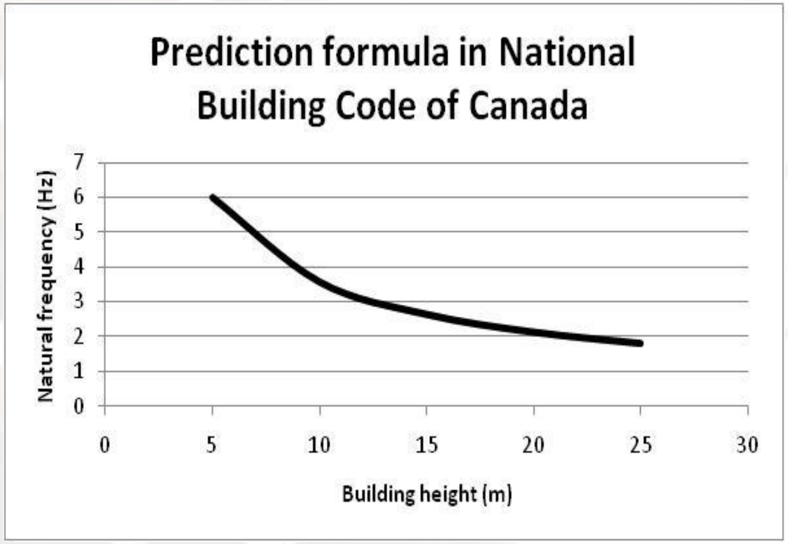


Structural steel frame with wood panels as in-fill walls

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?

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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

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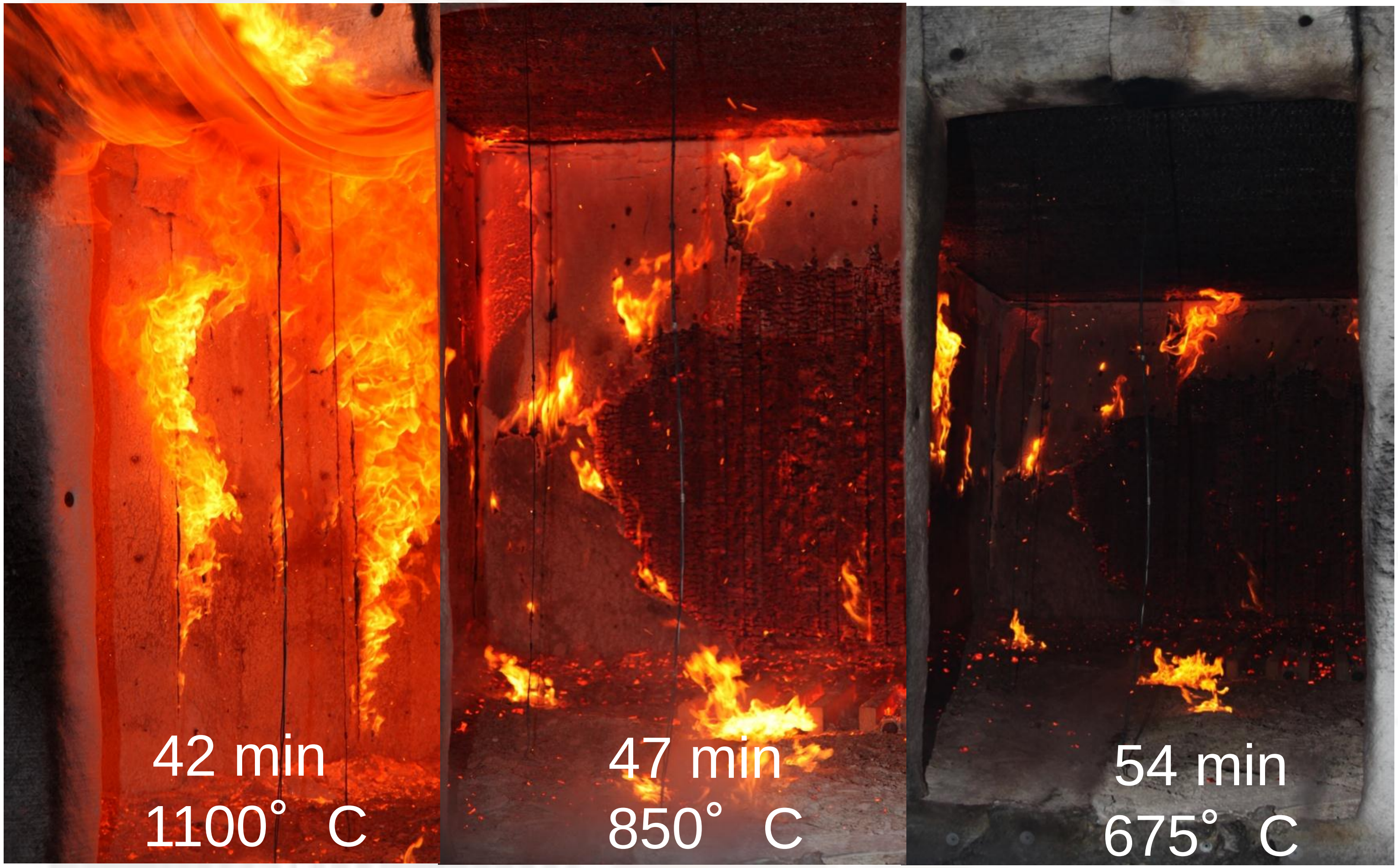
Room test details

Test #	1	2	3	4	5
Protected	Yes	Yes	No	Yes	No
Fire load	Propane	Furniture	Propane	Furniture	Furniture
Joint sealed	No	Yes	Yes	Yes	Yes
Smoke detector	No	Yes	No	Yes	Yes
Sprinkler indication	No	Yes	No	No	No

Room dimensions: 3.5m x 4.5m x 2.5m
CLT panels are 3-ply 105mm thick

Test 1 – active burning



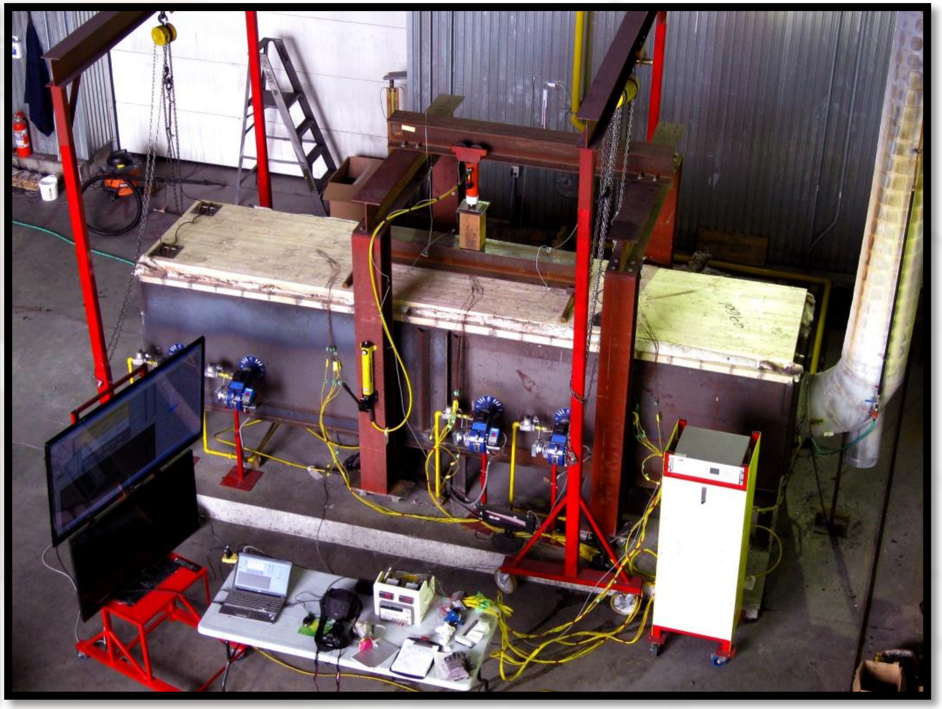
Fire Resistance – CLT assemblies

- 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

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Research approach – test program

# of Plies in CLT	Type X Gypsum	Fire	Model Prediction
3	-	CAN/ULC	67 min
3	1x 5/8"	CAN/ULC	96 min
3	2x 1/2"	CAN/ULC	116 min
3	2x 1/2"	Non-Std*	83 min
5	-	CAN/ULC	104 min
5	-	Non-Std	111 min
5	1x 5/8"	CAN/ULC	130 min
5	1x 5/8"	Non-Std	98 min

* Non-standard fire load from room test in project 1

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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

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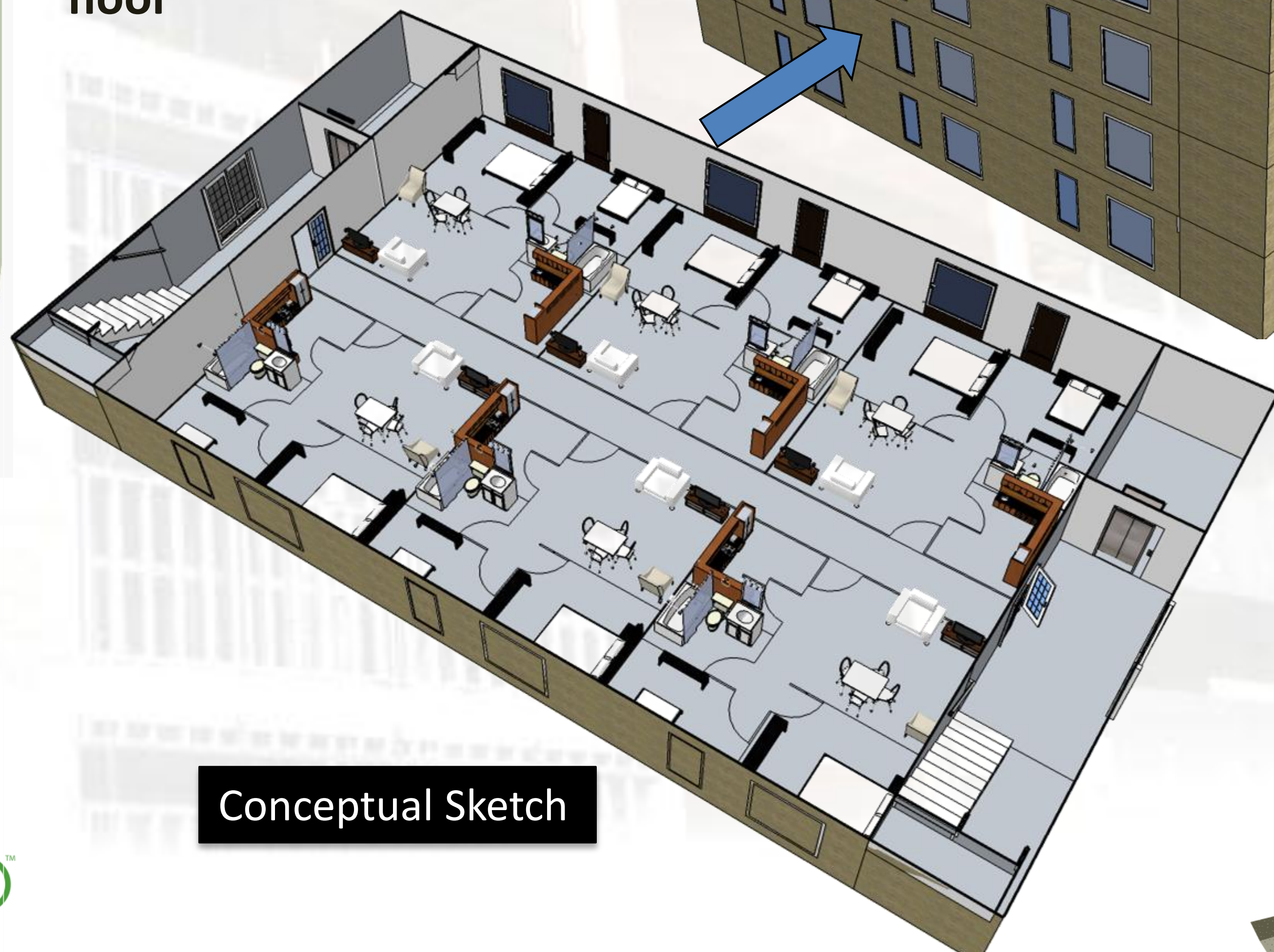
Case study

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



Conceptual Sketch

Source : Li 2012

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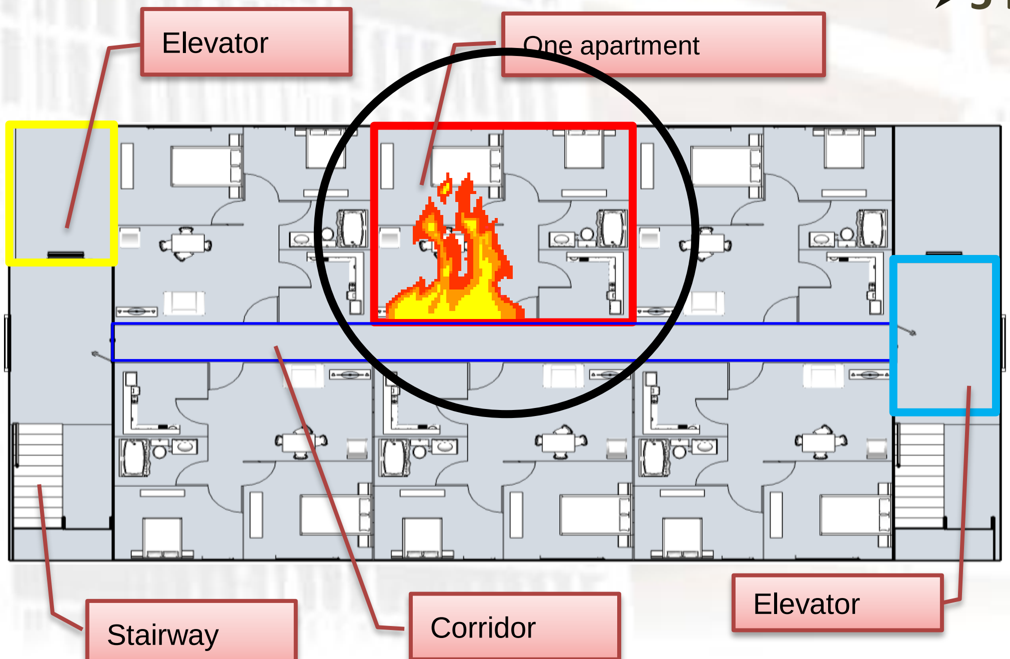
Case study – Storey and Apartments

- 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

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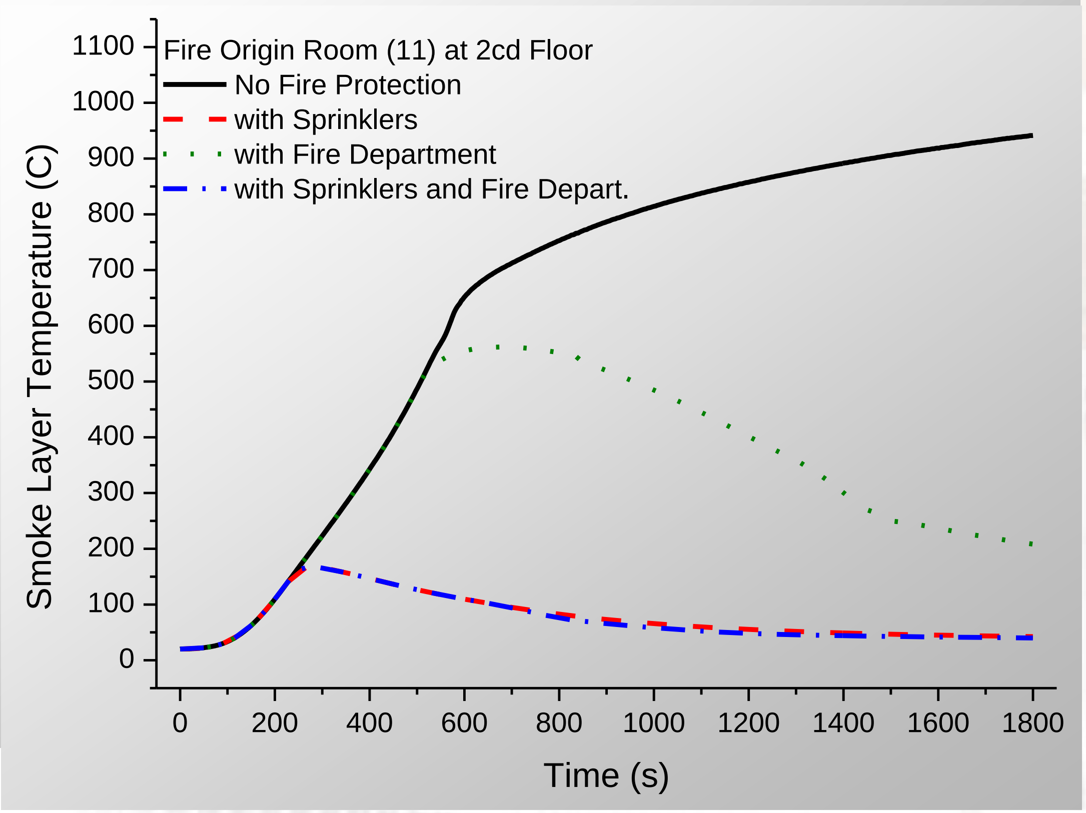
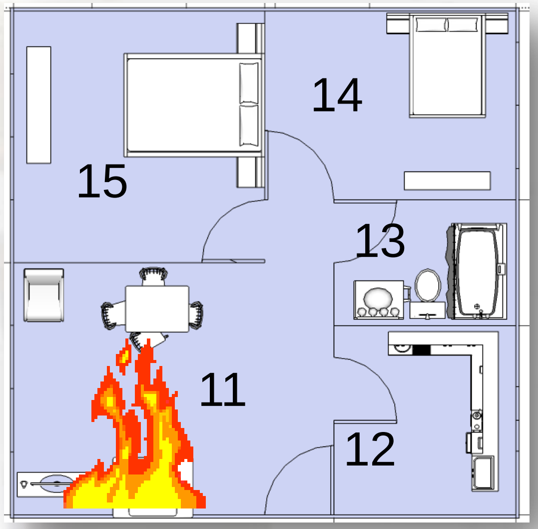
Case study - Fire in a room



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



Source : Li 2012

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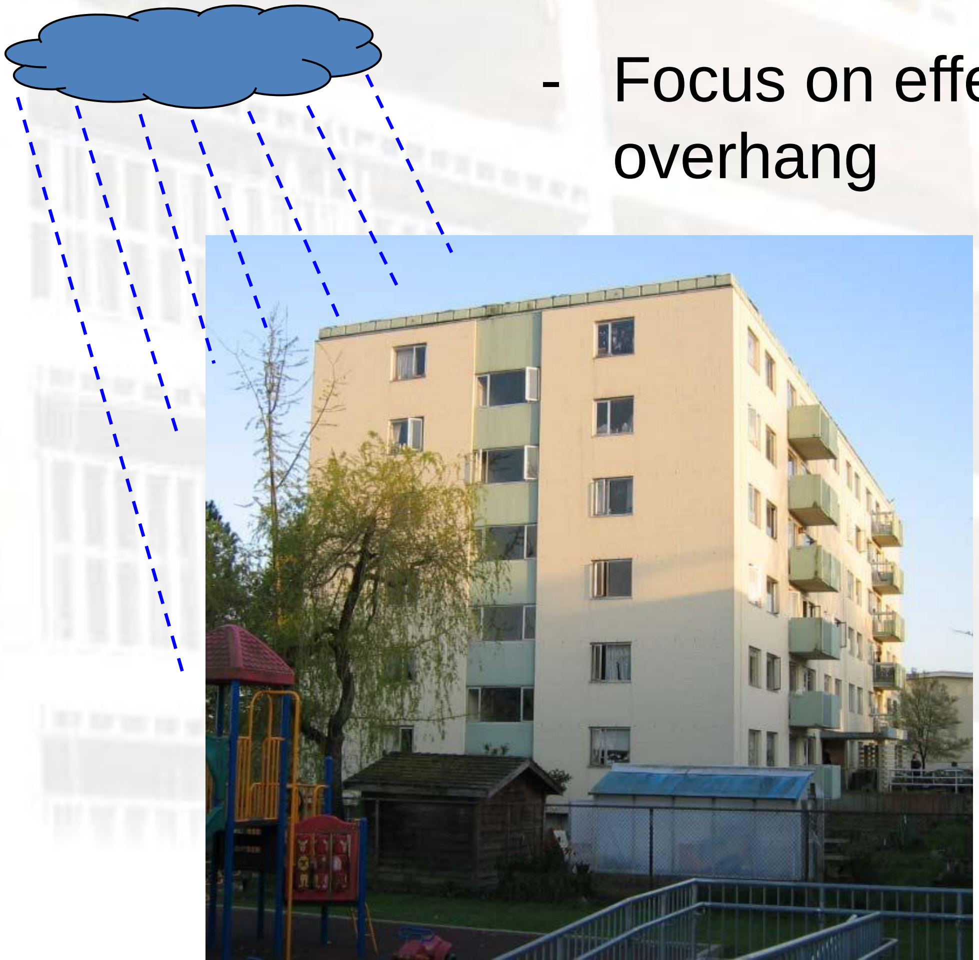
Long-term goal – Shift in design philosophy

- 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



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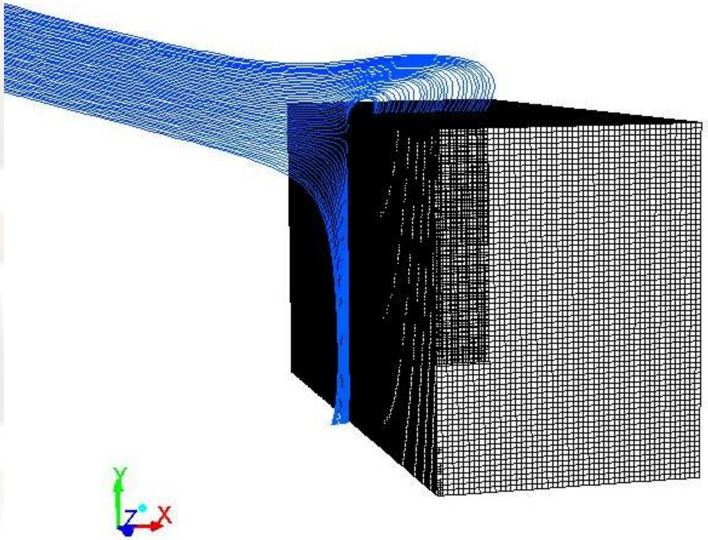
Research approach

- 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



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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

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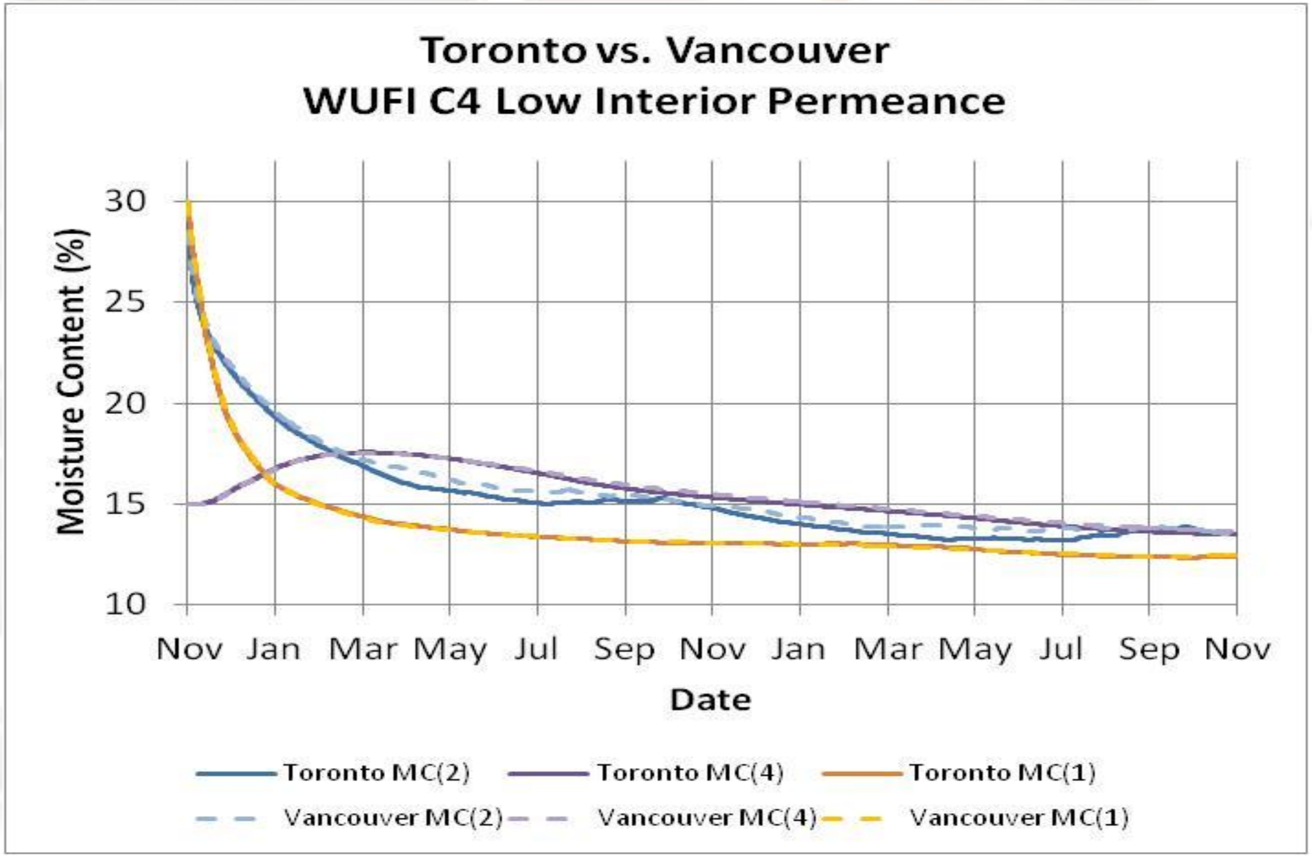
Research approach

- Modelling to supplement field testing – effects of climate, wall permeance, etc



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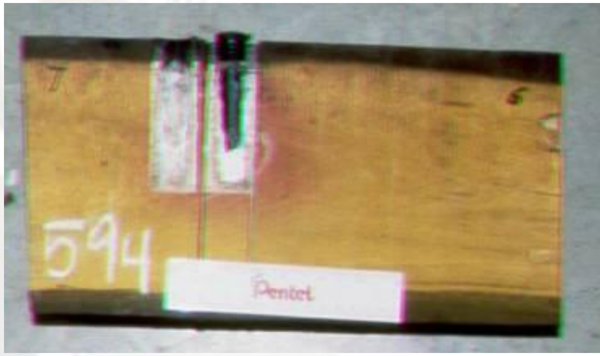
Second-line of defense - Durability

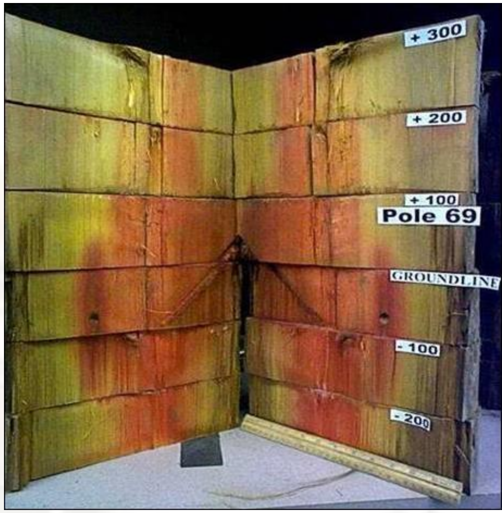
- Borate pretreatment to protect building envelope components from decay and mould (T4-4-C11)

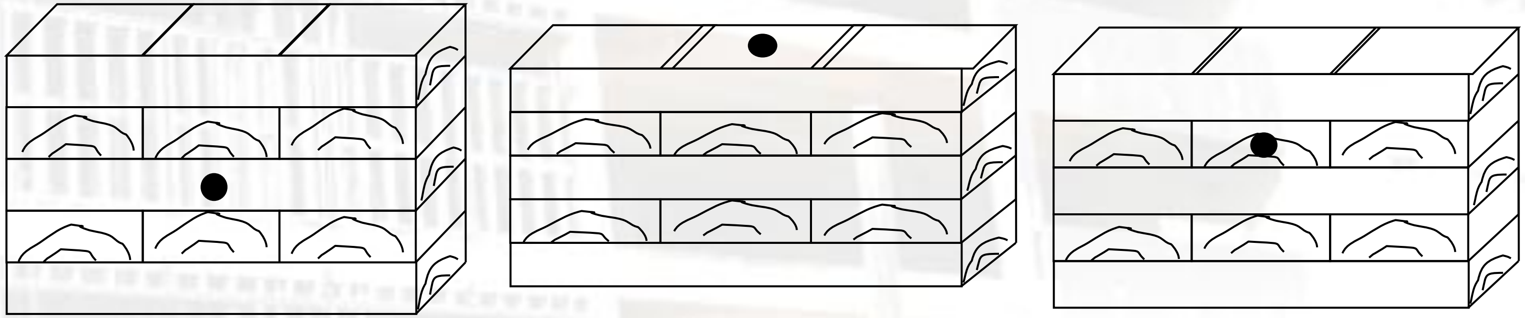
  - Use of boron rods, which release treatment chemical when a certain moisture level is reached



Research approach

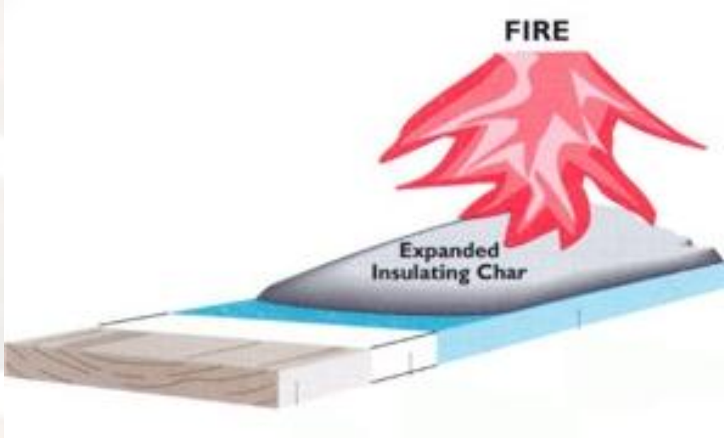
- Diffusion of chemical through wood in different directions
- Strategic application of boron rods on CLT – locations in product and in building assemblies





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

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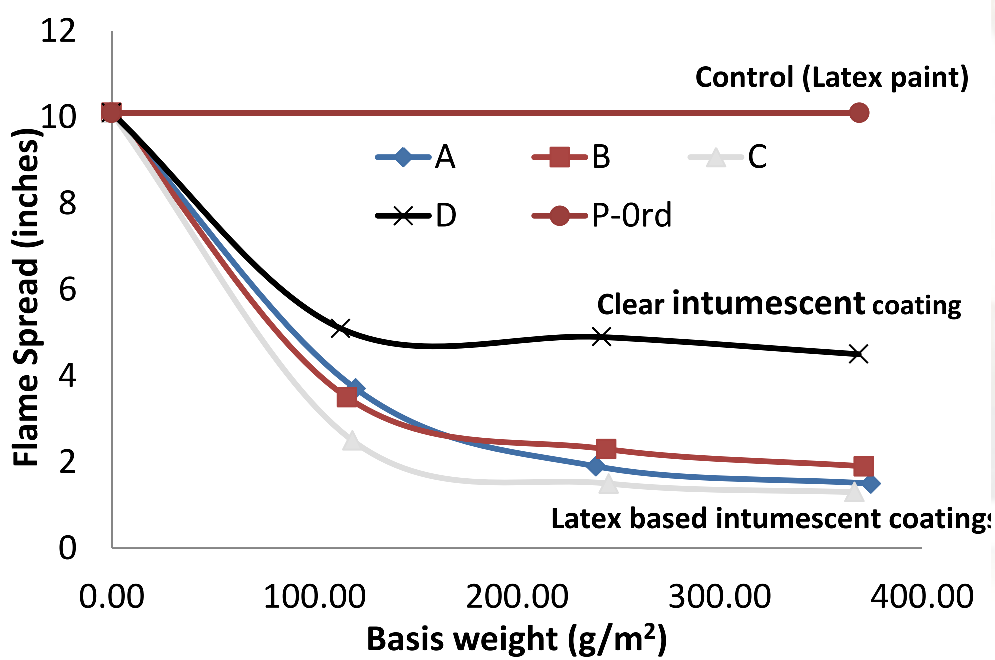
Research approach

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



Two-foot tunnel test

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Few comments on future research needs

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Future research needs – 1. Construction management

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

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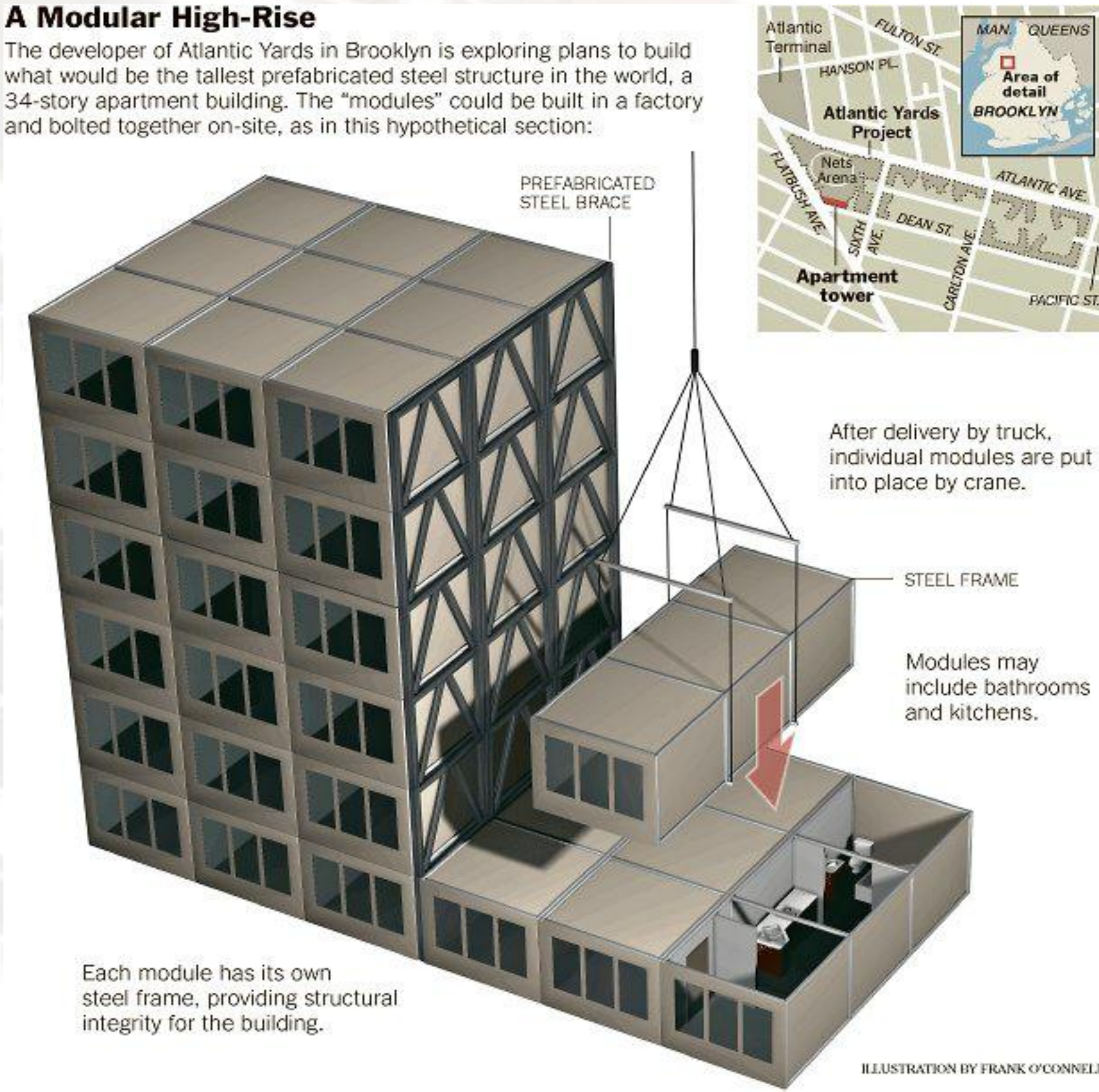
Future research needs – 1. Construction management



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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?

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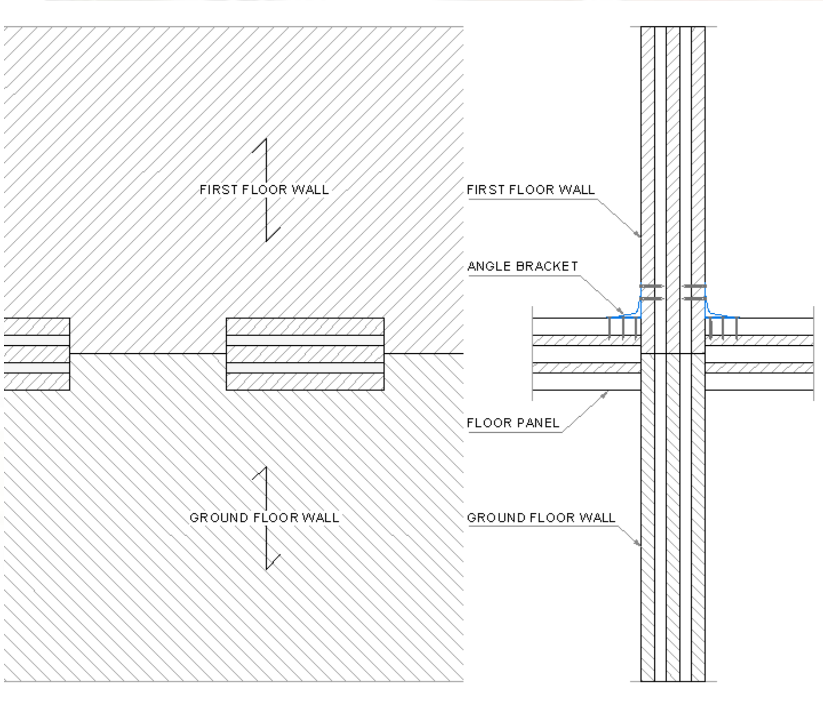
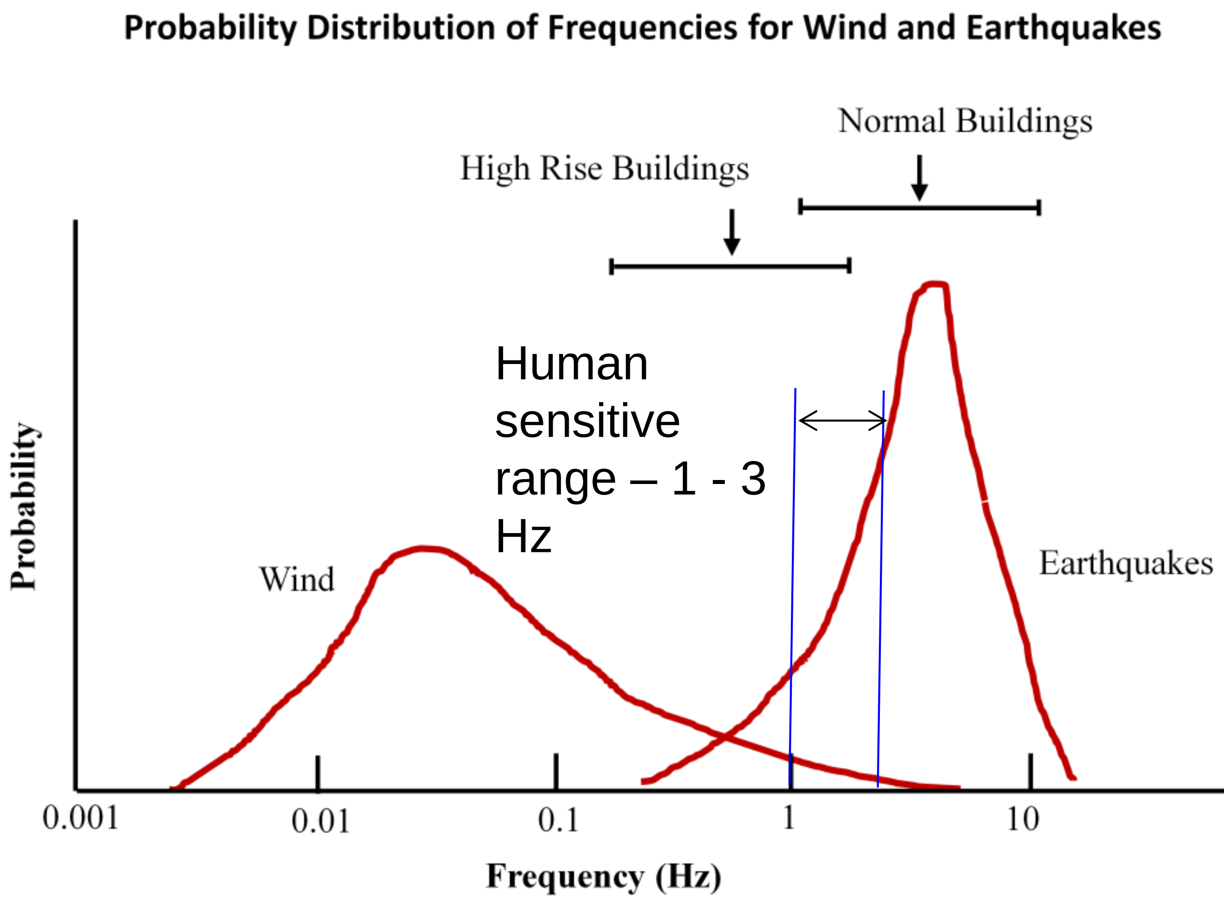
Future research needs – 2. Minimizing perpendicular to grain movement

- Innovative detailing is required



Source : Philipp Zumbrunnen

Future research needs – 3. Whole building vibration – occupant discomfort



(adapted from Augusti et al., 1984)

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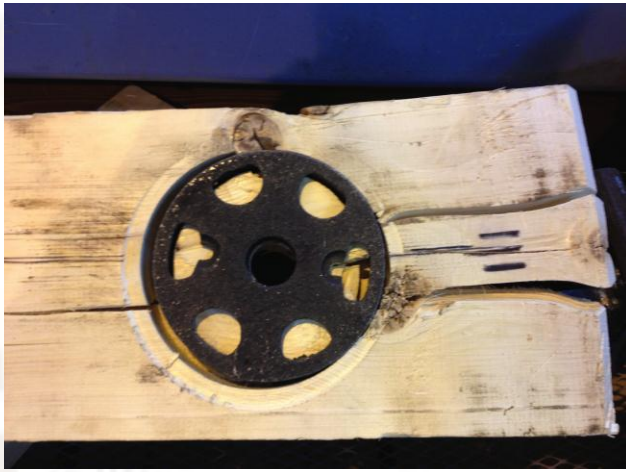
Future research needs – 4. Connection

- 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

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Thank you and Questions?

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