Tall Wood

The Next 20 Years, The Next 20 Storeys

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A copy of this presentation is available at:
http://www.ghl.ca/shared/Tall_Wood_Presentation_(Iredale_Dec_2013).pdf

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Andrew Harmsworth, M Eng, P Eng, CP

Principal, **GHL** Consultants Ltd

Email: ah@ghl.ca

BASc, Queen's University at Kingston, Civil Engineering

M Eng, UBC's short lived Fire Science program

25 years' experience in Equivalencies and Alternative Solutions

GHL Consultants Ltd

- Founded 20 years ago
- Building Code Consultants
- Fire Engineers
- Code reviews – both assisting clients and as Authorities
- No system design – won't sell you things you don't need

About GHL

- "Code Consulting" firm
- Prefer "Fire Engineering"
  - Focus on Part 3
  - Fire hazard analysis
  - Fire risk analysis
  - Structural fire resistance
  - Heat transfer
  - Smoke control design

8 Principals + staff (total 20)

David Graham, P Eng, CP Principal

Andrew Harmsworth, M Eng, P Eng, PE, CP Principal

Teddy Lai, Architect AIBC, MRAIC, CP Principal

Khash Vorell, M Eng, P Eng Associate Principal

Adam Nadem, AT.AIBC, AScT Associate Principal

Frankie Victor, AScT, BCQ Associate Principal

Jeffery Mitchell, M Eng, P Eng, CP Associate Principal

Wendy Morrison, AScT, BCQ Associate Principal

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Building Code Committee Work

- APEG Building Codes Committee (Khash Vorell / Andrew Harmsworth)
- BC Appeal Board (Frankie Victor)

Research Work

- BC Wood First Advisory Committee to Forestry Investment Innovations
- CAN 086 Task Group on Fire (Andrew Harmsworth)
- NEWBuildS Research Network (Andrew Harmsworth, Board of Directors) – 40 Master's and PhD Students
- Fire Risk Assessment for Alternative Solutions (Gary Chen)
- Effectiveness of Sprinkler Systems after an Earthquake.

Research Work

- 6 Storey Group C (Residential) – Code Change (Andrew Harmsworth / Gary Chen, 2009)
- Group D (Office) Studies – 6 Storey Frame and 8 Storey Heavy Timber (HT)
- MSc Studies on Effects of Fire as a Structural Load (Gary Chen) - Current
- Lead Author, Tall Wood Guide with FP Innovations

6 Storey Wood - 1871

Wikipedia

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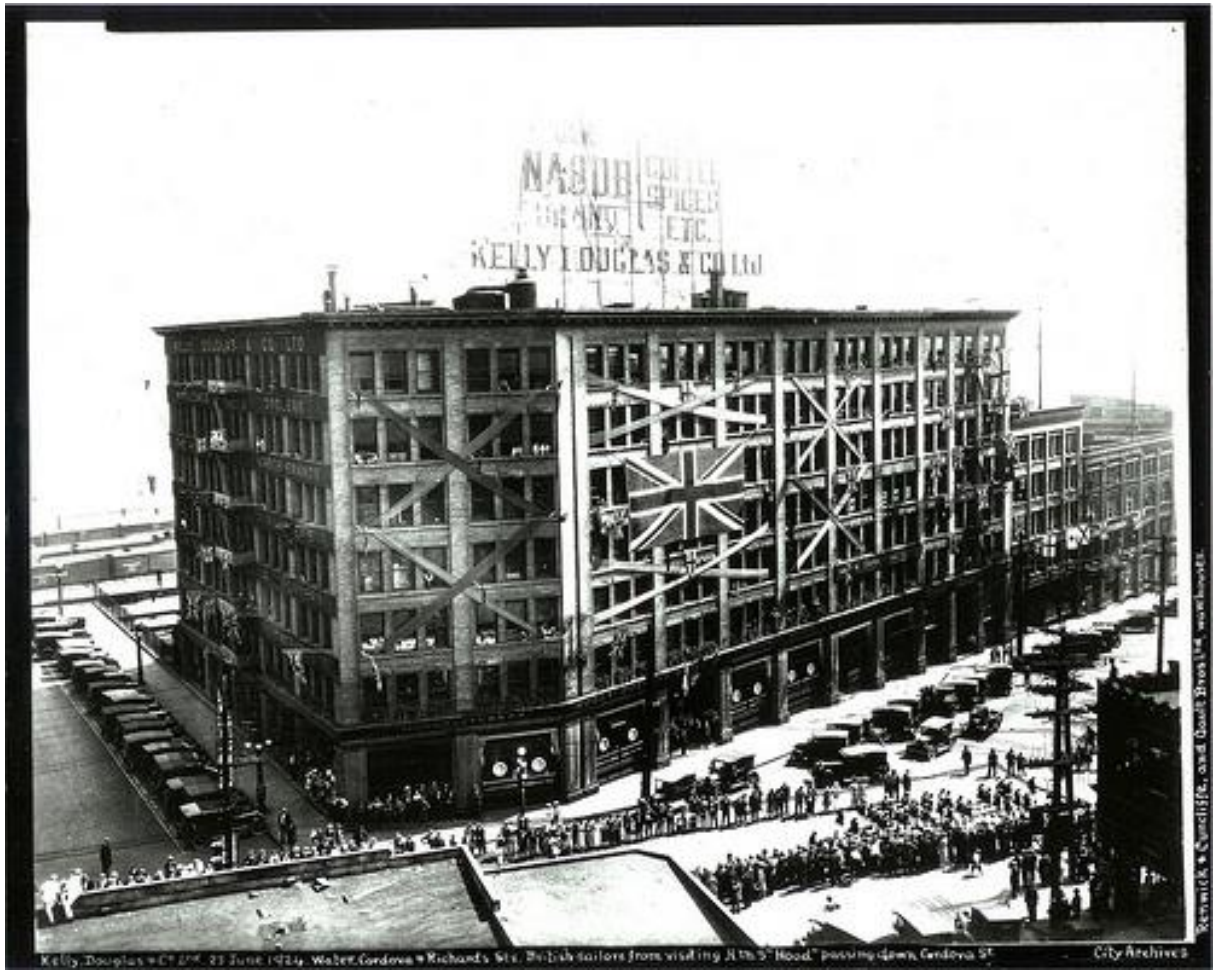
9 Storey Heavy Timber - 1905



Kelly Douglas Building, Vancouver

Today

Wikipedia

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What Happened

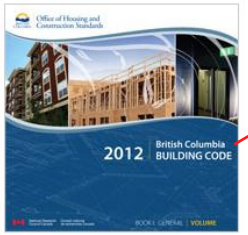
- Greater concern with fire safety.
- National Building Code of 1941.
- Initially prefaces with the idea that it was a ‘Guide’.
- Over time it became a restrictive document.

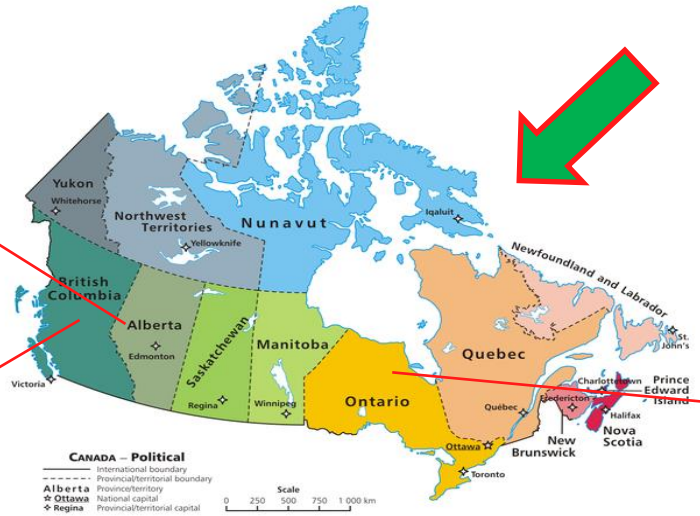
The Building Code System

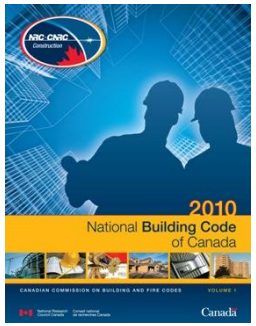
National Building Code is a **model code**

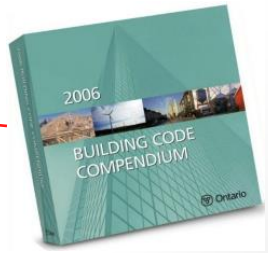
It is a consensus document:

- It regulates construction of buildings.
- Traditionally written by NRCC (Constitution).
- The Province adopts it on the public's behalf.
- Code measures are public interest decisions.









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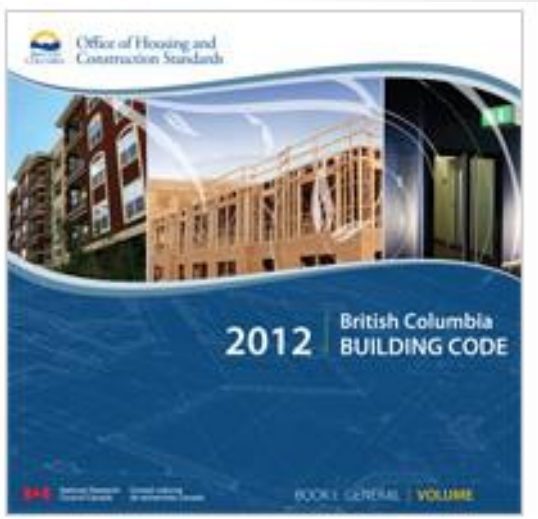

Buildings are subject to risks:

- Code compliance ≠ no risk.
- Code compliance = risks at acceptable level.

Entering a building is just like getting into a car, there is an acceptable level of risk.

Codes and Mass Timber

Vancouver

Québec City

Building Code Compliance

- **Acceptable Solutions**
- **Alternative Solutions**

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Courtesy FPInnovations

History and Background

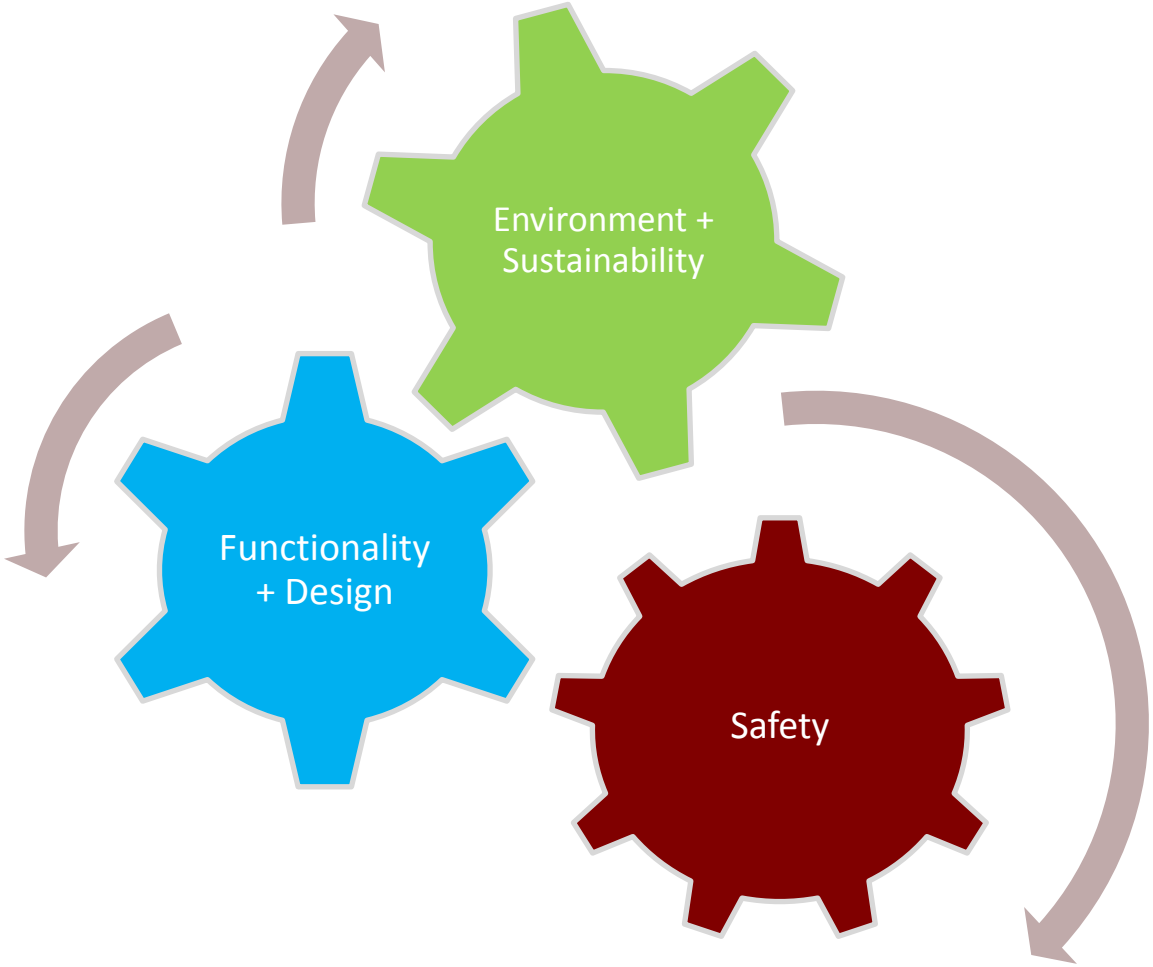
Use of Combustible Construction

- Up to early 1900's
  - Regulated by insurance industry
  - 5 and 6 storey wood frame was common
  - 8 and 9 storey HT common
- NBCC 1941, introduced height and area limits
- NBCC 1965, 3 storey height limit
- BCBC 1973 (NBCC 1970), 3 storey
- BCBC 1992 (NBCC 1990), 4 storey
- BCBC 2006 (April 4, 2009), 6 storey height limit

Thoughts on Codes

- Code should not care what material you use.
- All materials and design methods should be required to meet the same performance level.
- Code should be based on science, not emotion.
- Designers and Owners should be able to choose the best material for the job.

Safety Needs to Balance Other Goals



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New Concerns

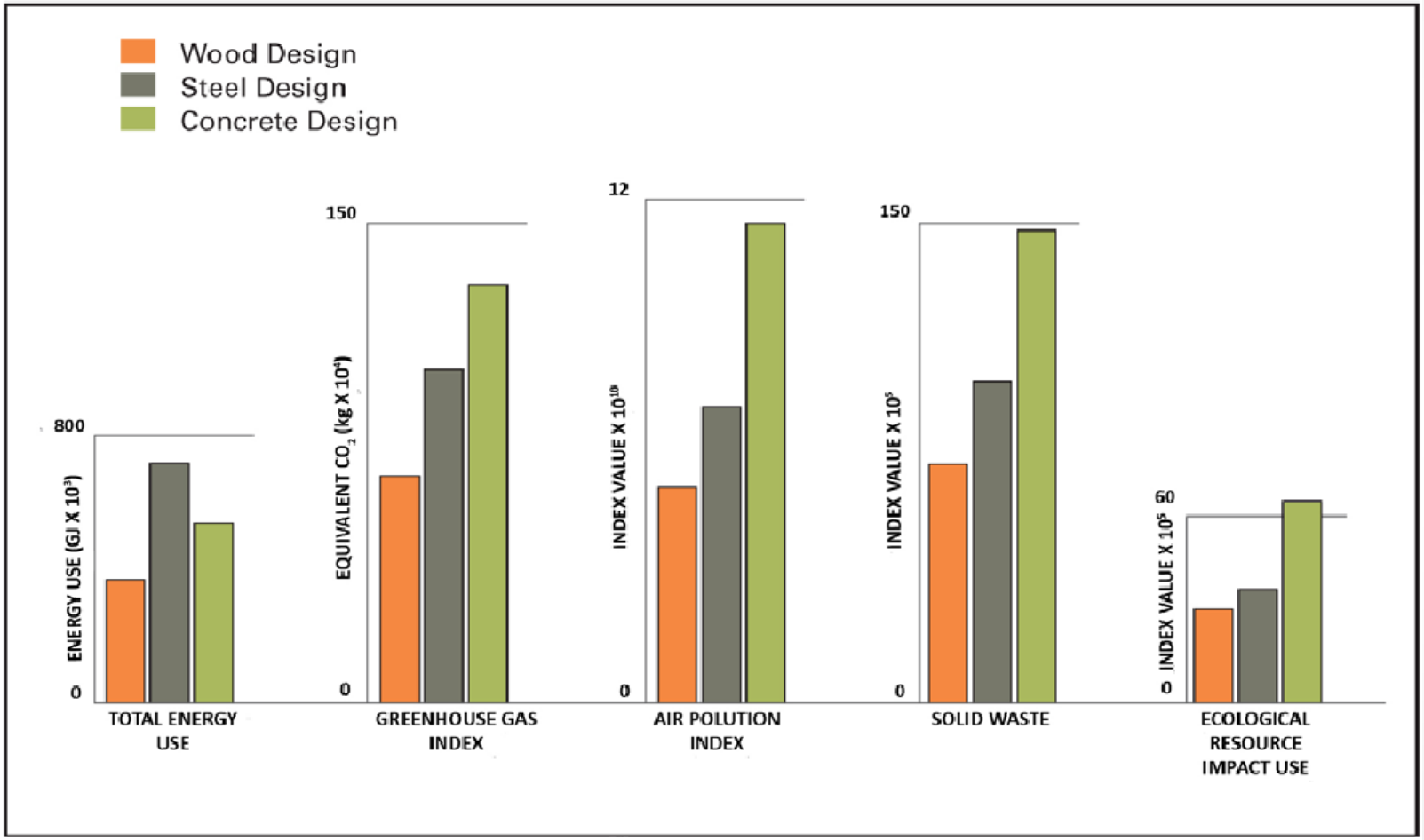
The Code should not prevent materials and methods that address concerns not addressed by the Code.

Why Wood?

Greenhouse gas concerns:

- Steel and concrete production produces large quantities of CO_2.
- Wood production produces less CO_2.
- Wood buildings sequester CO_2.

Environmental Impact of Structural Typologies



Courtesy CWC

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Code Evolution

- NBC up to 1995
- Many codes around the world

- NBC since 2005

- Australian & New Zealand codes

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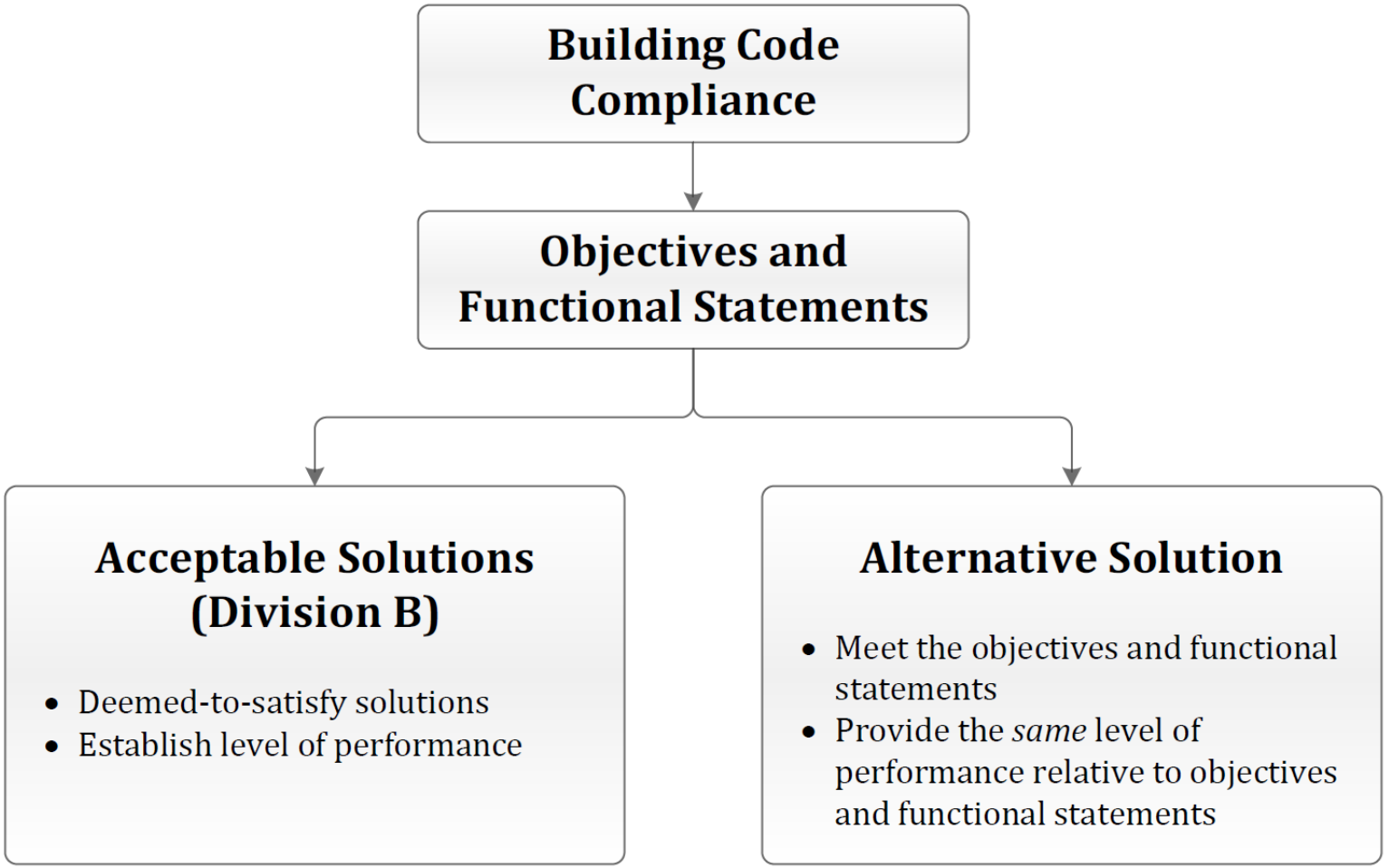
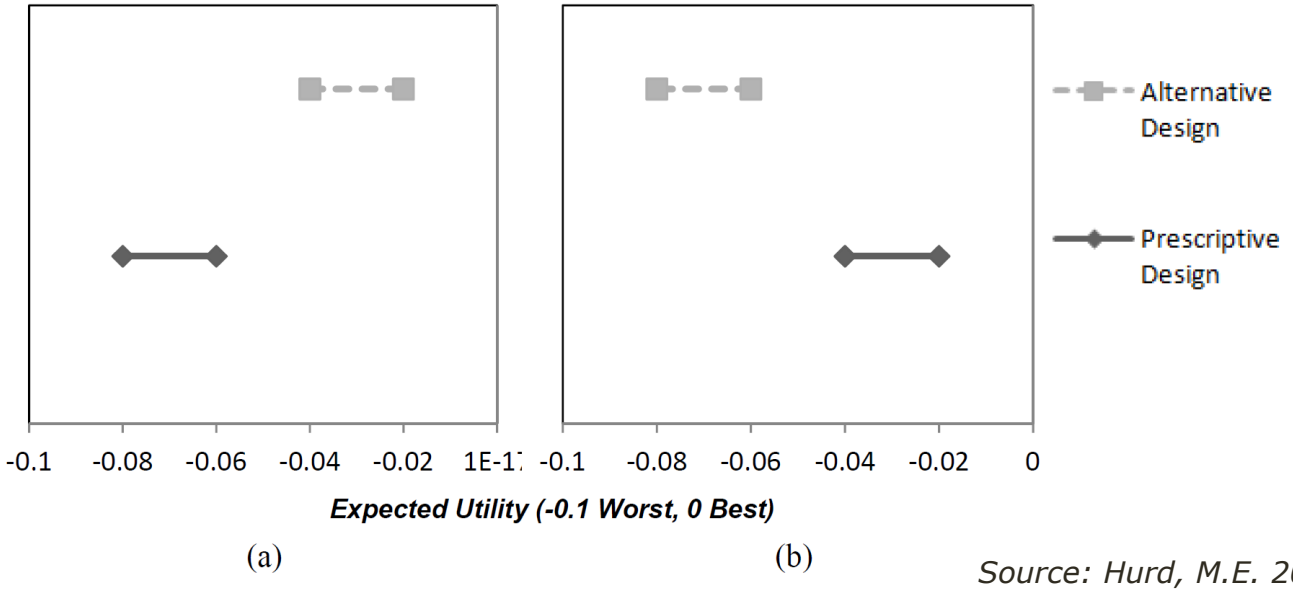
Objective-based Code Framework



Quantitative Risk Assessment

- Risk = Probability x Consequence
  - Reduce probability
  - Reduce consequence
  - Reduce probability and consequence



Source: Hurd, M.E. 2012

Fundamental

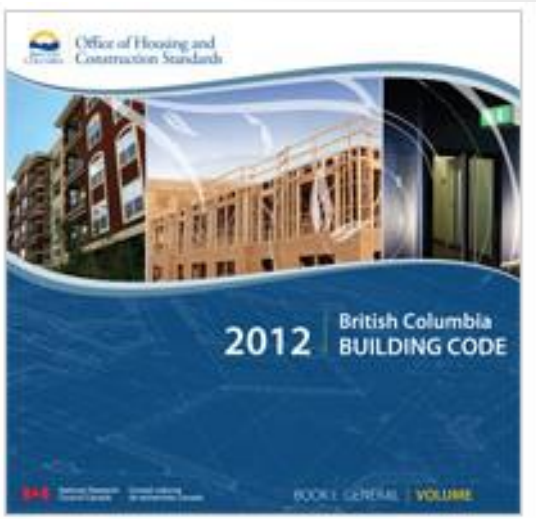
Division B is only one solution.

There can be other solutions.

Level of Performance

Limitation is that you must provide at least the level of performance that the Division B Solution provides.

BC 6 Storey Residential



GHL prepared the risk analysis.

Essentially an 'Alternative Solution' that was incorporated in the Code.

GHL argued that risks were equivalent to existing allowable building areas and heights if appropriate provisions were made.

Peer Review and Consultation

GHL's study on risks Peer Reviewed.

Public consultation.

Where Are We Now?

BC Code allows 6 Storey Residential, limited area.

Quebec interim changes.

NBC 2015 proposed changes to allow 6 storey wood frame published for comment.

GHL Experience - 6 Storey

Complex, requires good engineering.

Design team, Contractor's qualifications very important.

Definitely practical and safe.

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Construction Fires

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Laminated 2x6 elevator shaft

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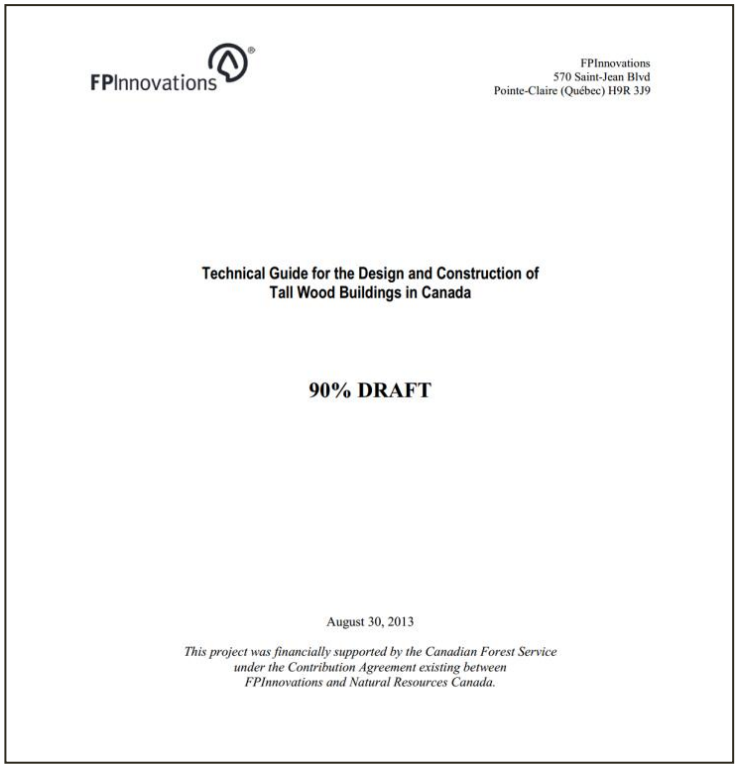
Mass Timber Terminology

Consensus is developing to use the term Mass Timber.

(Massive lost out – too late)

Avoids confusion with the specified sizes for Heavy Timber in Division B.

FPInnovations Tall Wood Guide



FPInnovations

FPInnovations
570 Saint-Jean Blvd
Pointe-Claire (Québec) H9R 3J9

Technical Guide for the Design and Construction of Tall Wood Buildings in Canada

90% DRAFT

August 30, 2013

This project was financially supported by the Canadian Forest Service under the Contribution Agreement existing between FPInnovations and Natural Resources Canada.

FPInnovations project funded by NRC

- 400 Pages.
- 70 on Fire
- Fire Section first to provide comprehensive review of fire issues in tall wood buildings.

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Approach Chosen

- Intent was to demonstrate that it CAN BE DONE.
- Nationally acceptable Risk Tolerance.
- Took a conservative approach.
- Recommends that an approach of encapsulation of combustibles:

Possible Approaches -

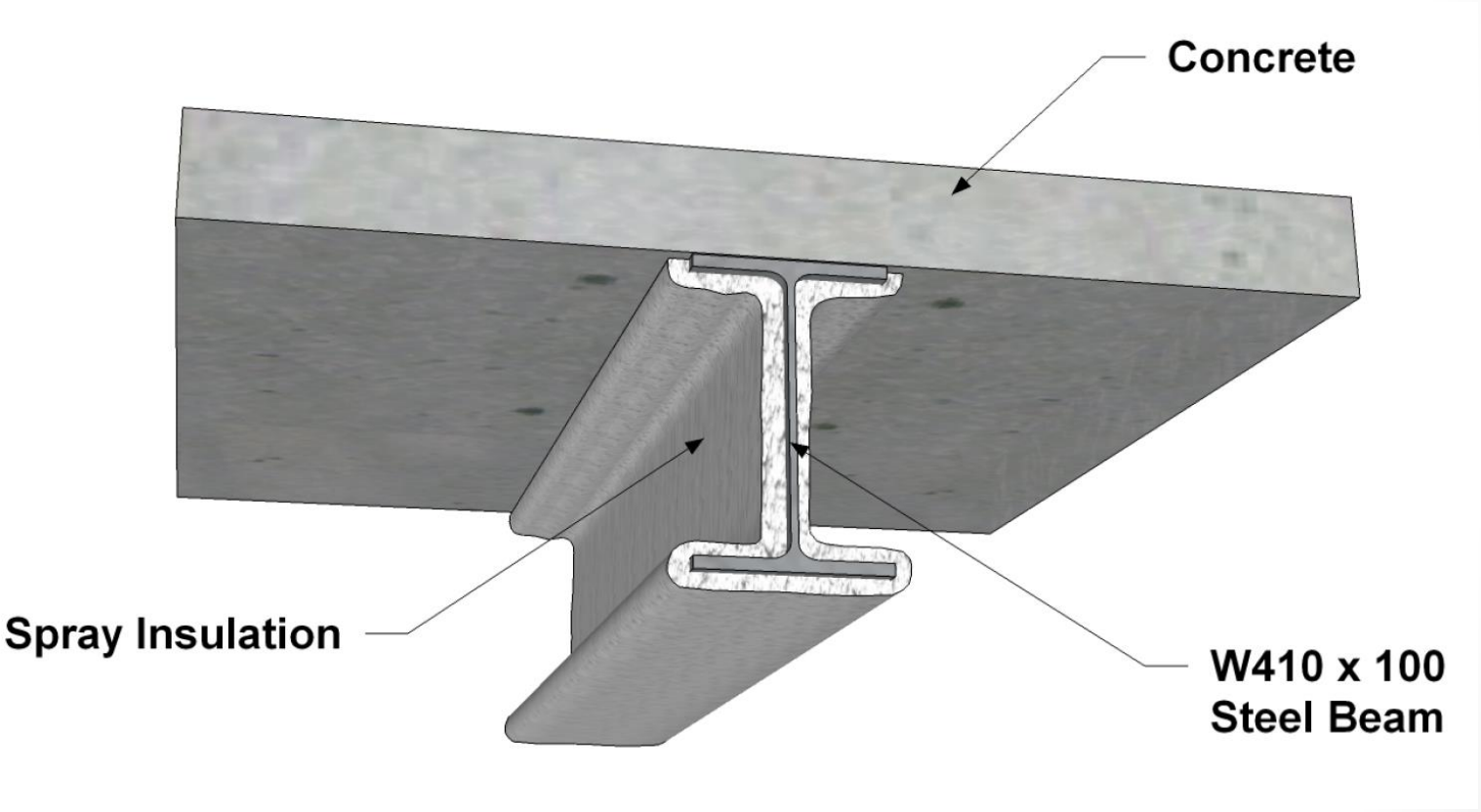
- Full Performance based assessment
  - Lack of performance criteria/ inconsistent benchmarks
  - Time consuming
- Extend permitted combustible construction based on Comparative Risk Analysis
  - WIDC
  - BC 6 Storey
- Equivalent Component Performance
  - Protect components for equivalent performance

Mass Timber Fire Resistance

Two methods:

- Encapsulation
- Char

Encapsulation



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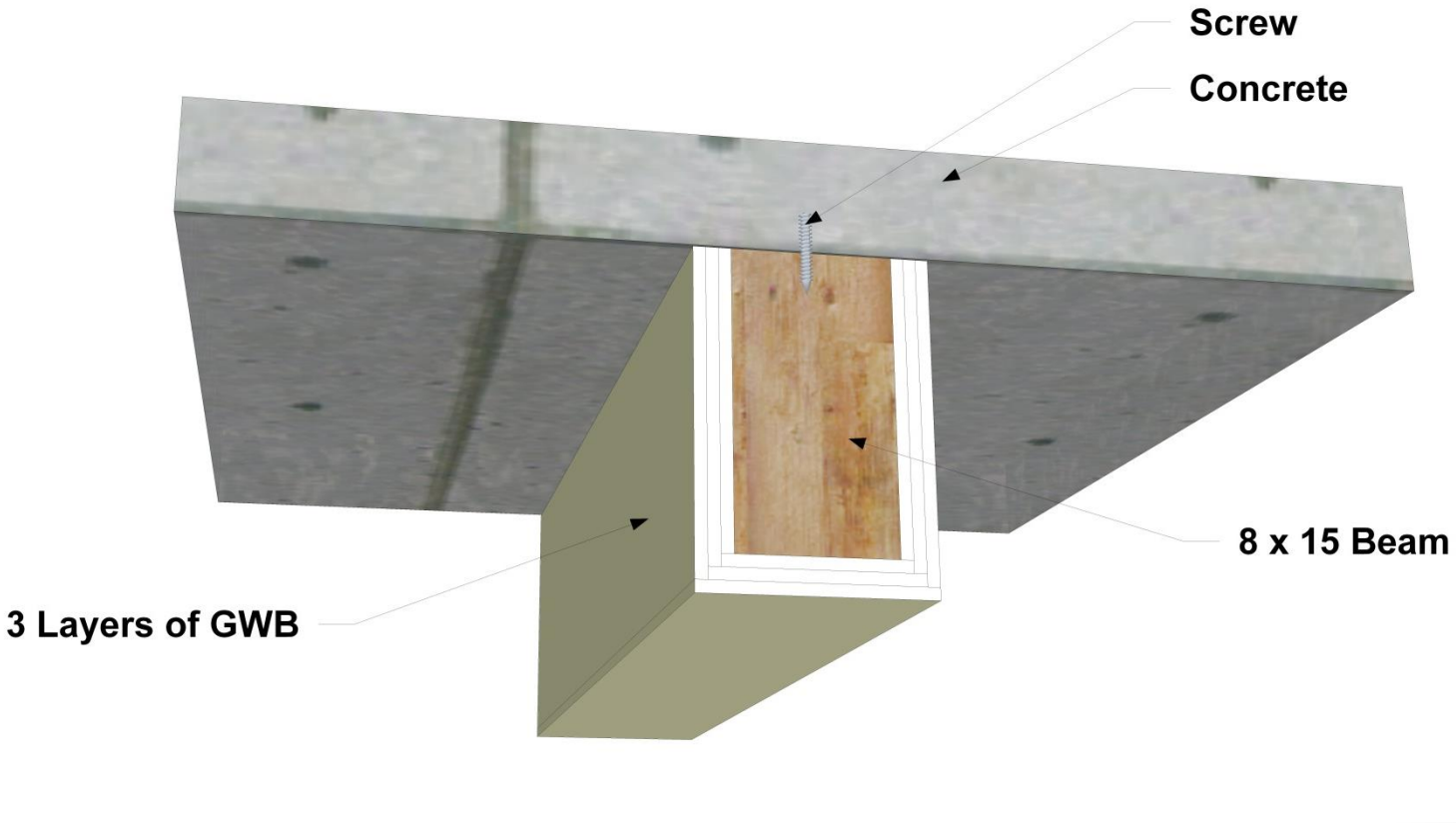
Encapsulation



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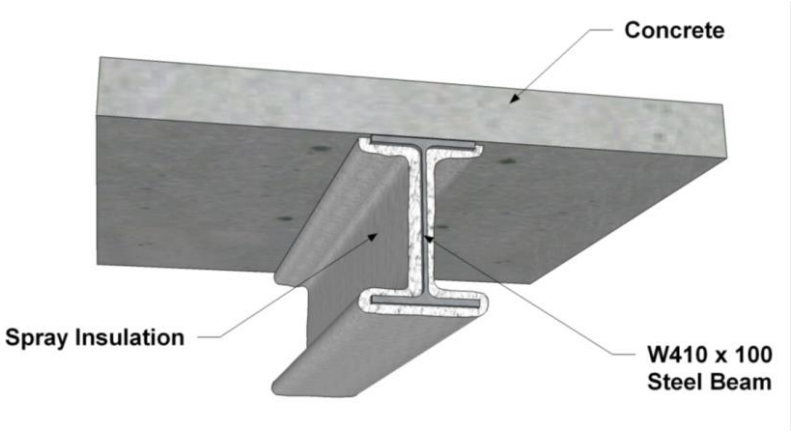
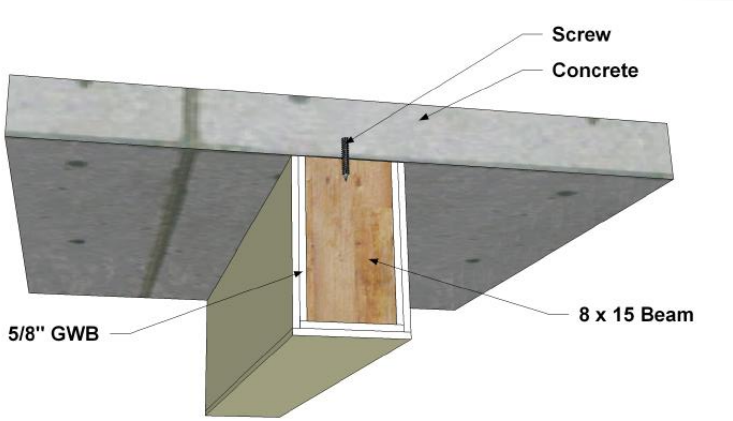
What is the Difference





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Complete Encapsulation

- Wood not affected by the fire for expected duration.
- Wood does not contribute to the fire for expected duration.
- 4 layers of ½in GWB.
- Makes the point that it CAN BE DONE.

Fire Resistance Rating of Gypsum Board Membranes

Gypsum Board Members	Fire Resistance Rating
One layer of 12.7mm (½in) GWB	15min
One layer of 15.9mm (⅝in) GWB	30min
Two layers of 12.7mm (½in) GWB	40min
Two layers of 15.9mm (⅝in) GWB	60min
Three layers of 15.9mm (⅝in) GWB	90min
Four layers of 15.9mm (⅝in) GWB	120min

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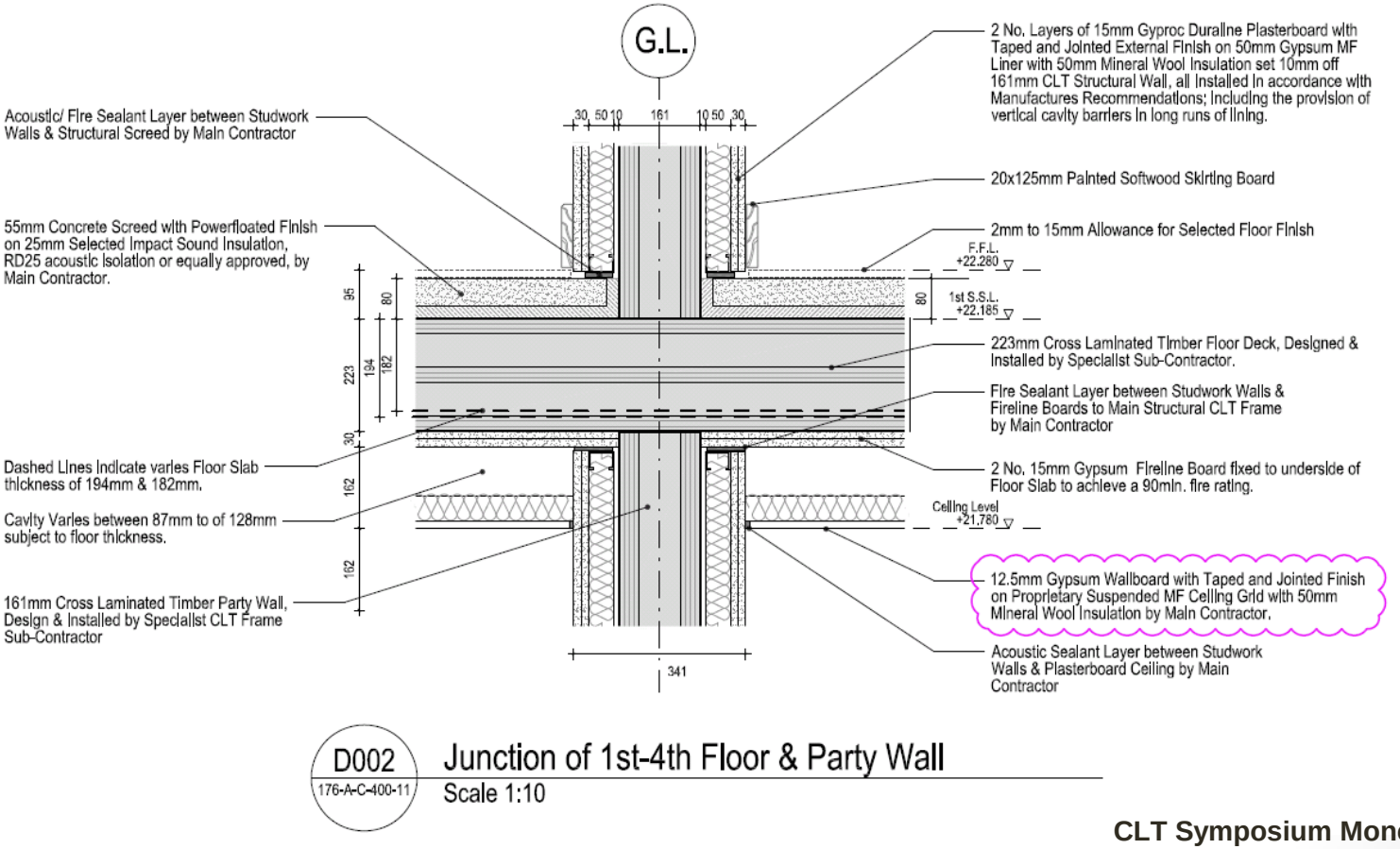
UK Early Example – Bridport House

Fire / Acoustic



D002 (176-A-C-400-11) Junction of 1st-4th Floor & Party Wall
Scale 1:10

CLT Symposium Moncton
Philipp Zumbrunn
12 October 2011

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Peel Off the Layers

Then, suggested we peel off the layers.

Char → Fire Resistance

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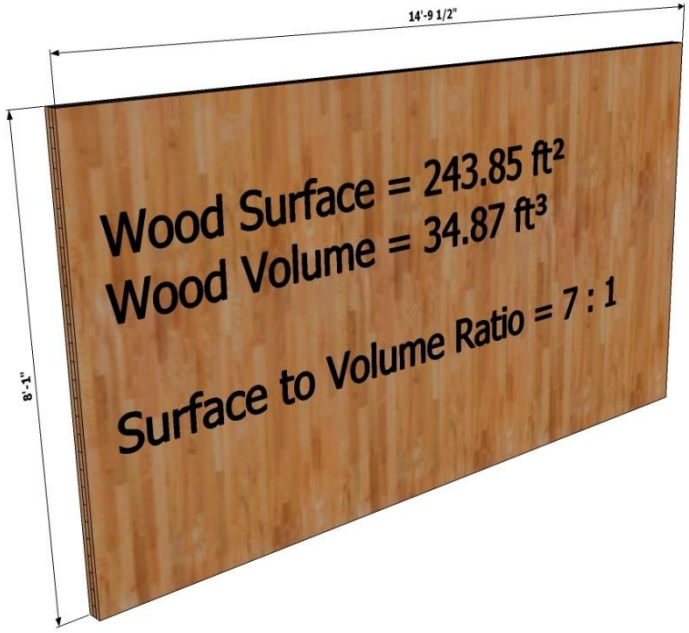
Inherent Safety of Mass Timber

- Why do we use small wood sticks to start a campfire?

Wood-Frame vs. Solid Timber

- Low surface to volume ratio – can rely on charring

Requires GWB protection for fire rating



GWB enhanced fire rating

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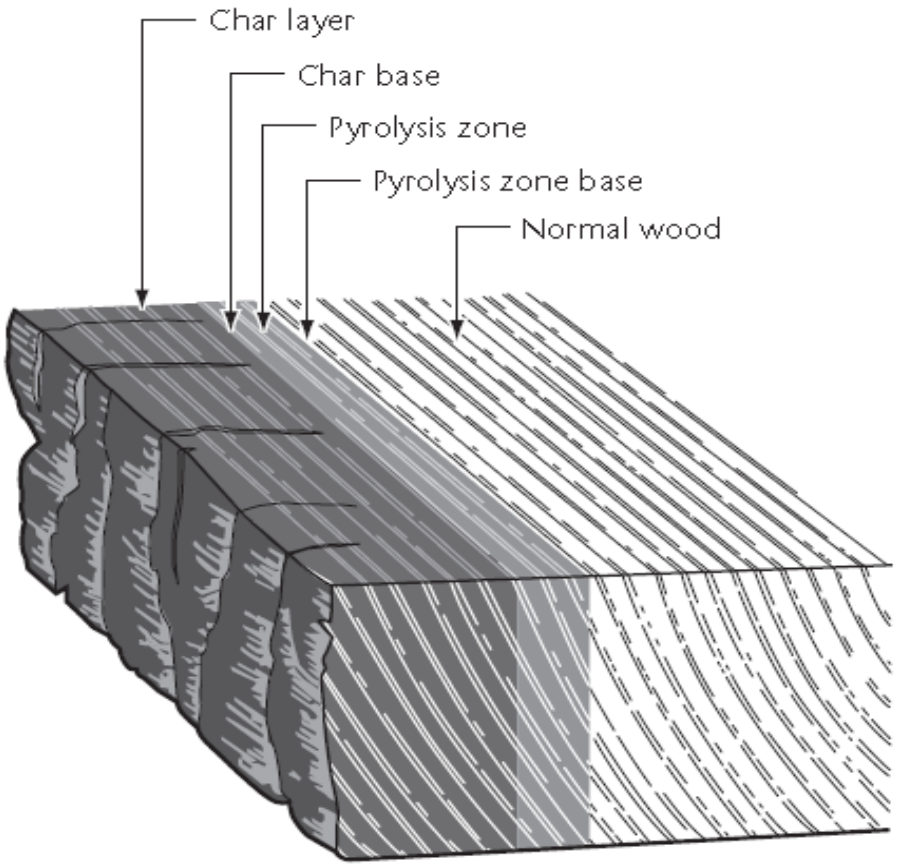
Char Layer – Small-Scale Flame Test



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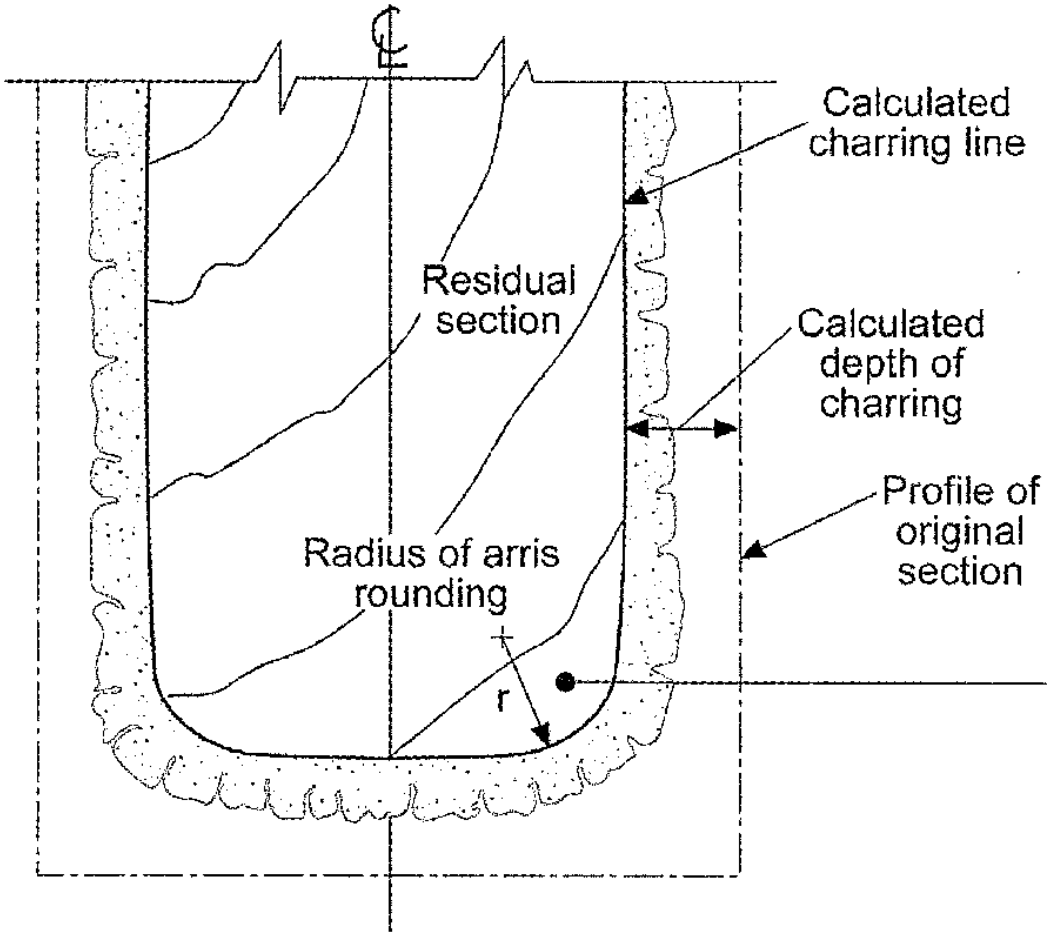
Concept of Mass Timber Design for Fire Resistance



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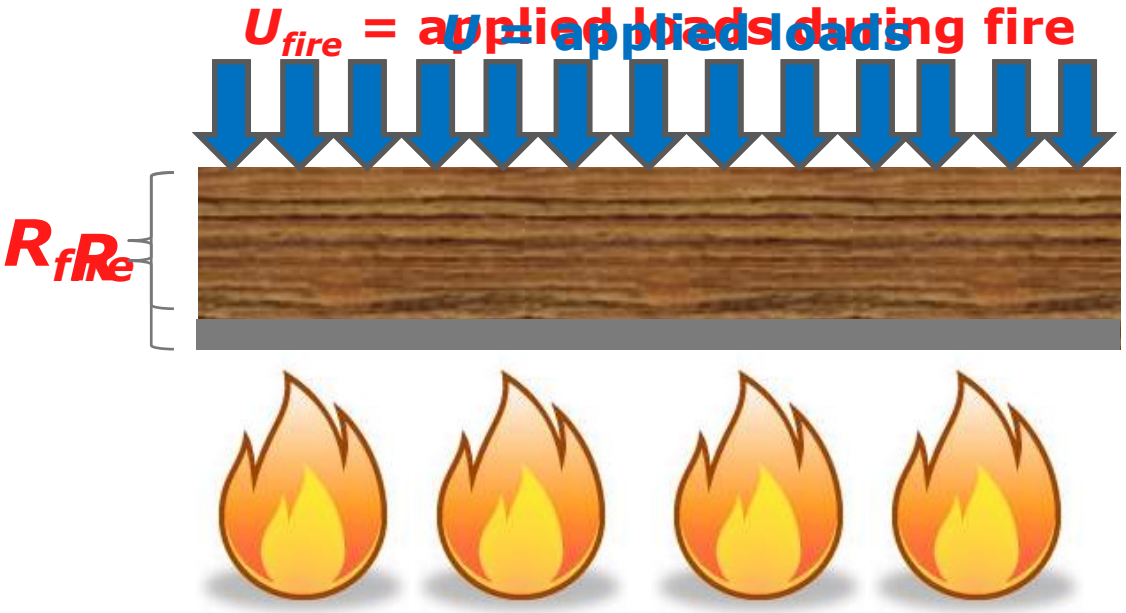
Limit State Design – for Fire

$$U_{fire} \leq \Phi_f R_{fire} \qquad (1)$$

where U_{fire} = the design action from the applied load at the time of the fire;
Φ_{fire} = the strength reduction factor for the timber material; and
R_{fire} = the nominal load capacity at the time of the fire, accounting for charring of wood members



Size of Members

Upsize of members for fire.

But this refers to critical collapse loads only.

Often performance governs (vibration, deflection).

Members may not need to increase in size.

What has greater risk?

2h Noncombustible

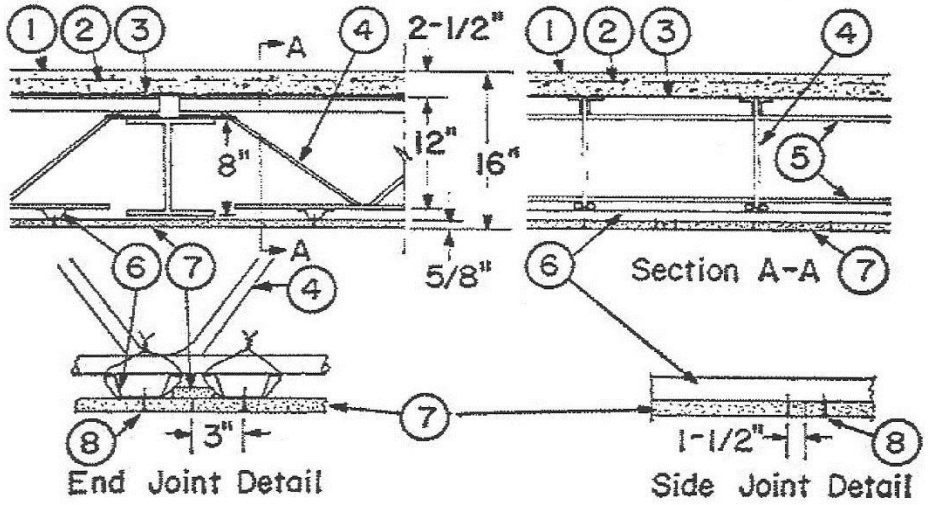
Fire Resistance Ratings - ANSI/UL 263

See General Information for Fire Resistance Ratings - ANSI/UL 263

Design No. G512

February 18, 2010

Restrained Assembly Rating — 3 Hr.
Unrestrained Assembly Rating — 3 Hr.
Unrestrained Beam Rating — 3 Hr.
Load Restricted for Canadian Applications — See Guide BXUV7



Beam — W8x35, min size.

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This, especially if wrapped in 2 layers of GWB

Comparison

Code refers to comparison of level of performance of the Alternative Solution.

Useful to look at an acceptable solution for Earth Sciences Building compared to the proposed solution.

Risk Analysis

- Another approach.

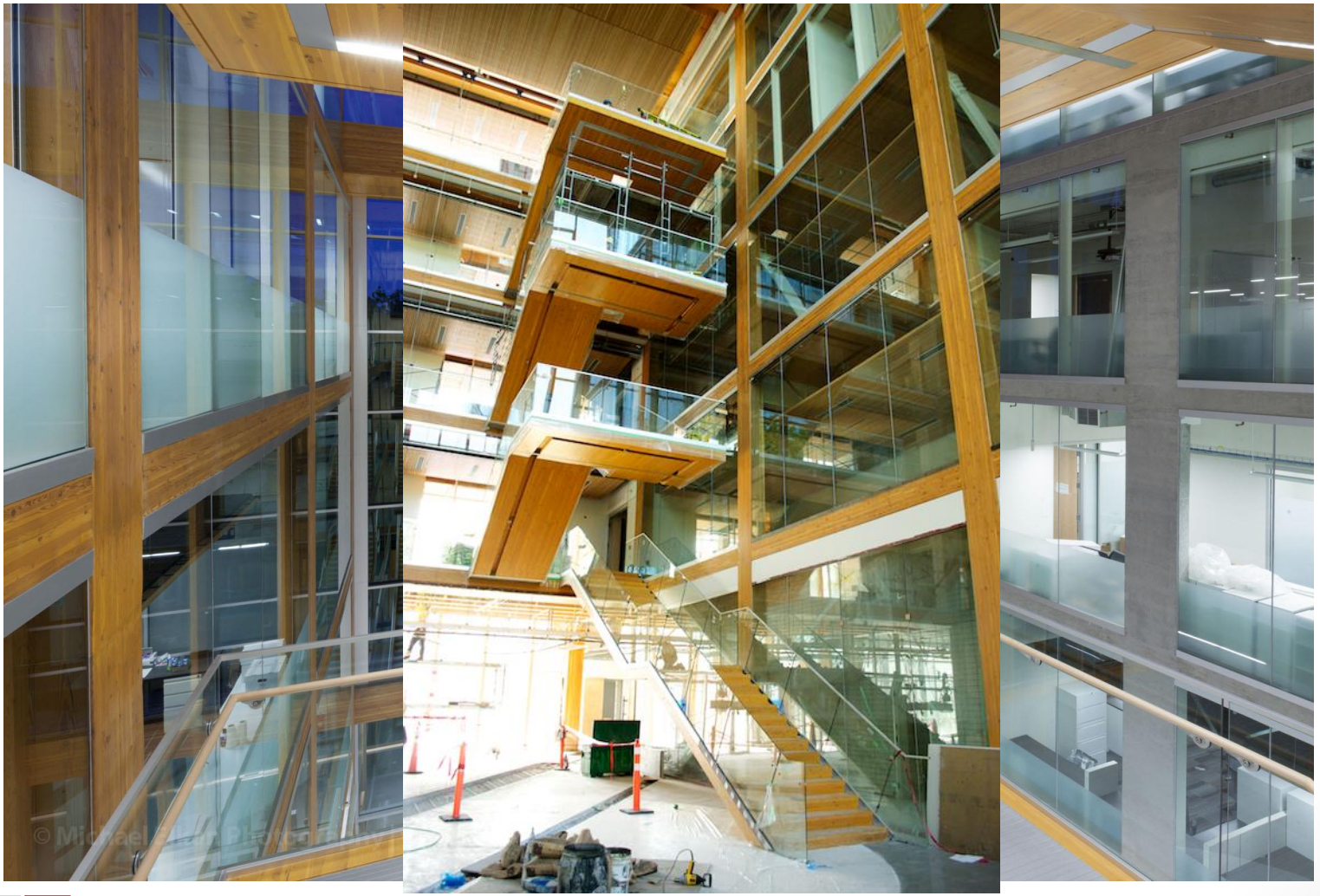
- UBC Earth Sciences Building.

5 Storey A-2 Occupancy
UBC Earth Sciences Building

Acceptable solution for A-2 occupancies:

- 1h noncombustible construction
- Alternative solution to address 1h mass timber

Earth Sciences Building



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Approach

Risk Analysis

Pre-Flashover

Post-Flashover

Pre - Flashover

95% sprinkler reliability.

Only necessary to address 5% probability.

Low occupant load, extra fire separations.

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Peer Reviewed

GHL was the proponent.

Gage-Babcock & Associates Ltd was the reviewer.

All large UBC buildings done by peer review.

Mass Timber vs Steel

Wood

- Expensive to protect.
- Highly reliable.
- Reproducible results.
- Contributes Fire Load

Steel

- Cheap to protect.
- How reliable?
- How reproducible are the results?
- Burns Out

Concrete

Concrete

- Agreed generally more fire safe than mass timber.
- Are fire rating designs and cover still applicable?
- Is 1/2in of cover acceptable per IBC?
- Spalling is unpredictable.

Concrete – how do you repair it - $30B loss in NZ

Firefighting Considerations

- If Sprinklered – no difference from sprinklered nc building
- Encapsulation == encapsulated steel
- Performance in the first half hour will be the same as concrete or steel building of the same design.
- Evacuation the same.
- Difference may be cleanup, as mass timber may continue to burn and char.
- Difference – If the sprinklers fail, longer cleanup

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Connections

Not specifically addressed for Steel or Concrete

Especially intumescent – problems noted

Intumescent Paint

Most Tested on Steel Beams – no movement or cracking

Effectiveness on connections, steel or wood is not known

We Used to Know How to Do It

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Protected Connections for Enhanced Fire Performance

b) Connection covered with wood paneling

Protected Connections for Enhanced Fire Performance

a) Fire-resistance test conducted on concealed plate
(credit: L. Peng (Peng, Hadjisophocleous, Mehaffey, & Mohammad, 2010))

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Issues

A few issues that came up worth discussing.

Issues

Performance targets not clear.

Why 2h FRR?

Why does ULC S101 only require 1 test?

Is criteria set by residential 1h compartment rating?

Sprinkler Reliability

To what degree can we rely on sprinklers?

Consensus of authors:

- On site water supply needed.

Addresses – seismic concerns:

- Fire after 2h?

US data confirms that sprinklers are 90% reliable; Canadian data, if monitored and supervised, reliability is much higher.

In my opinion, a fully sprinklered 2h combustible building can meet risk fully exposed, but not politically saleable in most areas.

Seismic

"An internal report of the City of Vancouver concludes that, at present, an M-7 earthquake would render the Greater Vancouver Water District supply system completely dysfunctional with 1000 water main breaks and 1000 service breaks." (Robertson 2000)

Conclusion: - We need an on site water supply

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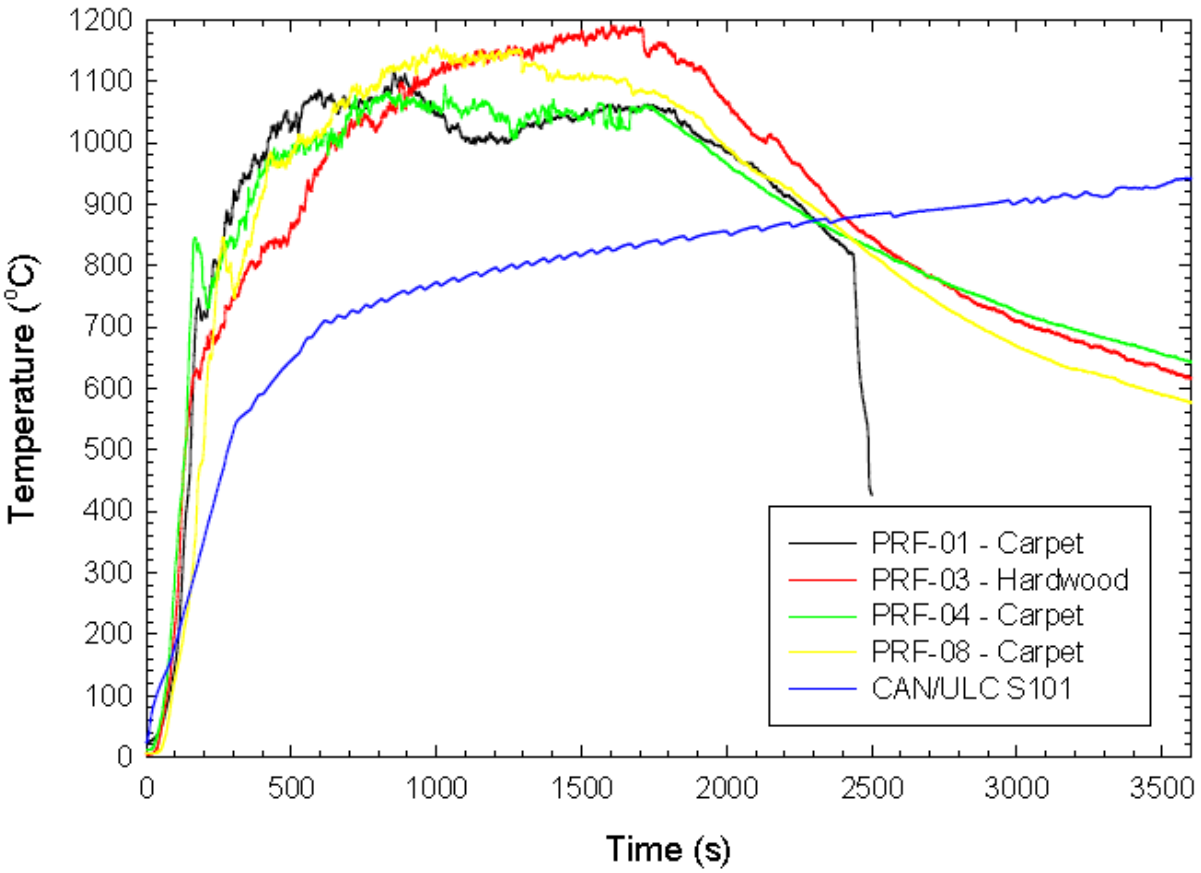
Standard Fire vs. Design Fire



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Design Fire

Is the standard fire acceptable, or do we need to look at real fires?

Conclusion:

- Office, Residential Occupancies – standard fire is acceptable.
- High hazard, should probably assess real fires.

Note if using reduced load, must use 'natural fire'.

Void Spaces

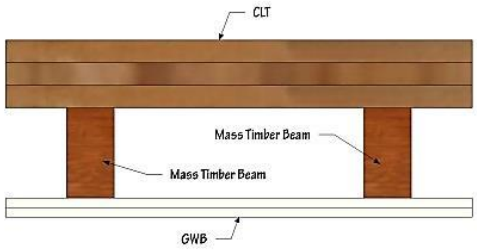
Limited but they will occur.

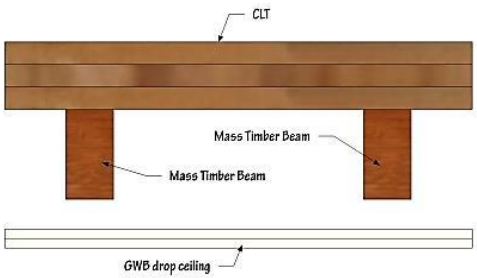
How big a void space is acceptable?

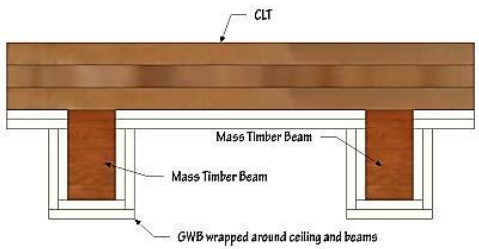
Unsprinklered (NFPA 13 provisions applicable).

- Sprinklered?

Approaches to Encapsulation Creating Concealed Spaces







Mass Timber within Occupied Spaces

Mass Timber typically FSR 40 to 50

- Wall and ceiling finishes up to 25 mm in thickness;
- Floor finishes of any thickness;
- Solid wood partitions that are not a part of floor to floor separations or exit separations;
- Light wood framing in partitions that are not a part of floor to floor separations or exit separations.

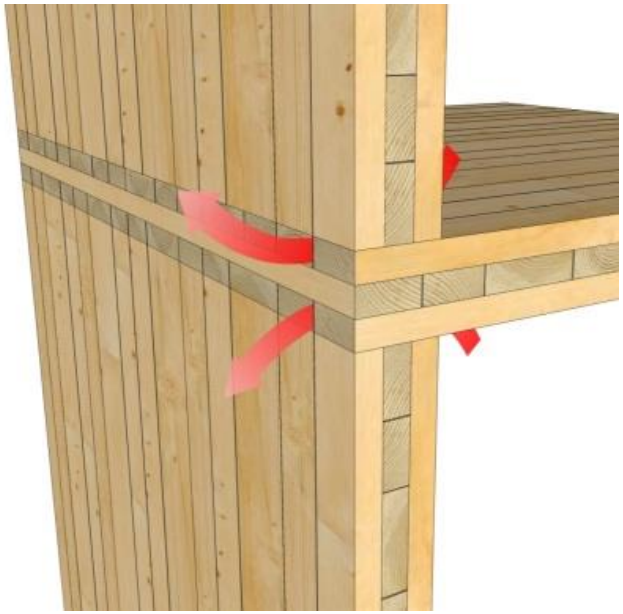
Firestopping

Don’t see a lot of issues.

Some public testing being done for WIDC.

But, be careful:

CLT Smoke Leakage Paths



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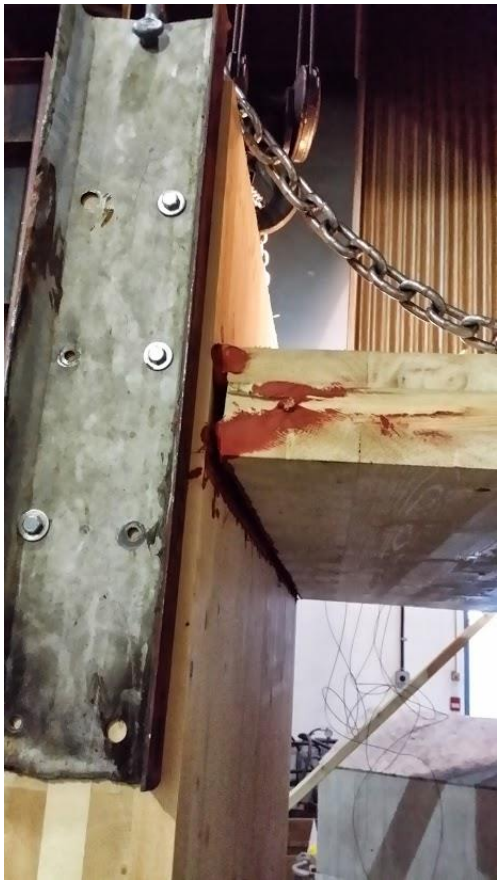
Fire Tests not so bad



Results to come

Exterior Cladding

Unlikely to be fully exposed.

Code has a nice performance Standard for this, just needs to be applied to the whole wall assembly.

Cladding

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What Was Accomplished

Various reports out there on tall wood.

Limited review of fire issues, many said very little.

Green/Kharsh/Triggs – some more detail and a lot of effort on detailing to address approach – good first step but needed a lot more detail.

First full summary of all the fire issues.

European Example

8 Storey Residential in London.

Eurban / CarbonEng, A Design Build Contractor with CLT.

Courtesy of Philipp Zumbrunnen.

Bridport House / Facts

- 7 weeks design period
- 10 weeks fabrication prior to start on site
- 12 weeks installation
- CLT Panels 1576m^3
- Steel Elements 1520kg
- 30 CLT deliveries

Bridport House / The Installation

Day 40

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Developments in Canada

NEWBuildS - Network for Engineered Wood-based Building Systems.

CAN/CSA O86 Task Group on Wood Fire Ratings.

NRC/CWC Research consortium on higher wood buildings.

FP Innovations CLT Development.

National Code Process.

NEWBuildS

NEWBuildS - Network for Engineered Wood-Based Building Systems:

- History of the Code studies
- Fire Tests of CLT rooms
- Hybrid Construction (Steel/Wood and Concrete/Wood)

NEWBuildS

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NEWBuildS

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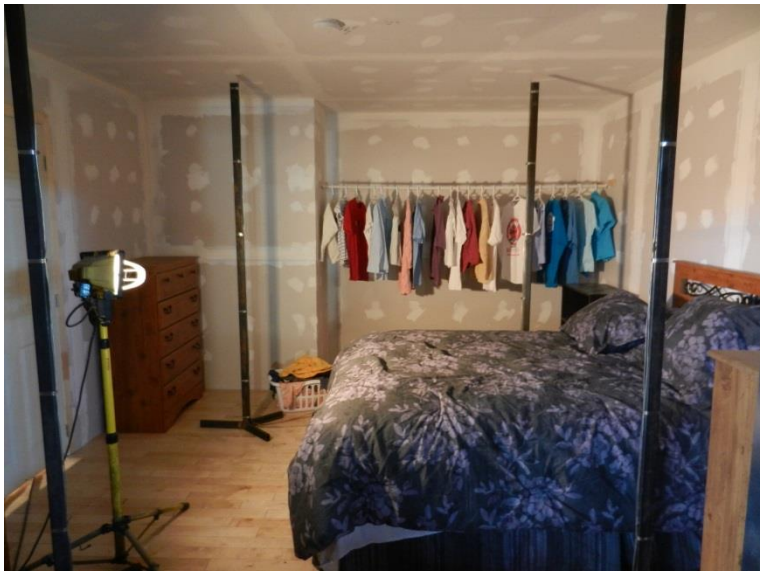
NRC/CWC Research Consortium

Research consortium on higher wood buildings:

- Looking at 6 storey combustible frame construction.
- Learned group similar to Code Committee.
- Comparative performance testing (fire and sound).

NRC/CWC Research Consortium

NRC/CWC Research Consortium



Fire Test Fuel

NRC/CWC Research Consortium

LWF Start of Test

CLT Start of Test

NRC/CWC Research Consortium

LWF Fire Test

CLT Fire Test

NRC/CWC Research Consortium

LWF

CLT

NRC/CWC Research Consortium

Steel

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The Future

My opinion:

- 6 storey is probably the practical limit for wood frame.
- 8 storey with prefab quality control.
- No significant limit on area for wood frame.
- Structures will set limit on height for Heavy Timber.
- Hybrid buildings of unlimited height and area.

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Wood Construction

Courtesy FPInnovations

FPInnovations

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Conceptually, How High Can We Go With Wood?

Courtesy FPInnovations

FPInnovations

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Green-Karsh 30-storey ~ 80m

36 storey ~ (95 m)
Switzerland

312 ft. (95 m) Sitka Spruce
Canada

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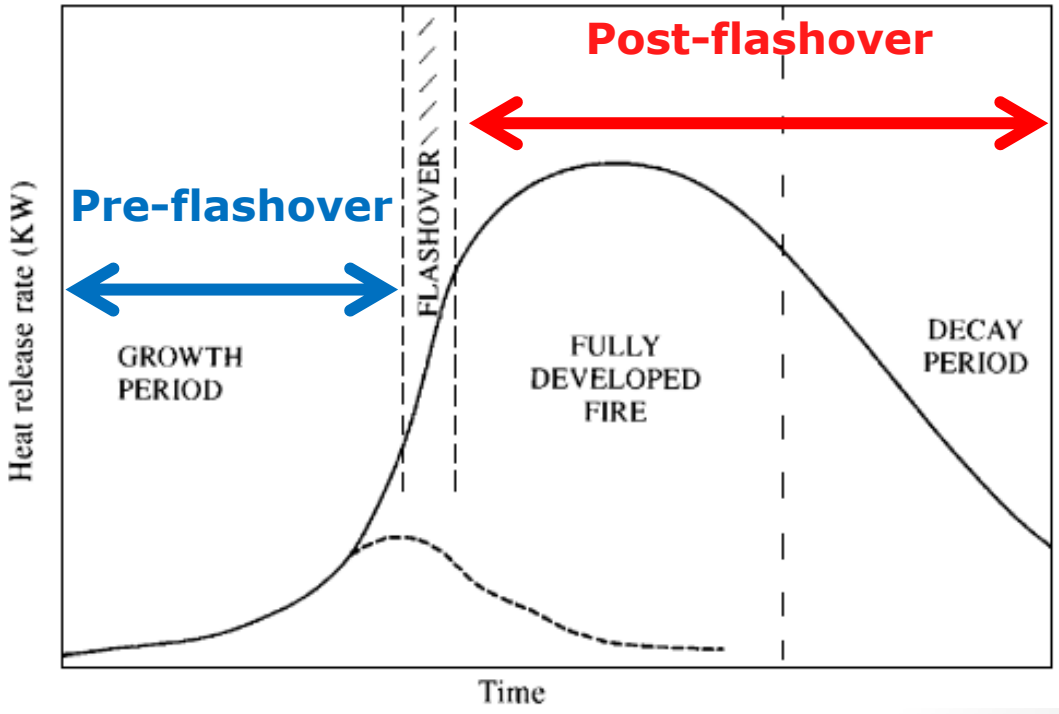
Fire Dynamics & Analysis

Fire Dynamics 101

- Writing an alternative solution require knowledge of fire science
- Compartment fire dynamics



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Pre-Flashover

Upper smoke layer (hot)

Lower smoke layer (cool)

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Pre-Flashover Fire Safety

- Fire detection → heat & smoke detectors, sprinklers
- Fire notification → fire alarm
- Evacuation → exit systems
- Limit fire growth and spread → fire separations & sprinklers

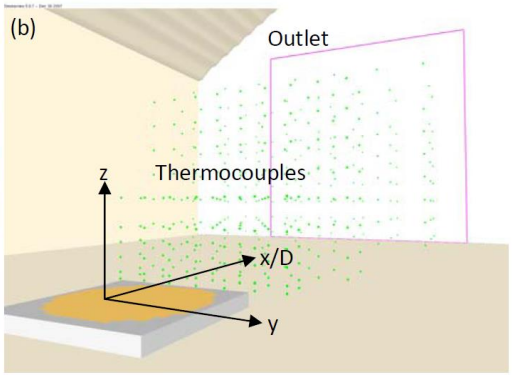
Flashover / Post-Flashover

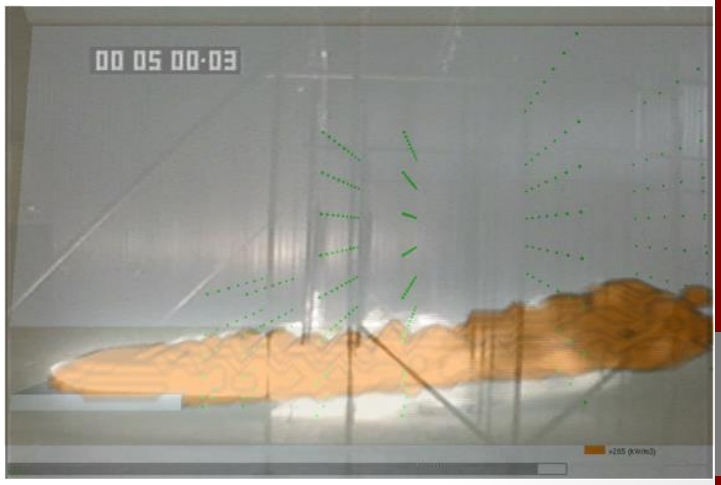
- Rapid fire development - temperatures > 600C
- All combustibles in a room burns simultaneously
- Occupants can’t survive
- Fire safety strategies:
  - Limit fire to the compartment of origin
  - Maintain integrity of exits for other occupants
  - Structural integrity in fire

Video – Christmas Tree Fire

Fire Modelling

- A scientific representation of reality
- For scientific research
- For engineering design





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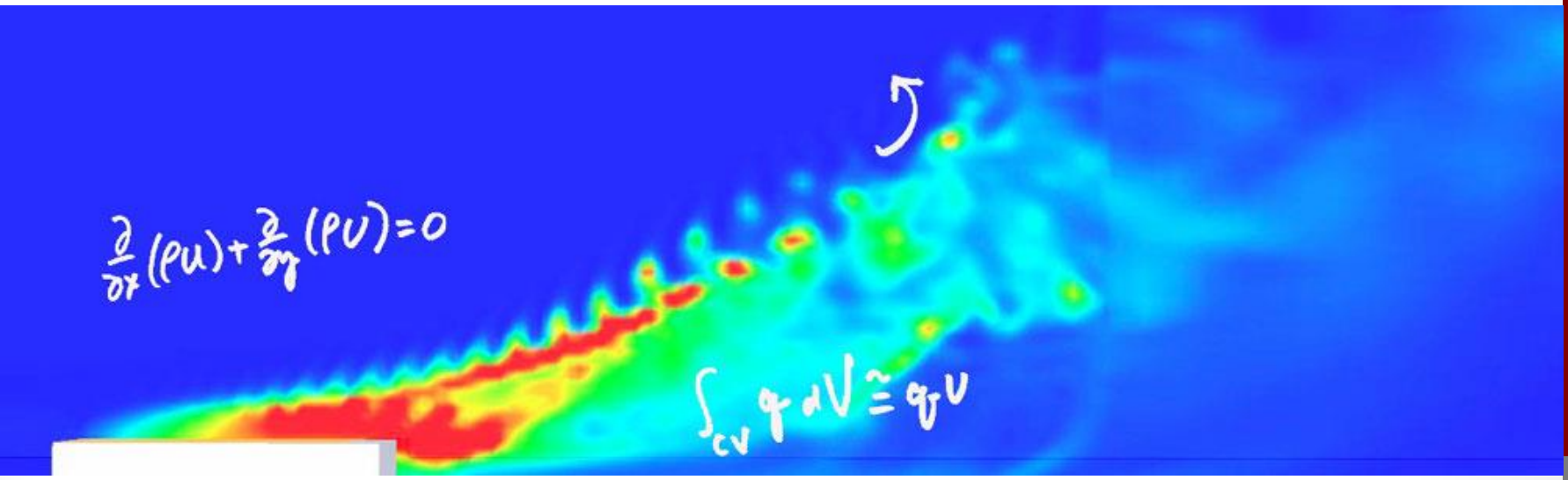
Fire Modelling

- Parametric models (from experiments)
- Zone models (mass and energy balances)
- CFD models (finite-volume approach)



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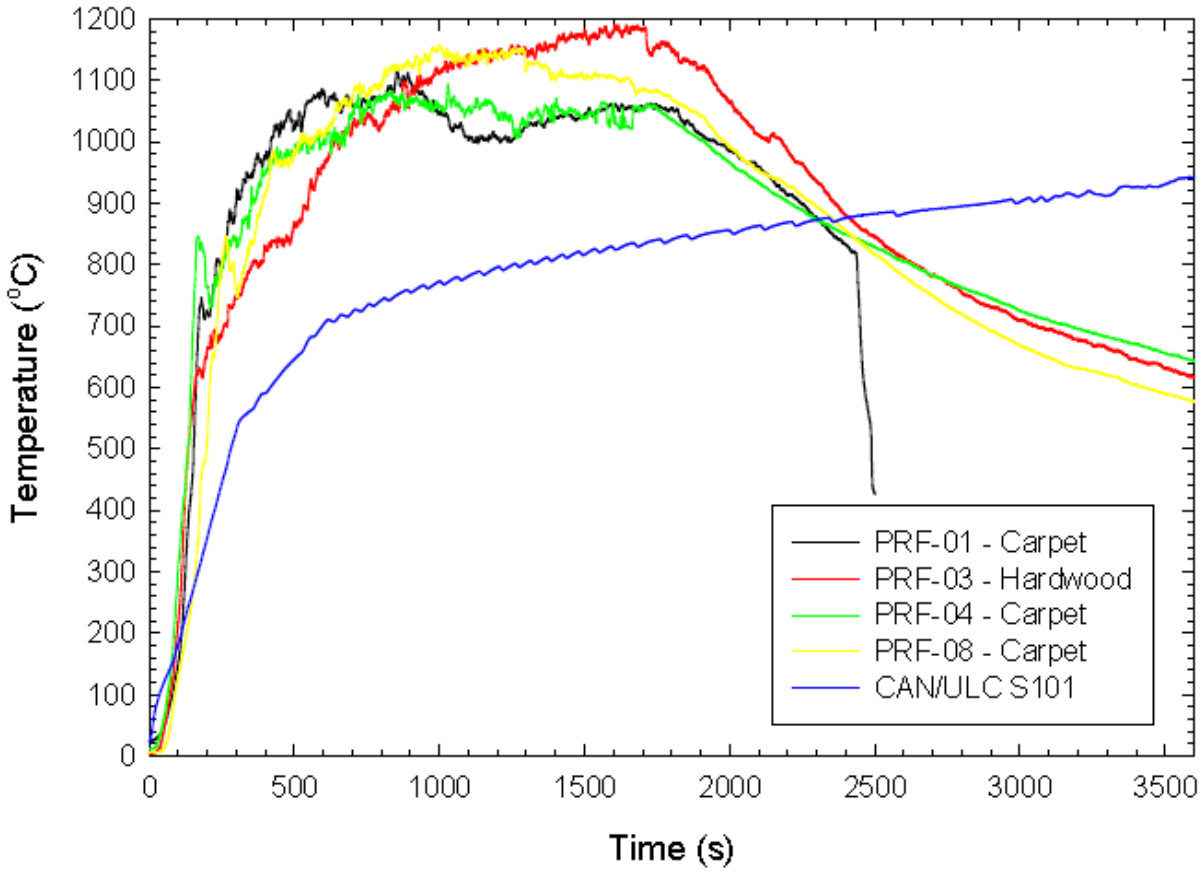
Standard Fire vs. Design Fires



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Fire Modelling

- Estimate temperatures
- Estimate sprinkler activation times
- Estimate tenability
- Heat transfer analysis

Demo – CFD Fire Modelling

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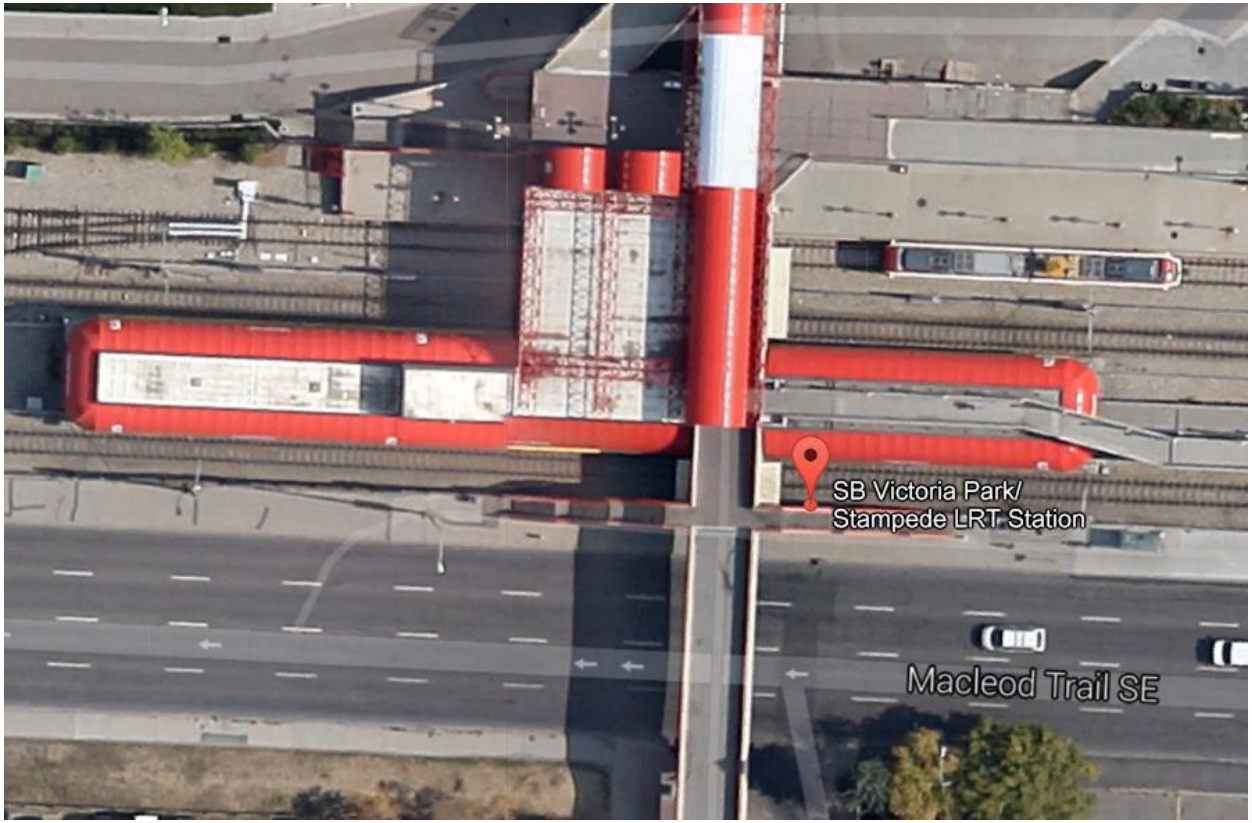
Evacuation Modelling

- City of Calgary, LRT Station



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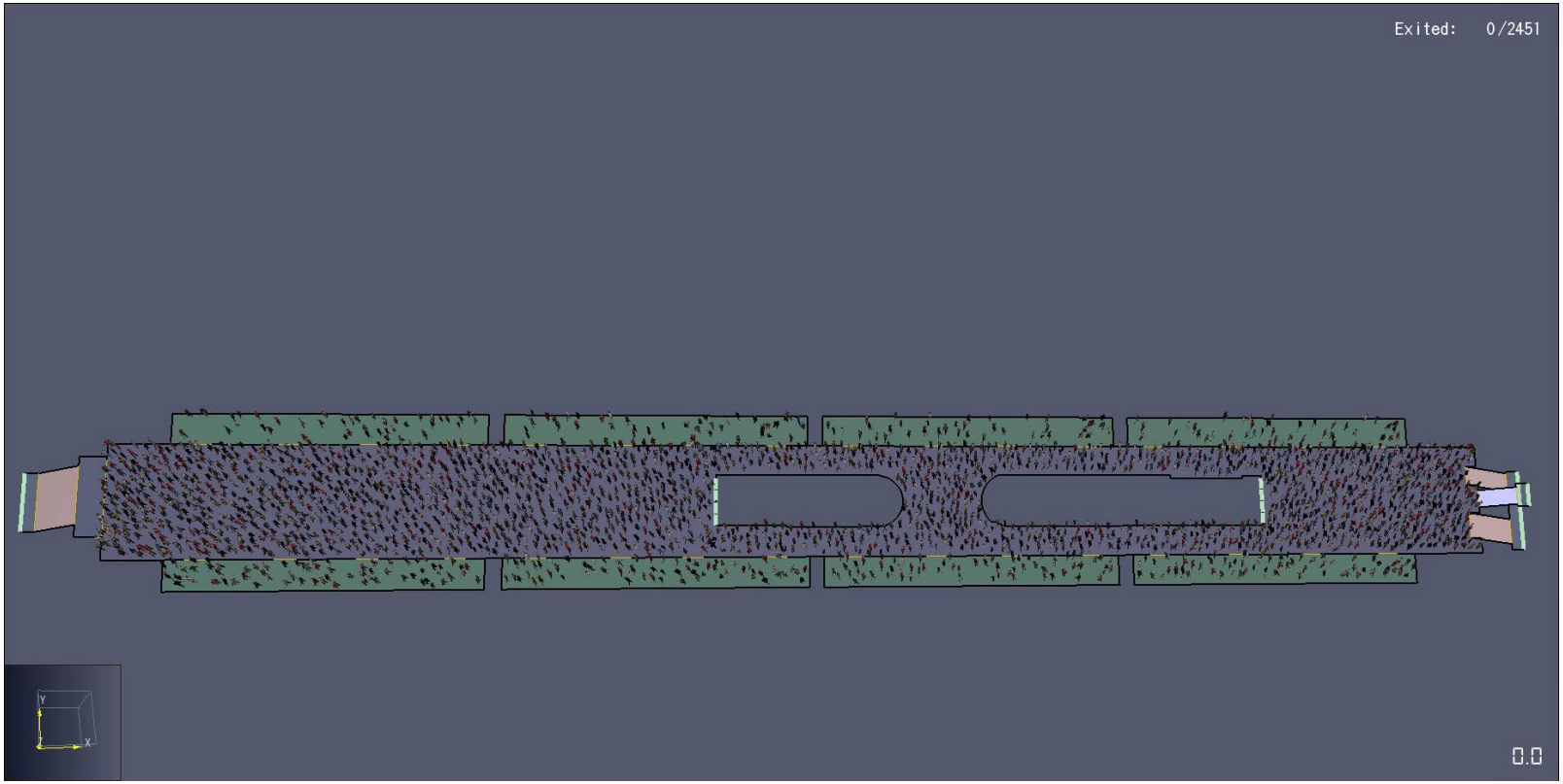
Evacuation Process

Evacuation Analysis

- SFPE Human Guides on Human Behaviour
- SFPE Handbook
- Computer-based evacuation modelling

Demo – Pathfinder Modelling



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Useful Links

- GHL CONSULTANTS LTD: www.ghl.ca
  Tall Wood Presentation: http://www.ghl.ca/shared/Tall_Wood_Presentation.pdf

- Woodworks! National:
  ww.woodworks.org/index.php?option=com_content&view=featured&Itemid=112

- Woodworks! Alberta:
  www.wood-works.org/index.php?option=com_sobipro&sid=61:Wood-WORKS-Alberta&Itemid=228

- Woodworks! BC:
  www.wood-works.org/index.php?option=com_sobipro&sid=61:Wood-WORKS-Alberta&Itemid=228

- Canadian Wood Council: Mid-Rise Construction in BC:
  http://www.cwc.ca/documents/case_studies/Mid-Rise-Construction-in-BC.pdf
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- Canadian Wood Council: Innovating with Wood:
  http://www.cwc.ca/documents/case_studies/Four%20demonstration%20Case%20Study_May_30.pdf

- Technical Guide for the Design and Construction of Tall Wood Buildings in Canada:
  http://ghl.ca/shared/Tall_Wood_Building_Technical_Guide.pdf

Questions?

Thank you

A copy of this presentation is available at:

http://www.ghl.ca/shared/Tall_Wood_Presentation_(Iredale_Dec_2013).pdf

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