Performance Based Design and Review – Building Code Case Studies

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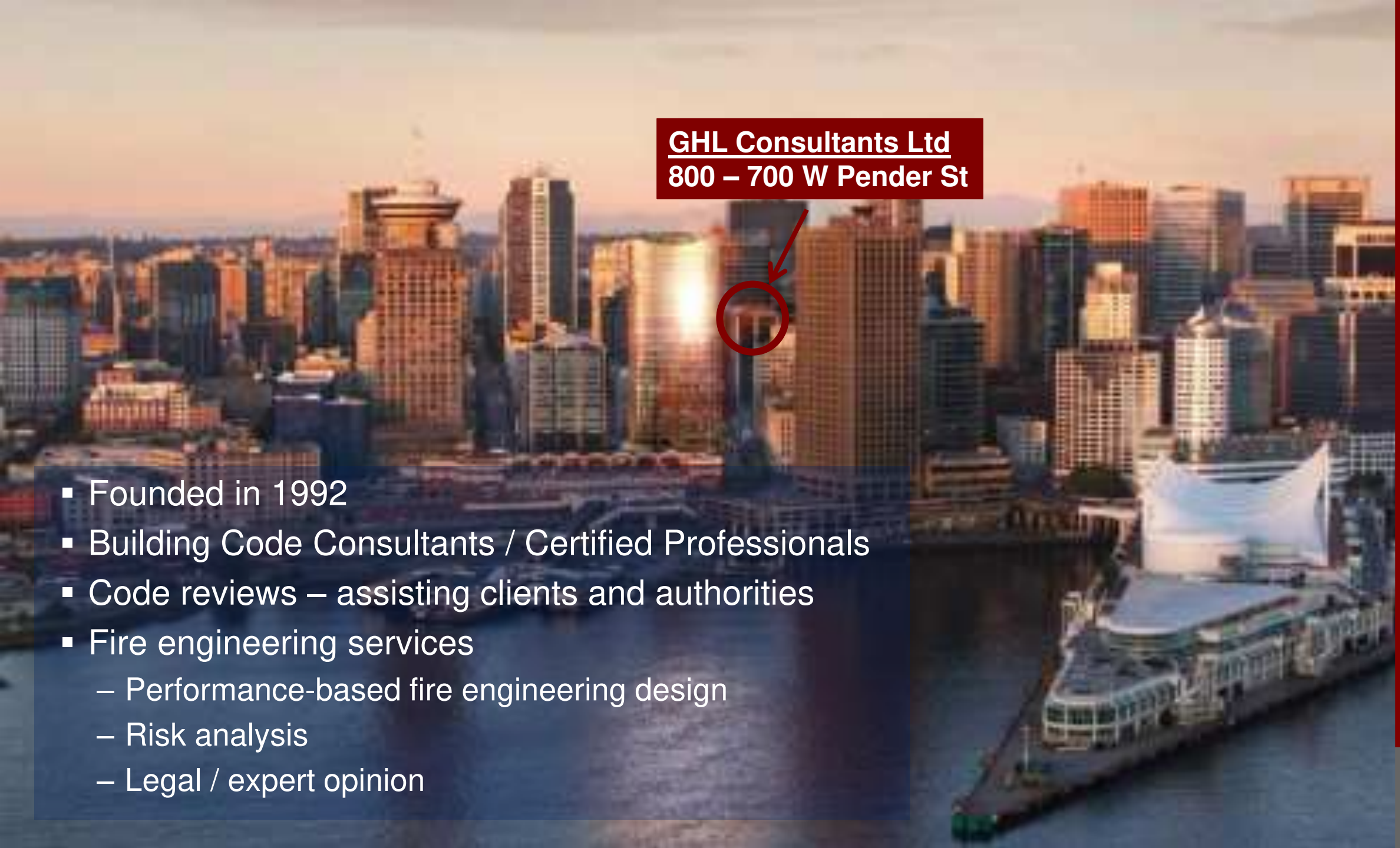

- Founded in 1992
- Building Code Consultants / Certified Professionals
- Code reviews – assisting clients and authorities
- Fire engineering services
  - Performance-based fire engineering design
  - Risk analysis
  - Legal / expert opinion

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37 Technical Staff including

- *15 Professional Engineers*
- *5 Professional Licensee Engineering*
- *12 Engineers with MASc or M Eng in Fire Safety Engineering (3 in progress)*

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S. Claire Yuan, MASc, P Eng, CP
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- BASc, University of Alberta, Chemical Engineering
- MASc, University of Waterloo, Mechanical Engineering - Fire Protection Program
  - Thesis: Challenges Faced in Application of Fire and Life Safety Design in Current Canadian Building Code *http://hdl.handle.net/10012/19114*
- Technical Committee – CSA O86 Engineering Design in Wood
- Performance Based Design and Code Change Proposal
  - Human Behavior – Atrium Evacuation
  - Spatial Separation – Sprinkler Performance
  - Mass Timber Research

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BRIEF HISTORY OF BUILDING CODE

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Where it All Begins

The Great Wall of China
(7th Century BC)

The Great Pyramid of Giza
(26th Century BC)

Taj Mahal
(Completed by 1643)

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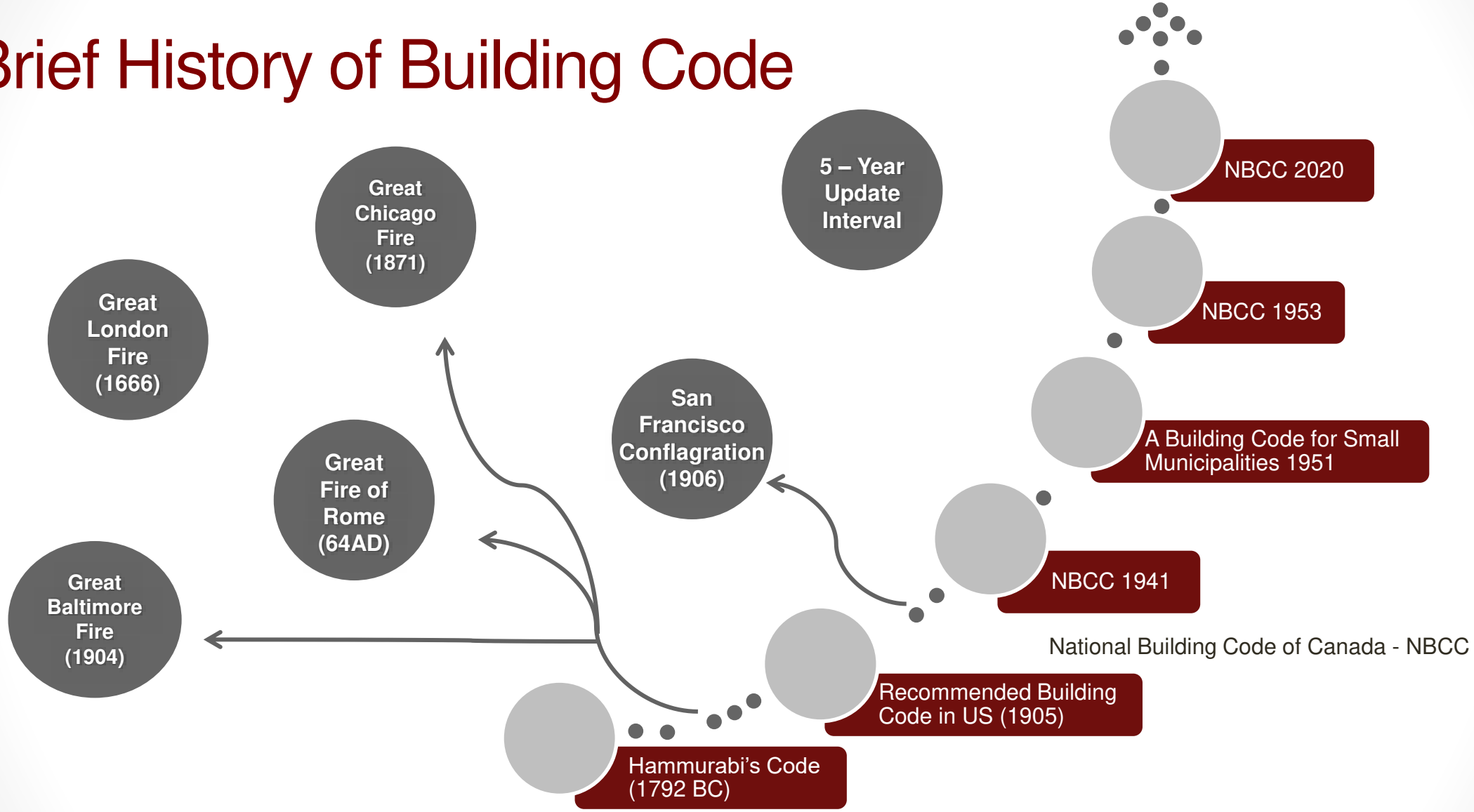
Brief History of Building Code



Current Canadian Building Code Framework

Prescriptive-based design

- Specific and quantitative requirements
- Straightforward and simple applications
- Limited flexibility

Objective-based design

- Specific and quantitative solutions
- Objectives and functional statements
- Support alternative designs with limitations on quantitative comparison

Performance-based design

- Focus on overall building design
- Objectives and functional statements
- Flexible for design team but difficulties in approvals

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Current Canadian Building Code Framework

Prescriptive-based design
"*Requirements*"

- Specific and quantitative requirements
- Straightforward and simple applications
- Limited flexibility

NBCC between 1960s and 1990s

Objective-based design

- Specific and quantitative solutions
- Objectives and functional statements
- Support alternative designs with limitations on quantitative comparison

Performance-based design

- Focus on overall building design
- Objectives and functional statements
- Flexible for design team but difficulties in approvals

NBCC 1960 (Attempted)

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Current Canadian Building Code Framework

Prescriptive-based design

- Specific and quantitative requirements
- Straightforward and simple applications
- Limited flexibility

NBCC between 1960s and 1990s

Objective-based design

"*Prescriptive Solutions*"

- Specific and quantitative solutions
- Objectives and functional statements
- Support alternative designs with limitations on quantitative comparison

NBCC since 2005

Performance-based design

- Focus on overall building design
- Objectives and functional statements
- Flexible for design team but difficulties in approvals

NBCC 1960 (Attempted)

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Current Canadian Building Code Framework

Prescriptive-based design

- Specific and quantitative requirements
- Straightforward and simple applications
- Limited flexibility

Objective-based design

- Specific and quantitative solutions
- Objectives and functional statements
- Support alternative designs with limitations on quantitative comparison

Performance-based design

"Scientific Design"

- Focus on overall building design
- Objectives and functional statements
- Flexible for design but difficulties to establish acceptable level of performance

NBCC 1960s (Attempted)

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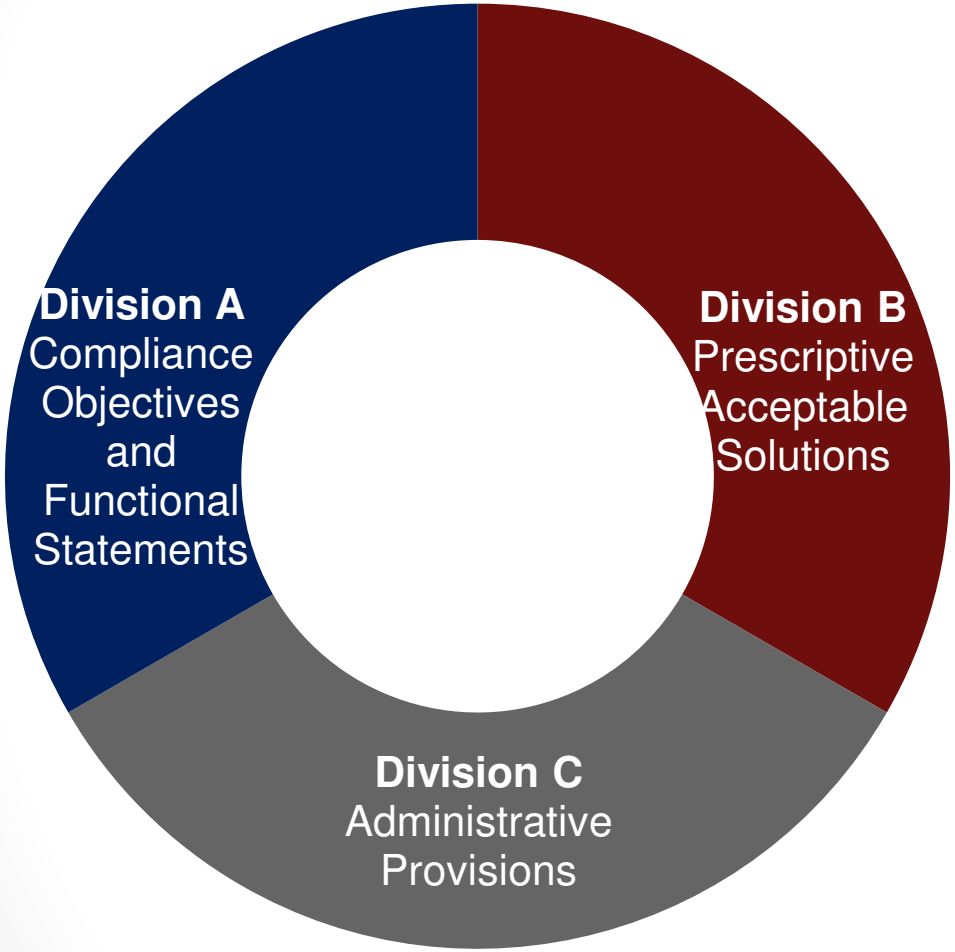
Current NBCC Framework



This presentation focuses on the building design with respect to Fire and Life Safety.

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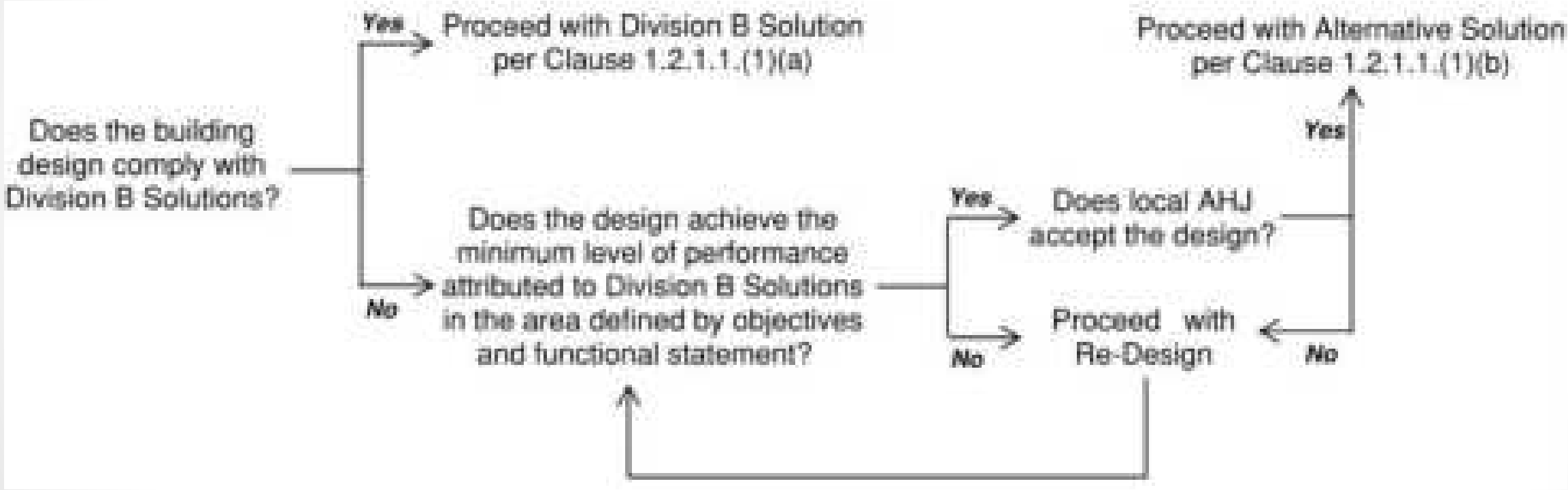
Current NBCC Framework



Current NBCC Framework

A-1.2.1.1.(1)(b) Code Compliance via Alternative Solutions. When a design differs from the acceptable solutions in Division B, then it should be treated as an "alternative solution." A proponent of an alternative solution must demonstrate that the alternative solution addresses the same issues as the applicable acceptable solutions in Division B and their attributed objectives and functional statements. However, because the objectives and functional statements are entirely qualitative, demonstrating compliance with them in isolation is not possible. Therefore, Clause 1.2.1.1.(1)(b) identifies the principle that Division B establishes the quantitative performance targets that alternative solutions must meet. In many cases, these targets are not defined very precisely by the acceptable solutions – certainly far less precisely than would be the case with a true performance code, which would have quantitative performance targets and prescribed methods of performance measurement for all aspects of building performance. Nevertheless, Clause 1.2.1.1.(1)(b) makes it clear that an effort must be made to demonstrate that an alternative solution will perform as well as a design that would satisfy the applicable acceptable solutions in Division B – not "well enough" but "as well as."

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CHALLENGES IN APPLICATION OF NBCC

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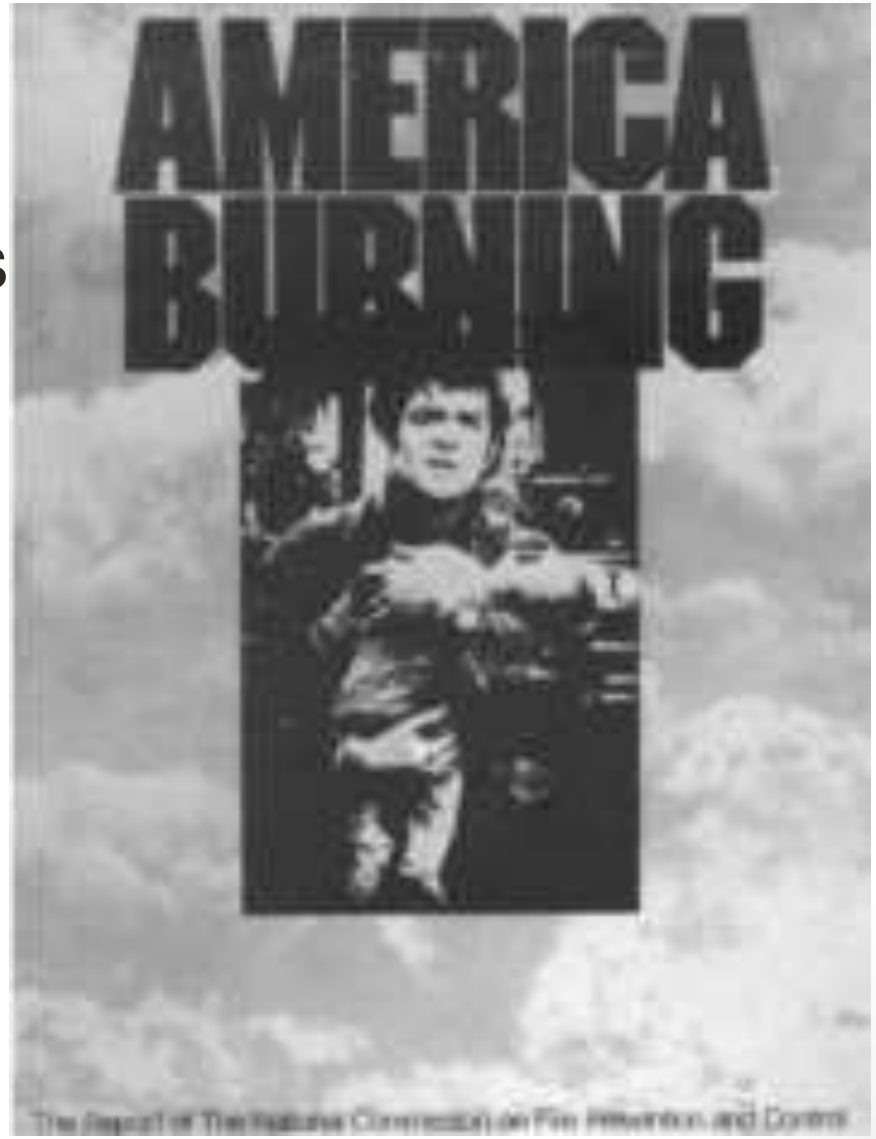
1970s and Before

- Lack of building fire safety measures
- High reliance on firefighting
- Realization of excessive fire deaths



Fire Safety Measures Since 1980s

- Fireblocking and Firestopping
- Smoke alarms
- Automatic detection
- Sprinkler
- Monitored and supervised systems

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Balance

- Is the current level of fire safety prescribed in code:
  - appropriate
  - too low
  - too high
- How does it fit into current societal concern around **affordability and sustainability**?

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Three Case Studies

Atrium Design
Evacuation

Spatial Separation between Buildings

Exposed Mass Timber Elements

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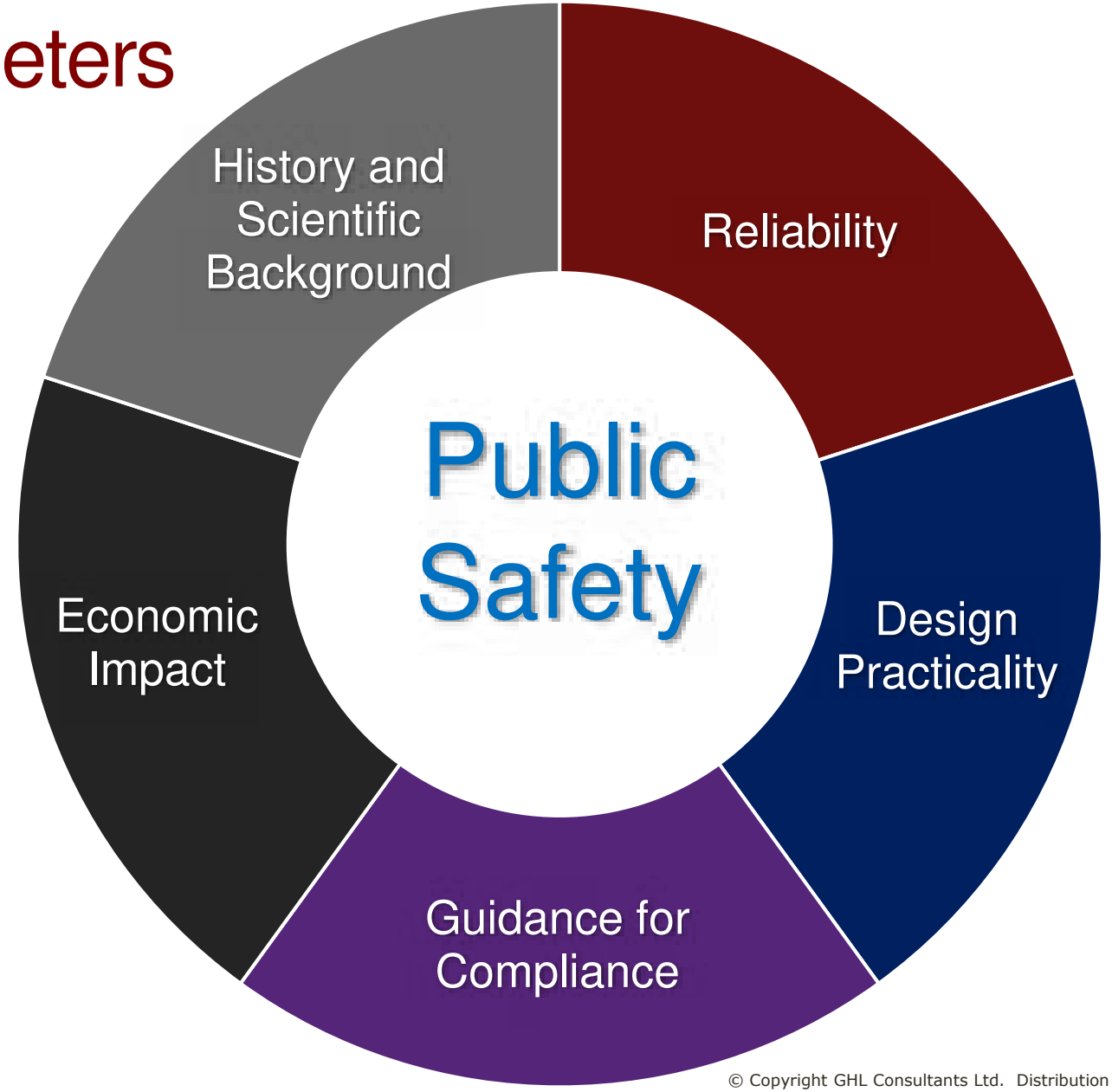
Five Parameters



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Different Levels of Experience

- Need appropriate designer and reviewer in the interest of public safety

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CASE STUDIES

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Three Case Studies

Atrium Design
Evacuation

Spatial Separation between Buildings

Exposed Mass Timber Elements

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Exposed Mass Timber Elements

Exposed Mass Timber Elements

- Simplified to focus on exposed mass timber elements only
- 3 storey, Group C, 3500m^2, sprinklered
- This material is not recognized in NBCC 2020

This case study is codified in BCBC's 2024 EMTC provisions

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This case study is codified in BCBC's 2024 EMTC provisions

Division B and Alternative Solutions

Article	Alternative Design	3.2.2.48EMTC	3.2.2.49	3.2.2.50
Building Height Permitted	3 Storeys	12 Storeys	3 storeys	3 storeys
Building Areas (m^2) Permitted	3,500m^2	6,000	4,000	3,000
Construction Requirement	Exposed CLT floor with rest of building non-combustible	EMTC	Noncombustible	Combustible or Noncombustible
Sprinkler	Yes	Yes	No	Yes
Fire Separation of Floor	2h	2h	1h	1h

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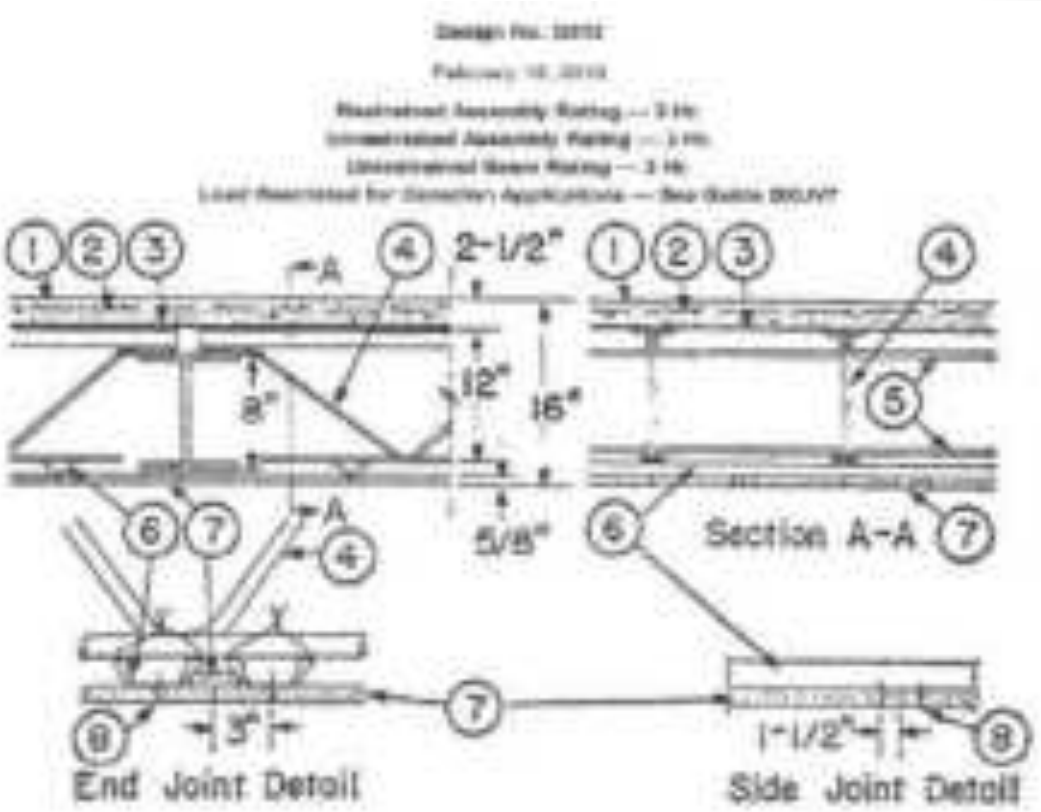
Division B Intent

Performance of Solutions - Reliability



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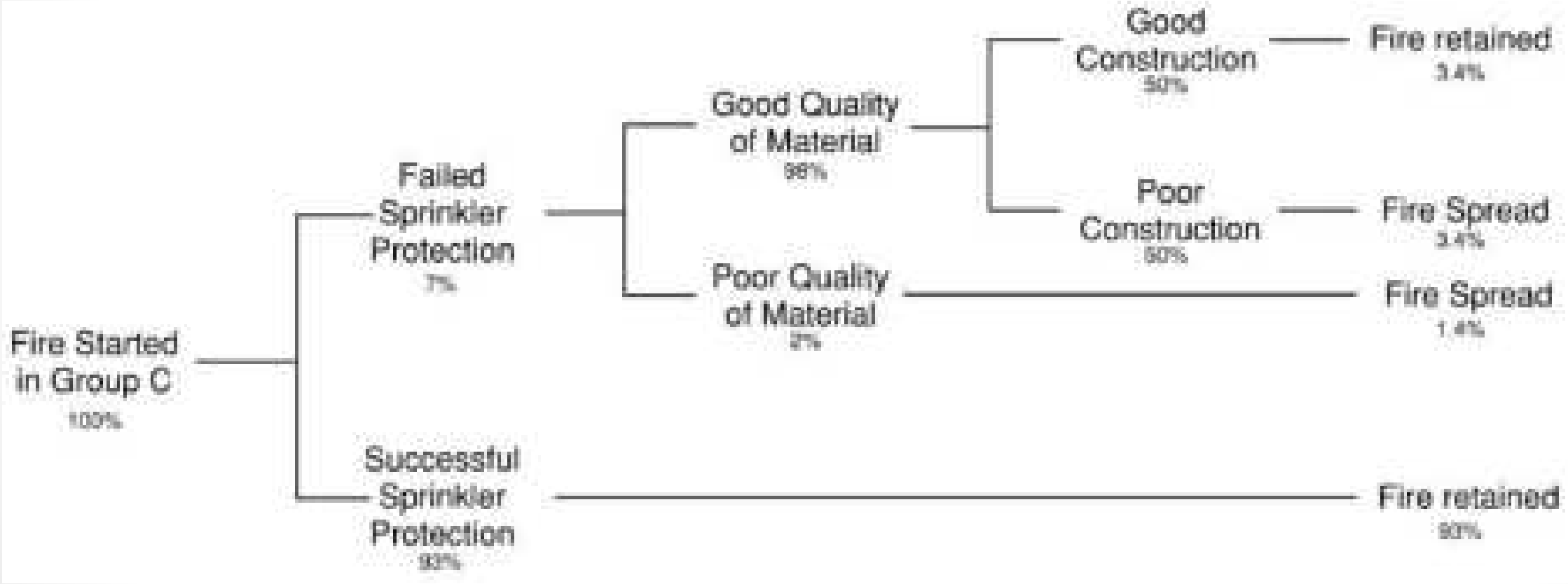
Fault Tree Analysis



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Conclusions

	Division B Article 3.2.2.49 No Sprinkler Protection, Noncombustible Construction	**Alternative Solution** Wet Sprinkler Protection, 2 hour rated CLT Construction
Design Intent	Could not satisfy	Yes, will offer exposed natural wood construction and building area of 3,500m²
Fire Science Support	Specifications appear to be generally accepted without history of their origin and carried over code review cycles without consideration of development of new technology	Forefront research and takes advancement of technology into considerations
Estimated Reliability (normal fire emergencies)	49%	66.3%
Cost Comparison	-	Typically 5%–10% higher
Design Practicality	Further studies on post-seismic design required, does not present a sustainable solution in building design.	Offers high seismic durability and post-seismic repair may be localized Reduced cost and construction time. Offers high sustainability in building design and construction

Spatial Separation

Spatial Separation between Buildings

- Simplified to focus on spatial separation of building face in one direction
- Division B Solutions and one Alternative Solution are presented
- To highlight important considerations that arise in current spatial separation designs

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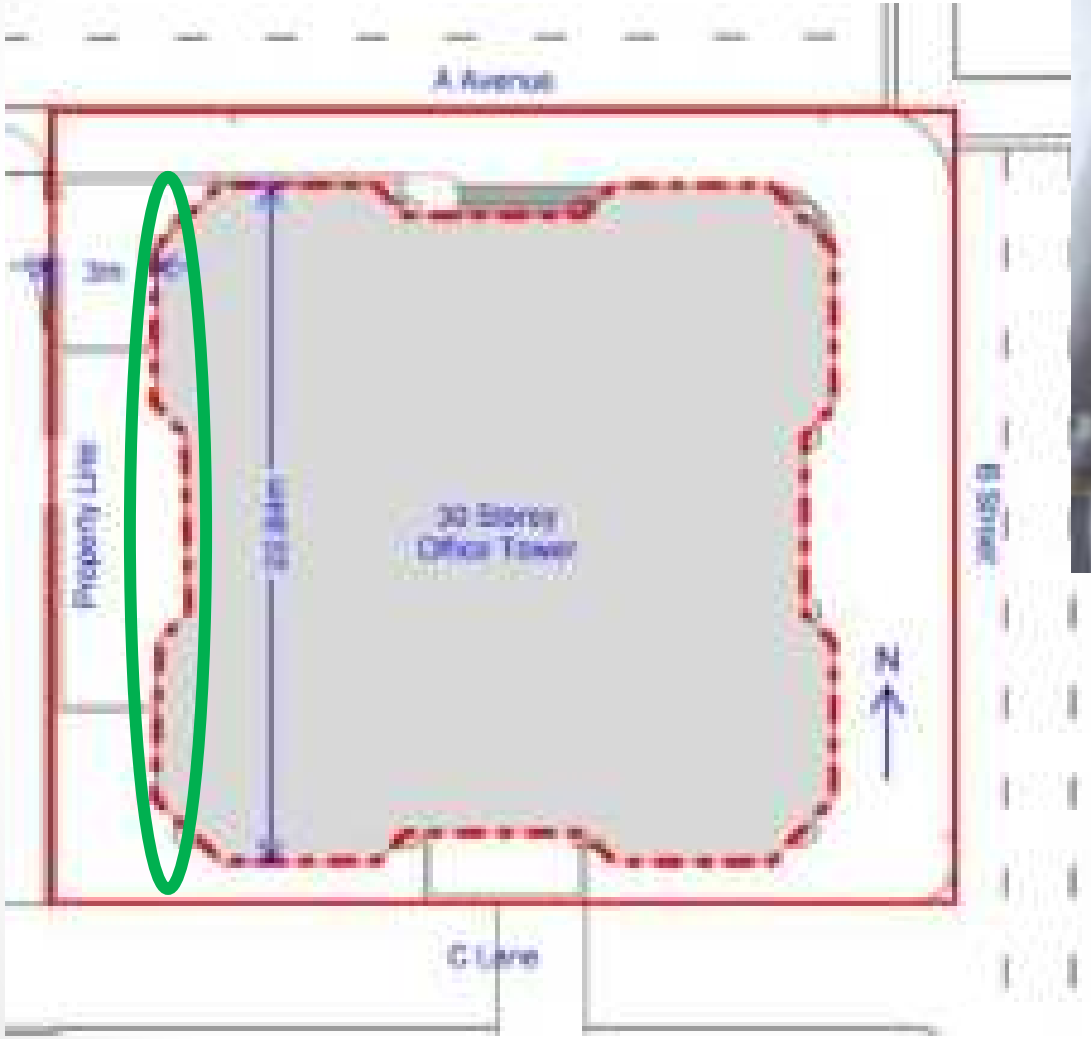
Spatial Separation



Division B Intent

Division B Solutions

or

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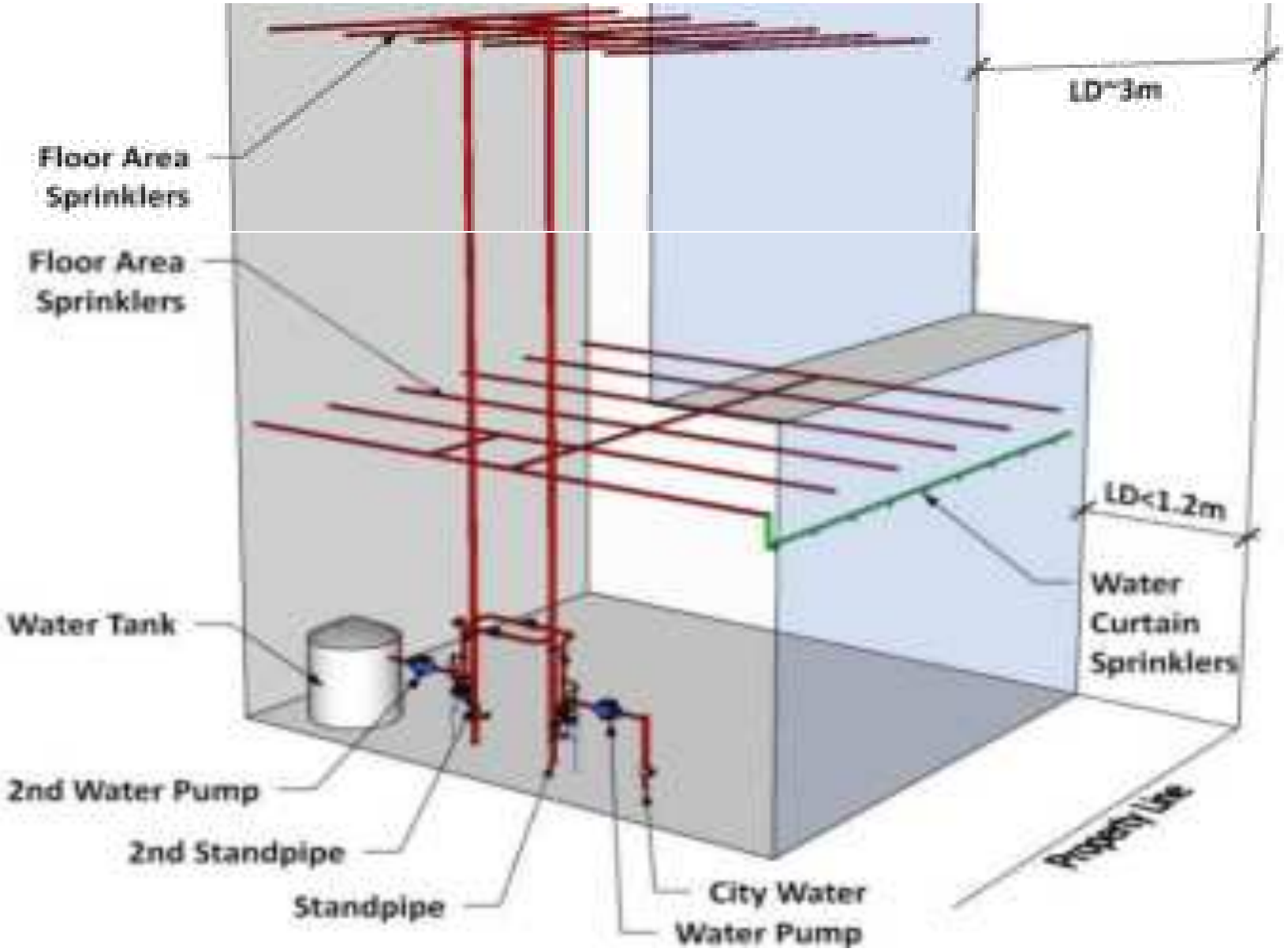
Alternative Solution



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only.

Summary of Solutions

	Division B Solution	Alternative Solution
Area of Opening without Protection	582.9m²	-
Area of Opening with Protection	2,066.6m²	2,649.5m²
Protection Method	1h fire rated glazing or Fire Rated Shutters	Sprinkler System with backup tank and secondary pump

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Performance of Solutions

- History and Scientific Background – Division B Solutions

- Based on unsprinklered residential Test 5 results from 1950s
- Assumptions were made and results was simplified for available design at time.
- Some Division B solutions are excessively simplistic
- Arbitrary factor of 2 for sprinklers

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Performance of Solutions

- Scientific Background – Alternative Solution

- Improved sprinkler systems
- Reduced radiation by >95%
- Appropriate radiation calculations

$$\frac{Radiant\ Intensity_{sprinklered}}{Radiant\ Intensity_{unsprinklered}} = \frac{\theta_{sprinklered}\sigma T_{sprinklered}^{4}}{\theta_{unsprinklered}\sigma T_{unsprinklered}^{4}} = \frac{0.12T_{sprinklered}^{4}}{0.07 \times (1200+273)^{4}} = 1$$

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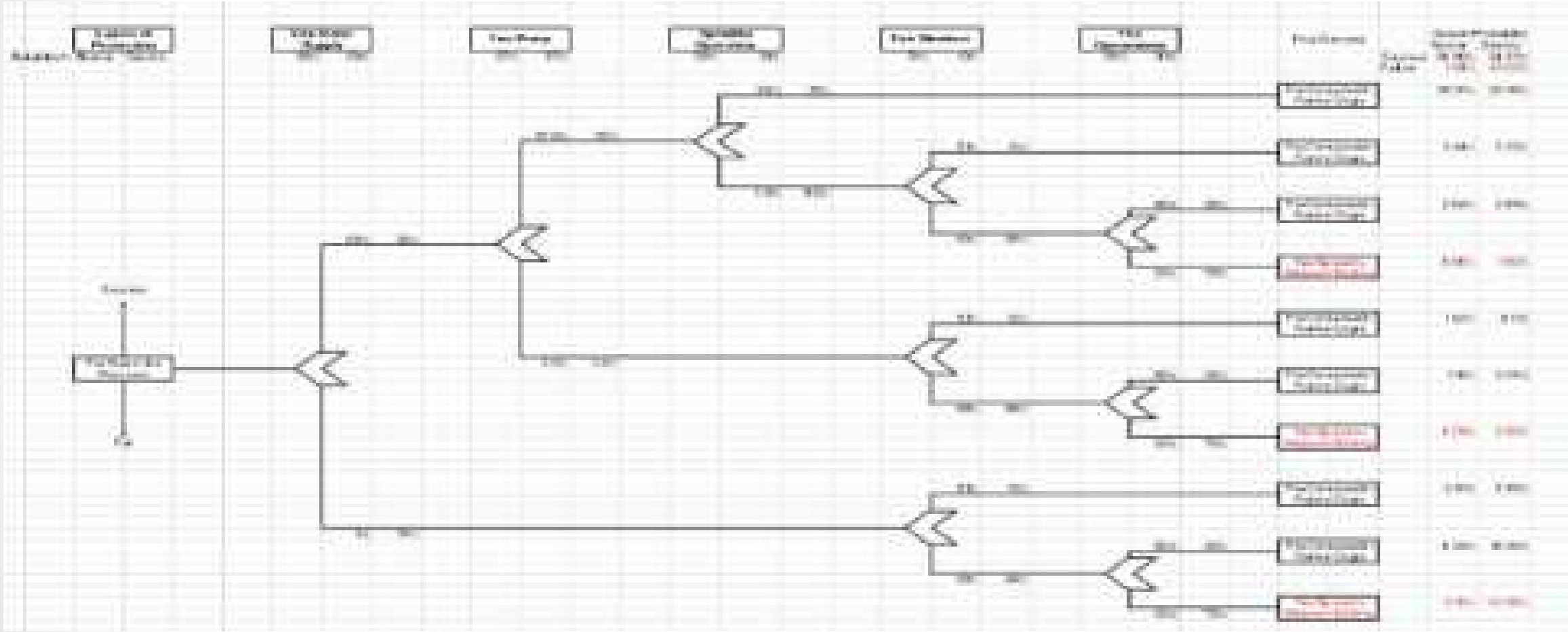
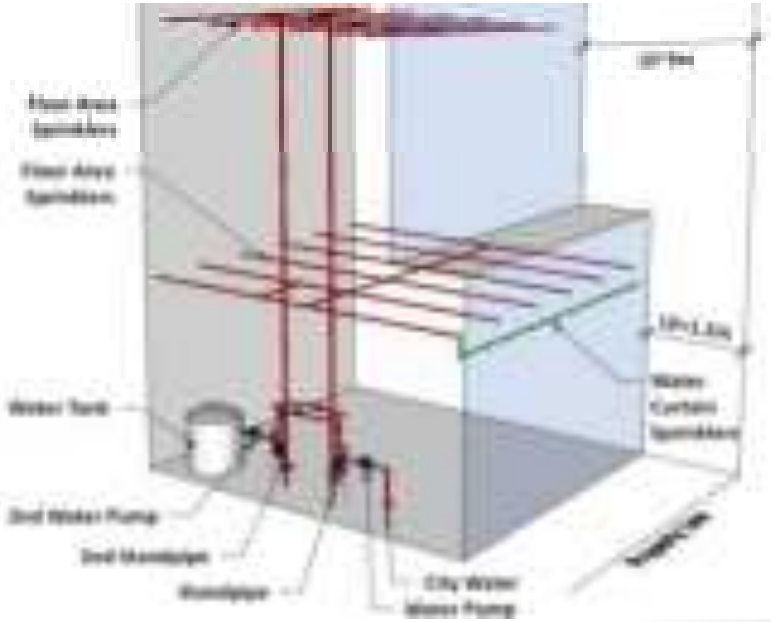
Risk Assessment – Fault Tree Analysis



Performance of Solutions

	Division B Fire Rated Shutters	Alternative Solution Sprinkler with back up tank etc
Probability of Effectiveness	70%	89% to 99%



Performance of Solutions

- Reliability - Earthquake

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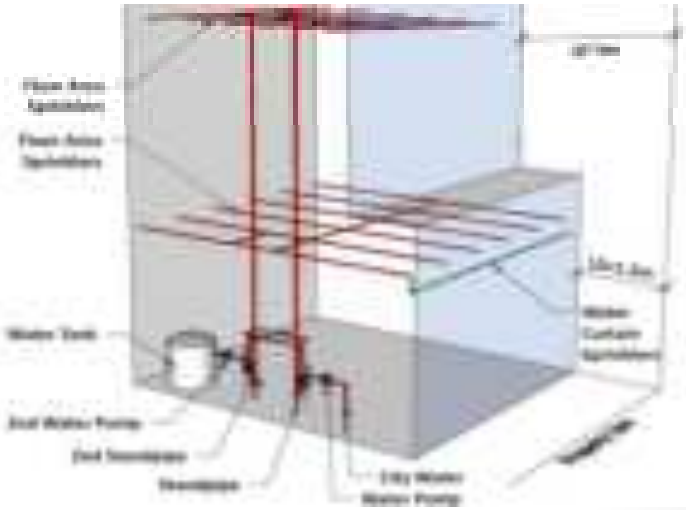
Reliability - Earthquake

	Division B Fire Rated Shutters/Glazing	Alternative Solution Sprinkler with back up tank etc
Probability of Effectiveness	<50%	~ 99% with additional tank water supply



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Economic Impact

Division B Solutions				Alternative Solution	
Fire Rated Shutters		Fire Rated Glazing		Sprinklers + Tank	
Total Area require protection	2649.5m^2	Total Area require protection	2649.5m^2	Tempered Glazing	Typical
# of fire shutters (15m^2)	180	Cost per m^2	$12,850.00	Sprinklers	Typical
Cost per piece	$25,000.00			Extra Pump + Tank	$50,000.00 - $250,000.00
Material Cost	$ 4,417,000	Material Cost	$ 34,028,000	Material Cost	$ 250,000.00

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Design Practicality

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Guidance for Compliance – inconsistency in Code

"5.6.3. Exposing Building. Where the exposing building or structure is protected throughout by an approved, properly maintained automatic sprinkler system or other approved automatic fire suppression system of adequate design for the hazard involved, no exposure hazard should be considered to exist."

Credit: @NFPA 80A

"In the case of a building that is sprinklered throughout, the automatic sprinkler system should control the fire to an extent that radiation to neighbouring buildings should be minimal. Although there will be some radiation effect on a sprinklered building from a fire in a neighbouring building, the internal sprinkler system should control any fires that might be ignited in the building and thereby minimize the possibility of the fire spreading into the exposed building. NFPA 80A, "Protection of Buildings from Exterior Fire Exposures," provides additional information on the possibility of fire spread at building exteriors."

Credit: @VBBL.2019

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Performance of Solutions

	Division B Fire Rated Shutters/Glazing	Alternative Solution Sprinkler with backup tank
History and Scientific Basis	Data based on limited experiments without later account for the full implications of new technology	Takes into consideration more recent related research findings and development of new technologies
Reliability (normal fire emergencies)	70%	89% to 99%
Reliability (post-earthquake fire emergencies)	50%	89% to 98% Subject to design and site operation
Approximate Cost Estimation	$4,417,000.00 / $ 34,028,000.00	$ 250,000.00
Design Practicality	May be altered or damaged and thus may not provide full function when needed	Impact of use / changes in the floor area is minimum to the design

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Atrium

Atrium Design
Evacuation

- Simplified to focus on occupant evacuation
- Only considering Division B Solutions
- Reference case to identify important design factors during appropriate Division B application
- Also to demonstrate considerations should be made during alternative solution development

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Division B Solution

or

Building Code Provision	Division B Solutions	Typical Building Design
Article 3.2.8.3 Sprinkler protection	Sprinkler designed to NFPA 13	Usually, the default building design in modern construction industry
Article 3.2.8.4 Smoke protection of exits and elevators	Vestibules to be provided at any openings, elevators serving more than one interconnected floor space (IFS) and exit opening directly into the atrium Or exit opening into the atrium to meet cumulative ceiling or be provided with protected floor space	Overall travel distance to be designed through alternative solutions
Article 3.2.8.5 Exiting	Provide protected floor area via Cumulative ceiling for all IFS floors, or Short [illegible] Full Atrium Design Protected floor spaces connecting directly to an exit and not less than 5.5m² of occupant load of each floor in IFS and are separated from IFS by a 2h fire separation	Overall travel distance to be designed through alternative solutions
Article 3.2.8.6 Fire Detection	500mm deep draft stops at the edge of floor openings. Smoke detectors provided in vicinity of draft stops. Closely spaced sprinklers may be required at draft stops per NFPA 13 if floor opening dimension is less than 1.000m in area and has a dimension less than 20ft	Usually, the default building design in modern construction industry
Article 3.2.8.7 Smoke Exhaust	Manual exhaust at 6 air changes/h for the atrium and connected floor areas	Mechanical system with controls as flow is typical in modern building design
Article 3.2.8.8 Fuel control load	Combustible control load of 15kg/m² within the IFS where the ceiling height exceeds 8m (combustible content generally refers to furniture, decorative interior finishes)	This would typically be achieved by limiting the furniture within the space

Atrium – Division B Solution

Building Code Provision	Division B Solutions	Typical Building Design Concerns
Article 3.2.8.4 Smoke protection of exits and elevators	Pressurized vestibules with doorways not less than 1.8m apart to be provided at any openings, elevators serving more than just interconnected floor space (IFS) and exit opening directly into the atrium. Or exit opening into the atrium to meet cumulative exiting or be provided with protected floor space.	Floor space may not be available to compensate the provision of additional vestibules.
Article 3.2.8.5 Exiting	Provide protected floor area via: - Cumulative exiting for all IFS floors, or - Stair treads and landings is not less than 0.3m² times total occupant load in IFS, or - Protected floor spaces connecting directly to an exit and not less than 0.5m² of occupant load of each floor in IFS and are separated from IFS by a 2h fire separation.	- Cumulative exiting will result in unrealistic stair width - Stair treads and landing may not be reasonably used - Floor space may not be desired to compensate the provision of Protected floor spaces

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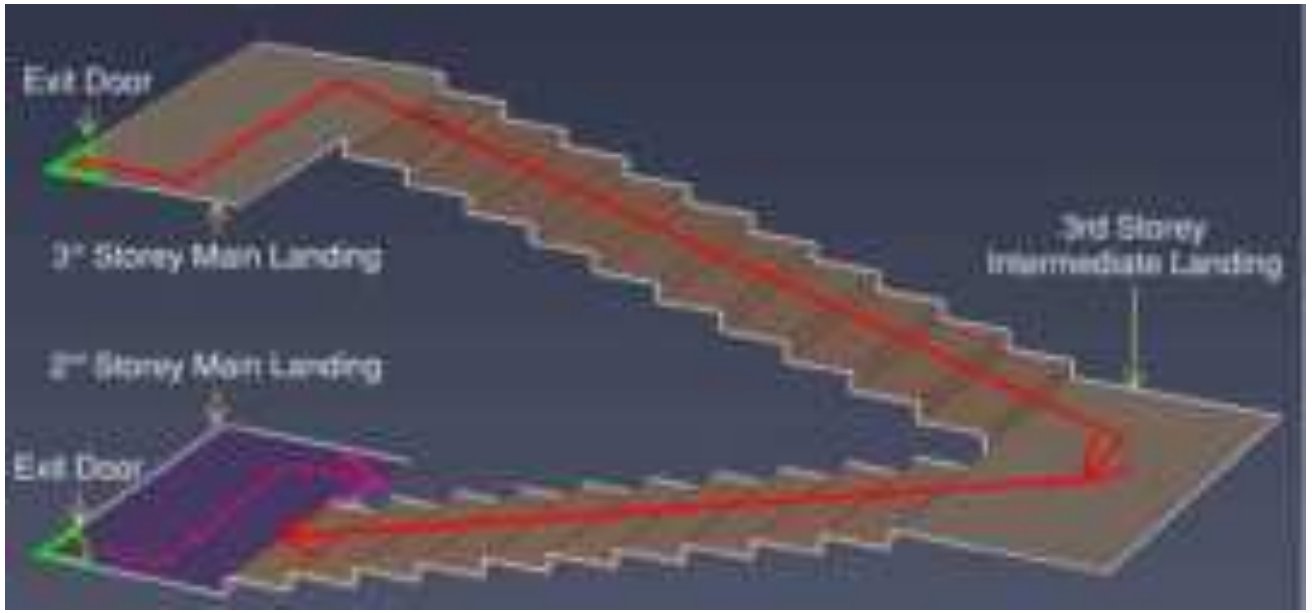
Atrium – Performance of Division B Solutions

- History and Scientific Background
- Reliability
- Economic Impact
- Design Practicality
- Guidance for Compliance



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Atrium – Performance of Division B Solutions

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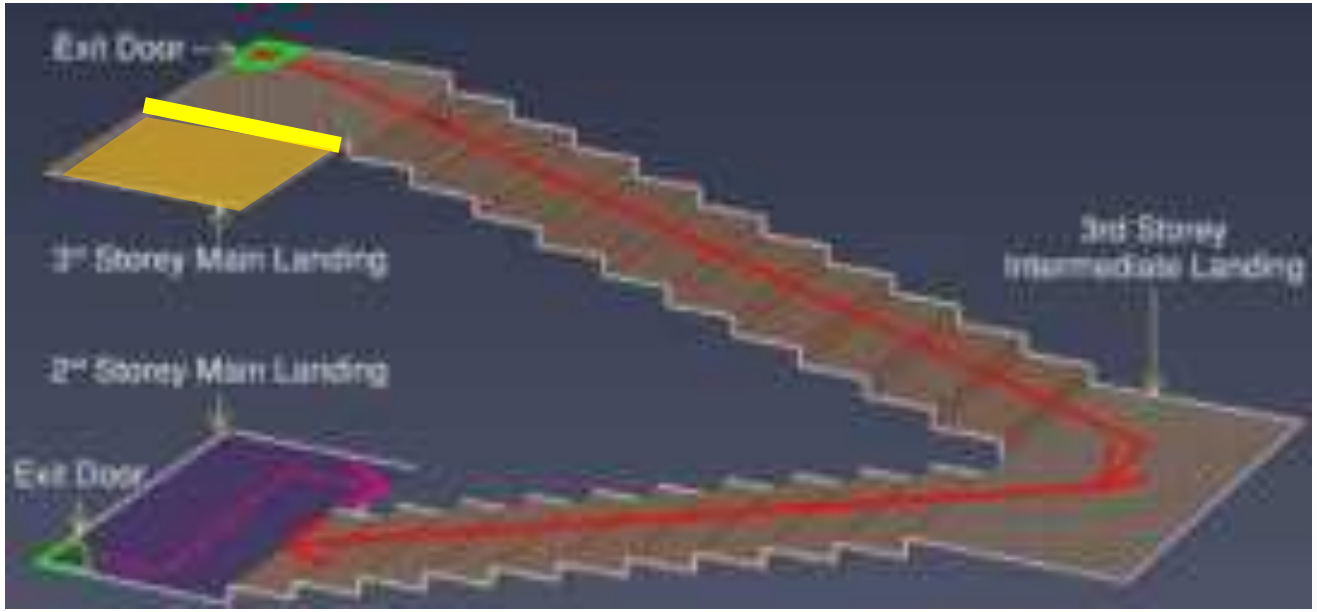

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CONCLUSION

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Looking Forward

"We shape our buildings; thereafter they shape us."

Winston Churchill

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Conclusions

- NBCC intents are qualitative and challenging for innovation, economics and sustainability
- Scientific gaps and lack of documentation in NBCC
- Outdated knowledge and tools within NBCC
- Inconsistency in NBCC leading to complexities
- Fail to recognize the local risks such as earthquakes in Division B Part 3
- Lack of guidance for appropriate design and review for innovative solutions

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Quantifying Level of Performance

- Statistic Assessment
  - Canadian Sprinkler Design and Reliability
  - Canadian Fire Statics reflecting modern design
- Smoke Control Measures – 1% Contaminated Air
- Application of seismics risk analysis specific to fire safety design

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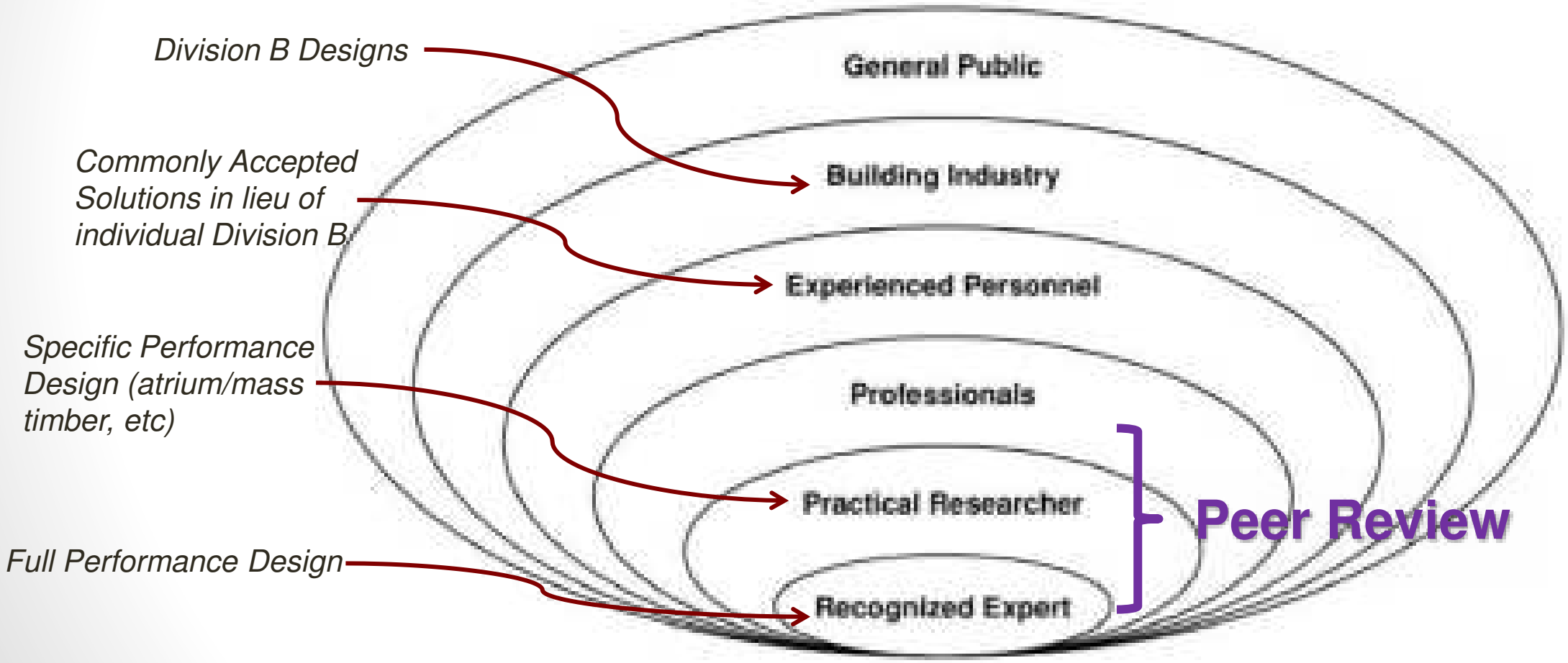
Potential Framework and Peer Review Process

- Appropriate Design and Review



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Future Works

- Do additional measures in modern design improve the level of safety?
- Re-assess the decisions of the early codes
- Encourage upgrading of the old housing stock pre-1980.
- Review Process

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Questions and Comments?

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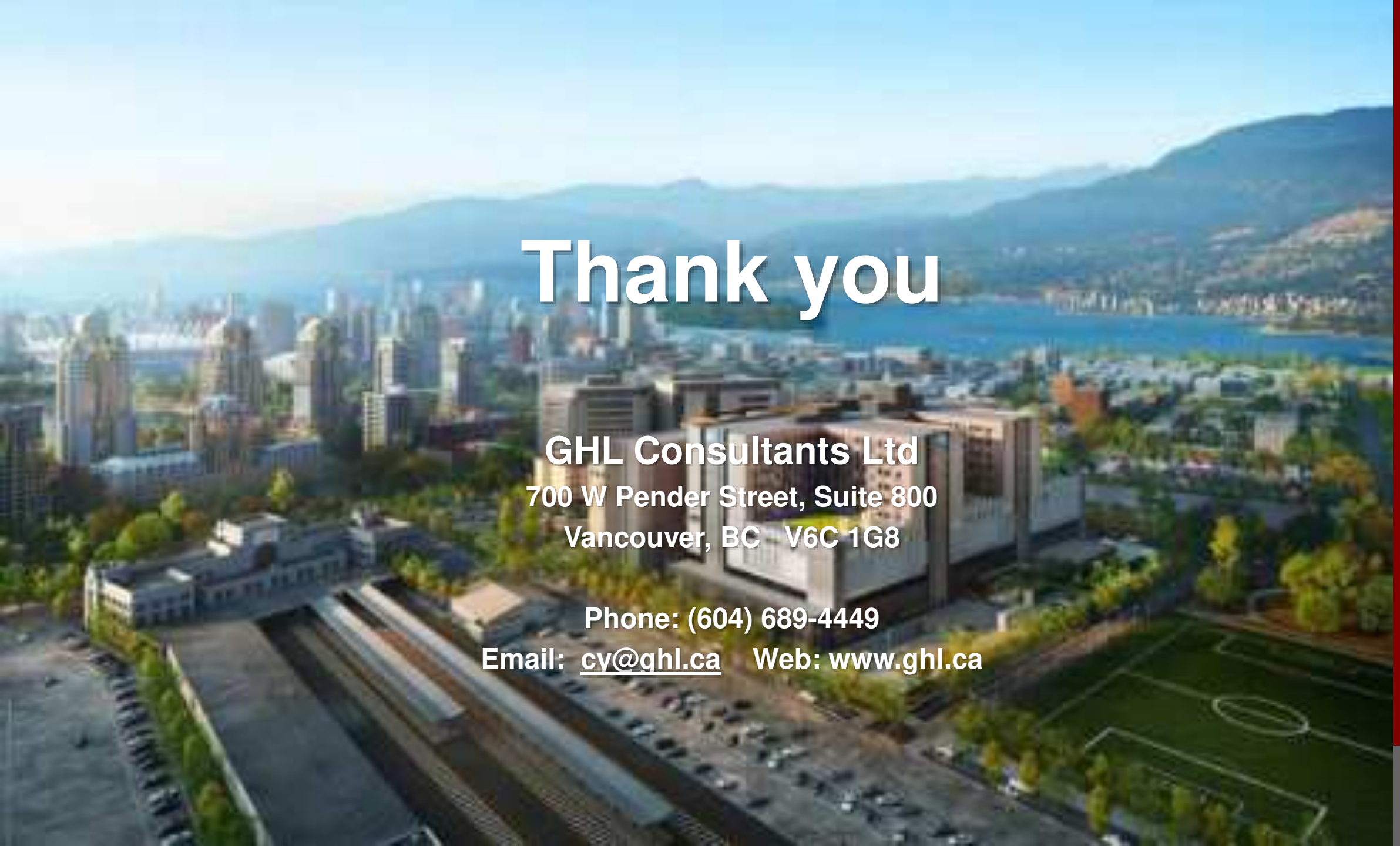

Thank you

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