Risk Analysis and Alternative Solution for Three- and Four-Storey Schools of Mass Timber and/or Wood-Frame Construction

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This technical report has been prepared by **GHL** CONSULTANTS LTD (GHL) for the Canadian Wood Council (CWC). The purpose of this report is to serve as a base for an alternative solution to permit the use of mass timber and/or wood-frame construction for schools of a larger size and area than currently permitted under Division B of the Building Code. The intent is that this report, and alternative solutions developed as a result, lead to a Code change request in the near future. The formulation of GHL's analysis and opinion is based on the science of fire engineering and review of the available literature. GHL's work shall not be construed as exhaustive. There may be other relevant considerations for this proposal including the risk analysis, proposed alternative solution approach, and Building Code change proposal that have not been identified by GHL. The applicable governing bodies (such as the National Research Council, Building and Safety Standards Branch, Vancouver Charter) responsible for Building Code changes, both at the national and provincial levels, shall be solely responsible for the act of amending the Building Code to permit the construction of larger school buildings of combustible construction, or making any changes to any provisions in the Building Code. It is the governing body's sole discretion to adopt, consider or accept, in part or in full, the work of GHL contained in this report. It is noted that the Building Code governing body is responsible for ensuring that all aspects of the Building Code are appropriately updated in any amendments made as a result of this proposal. GHL shall not be responsible for any loss of any kind that may arise due to any construction, building, or structure relating GHL's work in this report or any Building Code or construction regulation change. Should this report be made available to other organizations that have regulatory capacity in construction of buildings and structures, this disclaimer shall equally apply. By preparing this report, GHL does not express explicitly or implicitly any social, economic or political opinion, or any other non-technical opinion, as it relates to the Building Code change proposal. This report is intended to be purely technical in nature. Any inquiries on this report shall be directed to:

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EXECUTIVE SUMMARY

The acceptable solutions in Division B of the current Building Code limit the height of Group A, Division 2 (assembly) buildings of combustible construction to 2 storeys with a maximum area of $2400m^2$. For larger and/or higher buildings, the use of noncombustible construction is prescribed. This report has been prepared in support of the proposal to permit the construction of schools (considered Group A, Division 2 occupancies) up to 4 storeys using mass timber and/or wood-frame construction. It identifies key fire safety features offered by combustible construction materials including tested and currently widely available engineered mass wood products, such as glued-laminated timber and cross-laminated timber.

In order to address the future higher and larger schools, 2 new Building Code construction Articles are proposed. The increased areas in these new Articles are based on accepted Building Code concepts and on the increased areas for office buildings of combustible construction (included in the National Building Code 2015), which are permitted to include a school on the first 2 storeys. For the larger and higher schools, the use of mass timber floor assemblies and wood-frame wall loadbearing assemblies is proposed.

The concept of introducing a new construction Article that provides an acceptable level of performance is now well established with the introduction of Articles 3.2.2.50 and 3.2.2.58 in the National Building Code 2015 and the upcoming 12-storey encapsulated mass timber construction in the National Building Code 2020 recently endorsed by the BC government, which were based on demonstrating that the new construction Articles provide the level of safety prescribed by the National Building Code.

Additionally, it is proposed to increase the maximum height of assembly occupancies of conventional light wood-frame construction currently permitted by the Building Code from 2 storeys to 3 storeys, with the building area reduced proportionally based on the increased height.

This report includes a risk analysis, which identifies the risk areas defined by the objectives of the Building Code and evaluates the level of performance of the Building Code solutions for assembly occupancies vis-à-vis the level of performance offered by the proposed schools up to 4 storeys in building height. This is similar to the process of developing an alternative solution.

The risk analysis is both qualitative and quantitative, and analyzes technical risks anticipated by the fire safety objectives of the Building Code and process risks which are inherent in building design and construction. At the conclusion of this report, a numerical analysis is put forth to demonstrate that the proposed schools up to 4 storeys in height will provide a level of performance equivalent and superior to that provided by the current Building Code solutions. A generic alternative solution is also included to serve as a sample for developing individual alternative solutions for specific projects.

This report demonstrates that school building with the following characteristics will provide at least the same level of performance relative to fire safety as currently required by the Building Code:

- 4 storeys
  $4500m^2$ per storey
  Mass timber floors assemblies
  Wood-frame wall assemblies
- 3 storeys
  $1600m^2$ per storey
  Wood-frame construction

1. INTRODUCTION

The Vancouver School Board has identified the need for larger 3- and 4-storey schools which may include a daycare. Mass timber provides a sustainable cost-effective option for meeting this need. However, this option is not currently included as an acceptable solution in the Building Code.

The existing structure for planning and budgeting for new school buildings means that designers and stakeholders need to know at least 2 years in advance that their proposed design, in this case the use mass timber and/or wood-frame construction, is a feasible option. As such, this generic alternative solution has been developed to in order to seek acceptance in principle of a construction option for mass timber and/or wood-frame construction, for application to future projects.

> ***Mass Timber:*** *Wood members which are sufficiently large enough to provide* ***fire-resistance rating*** *greater than 45 minutes, complete with fire protected connections.*

> ***Acceptable Solutions:*** *Solutions prescribed by the Building Code deemed to provide an acceptable level of safety.*

> ***Fire-resistance rating****: The rating assigned to a building element or assembly based on a standardized fire test or calculations.*

2. BACKGROUND

The current National Building Code (NBC) and provincial Codes based on the NBC, permit combustible construction for buildings of assembly occupancy (Group A, Division 2), such as schools, up to 2 storeys in building height and 2400m^2 in building area. For buildings of Group A, Division 2 ("Group A-2") occupancy outside of these building heights and areas, noncombustible construction is prescribed. In light of increased knowledge in fire safety, advancements in wood technology and fire protection measures, and the evolution of Building Codes over the years, a review of the prescriptive Code in relation to Group A-2 occupancies, specifically schools (daycares and elementary schools to colleges and universities), has become necessary. This document includes a risk analysis prepared in support of the proposal to permit the use of mass timber and/or wood-frame construction for schools of larger building areas and heights than permitted by the current NBC. The proposed larger and higher buildings of mass timber and/or wood-frame construction will be analyzed, specifically focusing on fire safety requirements of Division B, Part 3 of the Building Code. A numerical risk assessment will also be provided to compare the level of performance provided by the options proposed to that provided by the acceptable solutions of the Building Code.

> ***Division B, Part 3:*** *This part of the Building Code is the section where the acceptable solutions for fire safety are found.*

> ***Alternative Solutions****: Solutions not included in Division B, Part 3 but which provide a level of safety equivalent to that provided by an acceptable solution.*

The risk analysis has been prepared as part of the development of a framework for an alternative solution for a generic school of mass timber and/or wood-frame construction, up to 4 storeys in building height, which may include daycare for children 30 months or older. The framework for the alternative solution is intended to identify key fire safety features offered by mass timber and wood-frame construction, and additional fire safety features required in school buildings up to 4 storeys in height. The intent is that this framework will ultimately lead to a Building Code change request on increasing the allowable areas and heights for schools of mass timber and/or wood-frame construction.

It should be noted that this study is not aimed at re-evaluating the accepted level of risk that is fundamental to the Building Code. The study is aimed at demonstrating that, with modern fire engineering practices, it is possible for an assessment and decision to be made regarding greater allowances for mass timber and/or wood-frame construction in school buildings to the extent following the level of performance established in the acceptable solutions (Division B) of the Building Code from a fire safety perspective.

It is noted that this study does not examine the costs and benefits of the different construction materials or methodologies that are available. This study has been prepared in the context of Part 3 fire safety requirements only.

In reviewing this report, it is important to recognize that the acceptable solutions in the Building Code are a set of possible solutions which meet the objectives of the Building Code. Solutions which are not included in the Building Code are not prohibited solutions; they are simply solutions whose safety has not yet been demonstrated to the Building Code committee and verified through the public review process. These solutions are typically ones which are new, unique, or less commonly used than the acceptable solutions in the Building Code. In recognition of the fact that the Building Code cannot and does not include all the possible solutions which provide the required level of performance, the Building Code permits the development of alternative solutions. In fact, some of the acceptable solutions that have been adopted into current Building Codes have been included overtime based on alternative solutions that were commonly proposed and widely used. For example, the Vancouver Building Bylaw (VBBL) now includes a sprinkler-based solution for addressing exit exposure; a solution which was only accepted through the alternative solution process prior to the 2014 version of the VBBL.

It is also important to recognize that all common building materials (both combustible and noncombustible) have inherent advantages and disadvantages which are required to be managed appropriately to provide an acceptable level of performance. Noncombustible construction is not necessarily superior to combustible construction in providing for occupant safety and appropriate building performance as will be demonstrated by the risk analysis.

3. METHODOLOGY

The risk analysis will be both quantitative and qualitative. The risk analysis will address 'Technical Risk' defined as the residual risk associated with a building that is built in full compliance with Division B without significant defect. In this study, technical risk will be used to evaluate whether a school up to 4 storeys in height and of mass timber and/or wood-frame construction would have the same fire risk (or afford the same level of fire safety) as a building of Group A-2 occupancy, up to 4 storeys in building height constructed using light-steel construction currently permitted by the Building Code.

This study will also include 'Process Risk' broadly defined as the practical concerns associated with constructing a 4-storey school of mass timber and/or wood-frame construction – that is, the risks associated with the capability of the industry to deliver a building that provides the level of performance anticipated by the Building Code. Real-world concerns related to designing and constructing buildings of mass timber and/or wood-frame construction are identified and analyzed as process risks.

The quantitative risk analysis will involve a comparison of the level of performance of the Building Code solutions and the solutions proposed by the alternative solution, and will include a numerical assessment.

The steps for the risk analysis will be as follows:

I. Identify the objectives of the Division B acceptable solutions and related process risks; this identifies which risks are relevant.
II. Evaluate the level of performance of the Division B acceptable solution in achieving the objectives of the Division B requirements.
III. Evaluate the performance of the alternative solution relative to the objectives of Division B and the identified process risks.
IV. Compare the performance between the Division B acceptable solution and the alternative solution.

For the purposes of this report, ‘risk’ refers to fire-related risk unless otherwise indicated and will be based on the fire safety objectives contained in the Building Code.

4. DEFINITIONS

This report is based on the following defined terms:

- **Referenced Building Code**

The terms “Building Code”, “Code” and Building Code reference numbers in this report generally refer to the NBC 2015 unless otherwise indicated. The NBC is the model Building Code on which the provincial Building Codes, including the BC Building Code are based, with some changes made to suit the unique objectives and considerations of each province. Similarly, the Vancouver Building Bylaw uses the BC Building Code as its model. Where reference is made to requirements unique to specific provincial Building Codes or Bylaws, references will be identified as such.

- **Objective-based Code**

An objective-based Code is one that is based on prescriptive requirements which are deemed to achieve one or more of the Code stated objectives. Canadian Building Codes are objective-based, and the stated objectives relate to Safety, Health, Accessibility, Fire and Structural Protection of Buildings, and Environment.

NBC up to 1995
Many Codes around the world

NBC since 2005

UK, Australian and
New Zealand Code

- **Combustible Construction**

Combustible construction is defined by the Building Code as the type of construction that does not meet the requirements of noncombustible construction. It typically involves the use of light wood-frame, heavy timber or mass timber.

- **Light Wood-frame Construction**

In conventional light wood-frame construction, the walls and ceilings are constructed using wood studs and joists protected by gypsum board.

- **Heavy Timber Construction**

Heavy timber construction is defined by the Building Code as the type of combustible construction in which a degree of fire safety is attained by placing limitations on the sizes of wood structural members and on the thickness and composition of wood floors and roofs, and by the avoidance of concealed spaces under floors and roofs. Traditional heavy timber construction has unprotected steel or iron connections with fire-resistance ratings which may be as low as 10min. The Building Code provides minimum sizes for heavy timber members. Heavy timber construction is permitted anywhere that the Building Code permits 45min combustible construction; however, it cannot be said to provide a 45min fire-resistance rating.

- **Mass Timber Construction**

Mass timber construction is generally considered construction using large timber members with sizes sufficiently large enough to provide a fire-resistance rating of more than 45min and where connections are fire protected. The fire-resistance rating of mass timber can be determined through standard fire testing or can be calculated using accepted engineering methodology such as those documented in Annex B of the 2014 edition (update 1) of CSA O86, "*Engineering Design in Wood*". This type of construction includes completely protected connections, and similar to heavy timber construction, inherently leads to the creation of a very limited number of concealed spaces.

- **Noncombustible Construction**

Noncombustible construction is defined by the Building Code as the type of construction in which a degree of fire safety is attained by the use of noncombustible materials for structural members and other building assemblies. This type of construction typically involves the use of concrete, masonry, light steel-frame or heavy gauge steel. Light steel-frame construction is similar to light wood-frame construction with walls and ceilings constructed using steel studs or joists instead of wood. Heavy gauge steel members are relatively large structural steel members which may or may not require protection (such as gypsum board or spray-applied fire proofing) to achieve the required fire-resistance rating.

- **Alternative Solutions**

Division B of the the Building Code consists primarily of prescriptive requirements as acceptable solutions. Due to the generic nature of the Building Code, it cannot and does not necessarily include all configurations, materials, and solutions which meet the required level of performance; as such, the development of other solutions is permitted. Solutions other than those prescribed by the Division B which provide the same level of performance as the Division B solutions are known as alternative solutions.

- **School Building**

A school building in this report is defined as a building or part of a building that does not contain a residential occupancy and that is associated with the gathering of persons for educational purposes and includes educational programs from Grade 1 to the highest university level. Such a building may contain a daycare for children who are at least 30 months in age.

5. CURRENT ACCEPTABLE SOLUTIONS FOR BUILDINGS OF GROUP A, DIVISION 2 OCCUPANCY

The Building Code allows buildings of Group A-2 occupancy, which includes schools, to be of combustible or noncombustible construction depending on building area and height. Generally, as the building area and building height increase, the construction requirements become more stringent to reflect the real and perceived elevated risks to life safety and property loss; noncombustible construction and sprinkler protection are 2 key provisions prescribed to address the higher risks. The following table provides a summary of the general construction requirements for buildings containing a Group A-2 occupancy only, or a Group A-2 occupancy (not designed to Articles 3.2.2.50 and 3.2.2.58) with other occupancies:

> ***Schools:*** *Schools are assembly occupancies classified as Group A, Division 2 occupancies.*

Table 1. Summary of general construction requirements for buildings of Group A-2 occupancy.

Code Reference	Maximum Building Height	Maximum Building Area[1]	Construction Type	Floor Assembly and Support Fire-resistance rating	Sprinkler Protection Required
Article 3.2.2.28	1 Storey	$400m^2$	Combustible	-	No
Article 3.2.2.27	2 Storeys	$600m^2$	Combustible	-	Yes
Article 3.2.2.26	2 Storeys	$2400m^2$	Combustible	45min	Yes
Article 3.2.2.25	2 Storeys	$800m^2$	Combustible	45min	No
Article 3.2.2.24	6 Storeys	Unlimited	Noncombustible	1h	Yes
Article 3.2.2.23	Unlimited	Unlimited	Noncombustible	2h	Yes

> ***Building Area:*** *The footprint of the building within the outside surfaces of exterior walls.*

> ***Building Height:*** *Number of storeys from the 1st storey and the roof.*

[1] Based on the maximum number of storeys permitted and facing 1 street.

Per the preceding table, for a building of combustible construction containing a school, the maximum building height and area permitted are 2 storeys and 2400m^2, respectively. For higher or larger buildings, noncombustible construction is prescribed. However, if this 2-storey building contained a Group C (residential) or Group D (office) major occupancy, the building area could conceivably be increased to up to 9000m^2 (a 375% increase in building area) per Articles 3.2.2.50 and 3.2.2.58 as further discussed below.

***Major Occupancy**: The principal use a building is intended for and includes subsidiary occupancies which are integral to the principal use.*

Group A, Division 2 – Assembly occupancy including schools
Group C – Residential occupancy
Group D – Office occupancy

6-storey Office occupancy, Group D, introduced in the NBC 2015.

6-storey Residential occupancy, Group C, was first introduced to the BC Building Code in 2009.

It is noted that the Alberta Building Code 2014 permits a 3-storey building of Group A-2 occupancy with maximum building areas of 1200m^2 and 400m^2 under Articles 3.2.2.26 and 3.2.2.25, respectively. This provision has been in the Alberta Building Code since the 1997 edition.

Based on a Code change first included in the NBC 2015, where a building is constructed to Articles 3.2.2.50 (Group C) or 3.2.2.58 (Group D), it is permitted to include a Group A-2 occupancy within the first 2 storeys without having to construct these storeys using noncombustible construction, provided it contains some residential or office use; that is, at least 11% of 1 storey. It is noted that these construction Articles permit significantly larger areas than currently permitted for Group A-2 buildings of combustible construction not containing a Group C or Group D occupancy, as described above. The construction requirements for Articles 3.2.2.50 and 3.2.2.58 are summarized in the following table:

Table 2. Summary of general construction requirements for buildings of Group C or D with A-2 occupancy.

Code Reference	Maximum Building Height	Maximum Building Area	Construction Type	Floor Assembly and Support Fire-resistance rating	Sprinkler Protection Required
Article 3.2.2.50	1 Storey	9000m^2	Combustible	1h	Yes
	2 Storeys	4500m^2			
	3 Storeys†	3000m^2			
	4 Storeys†	2250m^2			
	5 Storeys†	1800m^2			
	6 Storeys†	1500m^2			

Code Reference	Maximum Building Height	Maximum Building Area	Construction Type	Floor Assembly and Support Fire-resistance rating	Sprinkler Protection Required
Article 3.2.2.58	1 Storey	18000m^2	Combustible	1h	Yes
	2 Storeys	9000m^2			
	3 Storeys[†]	6000m^2			
	4 Storeys[†]	4500m^2			
	5 Storeys[†]	3600m^2			
	6 Storeys[2]	3000m^2			

Based on the above table, it is possible to construct a 2-storey building of combustible construction with building area of 9000m^2, with a school occupying the entire 1st storey and up to 89% of the 2nd storey, provided the remainder of the 2nd storey is occupied by a Group D occupancy. It is noted that buildings constructed to Articles 3.2.2.50 and 3.2.2.58 have additional unique fire protection requirements beyond those prescribed for other comparable buildings, including a 1h fire-resistance rating for roof assemblies, 60min duration for emergency power, locating of at least 25% (10% permitted per the current BC Building Code 2018) of the building perimeter within 15m of a street, etc.

Theoretically, it should be possible to construct a 2-storey school of combustible construction to Article 3.2.2.58, provided all other requirements for a building constructed to this Article (such as a 1h roof, etc) are met, without having to include a Group D major occupancy. However, the current interpretation is that the building will have to include a Group D major occupancy to be classified under Article 3.2.2.58 to start with. It is our opinion that the inclusion of a Group D major occupancy in a building designed to Article 3.2.2.58 which includes a Group A-2 occupancy at the 1st and 2nd storeys has no effect on the overall safety and performance of the building. Thus, a 2-storey 9000m^2 Group A-2 building of combustible construction is already inherently permitted through Article 3.2.2.58.

In summary, the current Division B requirements for a 2-storey school of combustible construction will be as follows and as illustrated in Figure 1:

- Maximum building area of 2400m^2 if the building contains only Group A-2 or includes major occupancies other than Group C or D,
- Maximum building area of 4500m^2 if the building includes Group C major occupancy and is constructed to Article 3.2.2.50.,
- Maximum building area of 9000m^2 if the building includes Group D major occupancy and is constructed to Article 3.2.2.58.

As discussed above, different maximum building areas would be permitted under Articles 3.2.2.50 and 3.2.2.58 depending on building height.

[†] Group A-2 occupancy permitted at first 2 storeys only.

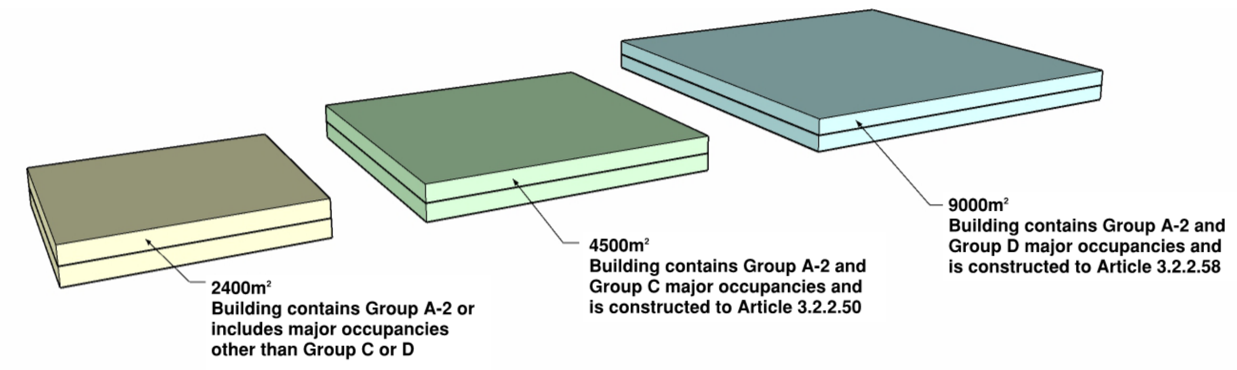

Figure 1: Illustration of the current Division B requirements for a 2-storey school of combustible construction.

6. PROPOSED NEW CONSTRUCTION ARTICLES

The Building Code, in acknowledging that it does not include all the possible solutions that will provide the required level of performance, permits the development of alternative solutions. The Building Code indicates that that there are 2 methods of achieving compliance; either using Division B acceptable solutions or using alternative solutions. The alternative solutions are required to meet the objective and functional statements outlined for the acceptable solutions and to provide the same level of performance relative to objectives and functional statements.

> ***Objective Statements**: The objectives the Code intends to achieve by implementing the acceptable solutions. The objectives relate to achieving safety, health, accessibility, fire and structural protection of buildings, and environmental protection.*

> ***Functional Statements**: The functions a building and its elements are intended to perform based on the implementation of the acceptable solutions.*

Historically, there has been extensive study and expansion of residential building size and area, from 45min 3-storey to 1h 4-storey Group C in the 1990 NBC, and then to 6 storeys in the BC Building Code in 2009 and the NBC in 2015.

Based on consultation with architects and engineers, it was established that there is a need for options for larger schools of mass timber and/or wood-frame construction up to 4 storeys in height. Two options were developed in the same format as the construction Articles currently in the Building Code; buildings of Group A-2 occupancy in general, up to 3 storeys with wood-frame floor and wall assemblies, and school buildings up to 4 storeys with mass timber floor assemblies and wood-frame wall assemblies.

There is currently no 1h combustible Group A-2 construction Article. A new 1h construction Article is proposed at 3 storeys with areas interpolated, resulting in a 3-storey Group A-2 category with building area of 1600m^2. It is noted that no additional fire protection features are proposed beyond increasing of the minimum structural fire resistance to 1h.

In order to achieve the school of 4 storeys with increased areas, it was decided additional safety features were appropriate, including those for the new NBC 2015 Group D provisions and the use of mass timber floors in conjunction with wood-frame walls.

6.1 **4-Storey, Group A-2, maximum 4500m^2**

In light of the most recent Building Code changes included under Article 3.2.2.58 (Group D, mixed use), the availability of engineered mass timber products (such as glue-laminated timber and cross-laminated timber) able to provide fire-resistance rating beyond 45min, and the steady advancements of fire protection capabilities since the current requirements were first included in the Building Code, it is proposed that the following new construction Article be considered as an alternative solution to the Building Code provisions:

This proposed Article is based on the building size permitted by Article 3.2.2.58 with the enhanced safety and reliability provided by mass timber floors.

Article 3.2.2.XX. Group A, Division 2, up to 4 Storeys, Sprinklered

1) A *school building* classified as Group A, Division 2 is permitted to conform to Sentence (2), provided

   a) it is *sprinklered* throughout,

   b) it is not more than 4 *storeys* in *building height*,

   c) it has a height not more than 18m measured between the floor of the *first storey* and the uppermost floor level that does not serve a rooftop enclosure for elevator machinery, a stairway or a *service room* used only for service to the *building*, and

   d) it has a *building area* not more than

      i) 18 000 m^2 if 1 *storey* in *building height*,
      ii) 9 000 m^2 if 2 *storeys* in *building height*,
      iii) 6 000 m^2 if 3 *storeys* in *building height*,
      iv) 4 500 m^2 if 4 *storeys* in *building height*,

2) Except as required by Sentence (3), the *building* referred to in Sentence (1) is permitted to be of *combustible construction* or *noncombustible construction*, used singly or in combination, and

   a) floor assemblies shall be *fire separations* with a *fire-resistance rating* not less than 1h,

   b) roof assemblies shall have a *fire-resistance rating* not less than 1h,

   c) *mezzanines* shall have a *fire-resistance rating* not less than 1h, and

   d) *loadbearing* walls, columns and arches shall have a *fire-resistance rating* not less than that required for the supported assembly.

3) Floor assemblies for a *building* referred to in Subclause (1)(d)(iii) or (iv) shall be constructed using *mass timber construction*.

All italicized terms will have the same meaning as they do in the current Building Code, except "*mass timber construction*" and "*school building*" which are intended to have the same meaning as defined in this report. Provisions relating to extremely tall roofs have been removed as it is not anticipated that this will be applicable to a school building up to 4 storeys in building height.

It is proposed that all requirements currently included in the Building Code for a building of Group D occupancy constructed to Article 3.2.2.58 be equally applicable to a building constructed to this proposed Article. This will include a 1h fire-resistance rating for roof assemblies, locating of at least 10% of the building perimeter within 15m of a street, 60min duration for emergency power, etc. It is proposed to conform to the current BC Building Code 2018 with respect to locating a minimum of 10% (rather than 25% prescribed by the NBC) of the building perimeter within 15m of a street. British Columbia adopted the above noted 10% requirement based on the consideration that the 25% requirement rendered a large cross-section of building sites unable to meet the 25% provision. It is noted that the 10% provision is proposed for the NBC 2020.

As previously described, Group A-2 buildings with building area close to 18000m^2 for 1 storey, and up to 9000m^2 for 2 storeys are already permitted by the Building Code under Article 3.2.2.58. The new Article proposes allowing school buildings at the 3rd and 4th storeys, with building areas as currently permitted by Article 3.2.2.58, with the additional feature of mass timber floor assemblies with wood-frame walls. Although not an objective of the Building Code, the proposed mass timber floor assemblies will provide a more durable fire separation compared to wood-frame floors for a building constructed to Article 3.2.2.58. Due to the monolithic nature of mass timber, it tends to be more resistant to damage caused by impact. Similarly, firestopping through mass timber is more robust and less susceptible to damage than firestopping through a conventional wood-frame floor assembly due to the robustness for the mass timber elements.

6.2 **3-Storey, Group A-2, maximum 1600m^2**

It is also proposed introduce a new construction Article to include a 3-storey category for all buildings of Group A-2 occupancy in general, with building area of 1600m^2 and 1h fire-rated floor assemblies as an alternative solution, based on the expansion of Article 3.2.2.26.

The proposed Article is based on the lack of a 1h combustible construction category in the Building Code and extrapolating the existing permitted building area over 3 floors, recognizing the reliability of sprinklers as occurred in the 1990 Code for residential construction.

Article 3.2.2.YY. Group A, Division 2, up to 3 Storeys, Sprinklered

1) A *building* classified as Group A, Division 2 is permitted to conform to Sentence (2), provided
   - a) except as permitted by Sentences 3.2.2.7.(1) and 3.2.2.18.(2), the building is *sprinklered* throughout,
   - b) it is not more than 3 *storeys* in *building height*, and
   - c) it has a *building area* not more than
     - i) 1600 m^2 if 3 *storeys* in *building height,*

2) The *building* referred to in Sentence (1) is permitted to be of *combustible construction* or *noncombustible construction*, used singly or in combination, and

a) floor assemblies shall be *fire separations* and shall have a *fire-resistance rating* not less than 1h,

b) *mezzanines* shall have a *fire-resistance rating* not less than 1h, and

c) *loadbearing* walls, columns and arches shall have a *fire-resistance rating* not less than that required for the supported assembly.

The following sections of this report present the risk analysis for the above proposed alternatives.

7. QUALITATIVE TECHNICAL RISK ANALYSIS

7.1 Summary of Risks Contemplated by Building Code

The Building Code is essentially a consensus document that regulates construction standards. The Building Codes are written and revised through each Code change cycle in an effort to better manage risks in buildings. As an objective-based Code, the NBC objectives, which are found in Section 2.2 of Division A, identify the risk areas that the Building Code recognizes. The required level of performance with respect to each Code objective is then set out in the acceptable solutions in Division B. The acceptable solutions define the boundary between "acceptable" and "unacceptable" risks and are used to evaluate alternative solutions. In this regard, a "Code compliant" or "Division B compliant" building does not mean the building is risk-free; rather, it means that the risks have been managed to a level that is deemed acceptable.

Code Compliant = Acceptable Level of Fire Safety

Recognizing that Division B defines the boundary between acceptable and unacceptable risks, this risk analysis will be approached by evaluating the proposed alternative solutions against the Division B solutions for buildings already permitted under Subsection 3.2.2. This will be done in 3 parts. The 1st will be an analysis of a 4-storey school building (Group A-2) constructed to the proposed new Article 3.2.2.XX relative to a 4-storey light wood-frame building of Group D occupancy constructed to Article 3.2.2.58 and permitted to include a school at the first 2 storeys. The 2nd will be an analysis of a 4-storey school building (Group A-2) constructed to the proposed new Article 3.2.2.XX relative to a 4-storey noncombustible (light steel-frame) Group A-2 building constructed to Article 3.2.2.24. The 3rd will be an analysis of a 3-storey Group A-2 building constructed to the proposed new Article 3.2.2.YY relative to a 2-storey Group A-2 building constructed to Article 3.2.2.26, and a 3-storey light steel-frame Group A-2 building constructed to Article 3.2.2.24.

The proposed solutions are compared with the acceptable solutions of the Building Code in Figure 2.

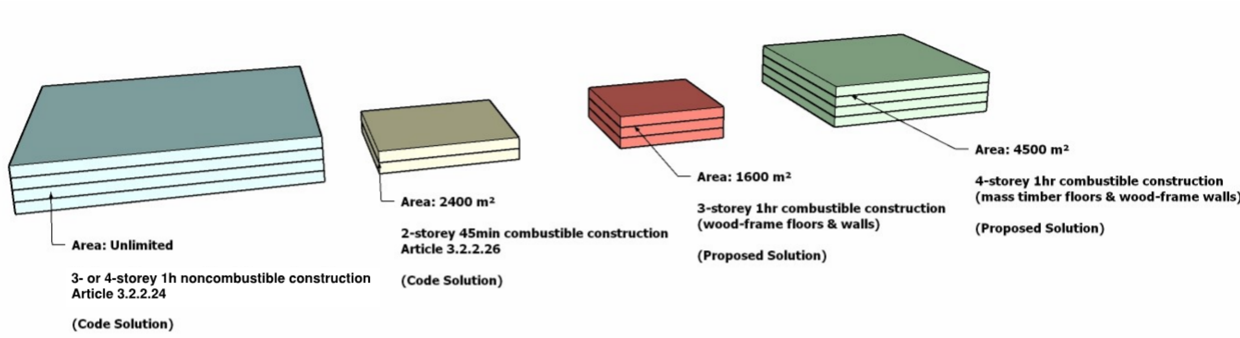

Figure 2: Comparison of the buildings proposed per this alternative solution and the Division B solutions for buildings already permitted under Subsection 3.2.2.

The risk areas that are defined by the fire safety and fire protection objectives of the Building Code are the following:

- *OS1 Fire Safety:* An objective of the Building Code is to limit the probability that, as a result of the design or construction of the building, a person in or adjacent to the building will be exposed to an unacceptable risk of injury due to fire. The risks of injury due to fire addressed in the Building Code are those caused by:

  OS1.1 Fire or explosion occurring
  OS1.2 Fire or explosion impacting areas beyond its point of origin
  OS1.3 Collapse of physical elements due to a fire or explosion
  OS1.4 Fire safety systems failing to function as expected
  OS1.5 Persons being delayed in or impeded from moving to a safe place during a fire emergency

- *OP1 Fire Protection of the Building:* An objective of the Building Code is to limit the probability that, as a result of its design or construction, the building will be exposed to an unacceptable risk of damage due to fire. The risks of damage due to fire addressed in this Code are those caused by:

  OP1.1 Fire or explosion occurring
  OP1.2 Fire or explosion impacting areas beyond its point of origin
  OP1.3 Collapse of physical elements due to a fire or explosion
  OP1.4 Fire safety systems failing to function as expected

- *OP3 Protection of Adjacent Buildings from Fire:* An objective of the Building Code is to limit the probability that, as a result of the design or construction of the building, adjacent buildings will be exposed to an unacceptable risk of damage due to fire. The risks of damage to adjacent buildings due to fire addressed in this Code are those caused by:

  OP3.1 Fire or explosion impacting areas beyond the building of origin

From these objectives, technical risks can be established as summarized in Table 3. It is noted that there may be other technical risks that are not addressed by the current Building Code; however, they are outside the scope of this report.

Table 3: Technical risks on fire safety addressed by the Building Code.

Technical Risk	Code Objective
Ignition	OS1.1, OP1.1
Fire spread beyond point of fire origin	OS1.2, OP1.2
Fire spread to neighboring buildings	OP3.1
Failure of fire safety systems to function as expected	OS1.4, OP1.4
Occupants not being able to recognize that there is a fire	OS1.4, OS1.5, OP1.4
Occupants not being able to evacuate the building	OS1.4, OS1.5, OP1.4
Fire department unable to conduct effective firefighting operation	OS1.2, OS1.3, OP1.2, OP1.3, OP3.1

7.2 ***Analysis of proposed 4-storey school relative to 4-storey Group D occupancy constructed to Article 3.2.2.58 with a school on the first 2 storeys.***

The construction requirements for the proposed 4-storey school and 4-storey Group D occupancy constructed to Article 3.2.2.58 with a school on the first 2 storeys are summarized in the following table:

Table 4: Summary of construction requirements for a 4-storey school and 4-storey Group D occupancy constructed to Article 3.2.2.58 with a school on the first 2 storeys.

	Division B	Alternative Solution
Building Height (storeys)	4	4
Building Area (m^2)	4500m^2	4500m^2
Gross Floor Area	18000m^2	18000m^2
Occupancy	Group A-2 at 1st and 2nd storey Group D at 3rd and 4th storey	School (Group A-2) on all storeys
Streets Faced	1	1
Sprinklered	Yes	Yes
Type of Construction Permitted/Required	Light wood-frame for floors and walls	Mass timber for floors / Light wood-frame for walls
Floor Assembly Fire-Resistance Rating	1h (2h between Group A-2 and D)	1h
Mezzanine Fire-Resistance Rating	1h	1h
Roof Fire-Resistance Rating	1h	1h

The technical risks identified are analyzed as follows:

- *Risk of Ignition: Will not increase*

  The risk of ignition for the proposed 4-storey school building will not increase as the proposed gross floor area will remain the same as the maximum permitted area for a 4-storey wood-frame building constructed to Article 3.2.2.58. A review of Subsection 3.2.2 indicates that the Building Code manages the risk of ignition by maintaining the same gross area in buildings. For example, a 1-storey building of combustible construction designed to Article 3.2.2.58 is permitted a building area of 18000m^2 and a 4-storey building is permitted a building area of 4500m^2(18000 m^2/4); the gross floor area for a building designed to this Article is always kept at 18000m^2.

  Further, the combustible contents of schools are similar to that found in office (Group D) buildings; that is, furniture and paper products, computers and similar devices. By maintaining the same gross floor area as permitted under Article 3.2.2.58 and given that the combustible contents in schools are similar to that found in office buildings, the risk of ignition – the probability of ignition and the consequential losses – will not increase. In fact, the risk of ignition could potentially decrease based on the use of mass timber floor assemblies in lieu of light wood-frame. Mass timber, based on its thickness acts as a heat sink, thereby limiting the probability of its ignition compared to thinner wood members used in wood-frame construction.

  Additionally, mass timber construction inherently leads to the creation of a very limited number of concealed spaces such that the risk of ignition of the building structure by building services typically located in concealed spaces ceiling will be limited.

  In a conventional wood-frame building, the floor voids represent a large unsprinklered area and source of fire spread. Mass timber eliminates most of the floor voids between wood joists or wood I-joists, and the potential for ignition by faulty services or ignition sources dropped into holes or crevices in floors is drastically reduced.

- *Risk of Fire Spread beyond Point of Origin: Will not increase.*

  Generally, there are 2 forms of fire spread in a building: interior and exterior (through unprotected openings). The current Building Code addresses fire spread by requiring sprinklers and fire separations. Sprinkler systems are active fire protection systems which are reliable and effective in controlling the growth and spread of a fire. Fire separations are passive; they provide a barrier against spread of fire, with or without the operation of sprinklers.

Fire Separation: *An assembly that acts as a barrier against fire spread from a compartment.*

Unprotected Opening: *Any part of a rated assembly (door, window, or hole) which has a fire-resistance rating less than is required for the fire separation it is part of.*

The proposed 4-storey school building will be sprinklered throughout in accordance with NFPA 13 "*Standard for the Installation of Sprinkler Systems*" as would be required for a building constructed to Article 3.2.2.58. Sprinklers are designed on a per storey area basis and based on the hazard presented. Therefore, the risk of interior fire spread will not increase based on the presence of sprinklers designed to the appropriate standard.

The use of 1h rated floor fire separations in the proposed school building will offer the same level of performance in resisting fire spread as would be achieved for a 4-storey wood-frame building constructed in accordance with Article 3.2.2.58. As previously noted, the combustible contents of schools are similar to that found in buildings of Group D occupancy; as such, fires occurring in both occupancy types are expected to be similar.

The proposed mass timber floor assemblies will provide a more durable fire separation compared to wood-frame floors for a building constructed to Article 3.2.2.58 with respect to resistance to damage caused by impact and firestopping will be more reliable. Therefore, the mass timber floors for the proposed school will provide more reliable resistance to fire spread beyond the point of origin than wood-frame floors of a building constructed to Article 3.2.2.58.

It is noted that the inclusion of interconnected floor spaces without the need for special protection is already permitted at the first 2 storeys of a building constructed to Article 3.2.2.58, such that the risk of fire spread for the proposed school which includes an interconnected floor space between the first 2 storeys will be no different than anticipated by the Building Code. Where the interconnection is proposed between storeys other than the 1st and 2nd storeys, the special provisions outlined under Subsection 3.2.8 would have to be met to mitigate the risk. Again, the level of risk presented in this case will be no different than anticipated by the Building Code for a Group D building constructed to Article 3.2.2.58 based on the measures outlined at Subsection 3.2.8 and the similarity between the combustible contents expected.

Interconnected Floor Space:
Superimposed floor areas on different storeys which are connected by openings between the storeys.

***Atrium:** Multi-level interconnected floor space.*

Furthermore, schools are typically more compartmentalized (to allow the creation of classrooms) than in typical office buildings which usually have more open floor plans. Although the partitions between classrooms are not required to be constructed as fire separations, they will serve to provide a degree of resistance to fire spread beyond the point of origin. Thus, the risk of interior fire spread will not increase, based on the presence of partitions.

Exterior fire spread through windows from storey to storey, or along the face of the building (which is not to be confused with fire spread to neighbouring buildings), will not increase as the same noncombustible cladding or the limited types of combustible cladding required for buildings constructed to Article 3.2.2.58 and buildings of noncombustible construction is proposed for the 4-storey school.

Finally, with respect to fire spread within concealed spaces, fireblocking already contemplated by the Building Code and the mandatory application of the NFPA 13 standard will appropriately manage the risk where present. Moreover, as previously noted, mass timber construction inherently leads to the creation of very limited number of concealed spaces. Therefore, the use of mass timber for floor assemblies of the proposed school, will mean a reduced number of concealed spaces compared to a 4-storey wood-frame building constructed to Article 3.2.2.58 and thus, fire spread in concealed spaces will not increase. In conventional wood construction, large unsprinklered areas are typically found in the floor joist spaces. Use of mass timber floors eliminates these floor joist spaces, greatly enhancing fire safety and reducing the risk of spread of fire.

- *Risk of Fire Spread to Neighbouring Buildings: Will not increase.*

The Building Code assumes a significant risk of fire spread to neighboring buildings. In order to manage this risk, the Building Code places a restriction on the allowable size of unprotected openings and exterior wall construction based on limiting distance. In doing so, the Building Code attempts to control the incident radiative heat flux on the exterior walls of neighbouring buildings. Employment of active and passive fire protection systems effectively lowers the radiation level, given that radiation heat transfer is highly dependent on the temperature and size of the emitting surface. By sprinklering the fire compartment, the Building Code assumes that the temperature will be lower, which is reflected in the doubling of unprotected openings allowed by the Building Code. Use of fire separations will also generally confine the fire to the compartment of origin such that the size and the number of the emitting surfaces will be controlled.

The approach of managing the risk of building-to-building exposure is well established in the current Code and is largely based on the results of the series of NRC tests known as the "St. Lawrence Burns".

> ***Limiting Distance:*** *Setback of a building from the property line or centre of a street.*

The same exposure protection approach will be taken with the proposed 4-storey school building and the size of exposing surfaces via the unprotected openings will be restricted on the same basis as a 4-storey wood-frame building constructed in accordance with Article 3.2.2.58. Further, the exterior cladding of proposed 4-storey school will be restricted to noncombustible or limited types of combustible materials, similar to that required for a 4-storey wood-frame building constructed in accordance with Article 3.2.2.58. Therefore, the risk of fire spread to neighbouring buildings will not increase.

> ***Exposure Protection:*** *Protection against building to building fire spread.*

- *Risk of Failure of Sprinkler System to Control / Suppress Fire: Will not increase.*

  As discussed, the NFPA 13 standard will be the applicable sprinkler standard for the proposed 4-storey school as will be required for a 4-storey wood-frame building constructed to Article 3.2.2.58. Additionally, given the sprinkler system will be designed for the hazard present and that sprinklers work on a per storey area basis, the risk of sprinklers failing to control a fire in the proposed school will not increase relative to a 4-storey wood-frame building constructed to Article 3.2.2.58.

  Additionally, the absence of unsprinklered void spaces where floor assemblies are of mass timber construction will significantly reduce the risk of fire in unsprinklered voids.

- *Risk of Occupants Not Able to Recognize that there is a Fire: Will not increase.*

  Occupant response time to fire cues and decision-making prior to evacuation will not increase based on the mandatory requirement of a central fire alarm and sprinkler systems within the proposed school building. The presence of fire alarm devices for notification of occupants and the fire department will be similar to that required for a 4-storey office building designed to Article 3.2.2.58. Therefore, the risk of occupants unable to recognize that there is a fire will not increase.

  Again, the absence of unsprinklered void spaces where floor assemblies are of mass timber construction eliminates the risk of a fire in the sprinklered void space not being properly detected.

- *Risk of Occupants Not Being Able to Evacuate the Building: Will not increase.*

  The occupant load at the 3rd and 4th storeys for the proposed school building is expected to be higher than anticipated by the Building Code for the 3rd and 4th storeys of a Group D building constructed to Article 3.2.2.58. The Building Code's general approach to evacuation in buildings is based on providing sufficient means of egress, and managing accessibility, availability, and integrity of exit systems.

  In this regard, a sufficient number of fire rated exits and exit capacity will be required and provided for the proposed school building such that the minimum level of performance required by the Building Code will be met.

> ***Occupant load**: Number of occupants per storey calculated based on the actual number of occupants expected or numerical occupant load factors specified in the Building Code.*

> ***Exit Capacity**: The number of occupants an exit is designed for, calculated based on the width of the exit and numerical exit capacity factors specified in the Building Code.*

> *Wider stairs in schools will compensate for increased number of occupants.*

Although evacuation will likely be slower in a school compared to a typical building of Group D occupancy, the overall risk with respect to occupant safety will be mitigated based on the consideration that the risk of fire spread beyond the point of origin will not increase as previously discussed, affording sufficient time for occupant evacuation. Further, the provision of emergency power for lighting and fire alarm systems for a duration of 60min for the proposed school, similar to that required for a building constructed to Article 3.2.2.58, will provide for adequate illumination for evacuation and the operation of fire alarm systems. The limits to fire spread beyond the point of origin, coupled with the availability of sufficient rated exits and exit capacity and emergency power for 60min will mean that the risk of occupants not being able to evacuate the building will not increase.

- *Risk of Fire Department Unable to Conduct Effective Operation: Will not increase.*

In comparison to a sprinklered 4-storey wood-frame building constructed to Article 3.2.2.58, the risk of fire department unable to conduct effective operations for the proposed 4-storey school will not increase. In sprinklered mid-rise buildings (4- to 6-storey), firefighting is generally conducted in the interior of the building using the standpipe system, and the sprinkler system provides significant relief to firefighting in comparison to unsprinklered buildings. As well, the effects of stack action, which is typically more prevalent in high buildings, will not be significant in mid-rise buildings.

Traditionally, unsprinklered 3-storey wood-frame buildings relied on exterior firefighting operations. With the advent of buildings protected with monitored and supervised sprinkler systems and related firefighting practices, the Building Code has shifted to reliance on the sprinkler and standpipe systems and interior firefighting access. This is reflected in several changes to the Building Code over time, including:

- Eliminating the requirement for fire rated roofs in sprinklered buildings; and
- Eliminating the requirement for access openings in exterior walls for firefighting from the exterior in sprinklered buildings.

These changes all reflect the fact that the Building Code does not anticipate exterior firefighting for sprinklered wood-frame buildings and recognizes the reliability and effectiveness of automatic sprinkler systems.

The proposed 4-storey school will be sprinklered and have a standpipe system as required for all 4-storey buildings and will not be a high building as described in the proposed new Article 3.2.2.XX. Therefore, with respect to firefighting the proposed 4-storey school will be no different than a building constructed to Article 3.2.2.58. The only difference between the proposed school and a 4-storey building constructed to Article 3.2.2.58 would be in the number of occupants using the exit stairs during evacuation which may interfere with firefighting operations. This condition will be mitigated by the provision of sufficient exit capacity for the increased occupant load anticipated for a school. It is noted that the Building Code does not include a requirement to increase the size of exit stairs depending on occupancy and assumes that firefighters will be able to perform their duties in all kinds of occupancies regardless of occupant load. On this basis, it can be concluded that the risk of the fire department unable to conduct effective operations will not increase.

Based on the above analyses, it can be concluded that the proposed 4-storey school will provide a similar level of performance compared to that provided by a 4-storey Group D occupancy constructed to Article 3.2.2.58 with a school on the first 2 storeys.

7.3 Analysis of proposed 4-storey school relative to a 4-storey Group A-2 occupancy of light steel-frame construction constructed to Article 3.2.2.24

The construction requirements for the proposed 4-storey school and 4-storey Group A-2 occupancy of light steel-frame construction designed to Article 3.2.2.24 are summarized in the following table:

Table 5: Summary of construction requirements for the proposed 4-storey school and 4-storey Group A-2 occupancy of light steel-frame construction designed to Article 3.2.2.24.

	Division B	Alternative Solution
Building Height (storeys)	4	4
Building Area	Unlimited	4500m^2
Gross Floor Area	Unlimited	18000m^2
Occupancy	Group A-2 (Any type)	Group A-2 (School)
Streets Faced	1	1
Sprinklered	Yes	Yes
Type of Construction Permitted/Required	Noncombustible (light steel-frame for floors and walls)	Mass timber for floors Light wood-frame for walls
Floor Assembly Fire-Resistance Rating	1h	1h
Mezzanine Fire-Resistance Rating	1h	1h
Roof Fire-Resistance Rating	0h	1h

The technical risks identified are analyzed as follows:

- *Risk of Ignition: Will not increase.*

  The risk of ignition will not increase based on the consideration that as the gross floor area in the proposed 4-storey school building is limited to 18000m^2 while a Group A-2 building constructed to Article 3.2.2.24 is permitted to have unlimited building area. As previously noted, a review of Subsection 3.2.2 indicates that the Building Code manages the risk of ignition by maintaining the same gross volume in buildings. Thus, the limited floor area proposed for the 4-storey school will mean a lower likelihood of ignition compared to a Group A-2 building with unlimited floor area.

  Further, the risk of ignition will not increase due to the use of mass timber for floors assemblies and wood-frame for wall assemblies. In mass timber construction, large timber members are used to form a structural frame and are generally left exposed as their large mass provides an inherent degree of fire resistance and resistance to ignition. It is noted that Subsection 3.1.5 of the Building Code permits the use of some combustible elements in a building of noncombustible construction such as a Group A-2 building constructed to Article 3.2.2.24. Combustible elements permitted include up to 25mm thick wood wall and ceiling finish, solid lumber partitions and partitions which contain wood-framing. Considering the amount of wood permitted in a building constructed to Article 3.2.2.24, the risk of ignition will not increase based on the proposed use of mass timber floors and wood-frame walls for the proposed school buildings.

Additionally, mass timber floor construction inherently limits the number of concealed spaces and eliminates the voids found in joist construction. Further, concealed spaces which remain will be required to be appropriately protected in accordance with the Building Code and NFPA 13 such that the risk of ignition by building services typically located in concealed spaces ceiling will be limited.

- *Risk of Fire Spread beyond Point of Origin: Will not increase.*

As previously discussed, the current Building Code addresses fire spread by implementing sprinklers and fire separations. Sprinklers are active fire protection systems and fire separations are passive; they independently provide a barrier against spread of fire.

The proposed 4-storey school building will be sprinklered throughout in accordance with NFPA 13 as would be required for a building constructed to Article 3.2.2.24. Sprinklers are designed on a per storey area basis and based on the hazard presented. Therefore, the risk of interior fire spread will not increase based on the presence of sprinklers designed to the appropriate standard.

The use of 1h rated floor fire separations in the proposed school building will offer the same level of performance in resisting fire spread as would be achieved for a 4-storey light steel-frame building constructed in accordance with Article 3.2.2.24. The performance of fire separations is measured by the CAN/ULC-S101, "*Standard Methods of Fire Endurance Tests Of Building Construction And Materials*", the standard fire test for building elements and assemblies. The test exposes assemblies to the standard time-temperature curve and assigns an hourly rating based on the passing criteria. The standard test is not predicated on the assembly's material of construction. When the fire test determines a fire-resistance rating of 1h for a wood stud wall, a steel stud wall, or a concrete wall, all 3 types of construction are considered as having the same level of fire resistance of 1h based on the fire test. Therefore, when a 1h rated fire separation is used in a 4-storey building of mass timber and/or wood-frame construction, the separation is considered to offer the same level of protection as will be offered by a 1h rated fire separation in a 4-storey light steel-frame building. Further, although not an objective of the Building Code, the proposed mass timber floor assemblies will provide a more durable fire separation compared to directly Code conforming steel-framed assemblies. Due to the monolithic nature of mass timber, it tends to be more resistant to damage caused by impact. Furthermore, the probability of a compromised fire separation due to improper construction and alterations over the life of the building is higher with steel-frame construction than with mass timber construction.

Similarly, firestopping through mass timber is more robust and less susceptible to damage than firestopping through a steel stud wall or floor assembly and the mass timber remains in place with minimal movement on exposure to fire. On the other hand, steel joists tend to expand and distort on exposure to fire, exposing joints and shifting firestopping more easily. Therefore, the mass timber floors for the proposed school will provide the same or more reliable resistance to fire spread beyond the point of origin than the floors of a steel-frame building constructed to Article 3.2.2.24.

As previously discussed, the inclusion of interconnected floor spaces would already be permitted at the first 2 storeys of a building constructed to Article 3.2.2.24 without the need for the implementation of special features. This interconnection is permitted regardless of construction type. Where the interconnection is proposed between storeys other than the 1st and 2nd storeys, the special provisions outlined under Subsection 3.2.8 will have to be met to mitigate the risk. Therefore, the level of risk presented in this case will be no different than anticipated by the Building Code for a building constructed to Article 3.2.2.24.

Exterior fire spread through windows from storey to storey, or along the face of the building, will not increase as the same noncombustible cladding or the limited types of combustible cladding prescribed for buildings of noncombustible construction is proposed for a 4-storey school.

As previously noted, mass timber construction inherently leads to the creation of very limited number of concealed spaces. Fireblocking already contemplated by the Building Code and the mandatory application of the NFPA 13 standard will appropriately manage the risk of fire spread in concealed spaces where present. Thus, fire spread in concealed spaces will not increase.

- *Risk of Fire Spread to Neighbouring Buildings: Will not increase.*

The risk of fire spread to neighbouring buildings will not increase in the proposed 4-storey school occupancy over a 4-storey light steel-frame building designed to Article 3.2.2.24. The Building Code assumes fire spread to neighbouring buildings by means of radiation heat transfer. This phenomenon is generally more prevalent in post-flashover fires when the compartment has attained high temperatures. The risk of fire spread to neighbouring buildings can be evaluated based on the consequence of fire due to the use of the proposed mass timber and/or wood-frame construction and the probability of the compartment reaching flashover.

Sprinklers have been shown to have an effectiveness exceeding 95% to 99% in limiting the growth and spread of fire. Advancements in fast response and quick response sprinklers, along with monitoring and supervision of sprinkler systems have substantially increased the reliability of such systems. As such the probability that a fire in the proposed 4-storey school will reach flashover is limited based on the presence of sprinklers.

It is noted the primary cause of sprinkler failure is being shut off. The use of monitored and supervised systems minimizes this risk and, in a school environment, maintenance requiring shut down of systems generally occurs when the schools are closed.

> ***Monitored and Supervised Sprinkler System:*** *The system alerts staff and fire department of a shutdown or fire.*

Further, the use of mass timber floors in combination with wood-frame walls will not have a significant impact on the severity of a post-flashover compartment fire compared to a building of noncombustible construction designed to Article 3.2.2.24. Firstly, a building of noncombustible construction designed to Article 3.2.2.24 is permitted to include some wood walls and wall and ceiling finish as previously discussed which will contribute to a post-flashover fire. Secondly, while the proposed mass timber floor and wood-frame walls may become involved in the fire in a post-flashover event, this will generally be limited due to the charring properties of mass timber elements. Thirdly, given that the maximum burning rate of a post-flashover fire is generally governed by the ventilation factor (oxygen) and not the volume of combustibles (fuel), the use of wood for the proposed 4-storey school will not lead to a significant contribution to overall compartment temperature and the degree of radiation reaching neighbouring buildings. Lastly, the same exposure protection approach will be taken with the proposed 4-storey school building and the size of exposing surfaces via the unprotected openings will be restricted on the same basis as for a 4-storey steel-frame building constructed in accordance with Article 3.2.2.24.

Further, as previously discussed, a fire rated wall of combustible construction will have a similar resistance to fire spread as would a steel-frame wall of the same fire-resistance rating. Also, the exterior cladding of proposed 4-storey school will be restricted to noncombustible or limited types of combustibles required for a building of noncombustible construction. Based on the foregoing, the risk of fire spread to neighbouring buildings will not increase.

- *Risk of Failure of Sprinkler System to Control / Suppress Fire: Will not increase.*

  The risk of failure of the sprinkler system to control/suppress a fire will not increase based on the consideration that the sprinkler system will be designed to the same NFPA 13 standard required for a 4-storey building of noncombustible construction. Sprinklers typically operate very early on when the fire is limited in size typically to a small area. Where the sprinkler system is designed and operates appropriately, that is during the initial stages of a fire, its ability to control the fire will be independent of construction type (combustible or noncombustible). Given the risk of fire spread will not increase based on the use of mass timber and/or wood-frame construction for the proposed 4-storey school, it can be reasonably expected that the size of fire at the time of sprinkler activation will be no different than anticipated for a building of noncombustible construction designed to Article 3.2.2.24.

- *Risk of Occupants Not Able to Recognize that there is a Fire: Will not increase.*

  The risk of occupants not being able to recognize that there is fire will not increase as the systems for fire detection and notification are independent of construction type. The proposed 4-storey school will be provided with a monitored fire alarm system on the same basis as a 4-storey building of noncombustible construction designed to Article 3.2.2.24. Therefore, occupant response time to fire cues and decision-making prior to evacuation will not increase.

- *Risk of Occupants Not Being Able to Evacuate the Building: Will not increase.*

  The risk of occupants not being able to evacuate the building will not increase based on the consideration that occupant load is independent of construction type and, as such, the occupant load for the proposed school building is expected to be the same as a Group A-2 building of similar size constructed to Article 3.2.2.24. The Building Code's general approach to evacuation in buildings is based on providing sufficient means of egress, and managing accessibility, availability, and integrity of exit systems. In this regard, a sufficient number of fire rated exits and exit capacity will be required and provided for the proposed school building such that the minimum level of performance required by the Building Code will be provided. In fact, the risk of occupants not being able to evacuate the building could potentially decrease based on the consideration that the proposed school will have emergency power for lighting and fire alarm systems for a duration of

60min compared to a Group A-2 building constructed to Article 3.2.2.24 for which emergency power is only required for 30min. The longer duration of emergency power will provide for adequate illumination for evacuation and the operation of fire alarm systems.

- *Risk of Fire Department Unable to Conduct Effective Operations: Will not increase.*

  In comparison to a sprinklered 4-storey steel-frame building constructed to Article 3.2.2.24, the risk of fire department unable to conduct effective operations for the proposed 4-storey school will not increase. In sprinklered mid-rise buildings (4- to 6-storey), firefighting is generally conducted in the interior of the building using the standpipe system, and the sprinkler system provides adequate relief to firefighting in comparison to unsprinklered buildings. The proposed school will be sprinklered and have a standpipe system as required for all 4-storey buildings

  Furthermore, the effects of stack action, which is typically more prevalent in high buildings, will not be significant in the proposed school which will not be a high building as described in the proposed new Article.

  Additionally, the proposed school will have additional features not required for a building constructed to Article 3.2.2.24, including emergency power for lighting and fire alarm systems for a 60min duration; a building constructed to Article 3.2.2.24 would be permitted to have emergency power for 30min where it is not a high building. The increased emergency power duration will serve to facilitate evacuation and firefighting activities for a longer duration. Based on the foregoing, the risk of fire department not being able to conduct effective operations will not increase.

Based on the above analyses, it can be concluded that the proposed 4-storey school will provide a similar level of performance compared to that provided by a 4-storey Group A-2 occupancy of light steel-frame construction designed to Article 3.2.2.24.

7.4 Analysis of a 3-storey Group A-2 building constructed to the proposed new Article 3.2.2.YY relative to a 2-storey wood-frame and a 3-storey light steel-frame Group A-2 building constructed to Articles 3.2.2.26 and 3.2.2.24, respectively

The construction requirements for the proposed 3-storey Group A-2 building constructed to the proposed new Article 3.2.2.YY, a 2-storey wood-frame and a 3-storey light steel-frame Group A-2 building constructed to Articles 3.2.2.26 and 3.2.2.24 respectively are summarized in the following table:

Table 6: Summary of 3-storey Group A-2 building constructed to the proposed new Article 3.2.2.YY, a 2-storey wood-frame and a 3-storey light steel-frame Group A-2 building constructed to Articles 3.2.2.26 and 3.2.2.24, respectively.

	Division B		Alternative Solution
Construction Article	3.2.2.24	3.2.2.26	3.2.2.YY
Building Height (storeys)	3	2	3
Building Area	Unlimited	2400m^2	1600m^2
Gross Floor Area	Unlimited	4800m^2	4800m^2

	Division B		Alternative Solution
Occupancy	Group A-2	Group A-2	Group A-2
Streets Faced	1	1	1
Sprinklered	Yes	Yes	Yes
Type of Construction Required/Permitted	Noncombustible	Combustible	Combustible
Floor Assembly Fire-Resistance Rating	1h	45min or NC	1h
Mezzanine Fire-Resistance Rating	1h	45min or NC	1h
Roof Fire-Resistance Rating	0h	0h	0h

The technical risks identified are analyzed as follows:

- *Risk of Ignition: Will not increase.*

  The risk of ignition will not increase as the gross floor area for the proposed 3-storey Group A-2 building will remain the same as the gross floor area (i.e. 4800m^2) permitted for a 2-storey wood-frame building constructed to Article 3.2.2.26. As previously discussed, this conclusion is based on the consideration that the Building Code manages the risk of ignition by maintaining the same gross area in buildings. It is noted risk of ignition will also not increase for the proposed 3-storey building compared to a steel-frame building which is permitted to have unlimited building area per Article 3.2.2.24.

- *Risk of Fire Spread beyond Point of Origin: Will not increase.*

  The proposed 3-storey wood-frame building will be sprinklered throughout in accordance with NFPA 13 as would be required for a building constructed to Article 3.2.2.24 or 3.2.2.26. Sprinklers are designed on a per storey area basis and based on the hazard presented. Therefore, the risk of interior fire spread will not increase based on the presence of sprinklers designed to the appropriate standard.

  The use of 1h fire-rated floor fire separations in the proposed building will offer a higher level of performance in resisting fire spread compared to a 2-storey wood-frame building constructed in accordance with Article 3.2.2.26 permitted to have 45min fire rated floor assemblies of combustible construction or unrated floor assemblies of noncombustible construction. Further, the level of performance provided by the proposed 3-storey building will be the same as will be provided by a steel-frame building constructed to Article 3.2.2.24 as both will have 1h fire-rated floor assemblies. In fact, the extent of fire spread is expected to be limited based on the required floor fire separations in conjunction with the reduced floor area per storey proposed for a 3-storey wood-frame building (1600m^2) compared to a 2-storey wood-frame building with building area of 2400m^2 and a steel-frame building with unlimited building area.

The extent of vertical fire spread through windows from storey to storey, or along the face of the building, could potentially increase compared to a 2-storey wood-frame building. However, this is mitigated by the consideration the building height does not exceed 3 storeys and the overall area of the exterior building face will be no greater than that for a 2-storey wood-frame building. A review of Subsections 3.1.4 and 3.2.2 shows that noncombustible cladding is only required for wood-frame buildings over 4 storeys in height; the risk of fire spread along the face of shorter buildings is deemed to be low enough to permit combustible cladding. Further, the total floor area and occupant load potentially impacted by the risk of exterior fire spread will be no different than that presented by a 2-storey wood-frame building.

With respect to fire spread within concealed spaces, fireblocking already contemplated by the Building Code and the mandatory application of the NFPA 13 standard will appropriately manage the risk where present. Moreover, as the total gross floor area will not change between a 2-storey and 3-storey wood-frame building, it is expected that the total area of concealed spaces will remain the same.

- *Risk of Fire Spread to Neighbouring Buildings: Will not increase.*

  The same exposure protection approach will be taken with the proposed 3-storey wood-frame building as would be required for a 2-storey wood-frame building constructed to Article 3.2.2.26 and a 3-storey light steel-frame building constructed to Article 3.2.2.24. This approach is based on the presence of sprinklers and calculated based on the exposing building face on a storey by storey basis. Given that the area of the exposing building face used in determining exposure requirements will reduce for the proposed 3-storey wood-frame building compared to the Building Code permitted 2-storey wood-frame building constructed to Article 3.2.2.26 and a 3-storey light steel-frame building constructed to Article 3.2.2.24, it is expected that the risk of fire spread to neighbouring buildings will not increase.

- *Risk of Failure of Sprinkler System to Control / Suppress Fire: Will not increase.*

  The NFPA 13 standard will be the applicable sprinkler standard for the proposed 3-storey wood-frame building as will be required for a 2-storey wood-frame building constructed to Article 3.2.2.26 and a 3-storey light steel-frame building constructed to Article 3.2.2.24. Additionally, given the sprinkler system will be designed for the hazard present and that sprinklers work on a per storey area basis, the risk of sprinklers failing to control a fire in the proposed 3-storey wood-frame building will not increase relative to a 2-storey wood-frame building or a 3-storey light steel-frame building.

- *Risk of Occupants Not Able to Recognize that there is a Fire: Will not increase.*

  The risk of occupants not being able to recognize that there is fire will not increase as the systems for fire detection and notification are independent of building height and construction type. The proposed 3-storey wood-frame building will be provided with a monitored fire alarm system on the same basis as a 2-storey wood-frame building constructed to Article 3.2.2.26 and a 3-storey light steel-frame building constructed to Article 3.2.2.24. Therefore, occupant response time to fire cues and decision-making prior to evacuation will not increase.

- *Risk of Occupants Not Being Able to Evacuate the Building: Will not increase.*

  The risk of occupants not being able to evacuate the building will not increase based on the consideration that the total occupant load is expected to remain the same between the proposed 3-storey wood-frame building and the Code permitted 2-storey wood-frame building constructed to Article 3.2.2.26. As noted, the Building Code's general approach to evacuation in buildings is based on providing sufficient means of egress, and managing accessibility, availability, and integrity of exit systems. Travel time within exit stairs would increase due to 1 additional storey for the proposed 3-storey wood-frame building; however, this will be mitigated by the reduction in travel time to an exit within a storey due to smaller building area and potentially less queuing at exits as a result of fewer occupants per storey.

- *Risk of Fire Department Unable to Conduct Effective Operation: Will not increase.*

  In comparison to a sprinklered 2-storey wood-frame building constructed to Article 3.2.2.26 and a 3-storey light steel-frame building constructed to Article 3.2.2.24, the risk of fire department being unable to conduct effective operations for the proposed 3-storey wood-frame building will not increase. As discussed, the Building Code does not anticipate exterior firefighting for sprinklered wood-frame buildings and recognizes the reliability and effectiveness of automatic sprinkler systems. However, if required, the fire department has the equipment and ability to fight a fire in the proposed 3-storey wood-frame building from the exterior on the same basis as a 3-storey light steel-frame building of equal height constructed to Article 3.2.2.24.

Based on the above analyses, it can be concluded that the proposed 3-storey Group A-2 building constructed to the proposed new Article 3.2.2.YY will provide a similar level of performance compared to that provided by a 2-storey wood-frame and a 3-storey light steel-frame Group A-2 building constructed to Articles 3.2.2.26 and 3.2.2.24, respectively.

7.5 Summary of Qualitative Technical Risk Analysis

It can be concluded based on the foregoing discussions, that the fire safety risks which are recognized by the Building Code through the Code objectives will be appropriately managed in proposed 3- or 4-storey Group A-2/school buildings of mass timber and/or wood-frame construction. Thus, the level of performance anticipated by the Building Code will be achieved.

7.6 Quantitative Technical Risk Analysis

The following is a numerical risk assessment that provides a numerical comparison between the proposed 4-storey school and 3-storey Group A-2 building and the Building Code contemplated buildings.

For each risk factor, a numerical rating is assigned by multiplying the probability of occurrence and severity of the consequence should the risk identified happen. As shown in Table 7, values from 1 to 3 are assigned for the probability of occurrence to represent a low (1), medium (2), or high (3) probability of a particular risk occurring. Similarly, values from 1 to 3 are assigned to represent a minor, moderate, or major consequence should a particular risk occur.

Table 7: Calculation of Risk Factors

		Consequence		
		Minor (1)	*Moderate (2)*	*Major (3)*
Probability of occurrence	*Low (1)*	1	2	3
	Medium (2)	2	4	6
	High (3)	3	6	9

Two numerical risk assessment tables have been presented. Table 8 is a numerical risk analysis of a 4-storey school constructed to the proposed new Article, relative to a 4-storey light wood-frame building of Group D occupancy constructed to Article 3.2.2.58 and permitted to include a school at the first 2 storeys and a 4-storey light steel-frame Group A-2 building constructed to Article 3.2.2.24. Table 9 is a numerical analysis of a 3-storey Group A-2 building constructed to the proposed new Article based on Article 3.2.2.26 relative to a 2-storey Group A-2 building constructed to Article 3.2.2.26 and a 3-storey light steel-frame Group A-2 building constructed to Article 3.2.2.24.

The tables provide an assessment of each risk factor and a numerical rating for each. The tables also includes reasons why the risk factor under assessment is assigned a particular rating. For example, the risk of ignition in a steel-frame building constructed to Article 3.2.2.24 is deemed to be "medium" (2) based on the consideration that such a building will include combustible furnishings, combustible interior finishes and potentially partitions containing wood-frame materials as permitted under Subsection 3.1.5 of the Building Code. The consequence of ignition is deemed to be "minor" (1) based on the consideration that the building will be sprinklered; monitored and properly maintained sprinkler systems as required by the Building Code have been shown to be effective in controlling fires in the initial stages such that the probability of a fully developed fire of extended duration occurring in a sprinklered building is low. Accordingly, the risk to life and property will be low. To obtain a numerical rating for the "ignition" risk factor, the probability of occurrence is multiplied by the severity of the consequence (2 x 1 = 2).

Table 8: Numerical Risk Analysis providing comparison between a 4-storey school constructed to the proposed new Article 3.2.2.XX, a 4-storey light wood-frame building of Group D occupancy constructed to Article 3.2.2.58 and permitted to include a school at the first 2 storeys and a 4-storey light steel-frame Group A-2 building constructed to Article 3.2.2.24.

Risk	4-Storey Group A-2 Steel-Frame Building (Article 3.2.2.24)	4-Storey Group A-2 Wood-Frame Building (Article 3.2.2.58)	Proposed 4-Storey School Building (New Code Article)
Ignition	**Medium probability** – building finishes and furnishings **Minor consequence** – sprinklered building **(2)**	**Medium probability** – building construction, finishes, and furnishings **Minor consequence** – sprinklered building **(2)**	**Medium probability** – building construction, finishes, and furnishings **Minor consequence –** sprinklered building **(2)**

Risk	4-Storey Group A-2 Steel-Frame Building (Article 3.2.2.24)	4-Storey Group A-2 Wood-Frame Building (Article 3.2.2.58)	Proposed 4-Storey School Building (New Code Article)
Fire spread beyond point of fire origin	**Medium probability** – open floor plan, unlimited floor area, sprinklered building **Moderate consequence** – relatively large fire, potentially large occupant load, sprinklers may control fire **(4)**	**Medium probability** – open floor plan, limited floor area, sprinklered building **Moderate consequence** – relatively large fire, controlled number of occupants at top 2 storeys, sprinklers may control fire **(4)**	**Low probability** – limited floor area, partitions for classrooms, sprinklered building **Moderate consequence** – relatively large fire, potentially large occupant load, sprinklers may control fire **(2)**
Fire spread to neighboring buildings	**Low probability** –sprinklered building, passive protection by exterior walls **Major consequence** – significantly large fire **(3)**	**Low probability** – sprinklered building, passive protection by exterior walls **Major consequence** – significantly large fire **(3)**	**Low probability** – sprinklered building, passive protection by exterior walls **Major consequence** – significantly large fire **(3)**
Failure of sprinkler system to function as expected	**Low probability** –high reliability of sprinkler system **Major consequence** –open floor plan, significantly large fire **(3)**	**Low probability** –high reliability of sprinkler system **Major consequence** –open floor plan, significantly large fire **(3)**	**Low probability** –high reliability of sprinkler system **Moderate consequence** – Partitions for classrooms, relatively more controlled fire **(2)**
Occupants not being able to recognize that there is a fire	**Low probability** –high reliability of fire alarm system **Major consequence** – potentially large occupant load, relatively slow evacuation **(3)**	**Low probability** –high reliability of fire alarm system **Moderate consequence** – limited occupant load at top 2 storeys, relatively faster evacuation **(2)**	**Low probability** –high reliability of fire alarm system **Major consequence** – potentially large occupant load, relatively slow evacuation **(3)**
Occupants not being able to evacuate the building	**Low probability** – adequate exit capacity **Major consequence** – potentially large occupant load, relatively slow evacuation **(3)**	**Low probability** – adequate exit capacity **Moderate consequence** – limited occupant load at top 2 storeys, relatively faster evacuation **(2)**	**Low probability** – adequate exit capacity **Major consequence** – potentially large occupant load, relatively slow evacuation **(3)**
Fire department unable to conduct effective firefighting operation	**Low probability** – adequate fire department access and number of protected exits **Minor consequence** – sprinklered building **(1)**	**Low probability** – adequate fire department access and number of protected exits **Minor consequence** – sprinklered building **(1)**	**Low probability** – adequate fire department access and number of protected exits **Minor consequence** – sprinklered building **(1)**

Table 8 shows that a 4-storey school with mass timber floor assemblies and wood-frame walls following the proposed new Article 3.2.2.XX with fire safety features already outlined in the Building Code for buildings constructed under Article 3.2.2.58 will provide a level of performance that is at least equivalent to that provided by the buildings already permitted by the Building Code. This analysis supports the conclusion drawn from the qualitative assessment.

Table 9: Numerical analysis of a 3-storey Group A-2 building constructed to the proposed new Article 3.2.2.YY relative to a 2-storey Group A-2 building constructed to Article 3.2.2.26 and a 3-storey light steel-frame Group A-2 building constructed to Article 3.2.2.24.

Risk	3-Storey Group A-2 Steel-Frame Building (Article 3.2.2.24)	2-Storey Group A-2 Wood-Frame Building (Article 3.2.2.26)	Proposed 3-Storey Group A-2 (New Article 3.2.2.YY)
Ignition	**Medium probability** – building finishes and furnishings **Minor consequence** – sprinklered building **(2)**	**Medium probability** – building construction, finishes, and furnishings **Minor consequence** – sprinklered building **(2)**	**Medium probability** – building construction, finishes, and furnishings **Minor consequence –** sprinklered building **(2)**
Fire spread beyond point of fire origin	**Medium probability** – unlimited floor area, sprinklered building **Moderate consequence** – relatively large fire due to large floor area, potentially large occupant load, sprinklers may control fire **(4)**	**Low probability** –limited floor area, sprinklered building **Minor consequence** – relatively small fire and occupant load based on limited floor area, sprinklers may control fire **(1)**	**Low probability** –limited floor area, sprinklered building **Minor consequence** – relatively smaller fire and occupant load based on limited floor area, sprinklers may control fire **(1)**
Fire spread to neighboring buildings	**Low probability** – sprinklered building, passive protection by exterior walls **Major consequence** – significantly large fire **(3)**	**Low probability** – sprinklered building, passive protection by exterior walls **Major consequence** – significantly large fire **(3)**	**Low probability** – sprinklered building, passive protection by exterior walls **Major consequence** – significantly large fire **(3)**
Failure of sprinkler system to function as expected	**Low probability** –high reliability of sprinkler system **Major consequence** – significantly large fire due to large floor area **(3)**	**Low probability** –high reliability of sprinkler system **Moderate consequence** – relatively small fire and on limited floor area **(2)**	**Low probability** –high reliability of sprinkler system **Moderate consequence** – relatively small fire and on limited floor area **(2)**
Occupants not being able to recognize that there is a fire	**Low probability** –high reliability of fire alarm system **Major consequence** – potentially large occupant load, relatively slow evacuation **(3)**	**Low probability** –high reliability of fire alarm system **Moderate consequence** – limited occupant load, relatively faster evacuation **(2)**	**Low probability** –high reliability of fire alarm system **Moderate consequence** – limited occupant load, relatively faster evacuation **(2)**

Risk	3-Storey Group A-2 Steel-Frame Building (Article 3.2.2.24)	2-Storey Group A-2 Wood-Frame Building (Article 3.2.2.26)	Proposed 3-Storey Group A-2 (New Article 3.2.2.YY)
Occupants not being able to evacuate the building	**Low probability –** adequate exit capacity **Major consequence –** potentially large occupant load, relatively slow evacuation **(3)**	**Low probability** – adequate exit capacity **Moderate consequence** – limited occupant load, relatively faster evacuation **(2)**	**Low probability** – adequate exit capacity **Moderate consequence –** limited occupant load, relatively faster evacuation **(2)**
Fire department unable to conduct effective firefighting operation	**Low probability –** adequate fire department access and number of protected exits **Minor consequence** – sprinklered building **(1)**	**Low probability** – adequate fire department access and number of protected exits **Minor consequence** – sprinklered building **(1)**	**Low probability** – adequate fire department access and number of protected exits **Minor consequence** – sprinklered building **(1)**

Table 9 shows that 3-storey school of combustible construction with 1h fire rated floor assemblies following the proposed new Article will provide a level of performance that is at least equivalent to that provided by a 2-storey Group A-2 building constructed to Article 3.2.2.26 and a 3-storey light steel-frame Group A-2 building constructed to Article 3.2.2.24. This analysis also supports the conclusion drawn from the qualitative assessment.

8. PROCESS RISK ANALYSIS

Process risk relates to the risks associated with the capability for the industry to deliver a building that provides the level of performance anticipated by the Building Code. For this project, it relates specifically to practical concerns associated with constructing 3- or 4-storey school of mass timber and/or wood-frame. The current Building Code does not directly address process risks. However, it is considered in this case as a holistic approach towards providing an appropriate level of safety for schools up to 4 storeys not contemplated by the current Building Code. This risk analysis concentrates on the most onerous of the 2 proposed solutions; a 4-storey school with building area of 4500m^2.

The process risks identified as part of this analysis are the following:

8.1 Reliability of Assemblies

The ability of an assembly to continue to provide the required fire-resistance rating during the life of the building generally decreases over time, especially for membrane assemblies. The Building Code has traditionally addressed reliability of construction in certain critical areas of a building indirectly. For example, the Building Code has traditionally required concrete or masonry construction for firewalls (recently permits noncombustible construction, not necessarily masonry or concrete for 2h firewalls) and the horizontal fire separation of Division B, Article 3.2.1.2. However, the Building Code is explicit in noting that the 2h rated firewall not constructed using masonry or concrete construction must be protected against damage that would compromise the integrity of the firewall. Gypsum board membrane applied to framing and spray applied fire resistance materials could both be subject to damage throughout the life of a building.

The fire-resistance rating of light steel-frame assemblies that would be permitted by the current Building Code to be used for the construction of a 4-storey school is heavily reliant on the gypsum board membrane. There are listings available for light steel-frame assemblies which provide a 1h fire-resistance rating and would be permitted to be used which only include a single layer of gypsum board. This single layer would be highly susceptible to damage due to impact or the creation of openings at the joints due to inherent thermal expansion and building movement. Damage may also occur due to the ease with changes can be made to the assembly by building occupants. The same is applicable to light wood-frame assemblies. Mass timber on the other hand is not subject to the same degree of degradation or damage; due to its monolithic nature, it behaves much like concrete with respect to resistance to damage caused by impact and is not easily subject to changes by building occupants once it has been installed. Thus, over the life of the building it can reasonably be expected that the fire-resistance ratings of the mass timber floor assemblies will be maintained.

8.2 Protection of Connections

The current standard fire resistance test, CAN/ULC-S101, does not include a methodology for testing structural connections. However, it is generally expected that connections will be designed and protected to provide a fire-resistance rating equivalent to that provided by the connected assemblies. Protection of connections for light frame wood and steel assemblies is inherently provided by gypsum board. A common practice for heavy gauge steel is to protect exposed steel connections with intumescent paint; however, there is a lack of test data on the performance of intumescent paint on steel. It is noted that available preliminary test data that is related to the protection of metal connections for mass timber indicates that this approach may not work due in part to the charring of wood which may expose unpainted steel. Further detailed analysis and testing is recommended prior to the use of intumescent paint on connections in mass timber buildings. In order to provide the level of performance required for mass timber, protection of connections can generally be achieved with the use of internal connections (connections concealed within the timber structural members) or by protecting the connections with sacrificial wood or gypsum wallboard.

8.3 Quality Control

Laboratory tests clearly show that a single layer of gypsum wallboard on wood joists can achieve a 1h hour fire-resistance rating; however, there is little validation of actual constructed fire separations in the field. This is due to the fact that fire-rated assemblies with gypsum board membrane are highly dependent on correct installation. Testing by the National Research Council has shown that single layer designs are susceptible to improper joint construction, improper attachment of the gypsum wallboard and improper installation. Such errors in attachment and damage to the assembly can severely reduce the fire-resistance rating achieved in the field.

On the other hand, mass timber panels and assemblies such as CLT have the advantage of inherent fire resistance and favorable geometry and rigidity which allows for easy and precise installation. Mass timber also lends itself very agreeably to prefabrication which allows for quality control and limits errors in installation. The degree to which the use of mass timber allows for superior quality control was observed in the construction of the recently erected Brock Commons tallwood building at the University of British Columbia; tolerances in the prefabricated floor panels were within a few millimeters. Figure 3 below shows the Brock Common project during construction. The precision of the column locations from floor to floor is evident from the photograph.

Figure 3: Brock Commons Tallwood project showing precision of mass timber installation.

The use of mass timber floors as proposed for the taller and larger schools with wood-frame walls will lead to inherent quality control as the walls will have to be properly constructed in order to be able to support the floor assemblies which are monolithic and rigid; where the columns and walls are not properly aligned, the installation of floor assemblies will likely not be feasible.

In order to provide further assurance of quality control, it is also recommended that as part of permitting the use of mass timber for larger and taller schools, factory-built prefabricated assemblies be CAN/CSA-A277, "*Procedure for factory certification of buildings*" certified and site-built assemblies be required to adhere to a similar level of quality control.

Other concerns with wood-frame assemblies include improper treatment of concealed spaces including areas where fireblocking may be missed (see Figure 4), which could lead to rapid fire spread through the building. Mass timber inherently limits the creation of such concealed spaces and acts as a fireblock between storeys where is spans across vertical fire separations. This is illustrated in Figure 5.

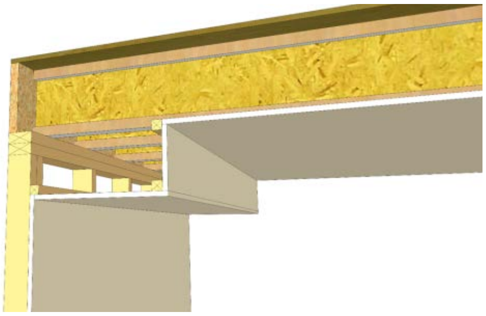

Figure 4: Wood-frame floors and walls with improper treatment of concealed spaces

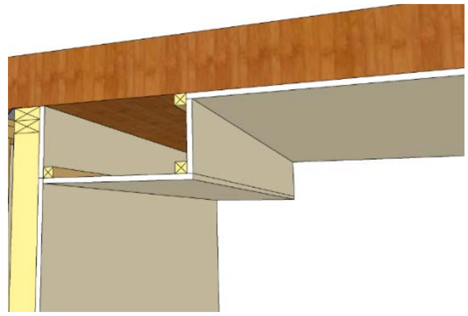

Figure 5: Mass timber floor assembly with wood-frame walls; concealed spaces are limited and the mass timber floor acts as fireblock between storeys.

8.4 Fire Safety During Construction

Buildings of combustible construction can be vulnerable to large fire losses should a fire commence during the construction stage before fire protection features have been fully installed in the building. The risks of construction fires are of course similar between school, residential, and office buildings at the construction stage. The proposed building size for the 3-storey option is smaller than permitted for 3-storey Group A-2 buildings, and inherently construction fire risk is reduced. With the 4-storey option, the use of mass timber floors is proposed; eliminating the use of wood joists and wood I-joists in floors significantly reduces both risk of ignition and speed of fire spread.

A review of construction fire safety for buildings of combustible construction is also becoming common place and is typically requested by Authorities Having Jurisdiction. It is recommended that construction fire safety be reviewed and addressed with a fire protection engineer's involvement as is becoming the norm.

8.5 Summary

The foregoing section has presented some process risks. This work should not be considered as exhaustive or complete. Some of the process risks may be addressed through Code changes and requirements specific to this proposal, while others may be best tackled by best practices guides and greater training.

9. SAMPLE ALTERNATIVE SOLUTION

9.1 Use of this Report

The preceding discussion identifies 2 solutions that can provide a level of performance equivalent to that currently prescribed by the NBC 2015, the BC Building Code 2018, and anticipated Vancouver Building Bylaw 2019.

This report will be submitted to the City of Vancouver who will be asked to provide a letter of support to give the School Board and Architects assurance that site specific Alternative Solutions based on the approaches described in this report can be reasonably negotiated such that Development Permit level designs can be submitted with reasonable assurance of approval.

It is noted that each individual project will have to be addressed and reviewed as a separate alternative solution which will be evaluated on its own merits. It is expected that this report, if accepted in principle, will form the basis for developing the individual alternative solutions and facilitate the review and approval.

A sample Alternative Solution outline is presented in Section 9.2. It is anticipated that such an alternative solution will be prepared by a fire protection engineer or other qualified professional.

9.2 Sample Alternative Solution Outline

PROJECT ***Vancouver Timber Schools – Generic 4-Storey School***

DATE ***March 25, 2019***

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i) Purpose

This report outlines the proposed generic alternative solution a generic 4-storey school in Vancouver, BC. The Vancouver School Board has identified the need for larger 3- and 4-storey schools which may include a daycare. Mass timber provides a sustainable cost-effective option for meeting this need. However, this option is currently not included as an acceptable solution in the Building Code. As such the following alternative solution has been prepared to analyze the proposed larger and higher buildings of mass timber and wood-frame, specifically focusing on fire safety requirements of Division B, Part 3 of the Building Code, in comparison to a 4-storey Group D (office) building permitted to include an assembly occupancy on the first 2 storeys and a 4-storey Group A-2 building of light steel construction.

ii) Referenced Building Code

This report is based on the National Building Code 2015 the “Building Code”. All references are to the 2015 edition of the Building Code unless otherwise noted. Vancouver Building Bylaw, 2019 edition is expected to be the same as the NBC 2015 relative to this report.

iii) Division B Solution

Under the current Building Code, a 4-storey school which is classified as an assembly occupancy (Group A, Division 2) would be classified under Article 3.2.2.24, which will prescribe the following:

Major Occupancy	Group A, Division 2
Permitted Building Height	Up to 6 storeys
Permitted Building Area	Unlimited
Sprinklered	Yes
Construction	Noncombustible
Floor rating	1h
Roof rating	0h
Mezzanine rating	1h

The current Building Code includes updates to Articles 3.2.2.50 (Group C) and 3.2.2.58 (Group D) which permit the inclusion of a Group A-2 occupancy within the first 2 storeys without having to construct these storeys using noncombustible construction. However, for a 4-storey school building, Article 3.2.2.24 would be applicable under the Building Code prescribed solution.

iv) Alternative Solution

The subject school will be 4 storeys. It is proposed to use mass timber and wood-frame construction and that the following new construction Article be considered as an Alternative Solution to the Code Solution:

Article 3.2.2.XX. Group A, Division 2, up to 4 Storeys, Sprinklered

1) A *school building* classified as Group A, Division 2 is permitted to conform to Sentence (2), provided
   - a) it is *sprinklered* throughout,
   - b) it is not more than 4 *storeys* in *building height*,
   - c) it has a height not more than 18m measured between the floor of the *first storey* and the uppermost floor level that does not serve a rooftop enclosure for elevator machinery, a stairway or a *service room* used only for service to the *building*, and
   - d) it has a *building area* not more than
     - i) 18 000 m^2 if 1 *storey* in *building height*,
     - ii) 9 000 m^2 if 2 *storeys* in *building height,*
     - iii) 6 000 m^2 if 3 *storeys* in *building height*,
     - iv) 4 500 m^2 if 4 *storeys* in *building height,*

2) Except as required by Sentence (3), the *building* referred to in Sentence (1) is permitted to be of *combustible construction* or *noncombustible construction*, used singly or in combination, and
   - a) floor assemblies shall be *fire separations* with a *fire-resistance rating* not less than 1h,
   - b) roof assemblies shall have a *fire-resistance rating* not less than 1h,
   - c) *mezzanines* shall have a *fire-resistance rating* not less than 1h, and

d) *loadbearing* walls, columns and arches shall have a *fire-resistance rating* not less than that required for the supported assembly.

3) Floor assemblies for a *building* referred to in Subclause (1)(d)(iii) or (iv) shall be constructed using *mass timber construction*.

All italicized terms are intended to have the same meaning as they do in the current Building Code, except "*mass timber construction*" and "*school building*" which are intended to have the following meanings:

- ***Mass Timber Construction:*** Mass timber construction is generally considered construction using large timber members with sizes sufficiently large enough to provide a fire-resistance rating of more than 45min, and where connections are fire protected. The fire-resistance rating of mass timber can be determined through standard fire testing or can be calculated using accepted engineering methodology such as those documented in Annex B of the 2014 edition (update 1) of CSA O86, "*Engineering Design in Wood*". This type of construction includes completely protected connections and similar to heavy timber construction, inherently leads to the creation of a very limited number of concealed spaces.

- ***School Building:*** A school building is defined as a building or part of a building that does not contain a residential occupancy and that is associated with the gathering of persons for educational purposes and includes educational programs from Grade 1 to the highest university level. Such a building may or may not contain a daycare for children who are at least 30 months in age.

Based on the proposed new Article 3.2.2.XX, the characteristics of the school will be as follows:

Major Occupancy	Group A, Division 2
Permitted Building Height	4 storeys
Permitted Building Area	4500m^2
Sprinklered	Yes
Construction	Mass timber construction (wood-frame walls)
Floor rating	1h
Roof rating	1h
Mezzanine rating	1h

v) Level of Performance of Division B Solution

Division B determines whether a building is required to be of noncombustible construction or permitted to have combustible construction based on the following factors that assess the fire risk; namely, occupancy, building area, building height, access for firefighting, and the presence of a sprinkler system. It is evident from the provisions in Subsection 3.2.2 that noncombustible construction is prescribed when the risk presented by the combination of these factors is deemed to be over a certain threshold.

Division B currently does not have an appropriate category for mass timber construction which has a performance in fire which is vastly superior to light wood-frame and better than certain types of noncombustible construction such as light steel-frame. The upcoming 2020 edition of the Building Code will include provisions for the use of Encapsulated Mass Timber Construction for buildings up to 12 storeys in recognition of the fire performance of mass timber elements.

The objectives and functional statements for the acceptable solution which prescribes noncombustible construction are as follows:

Function	Link	Objective
F02 To limit the severity and effects of fire or explosions **F03** To retard the effects of fire on areas beyond its point of origin **F04** To retard failure or collapse due to the effects of fire	so that	**OS1.2** a person in or adjacent to the building is not exposed to an unacceptable risk of injury due to fire or explosion impacting areas beyond it point of origin. **OS1.3** a person in or adjacent to the building is not exposed to an unacceptable risk of injury due collapse of physical elements due to a fire or explosion.
		OP1.2 the building is not exposed to an unacceptable risk of damage due to fire or explosion impacting areas beyond it point of origin. **OP1.3** the building is not exposed to an unacceptable risk of damage due collapse of physical elements due to a fire or explosion.

The intent of prescribing noncombustible materials for buildings required to be of noncombustible construction is to limit the probability that the construction materials will contribute to the growth and spread of fire, which could lead to harm to occupants or damage to the building.

It is noted that some combustible materials are permitted, if certain conditions are met, on the basis that these materials are deemed to insignificantly contribute to fire growth and spread.

vi) Level of Performance of Alternative Solution

In accordance with the proposed new Article 3.2.2.XX, it is proposed to use mass timber construction for floor assemblies of the 4-storey school and wood-frame for the wall assemblies.

The objective of the Building Code is to limit the risk of injury to the occupants and damage to the building as a result of fire spread beyond the point of origin. Noncombustible construction is prescribed for buildings over a certain size with the intent of limiting the risk that the building construction materials will be involved in the fire which could lead to fire spread beyond the point of origin.

During pre-flashover of a fire, fire detection, fire control/suppression, and limits to fire spread have been identified as part of the overall strategy to achieve the objectives of the Building Code. The performance of the proposed mass timber construction in the 4-storey school building is compared with light steel-frame construction permitted by Division B as follows:

- ***Limits to Fire Spread*:** Mass timber has been shown to have a low flame spread rating of 35 - 40 by nature of its mass. This inherent property limits its contribution to fire growth and spread. It is noted that a building required to be of noncombustible construction would be permitted to include combustible materials which could also contribute to fire growth and spread within the building.

- ***Fire Control/Suppression*:** The proposed 4-storey building will be sprinklered and required to have a monitored fire alarm system. Thus, in the event of a fire, the sprinkler system is expected to provide fire control similar to sprinklers in a building of noncombustible construction. Where sprinklers operate, they have been shown to be effective in controlling the fire and limiting growth and spread beyond the point or room of origin regardless of construction type. In the unlikely event that the sprinklers do not operate or fail to control the fire, the proposed mass timber floor assemblies can be expected to limit the probability of fire spread based on the inherent fire resistive properties of mass timber elements such that the level of performance provided will be similar to that provided by an assembly of noncombustible construction.

At the post-flashover stage of a fire, the level of performance of the building is measured by the fire-resistance rating of its assemblies, which is a measure of the ability of assemblies to endure the effects of fire in post-flashover temperatures.

Mass timber provides inherently high performance in fire and has a predictable and reproducible charring rate when exposed to the standard fire resistance test. A 1h rated mass timber assembly is assigned its fire-resistance rating based on CAN/ULC S101 which is the same test used to assign fire-resistance ratings for noncombustible construction. Thus, the level of performance with respect to fire endurance and limiting the probability of collapse in a post-flashover fire will be similar for both a mass timber assembly and one of noncombustible construction.

A minimum dimension of 96mm is recommended for the proposed mass timber floor assemblies constructed to the proposed new Article 3.2.2.XX. This commendation is based on the minimum thickness prescribed for mass timber elements in the upcoming NBC 2020. CSA-086, "*Engineering Design in Wood"*, prescribes char rates for mass timber of 0.65 to 0.8mm/min. 0.8mm/min equates to 48mm of char, plus a 7mm heated zone to represent the thermally damaged wood below the char front, the residual uncharred material which continues to retain its full properties as shown in Figure 6 will be 41m. Thus, floors will inherently not burn through in a 1h standard fire. It is noted that for structural purposes, the floor assemblies may be required have dimensions of more than 96mm.

Figure 6: Charred wood member showing char front and the residual uncharred material which continues to retain its full properties.

Further, as noted, the building will be equipped with a monitored fire alarm system similar to a building of noncombustible construction. In the event of a fire, it is expected that occupants will receive timely notification and would be able to evacuate the building before the development of untenable conditions. Schools typically have laid down procedures for evacuation, which are periodically rehearsed through fire drills. Thus, it can reasonably be expected that occupants will evacuate the building in a timely fashion.

A risk analysis included in this report evaluates the performance of the proposed schools against the level of performance anticipated by the Division B solution presented by the Building Code. This risk analysis demonstrates that the level of fire safety achieved by the proposed construction is equivalent to that prescribed by the Building Code.

Additional features that can be provided to further demonstrate and improve the level of fire safety include:

- Area smoke detection.
- Time Egress Analysis to confirm evacuation in less than 10min.
- Fire alarm strobes.
- Voice communication system as part of the fire alarm system.

vii) Summary

This report has described the approach to building code compliance for a generic 4-storey school in Vancouver, BC. Generally, the project will conform to the acceptable solutions in Division 3, Part B, of the National Building Code 2015 and will rely on an alternative solution to address the use of mass timber and wood-frame construction.

10. CONCLUSION

Generally, this report shows both qualitatively and quantitatively that there is no substantial increase in fire risk for a school building up to 4-storeys in height constructed with all the fire safety features that would be required for a building constructed to Article 3.2.2.58 of the current Building Code or a 3-storey Group A, Division 2 building with 1h fire-rated floor assemblies. Additionally, process risks have been discussed and recommendations put forth in relation to addressing these risks where they exist.

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