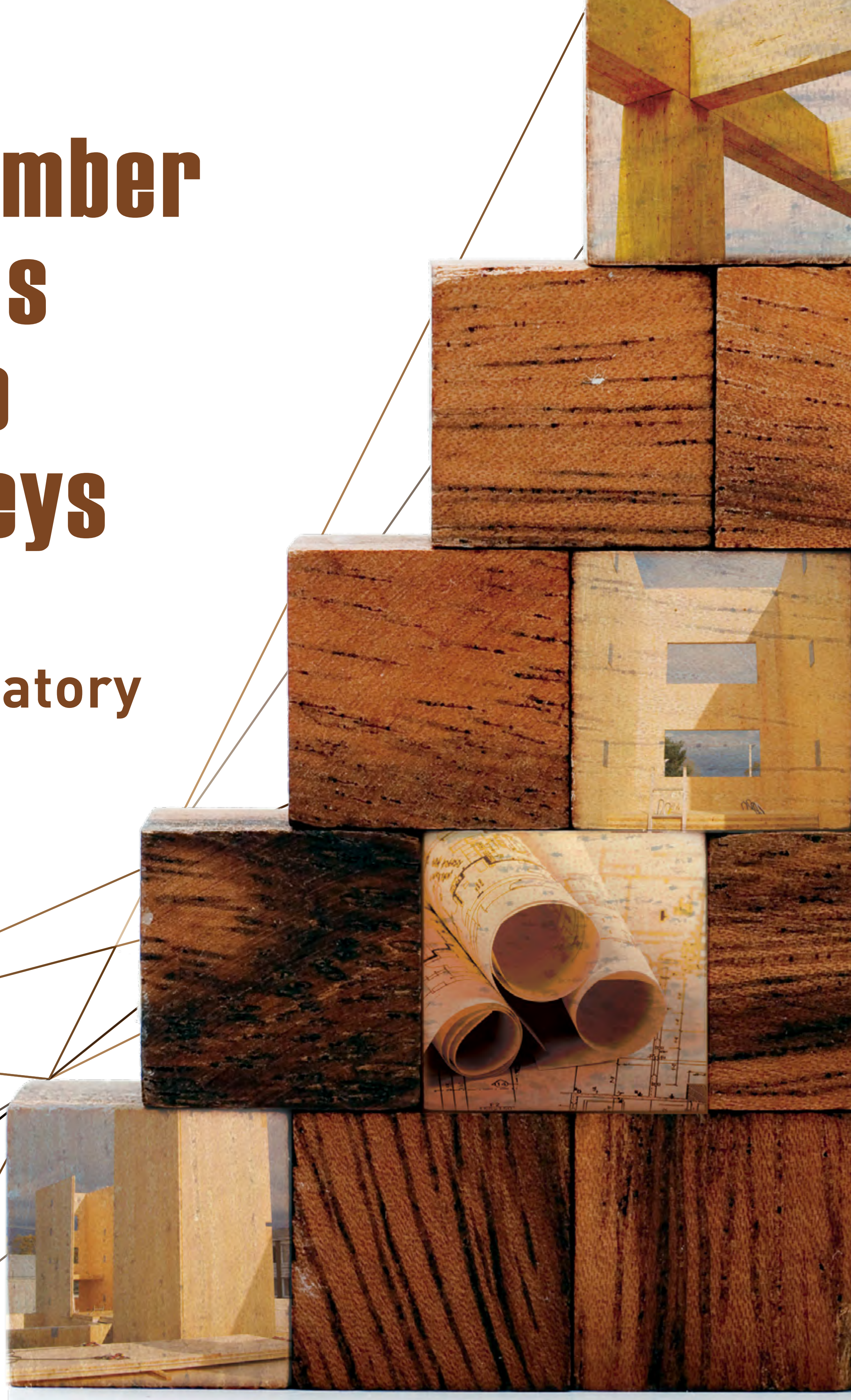
Mass timber buildings of up to 12 storeys

Directives and Explanatory Guide



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N.B.:
This document is intended specifically for professionals working in the construction of wood buildings up to 12 storeys. If designed and built in compliance with the conditions stipulated in Part 1 – Guidelines, and the technical specifications in Part 2 – Explanatory Guide of this document, these buildings are deemed to comply with the standards set out in the National Building Code 2010, amended for the province of Quebec. However, this does not exempt applicants from obtaining any other authorization(s) required by any law or regulation, as the case may be.

This document is a translation of the "Bâtiments de construction massive en bois d'au plus 12 étages" Guide published in August 2015. In the event of discrepancies, the French version prevails.

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Foreword

The Building Act seeks to ensure the quality of a building's construction and certain facilities as well as the safety of the public with access to these. This Act combines, within a single legislative framework, all laws and regulations under the responsibility of the Régie du bâtiment du Québec (RBQ). In compliance with this Act, a building must be designed and constructed in keeping with the provisions of the Québec Construction Code, Chapter I – Building (NBC, 2010, amended).

The construction of wood buildings no more than 6 storeys in height was introduced in the amended NBC 2010, hereinafter referred to as the Code. A wood building of up to 6 storeys can now be constructed under certain conditions stipulated in Division B of the Code. The prescriptions of the Code make no distinction regarding the construction system. Its provisions apply to all combustible construction systems, namely light-frame construction, post and beam systems, structural engineered wood, *glued-laminated timber*, *cross-laminated timber*, or *hybrid construction* (wood, concrete and/or steel).

Despite the introduction of provisions allowing the construction of wood buildings of up to 6 storeys, the Code does impose certain limits on the use of wood. Looking at research in the field and the development of wood construction on an international level, the limit on the number of storeys for *mass timber* structures in Canada seems restrictive. Research has shown that *mass timber* structures higher than 6 storeys can safely be built but that, at these heights, the use of mass timber rather than light-frame construction is necessary. This type of construction includes *glued-laminated timber*, *structural composite lumber* or *cross-laminated timber*.

The need to adapt Canadian construction standards to allow the equitable use of wood is recognized by Québec as well as other provinces. Moreover, the RBQ contributed to the development of proposals for the National Building Code of Canada 2015 (NBC 2015).

Currently, the Building Code's provisions do not take into account the particularities of each construction system; the 6-storey limit applies to all combustible structures, regardless of the construction system. A designer wishing to erect a wood building exceeding 6 storeys must file an equivalent measures application with the RBQ. This application must demonstrate compliance with the objectives of the Code.

Pursuant to Article 127 of the Building Act, the RBQ may approve, *"a design, building method or the use of material and equipment different from that prescribed by a code or regulation made under this Act, on conditions it sets, where it finds the quality equivalent to what is sought by the standards of the code or regulation"*. Therefore, the RBQ may establish conditions allowing the use of wood as a material that differ from the Construction Code's provisions for a building exceeding 6 storeys. These conditions are presented in the form of guidelines developed in collaboration with the experts of the FPInnovations Research Centre. The RBQ and its mandated experts consider that designers and builders with the required competencies who comply with the guidelines contained herein as well as other applicable standards and requirements can design and construct *mass timber* buildings providing the same level of quality and safety as buildings designed with other materials.

These guidelines are based on the 2010 edition of the Code and related standards as well as on the *Technical Guide for the Design and Construction of Tall Wood Buildings in Canada* (TWBG), published by FPInnovations in 2014. They are also based on the tall wood building demonstration project located in Quebec City, one of three projects selected further to a call for tall building demonstration projects issued in 2013 by Natural Resources Canada and the Canadian Wood Council. Finally, the minimum conditions set out in this guide are based on the results of tests conducted at the National Research Council Canada (NRC), which recently confirmed the performance levels of this type of construction. In March 2013, a working group consisting of government departments, agencies and fire departments, and operating under the responsibility of the RBQ was formed. The RBQ consulted this working group on guidelines for *mass timber constructions* exceeding 6 storeys.

Like any other construction material, wood is subject to certain minimum requirements, depending on its projected use. These requirements can involve structural resistance or fire resistance, whether the wood is used as a raw material, an element of a system, or a finishing material. Restrictions established in the Code apply not only to wood but to other construction materials, and are, in fact, limited only by their intrinsic characteristics as they relate to their intended use.

It is important for designers and builders to have a good knowledge of the characteristics and behaviour of wood, particularly as they relate to fire safety, structural behaviour and durability. The guidelines presented in Part 1 of this guide include the minimum provisions that shall be respected to ensure the quality of construction and the safety of occupants. Part 2, the Explanatory Guide, provides useful information and advice to guide designers and builders of tall wood buildings. When a particularity or a provision is not explicitly or directly addressed in this guide, the provisions of the Code shall prevail.

To allow the equitable use of wood in construction in Québec, the RBQ permits construction of *mass timber* buildings of up to 12 storeys, without requiring an application for equivalent measures, provided all guidelines set out in Part 1 of this guide are respected and the points set out in the Explanatory Guide are taken into account.

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Introduction

This guide provides the directives needed for designers of tall wood buildings to produce their designs, plans and specifications. It has been developed to give them the information and general concepts required, based on the selected system. The elements and details required to comply with the guidelines in this document must be incorporated from a project's initial design phase.

The project shall comply with all the provisions set out in Part 1 of the Guide.

Part 1 – Guidelines contains several sections, including one that deals with basic conditions and describes the minimum general conditions applicable to any project for the construction of a wood building exceeding 6 storeys. The following sections contain special provisions that specify and complete the basic conditions. The project must comply with all provisions set out in Part 1 of this guide: basic conditions, multiple occupancies, fire-resistance ratings, service penetrations in fire separations, vertical service spaces and stairwells, sprinkler system, environmental separation, smoke propagation, engineering design, structure and fasteners, safety and fire protection during construction, and finally, administrative directives.

Part 2 – Explanatory Guide, complements Part 1, providing technical clarifications and additional explanations for each provision set out in the Guidelines.

Parts 3, 4 and 5 provide additional information and requirements concerning the design team and coordination of the work, building maintenance, and other laws and regulations applicable to the project.

For additional technical recommendations, see the *Technical Guide for the Design and Construction of Tall Wood Buildings in Canada* (TWBG), published by FPInnovations and available from the following website: twbg.fpinnovations.ca.

General

The acceptable solutions found in Division B of the 2010 Quebec Construction Code, Chapter I – Building (Code) limit the use of structural wood elements in buildings of up to 6 storeys with a prescribed maximum building area. The guide presents provisions that shall be respected in a *mass timber construction* of certain types of buildings exceeding 6 storeys. All design and construction elements not cited in this guide shall comply with the requirements applicable to noncombustible construction and high buildings set out in the Code.

All design and construction elements not cited in this guide shall comply with the requirements applicable to noncombustible construction and high buildings set out in the Code.

The design of a building exceeding 6 storeys involves much more than the mere implementation of a structural and fire-resistance approach. Design teams must take into account the integration of all of the building's systems and performance levels as well as its enclosure, from the beginning of the design process. Moreover, close supervision of the work during the construction stages is mandatory to ensure compliance with the plans and specifications. This guide addresses these aspects and presents the principles and potential solutions to help the designers and construction teams navigate an integrated and multidisciplinary project.

Definitions

To understand this guide, it is essential to know the meaning of certain terms that are not explicitly defined in the Code. Shown in *italics* in this guide, the additional terms defined below apply to the guidelines presented herein.

***Cross-laminated timber* (CLT; in French, "bois lamellé-croisé"):** structural engineered wood product prefabricated according to ANSI/APA PRG 320 from at least 3 orthogonal layers of sawn lumber or *structural composite lumber* and glued with structural adhesives to form a rectangular structural element that is straight and flat, for use in roofing, flooring and walls.

***Encapsulation*:** passive fire protection method involving the use of thermal protection materials or membranes to protect the structural elements, mitigate the thermomechanical effects of fire on the latter, and delay the impact of the combustible structural elements on the severity of the fire for a given period.

***Glued-laminated timber (glulam*; in French, "bois lamellé-collé"):** wood product produced from the pressure-bonding of graded laminating stock whose grain is essentially parallel, and complies with CSA O122 or is preapproved by the Canadian Construction Materials Centre (CCMC), and fabricated in plants complying with CSA O177.

Figure 1 Example of *hybrid construction* (mass timber slabs with steel structure) (Photo: Binderholz)

***Hybrid construction* (in French, "construction hybride"):** type of construction involving a mix of *mass timber*, concrete, masonry or steel structural elements (e.g. wood-concrete composite slab).

***Mass timber construction* (in French, "construction massive en bois"):** type of combustible construction in which a degree of fire safety is attained by the use of structural elements as well as floors and roofs from wood elements of large dimension, and the elimination of concealed spaces in floors, walls and roofs. Structural elements of this type of construction include solid lumber, *glued-laminated timber* or *structural composite lumber* post-&-beam structural system, and a massive slab system of *cross-laminated timber* or other *structural composite lumber* elements. All of the aforementioned structural elements shall have fire-resistance ratings greater than those required for the type of heavy timber construction described in Paragraph 3.1.4.6.(1) of Division B of the Code.

***Podium*:** secondary structure or horizontal platform used to raise the main structure above grade.

***Structural composite lumber* (SCL; in French, "bois de charpente composite"):** products derived from wood (laminated veneer lumber [LVL], parallel strand lumber [PSL], laminated strand lumber [LSL] or oriented strand lumber [OSL]), preapproved by the Canadian Construction Materials Centre (CCMC), made for structural use and evaluated in accordance with ASTM D5456.

PART 1.
Guidelines

Part 1. Guidelines

1.1. Basic Conditions

1.1.1. The building may be of *mass timber construction* or *hybrid construction*.

1.1.2. The building shall be intended for Group C (residential) or Group D (business and personal services) occupancies, or a combination of the two. The building shall not house a care facility (Group B, Division 3 occupancy). Group A, Division 2 and Group E occupancies, as well as a parking garage are permitted on the first storey and in the basement on certain conditions (see Section 1.2 – Multiple occupancies).

1.1.3. The building height shall be:

1.1.3.1. no more than 12 storeys in the case of *mass timber construction* or *hybrid construction*; or

1.1.3.2. no more than 12 storeys in the case of *mass timber* or *hybrid construction* on a one-storey *podium* (see Section 1.2 – Multiple occupancies, for *podium*-type construction).

None of the floors (including mezzanines) shall be more than 40 m above grade. Note that the rooftop enclosure defined in Article 3.2.1.1 of the Code is not included in this calculation.

1.1.4. Except for the dimension of the *podium* (see Section 1.2 – Multiple occupancies), the building area shall not exceed 1500 m^2.

1.1.5. Interior partitions shall be of *mass timber construction* or constructed of noncombustible materials (e.g. light-gage steel framing).

1.1.6. No green roof is permitted on buildings of *mass timber* or *hybrid construction*.

1.1.7. The roof of a building of *mass timber* or *hybrid construction* shall be accessible by a stairway.

1.1.8. All requirements relating to high buildings apply to buildings of *mass timber* or *hybrid construction* where the floor level of the highest storey is more than 18 m above grade.

1.1.9. Unless otherwise indicated in another section of this guide, the building's design and construction elements shall comply with noncombustible construction requirements.

1.1.10. The municipal fire department shall be consulted on its specific firefighting regulations and requirements at the project's planning phase.

Additional technical information and clarifications can be found in Section 2.1 of this guide.

1.2. Multiple Occupancies

The building may accommodate a major occupancy of Group A, Division 2 (assembly occupancy), Group E (mercantile occupancy) or a parking garage on the first storey and in the basement, on the following conditions:

1.2.1. If the building includes a *podium*, it shall be of concrete construction and comply with the provisions of the Code applicable to noncombustible construction, and:

1.2.1.1. the *podium* shall be no more than one storey

1.2.1.2. the *podium*'s surface area is unlimited

1.2.1.3. a tower may be built on the *podium* (the *podium* may be topped by no more than one tower)

1.2.1.4. the horizontal fire separation between the *podium* and the tower located on top shall have a fire-resistance rating of not less than 2 hours

1.2.1.5. the tower on the *podium* shall have no more than 12 storeys and a surface area of no more than 1500 m^2

1.2.1.6. the height between the average grade level and the top floor (including mezzanines) shall be no more than 40 m.

1.2.2. When Group A and E occupancies are located on the first storey of a *mass timber* or *hybrid construction* building without a *podium*, the building's area shall be no more than 1500 m^2.

Additional technical information and clarifications can be found in Section 2.2 of this guide.

1.3. Fire-Resistance Rating

1.3.1. The floors shall form a fire separation with a fire-resistance rating of not less than 2 hours.

1.3.2. In buildings with dwellings of more than 1 storey, floors entirely contained within these dwellings, including those over basements, shall have a fire-resistance rating of not less than 1 hour, but need not be constructed as fire separations.

1.3.3. Mezzanines shall have a fire-resistance rating of not less than 1 hour.

1.3.4. Loadbearing walls, columns, arches, construction assemblies and fasteners shall have a fire-resistance rating of not less than 2 hours.

1.3.5. The roof shall have a fire-resistance rating of not less than 1 hour.

1.3.6. The roofing shall have a Class A rating.

1.3.7. Fire separations between suites, and between a public corridor and a suite require a fire-resistance rating of not less than 1 hour.

1.3.8. For storeys of *mass timber* or *hybrid constructions*, doors located in fire separations shall have a fire-protection rating of not less than 45 minutes, determined in compliance with CAN/ULC S104.

1.3.9. Walls, floors and ceilings of the parking garages shall be constructed of concrete.

1.3.10. All structural elements of mass *timber constructions* shall be completely protected by *encapsulation*. *Mass timber constructions* are considered to be adequately protected by:

1.3.10.1. the use of at least two layers of 16 mm Type X gypsum board panels fastened directly to the structural elements; or

1.3.10.2. the use of materials or assemblies which, when exposed to the temperature curve specified in CAN/ULC S101, can limit the temperature on the exposed face of the structural elements from reaching 300°C for at least 1 hour.

1.3.11. Concealed spaces within floors, loadbearing walls and non-loadbearing walls required to have a fire-resistance rating shall be filled with noncombustible insulation, unless the mass timber structural elements in these spaces are protected by two 16 mm Type X gypsum board panels fastened directly to them.

1.3.12. The fire-resistance rating of a material, an assembly of materials or a structural element of *mass timber* or *hybrid constructions* shall be determined based on:

1.3.12.1. the results of tests conducted in compliance with CAN/ULC S101

1.3.12.2. Appendix D-2.11 of the Code

1.3.12.3. design methods provided in Annex B of CSA O86-14; or

1.3.12.4. the 2014 version of Chapter 8 of the *Cross Laminated Timber Handbook* (Canadian edition).

Additional technical information and clarifications can be found in Section 2.3 of this guide.

1.4. Service Penetrations in Fire Separations

1.4.1. The continuity of a fire separation shall be maintained at its junction with another fire separation, a floor, ceiling, roof or exterior wall by products certified for this purpose.

1.4.2. Walls, partitions or floors shall form a fire separation and be constructed so as to constitute a continuous element.

1.4.3. Openings in a fire separation shall be protected by closures, shafts or other means in compliance with Subsections 3.1.8, 3.1.9 and 3.2.8 of Division B of the Code.

Additional technical information and clarifications can be found in Section 2.4 of this guide.

1.5. Vertical Service Spaces and Stairwells

1.5.1. Exit stairwells and elevator shafts may be entirely or partially of *mass timber*, noncombustible or *hybrid constructions*.

1.5.2. Exit stairs shall be separated from each other and the remainder of the building by a smoke-tight fire separation whose fire-resistance rating is not less than that required for the floor assembly they cross.

1.5.3. Scissor stairs are not permitted in buildings of *mass timber* or *hybrid construction*.

1.5.4. All vertical service spaces, including garbage chutes, shall be separated from the remainder of the building by a fire separation with a fire-resistance rating of not less than 2 hours and be of noncombustible construction.

Additional technical information and clarifications can be found in Section 2.5 of this guide.

1.6. Automatic Sprinkler Systems

1.6.1. The building shall be sprinklered throughout. The automatic sprinkler system shall be designed, constructed, installed and tested according to NFPA 13.

1.6.2. Sprinkler piping shall be noncombustible.

1.6.3. If the exit stairwells are of *mass timber* or *hybrid construction*, at least one sprinkler head is required beneath each landing of the exit stairway.

1.6.4. Exterior balconies with a perpendicular depth of more than 610 mm from the exterior wall, shall be protected by sprinklers. For the design of the balconies, see Section 1.7, Environmental Separation.

Additional technical information and clarifications can be found in Section 2.6 of this guide.

1.7. Environmental Separation

1.7.1. Assemblies separating dissimilar environments shall be designed in compliance with Part 5 of the Code – Environmental Separation.

1.7.2. The exterior building enclosure shall be designed to control potential condensation, adequately manage heat, air and moisture transfers within the building enclosure, and adapt to potential movements of the building.

1.7.3. The structure of the exterior balconies shall not be cantilevered.

1.7.4. Balconies shall be made of noncombustible materials or be of *mass timber construction* covered with noncombustible materials.

1.7.5. Exterior cladding shall be of noncombustible materials or comply with the requirements of Article 3.1.5.5 of the Code when subjected to testing according to CAN/ULC S134.

Additional technical information and clarifications can be found in Section 2.7 of this guide.

1.8. Smoke Propagation

1.8.1. Exits serving floor areas occupied by offices (Group D occupancy) shall be protected by a vestibule, unless the floor area includes a public corridor.

1.8.2. Mechanical means shall be designed and implemented to establish positive pressure in the exit stairs and public corridor for Group C or Group D occupancy, and in the vestibule for Group D occupancy. A minimum pressure difference of 12 Pa shall be maintained.

Additional technical information and clarifications can be found in Section 2.8 of this guide.

1.9. Engineering Design, Structure and Fasteners

1.9.1. In compliance with Article 4.1.1.3 of the Code, the building's structural elements shall be designed to provide the structural capacity and integrity required to safely and effectively withstand all loads, load effects and stresses that may reasonably be expected during the building's projected service life. Among others, the buildings and their structural elements shall be designed to guarantee their ultimate limit states (strength and stability) and serviceability limit states (deformation and vibration). The effects of wood shrinkage in *mass timber* or *hybrid constructions* shall also be taken into account at all times.

1.9.2. Wood structure and fastener designs shall comply with CSA O86-14, the Canadian standard for «Engineering Design in Wood», and Article 4.3.2 of this standard, «New or Special Systems of Design and Construction».

1.9.3. The arrangement of the structural system's elements and their interactions shall ensure resistance to the system's generalized collapse in the event of localized failure, in accordance with Article 4.3.3 of CSA O86-14.

1.9.4. The gravity loadbearing system of tall wood buildings shall be designed in compliance with CSA O86-14 and adapt to the lateral deformation associated with the seismic response of buildings. The entire structural system shall be designed to maintain the projected P-δ effects.

1.9.5. Sprinkler systems shall be designed to adapt to deflection sagging or deformation resulting from seismic loads and shrinkage. These systems shall remain functional after an earthquake to limit damage from fires that could occur.

1.9.6. The buildings' structural elements shall be designed to resist the most critical effect determined according to lateral wind and seismic loads. However, the lateral force-resisting system shall also be designed to take into account seismic loads and effects (see Seismic Force Resisting System[SFRS], Section 2.9), in accordance with Subsection 4.1.8 of the Code.

1.9.7. Wind loads and effects shall be assessed in accordance with Subsection 4.1.7 of the Code. Commentary I of the Code provides the procedure that can be used to conduct a static analysis of a building subjected to wind loads. Article 4.1.7.2.(1) of the Code requires the use of dynamic or experimental procedures for buildings whose height exceeds four times their minimum effective width or are taller than 60 m, as well as buildings whose properties make them sensitive to wind-induced vibrations.

1.9.8. Seismic loads and effects shall be assessed in accordance with the Code. R_d and R_o values as well as restrictions corresponding to the systems used shall comply with Table 4.1.8.9 of the Code. For other types of SFRS, R_d and R_o values shall be assessed according to Article 4.1.8.9.(5) of the Code. Otherwise, factors $R_d = 1.0$ and $R_o = 1.0$ shall be used, as specified in Table 4.1.8.9 of the Code for SFRS other than those defined.

1.9.9. Seismic design shall comply with the general objectives of the Code, i.e. ensure resistance to strong motions in order to protect the life and safety of the building's occupants and the general public, limit damage to the building when low to moderate motions occur, and ensure that civil protection buildings can continue to be occupied and remain functional after a strong tremor, even if a minimum amount of damage is anticipated in this type of building.

1.9.10. The capacity-based design concept shall be used in the seismic design of tall wood buildings. This design approach is based on a simple understanding of the way in which a structure can withstand significant deformations when subjected to major earthquakes.

1.9.11. Plans submitted by the structural engineer and by the structural component supplier's engineer shall clearly identify loads applied to structural elements for the proposed building type and projected site.

Additional technical information and clarifications can be found in Section 2.9 of this guide. This section also contains additional requirements pertaining to elements in the plans and specifications. It should be noted that these additional requirements are also part of the guidelines and shall be respected.

Additional requirements are specified in Section 2.9. They are also part of the guidelines and shall be respected.

1.10. Safety and Fire Protection during Construction

1.10.1. Ensure a clearance of at least 6 m between a combustible material and a boiler.

1.10.2. Ensure a clearance of at least 3 m between scrap containers for combustible materials and the exits.

1.10.3. During construction work, ensure that the waste chute is made of noncombustible materials or ends at least 2 m from the scrap container.

1.10.4. Ensure that the water supply is functional before the start of construction, as required in Article 3.2.5.7 of the Code.

1.10.5. Fence the site to restrict access, while maintaining access for emergency vehicles.

1.10.6. Provide a stairway giving access to every storey at all times during the building's construction.

1.10.7. Provide and maintain access routes to the construction site for fire department vehicles.

Additional technical information and clarifications can be found in Section 2.10 of this guide.

1.11. Administrative Directives

1.11.1. Supervision of the work is required and shall be carried out by an architect and/or engineer, depending on the field of expertise involved.

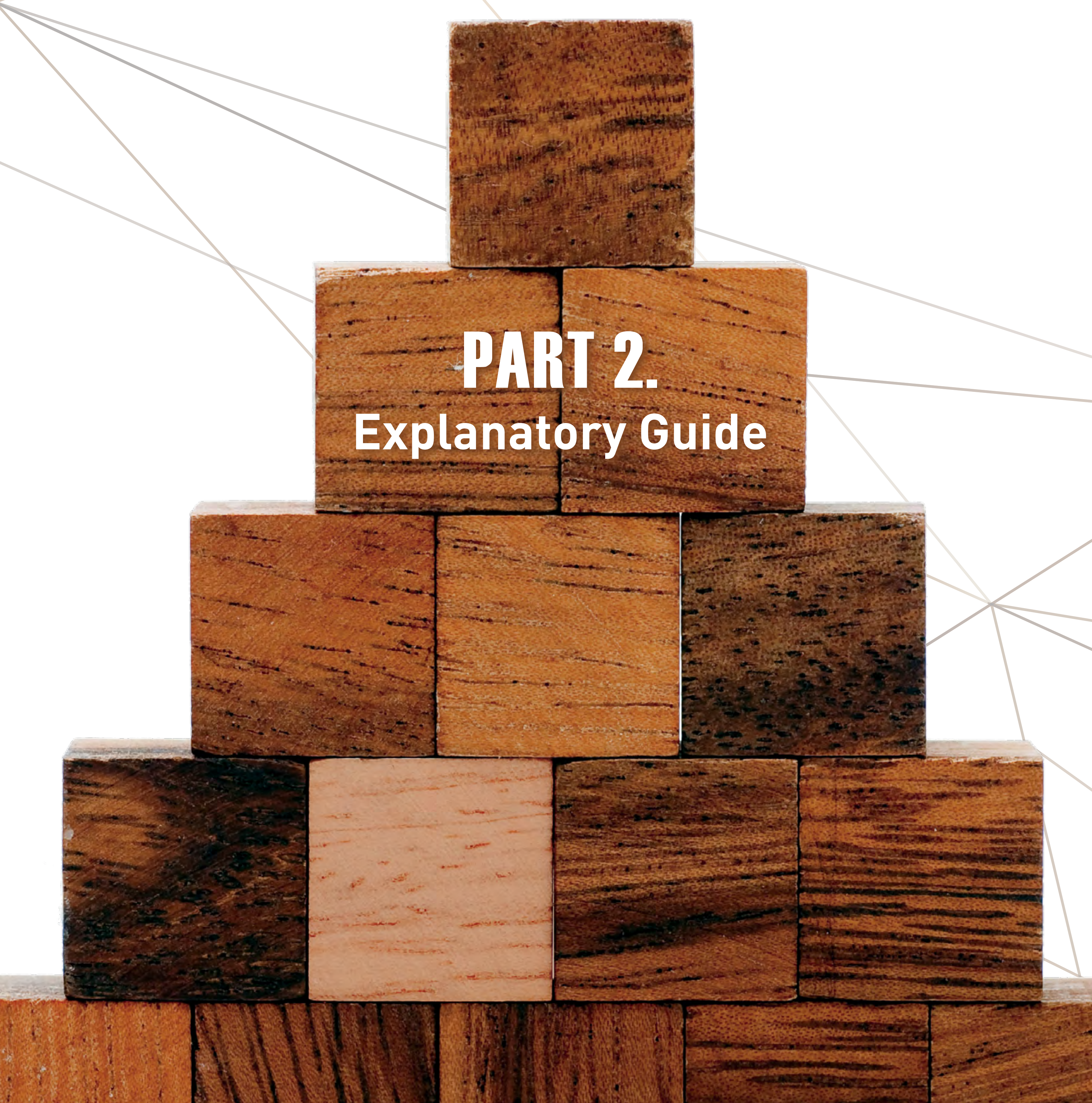
1.11.2. The designer responsible for the project shall provide the owner or co-owner with building maintenance recommendations in the form of a program addressing the management of water damage, maintenance of structural components, water infiltration and the wood shrinkage effect; the designer shall also note the importance of keeping structural wood elements completely encapsulated (see Part 4 – Building Maintenance, in this guide).

1.11.3. The maintenance program provided to the owners shall be recorded in a register kept on the premises.

1.11.4. Attestations signed and sealed by the professionals (architect and engineer) who assume responsibility for supervision of the site shall be provided to the owner or co-owner once work has been completed. These attestations shall confirm that the work was carried out in compliance with the technical requirements set out previously as well as construction plans and specifications.

Additional technical information and clarifications in Section 2.11 of this guide.

PART 2.
Explanatory Guide



Part 2. Explanatory Guide

Part 2 – Explanatory Guide provides additional technical clarifications and explanations for each section of Part 1 – Guidelines of this document. This information and useful advice will guide the designers and builders of tall wood buildings. More detailed technical information can also be obtained from the *Technical Guide for the Design and Construction of Tall Wood Buildings in Canada* (TWBG), published by FPInnovations (twbg.fpinnovations.ca.).

2.1. Basic Conditions

The building may be entirely of *mass timber construction* or a *hybrid construction* using a mix of wood, concrete and/or steel. *Cross-laminated timber*, *glued-laminated timber* and *structural composite lumber* may be used. The use of a light wood-frame in this type of construction, for either structural elements or partitions, is prohibited.

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According to the terms defined in the Code, a Group C building (residential occupancy) refers to a building, or part thereof, where sleeping accommodations are provided to occupants who are not harboured for the purpose of receiving care or treatment and are not involuntarily detained. A Group D building (business and personal services occupancy) refers to a building, or part thereof, used for conducting business transactions or rendering or receiving professional or personal services. Accommodating a care facility (Group B, Division 3), which includes a private seniors' residence subject to the Act respecting health services and social services (Chapter S-4.2) and applied by the Ministère de la Santé et des Services sociaux (MSSS – Department of Health and Social Services) is prohibited.

The Code recognizes that the risk level increases with a building's height and area. Traditionally, solutions prescribed in Subsection 3.2.2 of Division B of the Code established the floor area of buildings in proportion to their height in number of storeys, regardless of the type of construction. Moreover, no area or height limit is set on buildings exceeding 6 storeys, which must be of noncombustible construction. In these buildings, the loadbearing elements and floors require a fire-resistance rating of not less than 2 hours to achieve a level of compartmentalization deemed to be acceptable.

In principle, heights and areas in the guidelines are determined in line with a philosophy that has historically been used by the Code, while imposing a building height limit relative to ground level. This provision serves to limit the use of mezzanines, which could not only increase a building's height (in meters) but evacuation route distances as well.

The Code also recognizes that safety is increased when an automatic sprinkler system is used and fire compartmentalization is provided by separating structural elements with the fire-resistance rating required by the building's occupancy type and size.

Building height and area limits permitted in Division B of the Code have not yet been revised to reflect advances in building science and engineering, new techniques developed by fire departments, and innovative new wood systems and products that are currently classified under the Code as "combustible construction".

However, several national and international research projects on fire and structural performance, sound insulation and durability conducted over the past few years have shown that the use of *mass timber construction* can deliver a performance level at least equal to that of noncombustible construction traditionally required for buildings over 6 storeys. Thus, Equation 1, historically used by the Code, is modified as follows to reflect the increased performance of *mass timber construction*, based on a new *PF* factor:

Equation 1

$$A_{max} = \frac{A_B}{N} \bullet S \bullet SF \bullet CF \bullet PF$$

Where:

A_{max} = permitted building area for *mass timber* or *hybrid constructions* (m^2)

A_B = reference area (2250 m^2 for Group C combustible construction, according to the Code)

N = number of storeys:
= 1, 2, 3, 4, 5 or 6, according to the number of storeys and if the building is no more than 6 storeys
= 12 if the building is 7 to 12 storeys

S = sprinkler factor related to active protection by automatic sprinklers:
= 1.00 if the building is not protected by automatic sprinklers
= 2.00 if the building is protected by automatic sprinklers

SF = street facing factor:
= 1.00 if the building faces on 1 street
= 1.25 if the building faces on 2 streets
= 1.50 if the building faces on 3 streets or is protected by automatic sprinklers

CF = construction factor related to the fire-resistance rating of the construction elements:
= 1.00 if the fire-resistance rating is at least 45 minutes
= 1.33 if the fire-resistance rating is at least 1 hour
= 1.67 if the fire-resistance rating is at least 1.5 hours,
= 2.00 if the fire-resistance rating is at least 2 hours

PF = performance factor related to the construction system:
= 1.00 if the building is of traditional combustible construction (e.g. light wood-frame)
= 1.33 if the building is of *mass timber construction*.

The use of Equation 1 and appropriate factors makes it possible to obtain, in a rational manner, the areas permitted in the Code for Group C buildings of up to 6 storeys. It should be noted that, in the case of buildings over 6 storeys, firefighting operations are generally conducted inside the building. Therefore, the proportional relationship between the area and the number of floors in buildings of up to 6 storeys is no longer applicable since the risk induced by the area of the building is significantly reduced. Consequently, a conservative initial approach calls for setting coefficient *N* at 12 when a building is 7 to 12 storeys high.

Considering the intrinsic safety level of *mass timber construction* using the *PF* factor and extrapolating the *CF* factor for compartmentalization with a fire-resistance rating of not less than 2 hours, the building areas shown in Table 1 are obtained. It should be noted that, contrary to the Code, which allows various areas for Group C and D buildings of up to 6 storeys, this guide does not increase the building area based on the occupancy group.

Table 1 Building Area

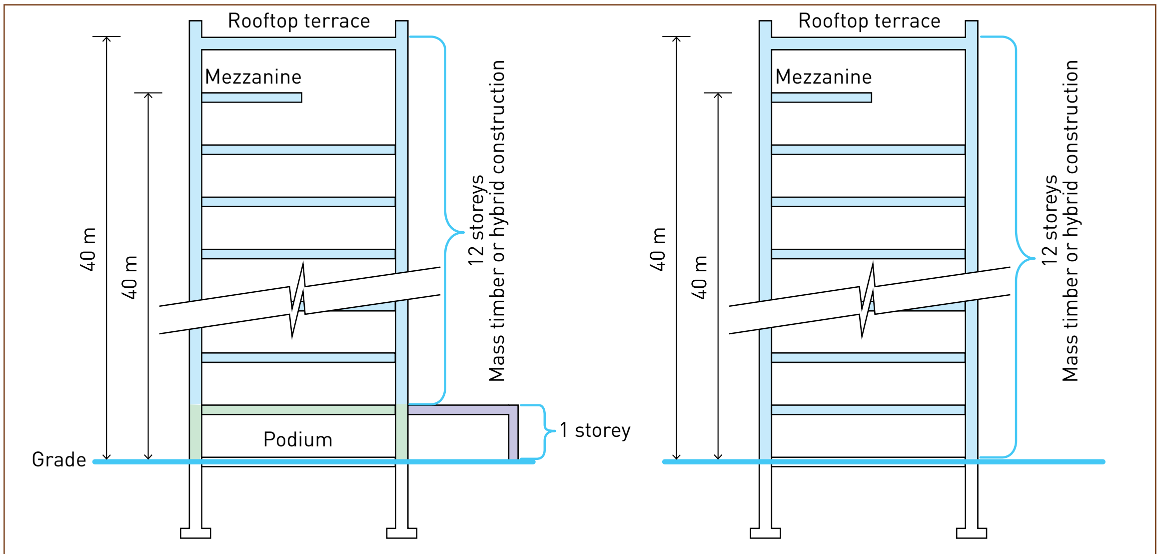
Height (storeys)	Type of construction	Fire-Resistance Rating	Sprinklers	Street	Building Area
Unlimited	Noncombustible	2 hrs.	Yes	N.A.	Unlimited
7 to 12	*Mass timber construction*	2 hrs.	Yes	N.A.	*1500 m²*
6	Noncombustible	1 hr.	Yes	N.A.	6000 m²
6	Combustible	1 hr.	Yes	N.A.	1500 m²
4	Combustible	1 hr.	Yes	N.A.	1800 m²
3	Combustible	45 min.	Yes	N.A.	1800 m²
3	Combustible	45 min.	No	3	900 m²

N.A. = not applicable.

These guidelines limit the height of *mass timber* and *hybrid constructions* to 12 storeys at all times. However, one storey can be added when this construction is erected on a one-storey concrete *podium*; this results in a total height of 13 storeys (12 wood + 1 concrete).

The 40 m limit is calculated in relation to the grade level and applies to the top floor, regardless of whether it is a storey, a mezzanine or a rooftop terrace. However, a rooftop enclosure is not included in the 40 m height calculation. Beyond this limit, more specialized construction systems requiring particular attention must be used.

Figure 2 Calculating the height of a building with and without *podium*



All the requirements applicable to high buildings set out in Subsection 3.2.6 of the Code must be respected in *mass timber* or *hybrid* buildings, when the height of the top floor is more than 18 m above grade, even if the building accommodates a Group D occupancy. This requirement aims at reducing the risk of smoke propagation and smoke contamination for its occupants and firefighters. It should be noted that other Code requirements for high buildings, including the protection of electrical cables, apply.

Installing a green roof on top of a building of *mass timber* or *hybrid construction* is prohibited. However, one can be built on the roof of a one-storey *podium* of noncombustible construction, provided criteria developed by the RBQ for the construction of green roofs are respected.

The roof must be accessible by means of a stairway. This stairway must be located inside the exit and be accessible by a trap measuring at least 550 mm by 900 mm, or by a rooftop enclosure.

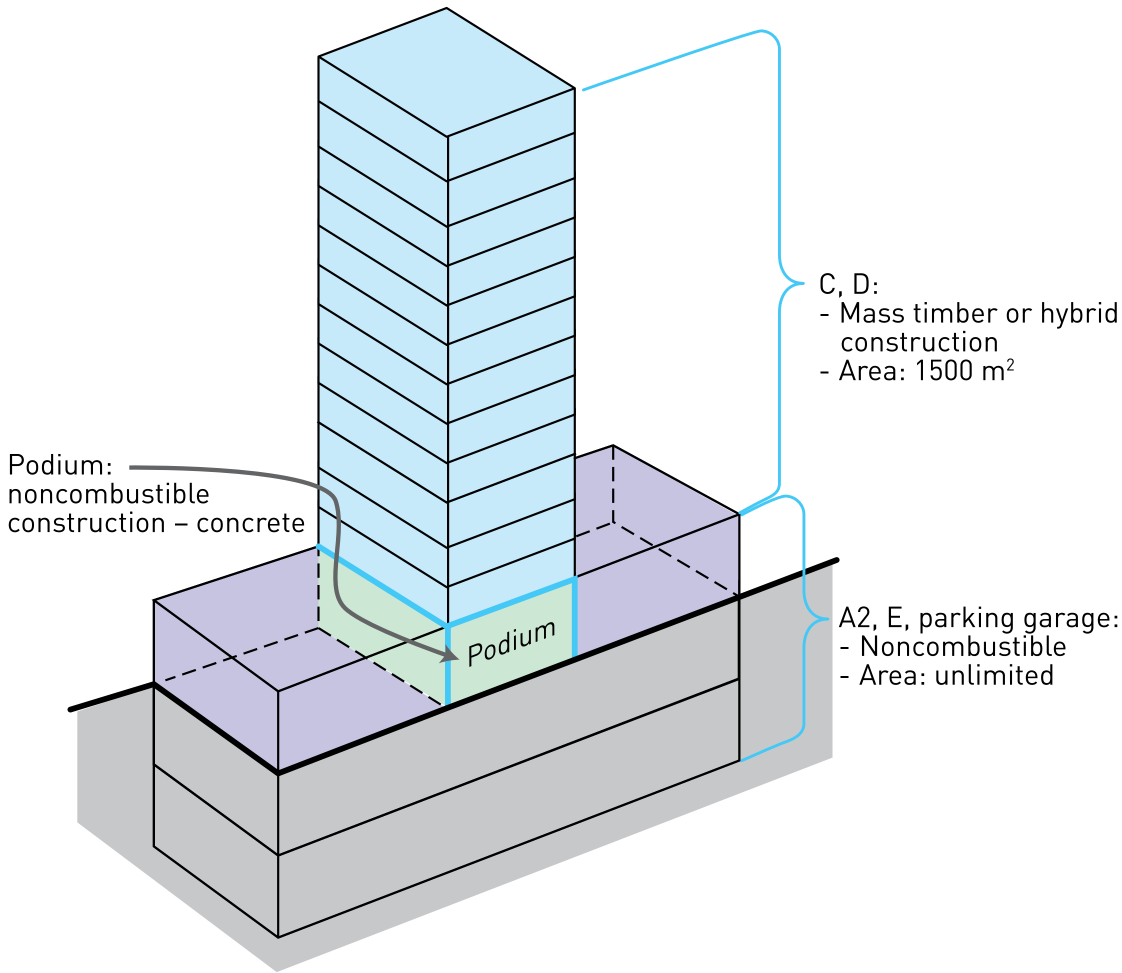
The performance level deemed to satisfy the acceptable solutions in Division B of the Code is based on various, occasionally implicit assumptions, including the need for an adequate water supply and the fire department's ability to respond within a reasonable timeframe. Additional details can be found in Appendix A-3 of the Code.

While the RBQ has set these guidelines, the municipality is responsible for defining the maximum size of buildings based on its means of intervention. Since a municipality can impose additional requirements on its territory, it is imperative that both the municipal fire department and the municipality be consulted at the project's planning stage. It is also essential that the municipal fire department approve this type of construction on its territory.

2.2. Multiple Occupancies

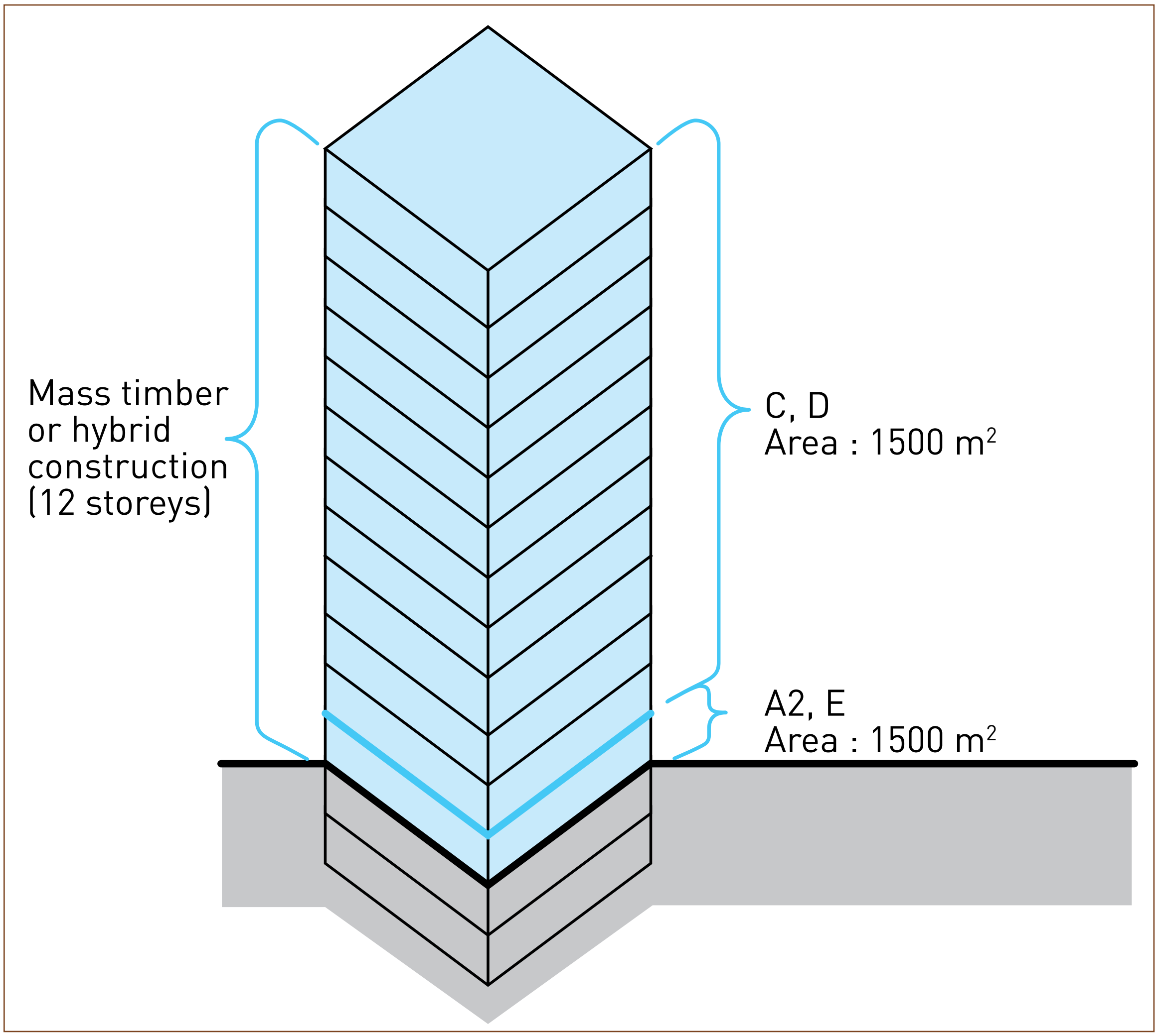
Multiple occupancies in a building is common practice, particularly in urban environments, as it maximizes land space and the building's volume, while making it possible to offer occupants a wider range of services. Thus, certain major occupancies are only permitted on the ground floor. In the case of multiple occupancies in a concrete *podium*, the interior of the *podium* must meet the requirements of a noncombustible construction and provide a fire-resistance rating of not less than 2 hours. No limit is imposed on the podium's ground floor area. However, the tower area of the upper storeys must comply with the limits of this document's guidelines, i.e. 1500 m² for a Group C or D building.

Figure 3 Occupancies permitted with a concrete *podium*



In the event that multiple occupancies are housed in a building of *mass timber* or *hybrid construction* rather than a concrete *podium*, the guidelines apply to the construction of the ground floor. Therefore, the area of the ground floor must not exceed 1500 m².

Figure 4 Occupancies permitted without a podium



Developments consisting of more than one tower over a distinct parking garage designed according to Article 3.2.1.2 of the Code, are not permitted.

2.3. Fire-Resistance Rating

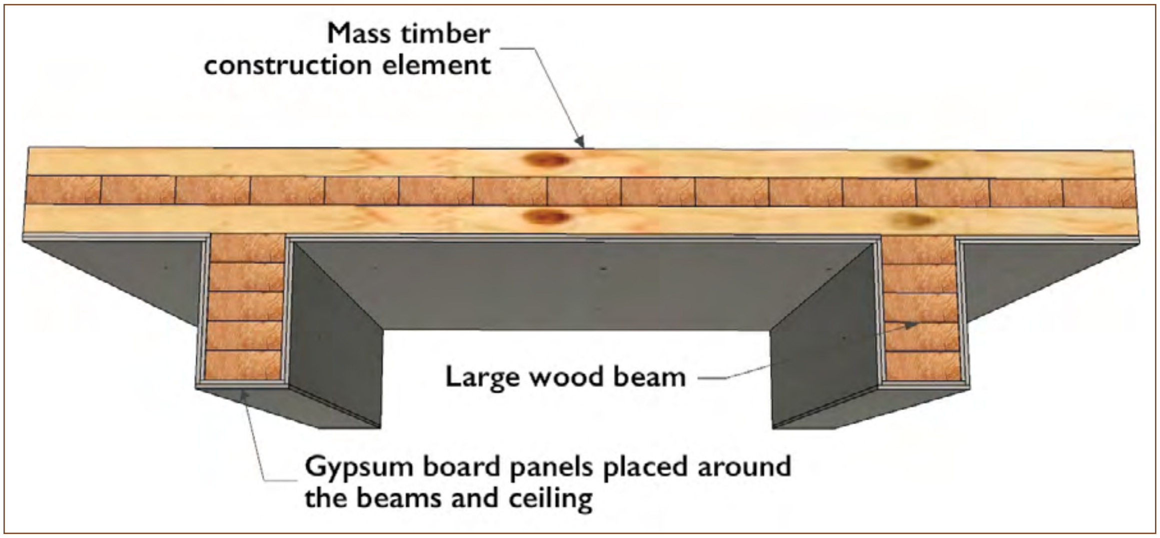
All the floors and loadbearing elements of *mass timber* buildings exceeding 6 storeys must have a fire-resistance rating of not less than 2 hours to comply with the objectives and functional statements [F03-OS1.2, OP1.2] and [F04-OS1.2, OS1.3, OP1.2, OP1.3]. These statements aim to limit the probability that the structural and separating elements will fail prematurely or collapse before occupants have been moved to a safe location and emergency responders have carried out their duties, as well as the probability that these elements will cause injury to persons and damage to the building. Functional statements F03 and F04 are directly linked to the notions of compartmentalization of buildings. Thus, the notions of fire-resistance and integrity of fire separations are essential for achieving the performance level defined by the objectives.

According to Article 3.1.7.1 of Division B of the Code, the fire-resistance rating of a material, an assembly or a structural element must be determined based on the results of tests conducted in accordance with CAN/ULC S101 standard or Appendix D of Division B. For buildings designed in accordance with these guidelines, the fire-resistance rating of an element can also be determined according to the design methods provided in Annex B of CSA O86-14 or the 2014 version of Chapter 8 of the Cross Laminated Timber Handbook, Canadian edition.

All construction materials are subjected to thermomechanical effects when exposed to heat flux (degradation of mechanical and/or physical strength as a result of temperature). There are several methods for obtaining the required fire-resistance rating, depending on the material used, including *encapsulation*. This is a basic method for protecting all construction materials from fire. It can delay the thermomechanical effects of fire on structural elements, as in the case of traditional noncombustible construction, as well as delay the contribution of wood structural elements to the fire. Tests conducted in compliance with CAN/ULC S101 or finite-element modelling can easily demonstrate that the use of two layers of 16 mm Type X gypsum board panels can maintain the temperature from reaching 300°C on the exposed face of wood structural elements for at least 1 hour, assuming that the ignition temperature of wood is 300°C.

Encapsulation is required for all structural elements of a *mass timber construction*. Moreover, two methods are permitted, i.e. complete *encapsulation* or suspended membrane *encapsulation*. Complete *encapsulation* consists in fastening two layers of Type X gypsum board panels directly to the wood elements (Figure 5).

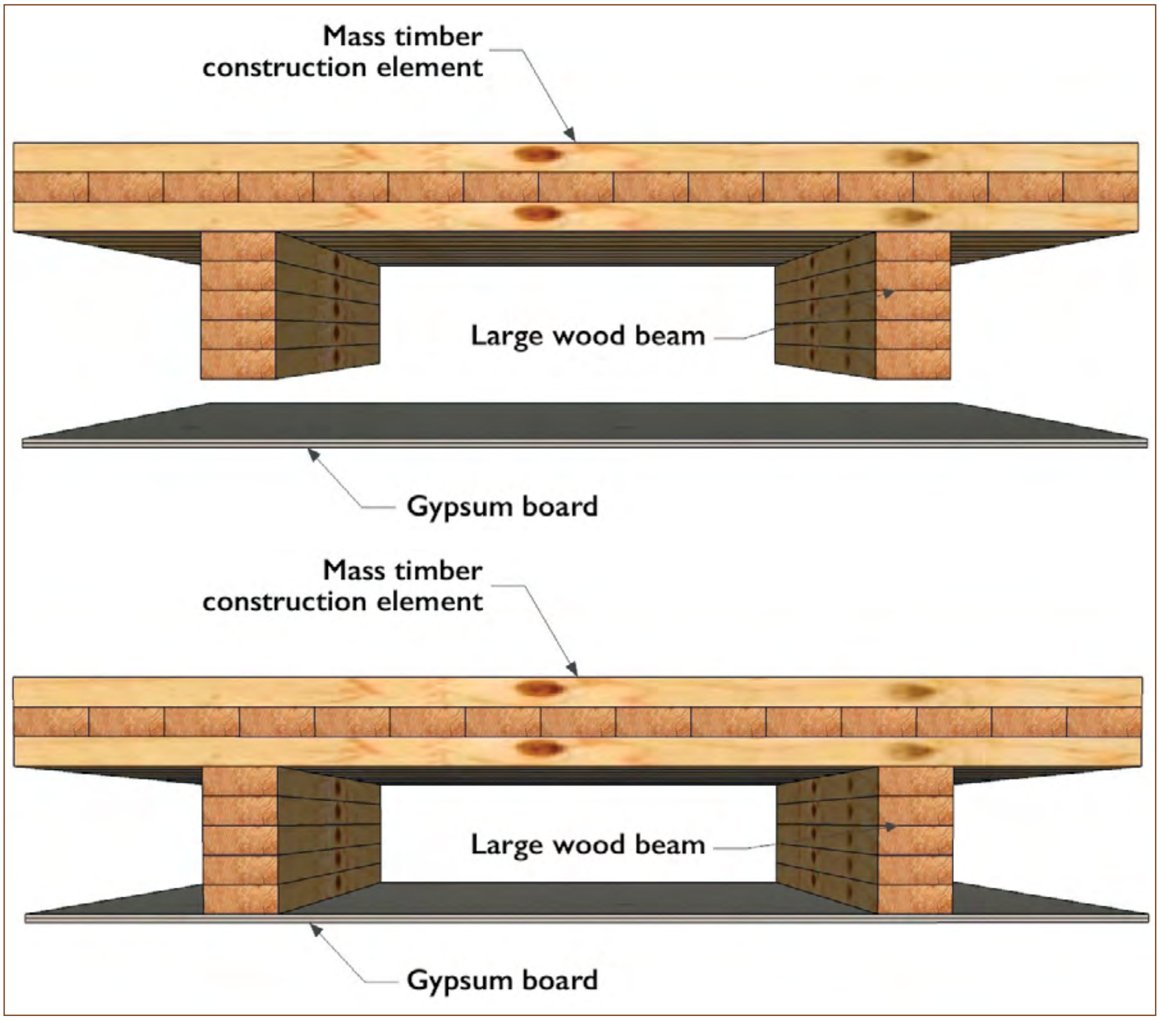
Figure 5 Complete *encapsulation* fastened directly to the wood elements



Suspended *encapsulation* relates to the use of materials or assemblies that are not fastened directly to the wood elements, but can keep the temperature from reaching 300°C on the exposed face of wood structural elements for at least 1 hour (Figure 6). This could refer to gypsum board installed on furring or on a suspended ceiling. It should be noted, however, that for this *encapsulation* method to be used, the assembly must have been tested according to the temperature curve specified in CAN/ULC S101. It is also mandatory for the concealed space located between the gypsum membrane and the wood element to be filled with noncombustible insulation.

It is mandatory for the concealed space located between the gypsum membrane and the wood element to be filled with noncombustible insulation.

Figure 6 Suspended membrane *encapsulation* (filling of spaces not illustrated)



It should be noted that assemblies and fasteners used to withstand gravity loads on the structure must have at least the same fire-resistance rating as the elements they support. The simplest method for increasing the fire-resistance of metal fasteners is to conceal (Figure 7) or protect them against exposure to fire by using a sufficient thickness of wood (Figure 8) or other preapproved covering material with the required fire-resistance rating. Sections 5.4.4, 5.4.5 and 5.4.6 of the *Technical Guide for the Design and Construction of Tall Wood Buildings in Canada* (TWBG) provides additional information for calculating the fire-resistance of structural elements as well as integrity and insulation criteria for separating elements such as walls, floors, roofs and partitions.

Figure 7 Metal assemblies and fasteners completely concealed before *encapsulation*

Figure 8 Metal assemblies and fasteners covered with wood before *encapsulation*

The fire-resistance of structural elements made from *mass timber* requires reduced cross-sections to be designed based on fire exposure time and charring rate, followed by a verification of their residual resistance. The reduced cross-section design method is detailed in Annex B of CSA O86-14 and Chapter 8 of the *Cross Laminated Timber Handbook*, 2014 Canadian edition.

If an assembly's metal components are located entirely within the reduced cross-section of a wood structural element designed in this manner, the assembly is deemed to be adequately protected, since the wood forming the reduced cross-section will protect the metal components from the effects of fire.

The 2-hour fire-resistance rating stipulated in the guidelines requires that the protection of fasteners be subjected to a careful and detailed study based on the type of construction selected for the project.

The 2-hour fire-resistance rating stipulated the guidelines requires that the protection of fasteners be subjected to a careful and detailed study based on the type of construction selected for the project.

In a platform-framed *mass timber construction*, the fasteners connecting the loadbearing elements usually serve to provide a path for lateral loads (wind and seismic) and do not require a fire-resistance rating, since the (unlikely) failure of the fasteners will not result in a structural failure of the gravity loadbearing system. Figure 9 illustrates situations where it would not be necessary to protect the fasteners against fire (assuming that no *encapsulation* is required). However, in the case of assemblies withstanding gravity loads such as those illustrated in Figure 10, the fasteners must be protected against the effects of fire to deliver the required fire-resistance rating. In *mass timber constructions* exceeding 6 storeys and designed according to these guidelines, the fasteners must be protected since structural elements must be encapsulated for at least one hour. Moreover, fasteners in a structure other than a platform-type must be concealed or covered to provide a fire-resistance rating of not less than 1 hour. Therefore, in the case of *encapsulation* with the required one-hour fire-resistance rating, the assembly must have a total fire-resistance rating of not less than 2 hours.

Figure 9 Platform framing whose assemblies do not require fire protection (*encapsulation* not illustrated)

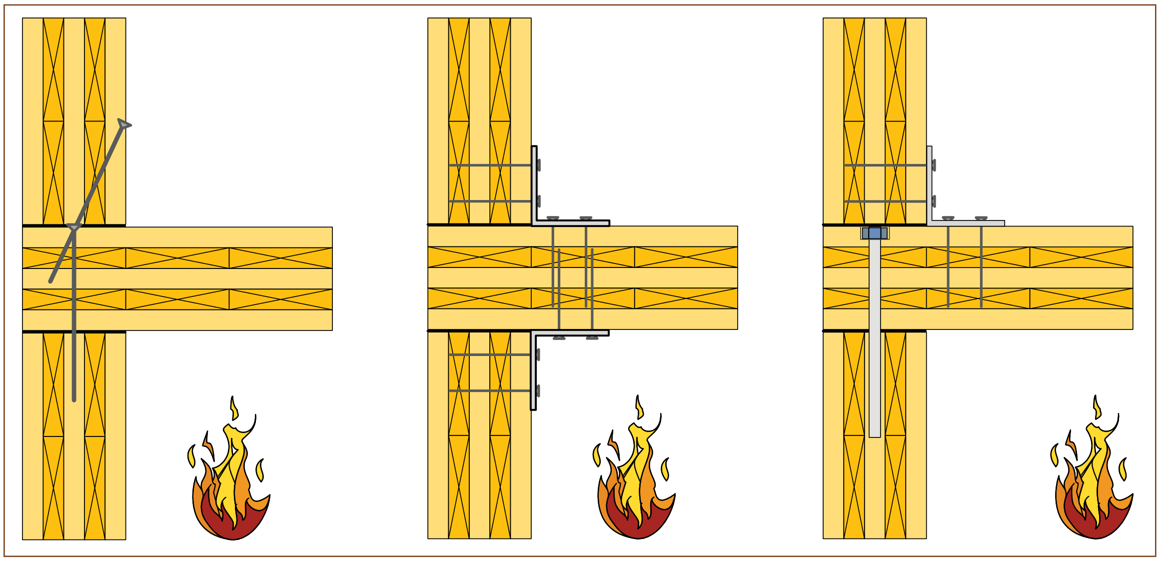
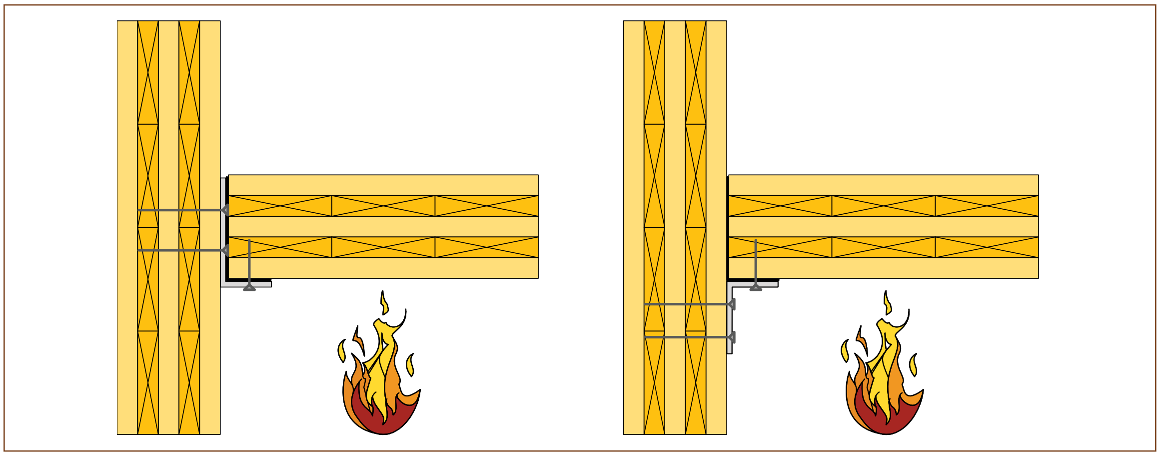


Figure 10 Balloon-framing whose assemblies require fire protection (*encapsulation* not illustrated)



The use of innovative assemblies and fasteners is permitted provided that, when exposed to the temperature curve specified in CAN/ULC S101, these assemblies can be shown to carry applied loads for the required period. Obtaining an evaluation report from the Canadian Construction Materials Centre (CCMC) is strongly recommended to document the performance of these fasteners and ensure that the structural strength values comply with CSA O86.

A fire can be divided into two basic stages: 1) ignition and growth (pre-flashover) and 2) fully developed (post-flashover). After flashover, the fire is mainly controlled by ventilation factors (limited oxygen supply), which keep the presence of mass timber or additional combustible elements from significantly increasing the temperature or effect on fire separations. However, they may increase the duration of the fire until burnout.

The compartmentalization concept based on fire separations (walls) is one of the passive fire protection measures serving the limit the fire's spread throughout a floor area.

In a building designed according to the guidelines contained in this document, a fire separation with a fire-resistance rating of not less than 1 hour will be required between the common corridor and suites as well as between suites. This requirement applies to Groups C and D occupancies, despite the relief provided in the Code for Group D occupancy. As in the case of wood structural elements, fire separations in *mass timber constructions* must be encapsulated using one of the two methods presented in Subsection 1.3.10 of this guide.

The doors of the suites must have a fire-protection rating of not less than 45 minutes to limit the spread of the fire from its original compartment. Tests and computer modelling have demonstrated that increasing the fire-protection rating of doors considerably delays the spread of fire to the common corridors and, consequently, to the building's evacuation routes. However, it is essential for doors to remain closed. To this end, they must be fitted with a closing and latching mechanism maintained in good working order throughout the service life of the building.

2.4. Service Penetrations in Fire Separations

All buildings exceeding 6 storeys must have a fire-resistance rating of not less than 2 hours to comply with the objectives and functional statements [F03-OS1.2, OP1.2] and [F04-OS1.2, OS1.3, OP1.2, OP1.3]. These seek to limit the probability that the structural and separating elements will fail prematurely or collapse before occupants have been moved to a safe location and emergency responders have carried out their duties, as well as the probability that these elements will cause injury to persons and damage to the building. Functional statements F03 and F04 are directly linked to the notions of compartmentalization of buildings. Therefore, as previously mentioned, the notions of fire-resistance and integrity of fire separations are essential for achieving the performance level defined by the objectives.

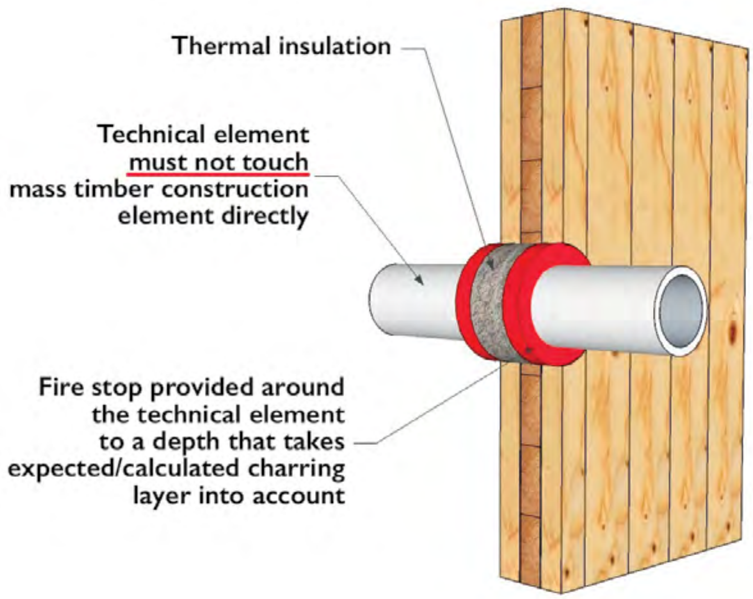
Figure 11 Fire stops penetrating *cross-laminated timber* and evaluated according to CAN/ULC S115 (Photo: Intertek)

To preserve the integrity and continuity of a fire separation, any penetration crossing a fire separation or a wall that is part of a construction requiring a fire-resistance rating must be sealed by a fire stop which, when tested according to CAN/ ULC S115 (Figure 11), achieves an F rating at least equal to the fire-protection rating required for closures in fire separations, in compliance with Table 3.1.8.4 of Division B of the Code.

A number of fire stops are preapproved for use in concrete or wood-frame constructions. It is therefore important to choose a fire stop certified for the specific intended use.

Although the protection concept is identical, it is important to pay special attention to the installation details of elements crossing the fire separation, to keep heat induction from causing premature charring of the wood and facilitating the passage of flames. This aspect is especially important for the vertical elements, where it is common practice to allow penetrating elements to rest on the structural or non-structural element before sealing the opening. Figure 12 illustrates an installation method calling for the installation of noncombustible thermal insulation around the penetrating element, in order to limit thermal conduction to the wood element.

Figure 12 Protection of service penetration in a vertical element.



The composition of some walls and partitions in *mass timber constructions* (e.g. *cross-laminated timber*) includes an air space between the wood panel and metal studs for sound insulation as well as better adjustment of the materials. When these walls are adjacent to a gypsum board drop ceiling, the air space inside the wall must not come into contact with the vertical service spaces, since the wall must extend to the underside of the floor slab.

2.5. Vertical Service Spaces and Stairwells

There is a variety of construction methods for framing vertical service spaces and achieving the required performance level. In some cases, platform-frame construction is used, with the elements constituting the walls of the service space thereby discontinued at every floor. In balloon-frame construction (although *mass timber construction* does not have concealed spaces), the walls of vertical service spaces are continuous in height while the floors are connected to the sides of these spaces by metal connections, joists or loadbearing walls located along the sides of the service space. In all cases, a sealing material pre-certified to CAN/ULC S115 standards must ensure the tightness of junctions between the floors and the walls of the service space. It is also essential to design the elements, including their assemblies, fasteners and supports, so their failure in the event of a fire does not compromise the integrity of the vertical service space (structural integrity and tightness against flames and smoke). Comment C of the *User Guide – NBC 2010, Structural Commentaries (Part 4 of Division B)* provides useful information on the structural integrity of firewalls whose philosophy fully applies to vertical service spaces, elevator shafts and exit stairways. Designers are strongly urged to study these commentaries to ensure the proper design of assemblies and fasteners.

It is essential to design the elements, including their assemblies, fasteners and supports, so their failure in the event of a fire does not compromise the integrity of the vertical service space.

Exit stairways are among a building's means of evacuation, allowing occupants to reach a safe location not exposed to the building's fire. These exit stairways also provide an access route for emergency responders. Although scissor stairs may be more attractive from an architectural point of view, they are not permitted in these types of buildings as they can create dead-end corridors and compromise smoke-tightness due to possible puncturing from one stairway to the other. Should one of the scissor stairways or the integrity of the walls be compromised, the other stairway would most likely be compromised as well. Consequently, the use of distinct stairwells, separate from each other, provides occupants with a second safe evacuation path while giving responders another access route.

2.6. Automatic Sprinkler System

All buildings exceeding 6 storeys must be sprinklered throughout, in compliance with Article 3.2.2.18 of Division B of the Code. Moreover, the sprinkler system must be designed, built, installed and tested according to NFPA 13 in order to comply with the objectives and functional statements [F02, F04-OS1.2, OS1.3, OP1.2, OP1.3], which is applicable to all types of construction.

According to NFPA 13, when an exit stairwell is of wood-frame construction, at least one automatic sprinkler head must be installed beneath all landings of the exit stairways, while only two heads are required when the stairwell is of noncombustible construction. This increases the level of active fire protection within the exit stairwell.

When an exit stairwell is of wood-frame construction, at least one automatic sprinkler head must be installed beneath all landings of the exit stairways.

The structural engineer must also design the connections of the sprinkler system to withstand seismic forces, in compliance with Article 4.1.8.18 of Division B of the Code and Subsection 9.3 of NFPA 13. Consequently, additional installation details must be developed to provide adequate gravity and lateral support for the piping. More information on the design of seismic effects and the requirements of Article 4.1.8.18 can be found in the *User Guide – NBC 2010, Structural Commentaries (Part 4 of Division B).*

2.7. Environmental Separation

In this type of building, exterior facades must be clad in noncombustible materials to limit the exterior propagation of a fire. A designer wishing to use wood cladding, in whole or in part, must ensure that the wall and its entire composition have been tested according to the CAN/ULC S134 standard. The guidelines set out in this document do not authorize systems such as curtain walls, given the diversity of their design. Each tall wood building construction project for which the use of this type of system is being considered must first be analyzed in conjunction with the RBQ.

Given the diversity of their design, curtain walls are prohibited. Each project in which the use of this type of system is being considered must first be analyzed in conjunction with the RBQ.

Balconies must also be built of noncombustible materials (e.g. prefabricated balconies suspended from the mass timber frame). If the balconies are of *mass timber construction*, they must be covered with noncombustible materials. However, the design of cantilevered balconies is prohibited. Eliminating this possibility limits the risk of infiltration of rain and snow. For additional information, see section 5.9 of the *Technical Guide for the Design and Construction of Tall Wood Buildings in Canada* (TWBG).

Balconies must be built of noncombustible materials. If they are of *mass timber construction*, they must be covered with noncombustible materials. Cantilevered balconies are prohibited.

In terms of longevity, a proper composition of the enclosure and its components will provide the tools needed to ensure the building's long-term durability. To this end, a building must be designed to control potential condensation and adequately manage heat, air, moisture and sound transfers through both indoor and outdoor environments, regardless of the type of construction considered.

Part 5 of Division B of the Code lists the requirements and objectives for achieving a proper composition of the enclosure and its components when they are exposed to outdoor environments or the soil, or when they separate two different indoor environments. These requirements apply to all buildings, except those covered by Part 9 of Division B of the Code or by the National Farm Building Code. Part 5 of the Code deals with control of condensation, heat transfer, airtightness, vapour diffusion, precipitation, surface water, soil moisture and sound transmission.

Chapter 6 of the TWBG provides more detailed information on the design of building enclosures. It summarizes the key considerations when designing a building's enclosure, particularly the principal aspects relating to differences in the design of tall wood buildings for Canada's different climate zones. This chapter aims to inform readers on the different loads of a building's enclosure and requirements regarding energy and building codes. It further summarizes basic principles in the design and assembly of building enclosures as well as the principles relating to finishing strategies, finally addressing the protection and durability of wood, including moisture management on the job site and the use of wood in outdoor applications. Meanwhile, Section 4.4 of Chapter 4 of the TWBG deals with sound insulation control in buildings.

A number of publications providing instructions for the design of building enclosures including handbooks and other reference documents dealing with the science of building, are available in Canada. They provide general directions for the design and construction of wood-based building enclosures offering durability and energy efficiency. These publications include: *Guide for Designing Energy-Efficient Building Enclosures* (2013), *Building Enclosure Design Guide* (2011), *Cross Laminated Timber Handbook* (2011), *High Performance Enclosures* (2013), *Building Science for Building Enclosures* (2005) and *Builder's Guide for North American Climates* (different versions). The fundamental design principles of building enclosures described in these publications can be applied to tall wood buildings. However, since most of the recommendations for the design of wood buildings only apply to buildings of up to 6 storeys, caution is essential when contemplating the design of tall buildings. Many assemblies, details or materials that are appropriate for use in low wood-frame buildings might not be suitable for taller buildings, due to increased environmental loads and higher expectations concerning durability.

Climate Considerations and Environmental Loads

The design of dissimilar environments must take into account climate loads dictated by the geographical regions where the buildings are to be erected (Division B of the Code). Indeed, the conditions to which the construction systems are subjected dictate the methods and best practices related to the design of the enclosure and its components. Heat, air, moisture and sound transfer calculations must comply with standard practices. The Code refers, in particular, to the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Handbook (2009 edition), which covers the fundamental principles related to the different mass transfers

In the case of tall buildings, the effects of increased wind and rain loads on the cladding structure and fastenings, as well as various other problems should be considered at the design stage. Several elements of the building's enclosure may be subjected to increased wind and rain loads. Designers must take these into account. The fundamental consideration in designing the enclosure of a tall wood building, compared to a wood building of lower height, is the effective treatment of heavier loads, particularly wind, rain and air pressure differences.

At the design stage, the effects of increased wind and rain loads should be considered. Several elements of the enclosure (structure, fasteners, cladding, etc.) may be subjected to these increased loads.

Increased wind loads may also cause the building's roof edge to lift. Therefore, certain roof applications commonly used in the construction of lower buildings may not be appropriate for tall buildings. It is therefore essential to use the right materials and follow manufacturers' recommendations.

Heat Transfers

Heat transfers refer us to the thermal resistance requirements of construction components or assemblies. In this instance, it is important to know the requirements specified in current energy codes.

It should be noted that most of the energy codes and programs are currently undergoing major revisions, which will have an impact on construction systems and their design. This will make it more important than ever to monitor the validation of enclosure concepts and compositions since increases in thermal resistance could lead to problems related to poor management of water infiltration and potentially greater condensation. In cold climates like Québec, the transfer of heat from the interior to the exterior takes longer than the reverse. Under these conditions, it is important to provide good interior and exterior protection systems (vapour barrier and air barrier/rain barrier).

Airtightness

Controlling airtightness is key to the efficient operation of a construction system because, in addition to offering the occupants acceptable environmental conditions, it can counter potential condensation problems resulting from the movement of air in walls and cavities.

The airtightness system is the main line of defence against air leaks. Materials used in this system must have an air permeability rating complying with Part 5, Article 5.4.1 of the Code. More detailed information on the control of air leakage is provided in Subsection 6.4.4 of the TWBG.

Vapour Diffusion

In terms of vapour diffusion, the principles remain the same. When a vapour pressure or temperature gradient is present, the system must consist of materials or components capable of controlling vapour diffusion. Part 5 of the Code requires that the permeability of vapour barriers be low enough to minimize moisture transfer by diffusion. More detailed information on the control of water vapour condensation is provided in Subsection 6.4.3 of the TWBG.

Precipitation

Rain is generally the main source of moisture in building enclosures. This makes it essential to control rainwater penetration. Compliance with the aspects addressed in the section on precipitation in Part 5 of the Code ensures good protection against the infiltration of rainwater. However, the rain barrier system may vary depending on the type of building. In the case of wood buildings, the exterior cladding is considered to be the first layer of defence against harsh weather, while the rain barrier system (installed behind the cladding) acts as the second line of defence. This method complies with the objectives of the Code, which seek to minimize the infiltration of precipitation and prevent its migration into the building. For materials applied on horizontal or sloping surfaces, such as roofs, the Code does provide certain specifications relating to the standards that must be respected. Obviously, all the materials, components and assemblies, and their joints and junctions, must be either sealed or allow the evacuation of water.

Typically, increasing the height of buildings increases their exposure to weather conditions (i.e. to wind and rain loads). The design team must take these increases in the load coefficient and other factors into account when calculating potential wind loads and the effect of rain on the enclosure.

Furthermore, rainwater blown against walls and windows by the wind accumulates as it flows down the walls to the ground. Certain devices, such as drip flashings, allow water to flow without contact with the building. This reduces the impact of wetting elements and materials beneath the flashings. However, it is likely that, in the case of tall wood buildings, water accumulation on the surface of the lower levels and windows will be greater than the accumulation of water on the surfaces of smaller buildings. Therefore, the water accumulation must be taken into account in the design of elements and water discharge systems on the surface of a building's enclosure.

The Code also notes that the location and development of the land on which a building is to be erected must include water recovery systems (slope, catch basins, etc.), to prevent the accumulation of surface water near the building.

Wood shrinkage and its effect on the enclosure

Shrinkage of wood involved in the construction of tall buildings is a phenomenon of the utmost importance. It is due to changes in the dimensions of wood components in response to variations in their moisture content (MC). In tall wood buildings, special attention must be paid to wood shrinkage, given the cumulative effect of changes in the dimensions of wood elements.

Special attention must be paid to wood shrinkage, given the cumulative effect of changes in the dimensions of wood elements.

Over time, the MC achieves a balance with the relative humidity of the air surrounding the wood. The MC of engineered wood, which is used in *mass timber construction*, falls within a range of 12% to 16%, a content far beneath the fibre saturation point (about 30%), but higher than the equilibrium moisture content found inside buildings (approx. 5% to 15%).

Therefore, it is essential to allow an initial shrinkage period for the wood elements in buildings of *mass timber construction*, followed by a variation in their dimensions during the year, given the variation in relative humidity within the building's enclosure. The mean relative humidity of indoor air is usually higher in summer than in winter, due to heating in cold weather. The MC of wood can then vary from 15% to 5% (and even more in the exterior walls). Thus, the wood in a building's elements expands during the summer and contracts during the winter. This makes it essential to allow for potential movement due to the shrinkage of all structural and non-structural components that could be affected.

Noise control and sound transmission

The building's enclosure controls the transmission of undesirable noise pollution from outdoor to indoor spaces. Urban noise from automotive traffic, trains, airplanes, factories and neighbours, in particular, are undesirable indoors as they hinder concentration and other activities such as conversation and sleep. The components of the building enclosure, with their soundproofing, damping and airtightness properties, have an impact on the transmission of noise from the outside. The selection of appropriate window, wall and roof assemblies and certain building enclosure interface details must be taken into account in the design of the sound insulation. However, Canadian building codes do not currently include noise control requirements for the exterior enclosure of buildings. The only requirements included in these codes relate to noise control inside buildings, particularly between units or covered spaces. As stipulated in Section 5.9 of Division B of the Code, each dwelling must be insulated from other parts of the building where noise can be produced by construction with a sound transmission class rating of at least 50. Moreover, the construction separating a dwelling from an elevator shaft or garbage chute must have a sound transmission class rating of at least 55.

An important aspect to consider in wood construction is indirect sound transmission. Although direct sound transmission through partitions (walls and floors) seems to produce good results in service, the phenomenon of indirect transmission can greatly influence the apparent sound transmission class (ASTC). Designers must therefore pay special attention to indirect transmission at the junctions between walls and floors. Section 4.4 of the TWBG provides more detailed information on controlling sound insulation in buildings.

The building enclosure also makes it possible to control flame and smoke propagation in case of fire. This enclosure must remain intact for a given period of time to prevent flames from moving in or out the building: this will primarily allow the occupants to safely evacuate the building and keep the structure from collapsing. Generally speaking, the components of the building enclosure must be protected against fire, and the cladding or cladding system must be designed to keep flames from spreading when they come into contact with the exterior of the building. This generally involves the use of noncombustible cladding and cladding supports as well as noncombustible mineral wool insulation, as in other tall buildings of noncombustible construction.

2.8. Smoke Propagation

Smoke propagation is a factor of great concern in tall buildings. Statistics show that most fatalities in tall building fires occur in the evacuation routes (stairways, corridors) and are caused by propagation of smoke from elsewhere in the building. It is essential to not only limit smoke rising in the elevator and other vertical shafts and its propagation to the upper storeys, but to keep smoke from migrating to the exit stairways as this migration could slow the evacuation of occupants to a safe location and either delay firefighting operations or render them inefficient.

The Code already provides measures for limiting smoke propagation in the stairways of tall buildings. These include venting the base of the stairwell. In a building of *mass timber* or *hybrid construction* designed according to the guidelines set forth in this document, mechanical pressurization of the exit stairs is required to obtain positive pressure with a minimum pressure difference of 12 Pa. Obviously, it is necessary to ensure that the maximum pressure created in the stairway does not prevent doors from opening. Each case is specific and must be subjected to calculations. The method used to achieve the performance level is left up to the designer. Method J described in the Appendix of the 1990 edition of the National Building Code is a good example of what was used in the past. NFPA 92A, "Recommended Practice for Smoke-Control Systems", can also be used, as described in Appendix B of Division B of the Code.

Mechanical pressurization of the exit stairways is required to obtain positive pressure with a minimum pressure difference of 12 Pa.

2.9. Engineering Design, Structure and Fasteners

The development of the structural plans and specifications is an important part of a project involving a *mass timber* or *hybrid construction* exceeding 6 storeys. Special attention must be paid to the analysis and sizing of the building system, when producing structural plans and specifications for this type of building. Until very recently, the Code did not authorize construction of wood buildings over 4 storeys. It is therefore important to bear in mind some of the particularities of wood construction.

In *mass timber* or *hybrid constructions* exceeding 6 storeys, special attention must be paid to the analysis and sizing of the building system when producing structural plans and specifications.

Code and Standards (General)

The scope of Part 4 of the Code is described in Subsection 1.3.3 of Division A of the Code. Buildings covered by this guide exceed 3 storeys in height and have an area greater than 600 m^2. Consequently, structural design rules established in Part 4 of Division B of the Code must be applied.

According to Article 4.3.1 of Division B of the Code, wood structures and their connections (fasteners) must be designed in compliance with the latest edition of CSA O86. Thus, CSA O86-14, "Engineering Design in Wood", shall be the reference when designing the elements and construction systems of wood buildings covered by this guide. This standard provides important new provisions, which will be included in the next edition of the National Building Code of Canada (NBC 2015).

Tall wood buildings and fasteners may be designed in conformity with Article 4.3.2 of CSA O86-14. Indeed, Article 4.3.2, "New or Special Design and Construction Systems" stipulates that "*new or special systems of design or construction of wood structures or structural elements not already covered by this Standard may be used where such systems are based on analytical and engineering principles, reliable test data, or both, that demonstrate the safety and serviceability of the resulting structure for the purpose intended*".

As with structural design standards applied to other materials, CSA O86-14 aims to ensure, in an acceptable manner, that a wood structure designed in compliance with this standard will safely meet the needs of its intended use. The structure is suited to its intended use if the structure, its components and assemblies are designed in compliance with the requirements of Article 4.3, Design Requirements, and Articles 5.1.2 and 5.1.3, Ultimate Limit States and Serviceability Limit States respectively, of CSA O86-14.

Moreover, unlike Part 3 of Division B of the Code, where the vast majority of technical provisions and performance levels are prescriptive and qualitative in nature, the technical provisions and performance levels of Part 4 of Division B of the Code are essentially geared to performance and reliability (an approach advocated by limit states design). These provide designers with greater flexibility in meeting the Code's objectives.

Connections (Fasteners)

Chapter 12 of CSA O86-14 sets out design criteria for fasteners commonly used in wood construction. However, new fastener systems are regularly used in *mass timber construction*. These fastener systems must be evaluated according to Article 4.3.2 of CSA O86-14, "New or Special Systems of Design and Construction". Unconventional fastening systems are evaluated based on the manufacturer's test data with proof interpreted by product evaluation bodies such as the Canadian Construction Materials Centre (CCMC). This organization publishes reports stating the design values recommended for the tested system. The CCMC evaluation reports publish design values in keeping with the principles of CSA O86. The project engineer may authorize an innovative fastener system, with or without third-party evaluation, if he is convinced that engineering due diligence has been carried out (according to Article 4.3.2 of CSA O86). However, if confirmation by a third-party evaluation body is required, the CCMC evaluation report must be provided. Finally, the procedure for calculating the design values of innovative fasteners and assemblies, according to test data is detailed in Subsection 4.2.3.6 of TWBG and must be compatible with CSA O86-14.

The structural behaviour of *mass timber constructions* subjected to seismic and wind loads is controlled, to a large extent, by the connections, which must be ductile and maintain integrity in case of overload. The connections should be designed to not only withstand design loads, but to absorb energy and maintain the system's structural integrity in case of overload (see Section 4.2 of TWBG).

Moisture content and load duration are important factors in designing connections; brittle failure modes must be avoided, especially in high seismic risk zones. The use of connections whose strength is controlled by failure of the wood (brittle failure, in particular) should be avoided and, if possible, ductility should be targeted, particularly in high seismic risk zones. When designing connections or assemblies, it is also important to take into account moisture and other service factors that influence the strength of the wood (or other materials). See CSA O86 and Section 4.2 of TWBG for advice in this area.

The structural behaviour of *mass timber constructions* subjected to seismic and wind loads is controlled, to a large extent, by the connections, which must be ductile and maintain integrity in case of overload. Moisture content and load duration are important factors in designing connections.

It is essential for all connections to provide rigidity solely against the flow of forces, as presumed in the design of the secondary system or structure to which they belong, to avoid unintentional forces of attraction that may exceed the capacity of the assembly. When rigidity is necessary – against wind or seismic loads, for example –, it must be controlled against the effects of the axial, shear and bending moment forces, which were taken into account in the design.

In wood structures, the energy produced by wind or seismic activity is dissipated by several mechanisms, such as internal friction, friction between structural elements and plastic deformation. During extreme seismic events, a large part of this energy dissipation is obtained by non-linear deformation of the mechanical connections resulting from the elasticity of the metal connectors and support of the wood elements. When wood is used in long, tall and light structures, the dynamic response to the wind load and man-made vibrations can be significant, and joints can contribute significantly in terms of damping and rigidity, to the structure's behaviour as a whole. For more details, see Section 4.2 of TWBG.

Arrangement of Bearing Systems

The arrangement of the structural system's elements and their interactions must ensure resistance to widespread collapse of the system in case of localized failure. To obtain adequate structural integrity, connections between structural components must be ductile and have a relatively high deformation and energy absorption capacity under abnormal load conditions. Appropriate details to resist low to moderate wind loads, and especially seismic loads, generally provide sufficient ductility.

The arrangement of the structural system's elements and their interactions must ensure resistance to widespread collapse of the system in case of localized failure.

There are several ways of designing the structure to ensure the integrity needed to support loads near severely damaged walls, trusses, beams, posts and floors. Some examples of concepts and details are listed in TWBG, Section 4.3.

The overall approach to the design of tall wood buildings requires the absorption of loads by columns and walls for gravity loads such as permanent loads (including superimposed loads), live loads and snow loads.

There are a number of elastic linear structural analysis programs, which can be used for modelling the system, including wall panels and floors, to obtain design loads for the gravity system (manual calculations may be used to check these design loads). Construction stages should also be analyzed to ensure that the design follows the construction sequence. The design of the gravity system's elements must comply with the requirements of CSA O86-14. See Section 4.3 of TWBG as well.

It is crucial to ensure that the gravity loadbearing system in tall wood buildings can adapt to the lateral deformation associated with the buildings' seismic response. Building deformation produces secondary forces and moments in the gravity system that must be taken into account in the design. It should be noted that the bigger and more rigid the gravity loadbearing system, the greater its interaction with the seismic force-resisting system (SFRS) in a tall wood building. The entire structural system must be designed to maintain the projected P-δ effects.

It is crucial to ensure that the gravity loadbearing system in tall wood buildings can adapt to the lateral deformation associated with the buildings' seismic response.

In addition, sprinkler systems must be designed to adapt to sagging or deformation induced by seismic loads and shrinkage. Sprinkler systems must remain functional to limit damage from fires that could occur after an earthquake. See Section 4.3 of TWBG as well.

Sprinkler systems must remain functional to limit damage from fires that could occur after an earthquake.

Seismic Force Resisting System (SFRS)

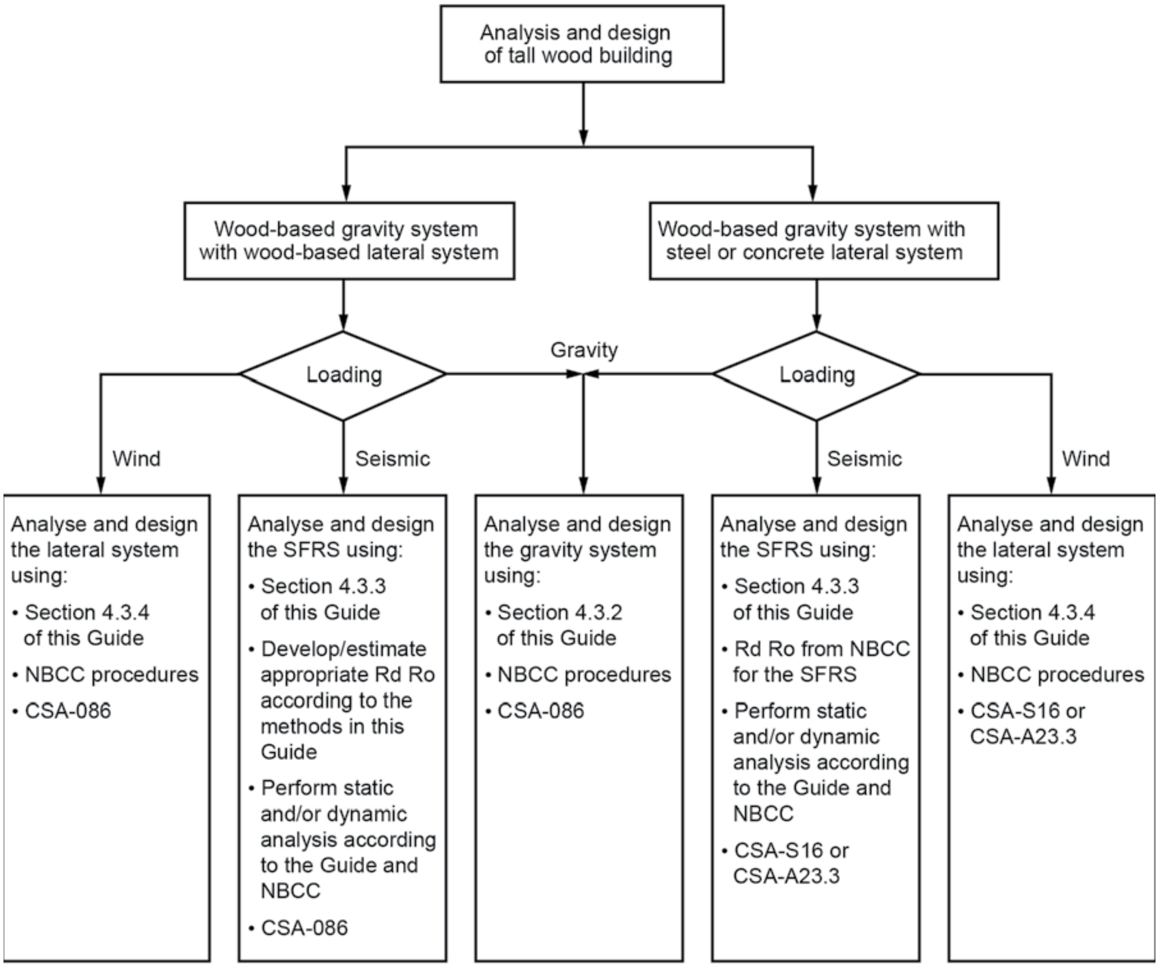
The transmission of seismic loads must be clearly defined at the structural design stage. The SFRS must also be clearly defined in the engineer's plans (i.e. the plans must specify the types of SFRS and the force transfer path to the foundations).

This resistance system is the structural part, which, in the design, provides the required resistance to seismic effects and forces. The SFRS design takes into account several factors such as the location, the type of soil and the configuration of the structure. The ductility of the SFRS (R_d) and its overstrength (R_o) are essential parameters that must be considered in calculating seismic forces. These two parameters are the force modification coefficients related to SFRS ductility and overstrength. The R_d and R_o values and applicable restrictions (related to the height of the SFRS) are provided in Table 4.1.8.9 of the Code. Maximum heights for wood SFRS, designed according to CSA O86-14, may be 15 m, 20 m or 30 m, depending on the type of system used, the seismic zone and certain other restrictions. Furthermore, in inactive seismic zones, particularly where $I_E \bullet F_a \bullet S_a(0.2)$ is below 0.35, no height limit is normally assigned to the SFRS. Finally, in compliance with Article 4.1.8.9.(5) of the Code, it is possible to assign R_d and R_o values and a height to a new type of SFRS, such as *mass timber construction*. For this purpose, it must be demonstrated by tests, research and analyses that the system's behaviour is at least equivalent to one of the usual types mentioned in Table 4.1.8.9 of the Code. For more information, see Subsection 4.3.3.1 of TWBG and Article 4.1.8.9 of the Code.

Analysis and Design

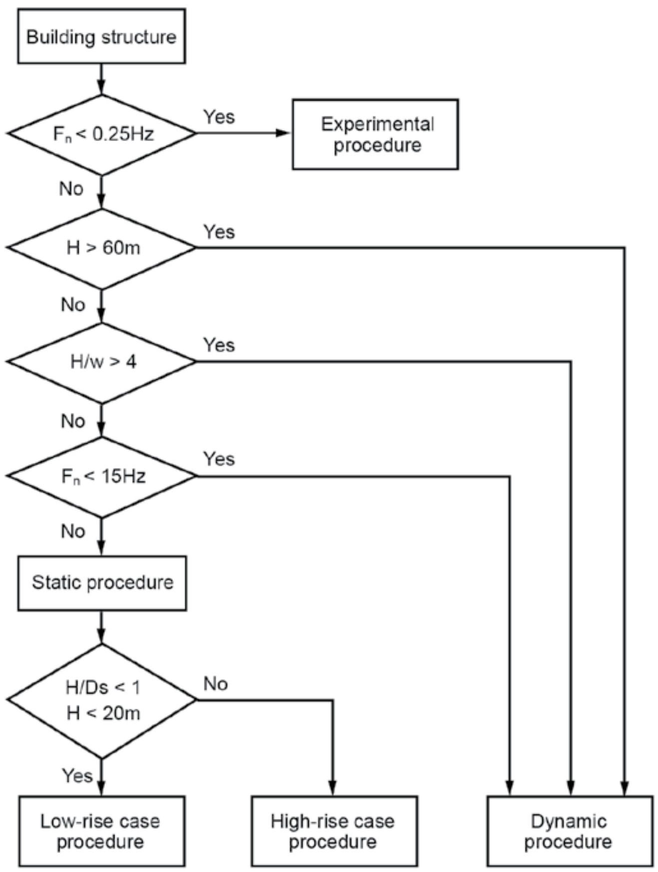
The analysis and design process for tall wood buildings is proposed in Subsection 4.3.1.4 of TWBG. The main avenues for the analysis and design of tall wood structures are presented in Figure 13. In addition, a simplified chart for determining the wind and design loads required to counter their effects is presented in Figure 14 (see Section 4.3 of TWBG as well).

Figure 13 Main avenues for the analysis and design of tall wood structures



The sections mentioned in this figure are those of TWBG.

Figure 14 Simplified chart for establishing wind and design loads countering their effects



Subsection 4.3.3 of TWBG presents seismic load analysis and design methods. It also provides additional details for determining force modification factors R_d and R_o. Subsection 4.3.3.2 of TWBG presents seismic analysis methods recognized in building engineering: equivalent static procedure, linear dynamic analyses, non-linear static analyses and non-linear dynamic analysis. Initial data required for the development of digital wood structure models when performing static and dynamic analyses are discussed in detail in Section 4.2 of TWBG. Some of the most important parameters are described below (see Subsection 4.3.3.2.5 of TWBG as well).

Properties of the element

Elements in a tall wood building are most likely composed of engineered wood products, used as either beam or post elements, structural wall panels, or both. In the case of hybrid buildings, certain steel, concrete or masonry elements may be present. For analysis and modelling purposes, the effective rigidity of engineered wood products or panels, with or without the effect of connectors, must be determined. The lower limit, upper limit and best estimates of the strength and rigidity properties (main curve, initial elastic stiffness) must be determined. This can be achieved through an examination of the analytical or test data available in the documentation (including the engineered wood product data sheets supplied by the manufacturers and developers of patented fasteners) or obtained by performing additional experimental tests on representative samples for specific applications (see Section 4.2 of TWBG).

Effective damping

Generally speaking, effective viscous damping for steel and concrete structures is deemed to fall within an interval of 2% to 5%. Wood buildings generally have slightly higher viscous damping values. It can therefore be assumed that the time-dependent damping values of the main load resistance elements and assemblies for inclusion in the dynamic linear models of wood structures fall within an interval of 3% to 5%, unless available experimental data justifies the use of higher values. It should be noted that the hysteretic damping effect will be explicitly included in the non-linear dynamic models. No viscous damping should be attributed to elements that contain friction devices.

Initial seismic movement data for analysis

Initial seismic movement data should be provided by a geotechnical expert for a site that uses the seismicity of the zone and the soil profile. NBC 2015 will publish a recommended procedure for establishing specific time-based variation analyses as well as data recommended based on time and site variations.

Hysteretic and main models for connections and assemblies

The non-linear load-deformation relationships of the main parts of the lateral load resistance system (connections and assemblies) should be obtained if non-linear dynamic analyses are to be performed. If the documentary analysis does not make it possible to obtain precise geometry and application, tests should be performed on representative samples (representative, for example, of the materials to be used as well as manufacturing and erection tolerances) by approved laboratories to establish the main and hysteretic curves appropriate for the analyses (see Section 4.2 of TWBG for more details).

Interaction between the properties and soil structure

In the case of tall wood buildings, the interaction between the soil and the foundation could affect the building's overall performance. The soil-structure interaction must be modelled accordingly during the development of linear or non-linear dynamic analyses. Soil properties are usually modelled with a series of horizontal and vertical springs; well-established procedures can determine the properties of these soil springs.

A geotechnical expert should be contacted to obtain the properties of the soil springs that will make it possible to establish the foundation geometry and soil conditions required at the base of the footings. The springs' properties with regards to upper and lower limits should be used to determine the building's response to resistance and movement requirements.

In the seismic analysis of tall wood buildings, a static linear analysis (procedure required by the Code) and a dynamic response spectrum analysis are recommended, in order to determine overall seismic demand at different floors, followed by a nonlinear static analysis to evaluate the failure sequence and hinge formation at different levels. For more details, see TWBG, Section 4.3.

Subsection 4.3.3.4 of TWBG presents the known and acceptable seismic design methods: force-based design, displacement-based design, and performance-based design.

Traditionally, seismic structural design has been mainly force-based. The reasons are largely historical and related to the way concepts are developed for other actions, such as dead and live loads (Priestley et al, 2007). In such cases, we know that force considerations are essential: if the structural resistance does not exceed applied loads, then a failure will occur. Therefore, seismic design provisions included in the Code (and in other construction codes worldwide) currently use a force-based approach. However, this procedure may present certain shortcomings when applied to tall wood structures. For these reasons, the other two design methods proposed in Subsection 4.3.3.4 of TWBG may also prove useful.

The Code does not specify exact performance levels for design based on the performance of buildings subjected to various load conditions. When performance-based design solutions are used, the designers should apply appropriate performance criteria based on available documentation. A detailed analysis of performance-based design is presented in Subsection 4.3.3.4.3 of TWBG. Nonetheless, the Code specifies the objectives and performance expected from seismic design (see the directions in Section 1.9 of this guide and Section 4.3 of TWBG).

Commentary J of the Code also stipulates the following: "*The damage caused to buildings by earthquake ground motions is a direct consequence of the lateral deflection of the structural system. The ability of a building to resist such ground motions arises largely from the capability of the structural system to deform without significant loss of load-carrying capacity. Article 4.1.8.13* [of the Code] i*s concerned with both the determination of lateral deflections and limits on those deflections to ensure satisfactory performance.*"

The Code then provides explicit avenues for establishing the realistic values of the expected maximum deformations, including torsional effects. Commentary J of the Code specifies the following: "*The deformation parameter that best represents the potential damage to the structural and non-structural elements is inter-storey deformation, also called inter-storey slippage. Article 4.1.8.13.(3)* [of the Code] *imposes inter-storey deformation limits at any level of the structure. Usually, the limit is 0.025* h_s *[where height* h_s *= inter-storey height], except for civil protection buildings and schools, for which this limit is 0.01* h_s *and 0.02* h_s *respectively. As DeVall [2003] noted, the limit of 0.025* h_s *represents the 'quasi-collapse' state [which is the equivalent of "significant damage"], but without collapse.* "

Commentary A of the Code provides guidelines that should be used to calculate the strength and rigidity properties of new materials. This commentary indicates that the strength of new materials should be defined on the basis of a 5% exclusion limit and that their rigidity should be defined on the basis of a 50% exclusion limit. When statistical sampling is used, a 75% confidence level is recommended for estimating the exclusion limit. It is also recommended that these criteria be used to determine the design strength of new wood products and connections to be used in tall wood buildings. See Section 4.3 of TWBG for more details.

The capacity-based design concept is of major importance in the seismic design of tall wood buildings. Used in the seismic design of concrete, steel and masonry structures, it must also be applied to the seismic design of tall wood buildings. This design approach is based on the simple understanding of how a structure withstands significant deformations when subjected to strong earthquakes. By selecting some of the lateral load resistance system's deformation modes, certain parts of the structure are chosen and properly designed and detailed for yield and energy dissipation when subjected to severe deformations. These critical modes of the lateral load resistance system, often qualified as "plastic hinges" or "dissipation zones", act as energy dissipators to control the resistance level in the structure. All other structural elements can be designed as non-ductile elements and are protected against actions that could generate failure, since the force they receive is greater than the one corresponding to the development of the maximum force that can be produced in potential plastic hinge regions. In other words, the non-ductile elements, resistant to actions from plastic hinges, must be designed to provide resistance based on overstrength rather than the weighted resistance indicated in the Code, the latter being used to determine the forces required in the hinge zones. This "capacity" design procedure allows to ensure that the selected means of energy dissipation can be maintained. The main steps of the capacity-based design procedure for wood structures are presented in Subsection 4.3.3.5 of TWBG.

The capacity-based design concept is of major importance in the seismic design of tall wood buildings.

It is appropriate to note that capacity-based design is not an analytical technique, but a design tool. It allows the designer to "tell the structure what to do" and desensitize it to the earthquake's characteristics which are, after all, unknown. Subsequently, careful detailing of all potential plastic zones will allow the structure to meet the designer's objectives. A capacity design approach can ensure a more predictable and satisfactory inelastic response under conditions in which even sophisticated dynamic analysis techniques can produce nothing more than gross estimates. This relates to the fact that a structure designed according to capacity should not develop undesirable hinge mechanisms or inelastic deformation modes, and would therefore not be sensitive to earthquake characteristics related to the magnitude of inelastic deformations. Capacity design, when combined with appropriate ductility detailing, makes it possible to produce maximum energy dissipation through rationally selected plastic mechanisms. Furthermore, as previously noted, structures designed in this manner will be extremely tolerant to the scope of ductility requirements that could be imposed by future major earthquakes. Moreover, further information on tests and analytical data related to various wood connections and useful in the implementation of a capacity design procedure for tall wood buildings is provided in Section 4.2 of TWBG.

Plans and specifications

In addition to requirements listed in the Code regarding technical drawings (see Subsection 2.2.4 of Division C of the Code), structural design documents for a wood building exceeding 6 storeys must include the information outlined below.

Gravity load resistance systems

The following elements, at the very least, must be included in the structural drawings:

a) General parameters: complete illustration of the distribution of gravity loads, i.e. live loads due to occupancy (uniform and concentrated distributions) and permanent (dead) loads. Reference plans showing the loads involved may be required to provide an adequate description of load distribution on the floors. Regarding the roofs, it is necessary to include snow load diagrams illustrating, among others, accumulation, slopes and valleys.

b) Specifications and standards for the elements of *mass timber constructions*: *glued-laminated timber*, *cross-laminated timber*, engineered wood products (standardized or proprietary), products for treating materials, reinforcing materials, steel fasteners, anchor bolts and other hardware or materials used in the building's construction

c) The dimensions of the beams and slabs as well as the characteristics of the connections and related supporting elements, such as nailing/screwing patterns, (types, lengths, minimum penetration, spacing, etc.)

d) Shear flows around openings and at the junction of the seismic force-resisting systems (SFRS)

e) Wall elements and columns, including details of their support

f) Floor-to-floor connection details related to the gravity loads

g) Details of the connections of loadbearing elements to the concrete foundations.

Lateral force-resisting systems (wind and seismic)

The following elements, at the very least, must be included in the structural drawings:

a) General parameters: complete illustration of the lateral load distribution, i.e. wind data (including diagrams), seismic data, site characteristics, risk category, type of SFRS, SFRS ductility-related force modification (R_d) and overstrength force modification coefficients (R_o)

b) Building's intrinsic characteristics: the design period of the building, in each direction, for seismic loads and deformation design

c) The lateral seismic design force acting on the base of the structure and the storeys in both directions

d) The building's horizontal deflection forecasts due to wind and seismic loads

e) Details of the lateral force resistance systems, regardless of the gravity load design

f) Elevations of the lateral resistance systems, shear transfer details, nailing/screwing patterns (types, lengths, minimum penetration, spacing, etc.), and the openings

g) Specifications and standards relating to *mass timber construction* elements: *glued-laminated timber*, *cross-laminated timber*, engineered wood products (standardized or proprietary), products for treating materials, reinforcing materials, steel fasteners, anchor bolts and other hardware or materials used in the building's construction

h) The general layout and details of the anchoring devices (including shrinkage compensation devices, if applicable), and their location on the plan

i) The location of anchoring devices on the concrete foundations' structural plans, including any additional reinforcements

j) Details of the diaphragms, transfer elements, and members

k) Nailing/screwing patterns (types, lengths, minimum penetration, spacing, etc.) and the blocking (furrings) of floor and roof diaphragms

l) Distribution of stresses in the diaphragms, openings and junction of the loadbearing walls

m) Details of the lateral shear through the floors.

Additional details to be included in the drawings

At the design stage, the following elements must also be examined and included in the structural drawings:

a) Construction tolerances

b) Total anticipated shrinkage, after shrinkage for each storey

c) Anticipated shrinkage values of all structural materials to be used as well as all other wood materials that could have an impact on the vertical deformation of the building resulting from shrinkage of the wood elements. An estimate of the potential vertical deformation must be included to ensure the construction of non-bearing elements using the appropriate methods; for example, these elements could be expansion joints in the plumbing stacks (the materials must allow a degree of movement)

d) Standardized shrinkage characteristics of the wood used in the construction of the project (design assumptions: shrinkage factor, initial and final moisture content)

e) Any notch that is, or can be made in the structural elements of the floor, roof and wall.

2.10. Safety and Fire Protection during Construction

Building safety and fire protection requirements dictated by the Code and this document refer to fully functional passive and active protection measures. Passive protection essentially includes fire-resistance concepts (compartmentalization and structural capacity), while active protection consists in providing fire protection from an automatic fire detection or suppression system (such as sprinklers).

During a building's construction, however, these active and passive protection measures are not necessarily in place or operational. Therefore, should a fire occur during construction, it can grow and spread must faster than in a building adequately compartmentalized using fire separations, firewalls and functioning sprinklers.

At the project's planning stage, it is essential to consult the fire department on regulations in effect on the territory during the building's construction. Additional provisions, including the development of a fire safety plan, the number of portable extinguishers required on the site, and access for vehicles, could also be required. In addition, the fire department may apply Section 5.6 of the National Fire Code of Canada 2010, which contains fire safety requirements during the construction of a building.

It is essential to consult the fire department on regulations in effect during construction. Additional provisions could be required. It is also essential to provide a risk management and control program on the site.

In addition to the guidelines set forth in this document, it is essential to provide, on site, a risk management and control program implemented by a superintendent well informed of the requirements from the fire department and insurance companies. This program should address the following aspects, without necessarily being limited to them:

- Portable heaters
- Prohibiting or limiting the use of propane heating during the project, to ensure it does not represent a fire hazard
- Job site security (security guard, patrol service, surveillance cameras, etc.)
- Hot work (welding, cutting, hot roofing, tarring, etc.)
- Safe storage of combustible materials and fuels
- Management of waste and debris (daily pick-up, no burning on site, etc.)
- Installation and inspection of electrical work.

Ensuring that the site complies with the standards of the Commission de la sécurité et de la santé du travail (CSST – Occupational Health and Safety Board) is also recommended.

Finally, the prefabrication of wall and floor assemblies should be privileged from the beginning of the project, since prefabrication of the elements considerably reduces construction time. Furthermore, installing gypsum board panels in the plant further reduces the probability of fire on the job site.

The prefabrication of wall and floor assemblies should be privileged.

More detailed information on safety and fire protection measures during construction can be found in TWBG, Section 5.13, the National Fire Code of Canada 2010, NFPA 241 and a number of other reference handbooks from the Canadian Wood Council.

2.11. Administrative Directives

It is important for future owners or co-owners to be well informed on the particularities of *mass timber construction*, as they relate, among others, to the importance of conserving gypsum panels to ensure the *encapsulation* of the wood structural elements. For this reason, future owners must be provided with a maintenance program.

The owner or co-owner must obtain, from the architect or engineer who designed the project and is responsible for overseeing the work, an attestation certifying that the guidelines set out in this document have been respected.

The RBQ considers the attestation delivered to the owner or co-owner to be an equivalent measure that will serve to determine which projects have been designed in compliance with the criteria set forth in this guide. Since this attestation will be linked to the building throughout its service life, it is important that it be kept on the premises for consultation.

Part 3. Work Team and Coordination

Coordinating every aspect of design and construction that could impact the integrity of the building is crucial. Holding a kickoff meeting between the professionals and the contractor is essential for clearing up certain elements relating to the production of the technical drawings. Issues to be addressed at this meeting include interactions among the various trades, the matter of drill holes and notches in structural elements when permitted, and relevant questions concerning dimensional shrinkage. Stakeholders representing the building's mechanical trades (including electricity and plumbing) must also attend this meeting. It is important for the team to be clearly advised, among others, that cutting structural elements to facilitate the passage of technical installations and equipment is strictly prohibited without the approval of the structural engineer responsible for the project.

It is essential to hold a kickoff meeting between the professionals and the contractor.

Furthermore, the shrinkage of wood materials used in the building's structure calls for coordination among all members of the design team, given that shrinkage not only has an impact on the structure, but on vertical services, sprinkler systems and the enclosure, for example.

To mitigate the risk of shrinkage, swelling or subsidence and their harmful effects on the design of tall wood buildings, the following practices must be privileged by the team:

a) Reducing the initial moisture content (MC) of wood and wood products will allow a significant reduction of the number of vertical movements that can occur.

b) It is highly important to protect wood and wood products from water sources as much as possible during the building's construction and service life. Outdoor storage of wood products on the construction site should be limited. Materials should be delivered just in time for installation to avoid potential wetting. All products should be delivered packaged. Measures should be taken in advance to minimize wetting on the site. Wood-based composite and engineered wood products generally require more attention during storage and handling, since most are produced under very low MC conditions with greater exposure of end-grain fibres and other surfaces, and more spaces created during manufacturing. Therefore, these products may be more sensitive to moisture absorption during wetting incidents than traditional lumber. A construction site protected against poor weather conditions is recommended.

It is highly important to protect wood and wood products from water sources as much as possible during the building's construction and service life.

c) An appropriate construction sequence also plays an important role in reducing wetting, shrinkage and other moisture-related problems. Swelling caused by moisture resulting from construction activities, such as the pouring of a concrete covering, should be taken into consideration; this type of activity should be completed during the first stages of construction. The use of prefabricated and dried wood-based elements or concrete elements is recommended. Chapter 7 of TWBG provides additional information on prefabrication.

d) Wood products can dry naturally under protected conditions, in well-ventilated environments where the relative humidity is not too high. Enough time must be provided for drying. In the event that wood elements have been exposed to rain during transportation or construction, the walls and roofs must not be closed until the structural materials have had time to dry to an acceptable moisture level. Under cold and wet conditions, the use of heating can dry wood efficiently and improve construction efficiency. Rigid components (technical equipment, pipes, elevator shafts, cladding) should be installed as late as possible during construction to minimize damage related to future settling of the wood structure.

e) In addition to shrinkage, the team must take other causes of vertical movement in wood structures into account in the building's design. These include vertical load effects (deformation caused by compression loads, including instant elastic deformation and creep) and the effects of closing spaces between elements (settlement).

f) Differential shrinkage between different types of wood products and between wood and other materials, such as steel and concrete, must also be taken into account. For example, this type of shrinkage occurs where the wood structural elements are connected to rigid components made of other materials, such as masonry (cladding), concrete (elevator shafts), mechanical elements and plumbing, and where wood products such as lumber, mass timber and engineered wood products are used. For steel components in assemblies, oblong holes that allow the movement of dowels and eliminate direct contact between concrete, masonry and wood-based elements, are among the preferred design details.

Differential shrinkage between different types of wood products and between wood and other materials, such as steel and concrete, must be taken into account.

Part 4. Building Maintenance

The Safety Code requires an owner to maintain his building "*in safe and proper working condition*" (Québec Safety Code, Chapter VIII – Building, and National Fire Code of Canada 2010 [amended], s. 345).

The maintenance program must be adapted to the special needs of each building. Moreover, the owner must be well informed of his maintenance obligations over the short and long term, depending on the building's type of construction of his building. The designer is required to provide future owners with a maintenance register.

For additional information, see Chapter 9 of TWBG, Monitoring & Maintenance.

Part 5. Other Laws and Regulations Applicable to the Project

If all requirements stipulated in this document's guidelines are respected, there is no need to submit a request for equivalent measures to the RBQ as the building is then presumed to comply with the regulations. However, this does not exempt professionals and builders from their obligation to comply with all applicable regulatory provisions. The applicant must also obtain any other authorization(s) required by any law or regulation.

The RBQ may, at any time, require that plans, work monitoring reports and attestations be submitted for verification and control purposes.

Once the Building chapter of the Construction Code allows buildings of *mass timber construction* exceeding 6 storeys, these guidelines will no longer be valid.

If all requirements stipulated in this document's guidelines are respected, there is no need to submit a request for equivalent measures to the RBQ as the building is then presumed to comply with the regulations.

Once the Building chapter of the Construction Code allows buildings of *mass timber construction* exceeding 6 storeys, these guidelines will no longer be valid.

Conclusion

Developed for designers and builders, this guide sets out the conditions established by the RBQ under Article 127 of the Building Act to approve the use of wood as a structural material, which differs from the provisions of the Québec Construction Code, Chapter I – Building (NBC 2010 amended). A building designed and constructed in accordance with the conditions established by the RBQ and taking into account the technical specifications described in this guide is presumed to comply with the standards set forth in the Code and deemed to ensure public safety.

This guide, it may be recalled, addresses three types of construction:

- Mass timber, *structural composite lumber* and *glued-laminated timber* (*glulam*) post-&-beam structural systems
- *Cross-laminated timber* (CLT) structural system
- *Hybrid* (wood, steel and/or concrete) structural system
- as well as a combination of these.

The RBQ distributes this guide, developed in collaboration with the mandated experts of the FPInnovations Research Centre. This document is based on the 2010 edition of the Code and related standards, as well as the *Technical Guide for the Design and Construction of Tall Wood Buildings in Canada* (TWBG), published by FPInnovations in 2014. The RBQ and FPInnovations wish to thank all authors and revisers who contributed to the writing of the TWBG.

This guide is also based on the tall wood building demonstration project located in Quebec City. This was one of three projects selected further to a call for tall building projects issued in 2013 by Natural Resources Canada and the Canadian Wood Council. Minimum conditions set out in this guide are based on the results of tests conducted at the National Research Council Canada (NRC), which recently confirmed the performance levels of this type of construction.

Finally, in May 2013, the Government of Québec published the Wood Charter, thus announcing that the RBQ would facilitate and permit the construction of wood buildings, as is done elsewhere in the world. The distribution of this guide is therefore consistent with the Government's intention to allow an equitable use of wood in construction in Québec, while meeting the safety requirements spelled out in the Code.

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List of Figures

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