The Canadian Guide to Mid-Rise Wood Construction

CWC Publications

Who We Are

ABOUT THE CANADIAN WOOD COUNCIL

Founded in 1959, the Canadian Wood Council (CWC) is Canada's unifying voice for the wood products industry. As a national federation of associations, our 13 members represent hundreds of manufacturers across the country.

For over 60 years, we have supported our members by accelerating market demand for wood products and championed responsible leadership through excellence in codes, standards, and regulations. We also deliver technical knowledge for the construction sector through our market leading Wood *WORKS!* initiative.

WOOD *WORKS!*

Wood *WORKS!* is a national initiative by the CWC advocating for the adoption of wood in the building and construction sector. With the goal of transforming markets and promoting holistic built environments, this industry-led initiative enables innovative systems integration, strategic market outreach, and supports the sector through training, best practices, research, networking and direct technical support.

OUR COMMITMENT TO SUSTAINABILITY

At the Canadian Wood Council, we recognize that wood is the only renewable material in the construction sector. It is our obligation and privilege to work with our partners to conserve our Boreal Forests and identify regenerative resource management practices, while continuing to deliver quality and essential products. We are also committed to reducing our emissions output through investigative supply chain management.

ASK CWC

We provide support across Canada for your questions on using structural wood in your designs. Connect with us at helpdesk@cwc.ca or (613) 747-5544 for information on your local Wood *WORKS*! chapter and representative.

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The Canadian Wood Council acknowledges that our head office in Ottawa is located on unceded Algonquin Anishinabe territory. It honours the peoples and land of the Algonquin Anishinabe Nation and all First Nations, Inuit, and Métis peoples.

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cecobois
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sur la construction
commerciale en bois

wood *WORKS!*
A Canadian Wood Council Program

The Canadian Guide to Mid-Rise Wood Construction

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It is intended that this guide is to be used in conjunction with competent engineering design. The authors, Studio Veronica Madonna Architect, Steven Street Mass Timber Consulting, Ontario Wood *WORKS!*, the Canadian Wood Council, Fed Nor, NRCan and their contractors make no warranty, expressed or implied, or assume any legal liability or responsibility for the use, application of and/or reference to the information included in this publication and/or omissions in this work, or for any engineering designs, plans, or construction prepared from it. Consult your local jurisdiction or design professional to assure compliance with code, construction, and performance requirements. This guide does not exempt applicants from obtaining any other authorization(s) required by any law or regulation, as the case may be.

Introduction to the Mid-Rise Guide

The Mid-Rise project and the ensuing publication were conceived in order to provide a guide for opportunities that have been created by Canadian Code Provisions progressing, allowing 6 storey wood buildings over at least a decade.

The foundation for some of the ideas contained within, came from the Wood *WORKS!* program hosting regional focus groups, made up of key industry stakeholders. They were held at various locations across Canada during 2019. From the focus-group conversations and the research gathered and analyzed, it was evident that each province was at varying degrees of adoption, understanding and application for wood buildings up to 6 storeys. The opportunities that are available for wood use in mid-rise development are varied and many and it is hoped that some of the illustrations and information contained inside this guide will continue to inspire the design and construction industry.

The Code Matrix captures the variations of code provisions currently in use in each of the Canadian provinces, and highlights Part 3,4 and 5 requirements for wood buildings up to 6 storeys in height. Permissible building types, heights and areas, permitted mixed major occupancies, required fire resistance ratings and sprinkler provisions are illustrated.

The flow of the sections is laid out to mirror basic project planning steps that are generally undertaken by design teams. A keen understanding of what is allowed by code, creates the conversation around ideas for buildings and potential project opportunities. The location of a site, how it fits into local planning and zoning regulations, and a business case that makes it achievable, are all stages a design team navigates early with a client. Many factors drive the business case. Goals set early for greener and environmentally sustainable development, applications of sustainable materials having significantly lower embodied carbon, can be incorporated into design principles. Schedule often drives design and project efficiency, creating consideration into using prefabricated and modular wood structural systems.

Part 5 of the guide contains some technical considerations for 5- and 6- storey wood buildings is laid out to help designers better understand some of the practical considerations needed for the construction and design of mid-rise wood buildings. It is written for design professionals in the construction industry, and builders with the necessary skills to consider taller wood buildings.

This guide is illustrated to be relevant to all design and building professionals involved in building our future environments, including architects, engineers, the development community, material suppliers, manufacturers, building inspectors, municipal officials and planners, project managers, contractors, innovators, and the general public at large.

We hope that you will find this guide very useful and if you need any further technical support please contact one of our technical managers who would be pleased to help you with your project.

Sincerely,

Marianne Berube
Executive Director
ON Wood *WORKS!*/ Canadian Wood Council

1 Code Matrix See pdf attachments page 224

1.1 Group C, Residential Occupancy

1.2 Group D, Business and Personal Services Occupancy

2 Canadian Code Provisions for Mid-Rise Wood Buildings

2.1 Introduction

Wood has the ability to have a multifaceted impact involving social, economic, environmental, and cultural benefits. It is a valuable consideration in addressing the needs of more affordable housing, catalyzing an industry to produce new jobs and skillsets, and improving our overall efforts for climate stability. The ability to utilize wood construction for mid-rise buildings provides an opportunity to address all of these factors. As set out by current code requirements, the provisions allow for greater density, and mixed occupancies that benefit many parts of Canada.

The construction sector can offer considerable opportunities for reducing greenhouse gas emissions both in embodied and operational carbon. It is estimated that approximately 40% of the greenhouse gas emissions[1] are due to the building industry alone. On a global scale, embodied carbon constitutes 11% of the annual greenhouse gas emissions and equals 28% of the building sector emissions. On a building and construction scale, embodied carbon comprises over 90% of the total carbon output. As performance of buildings continue to improve over time, operational carbon is expected to reduce further. However, embodied carbon is trapped in place once the building is completed construction and once embodied, cannot be improved upon over time. This makes it an important consideration for the future impact of carbon.

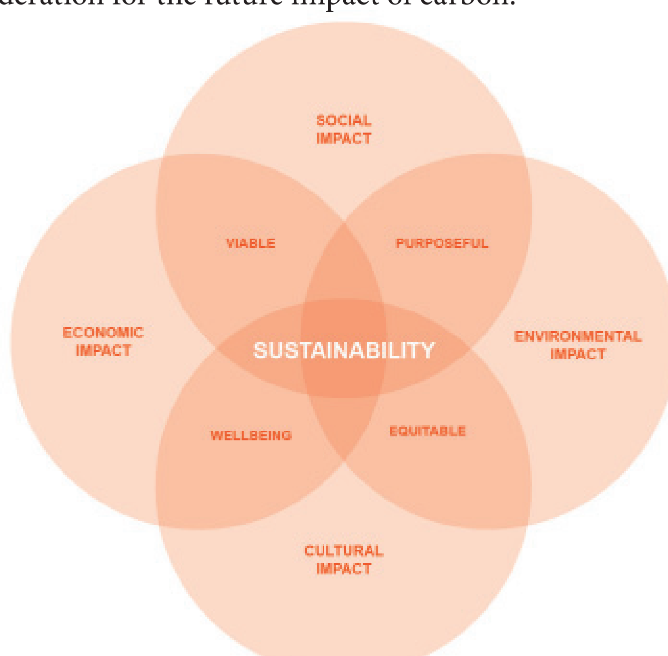


Figure 2.1: The multifaceted impact on social, economic and environmental benefits providing a holistic approach to sustainability.

1 (Architecture 2030, n.d.)

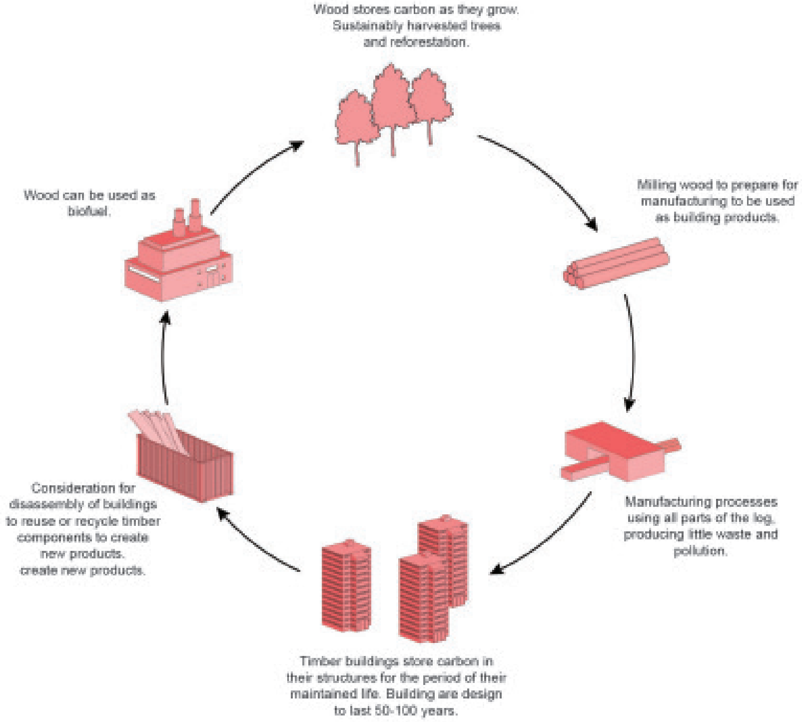


Figure 2.2: Lifecycle diagram of timber.

Wood is a renewable and naturally growing material that can sequester carbon from the earth's atmosphere. The manufacturing of wood products for construction produces lower carbon emissions from fossil sources than other building materials; therefore, offering a low embodied carbon solution. Prefabricated processes commonly used for products like mass timber create less waste and use less energy than traditional building materials. The potential for reducing on site construction is another factor that benefits the environment.

Considerations for embodied and operational carbon must be integrated into the design parameters at an early stage. To avoid negative impacts, sustainable forestry management must be practiced, and considerations must be made for end-of-life use of the material.

In addition to the environmental benefits, buildings made of wood have an environmental and economic impact. Building with wood offers new economic opportunities in Canada through the industrialization of engineered and prefabricated wood products. The industry has the potential to be a market leader in the delivery, knowledge and skills. Wood buildings can be constructed quickly to provide for rapid and affordable housing that is needed in many areas of the country, as well as the prospect of taller buildings for densifying urban centres.

Socially, wood can offer many benefits. In addition to providing affordable and durable housing, many rural communities rely on the forestry sector. Strengthening the wood industry can positively impact rural communities and reduce depopulation, unemployment, and poverty.

In considering the sustainability agenda of any product, wood moves beyond the triple bottom line and brings in the fourth element, which includes the cultural impact. Cultural impact goes beyond the three pillars and places importance on wellbeing and equitable impact of a community. Wood buildings provide a dignified approach to living with biophilic qualities aiding in the overall health and wellbeing of those who inhabit them.

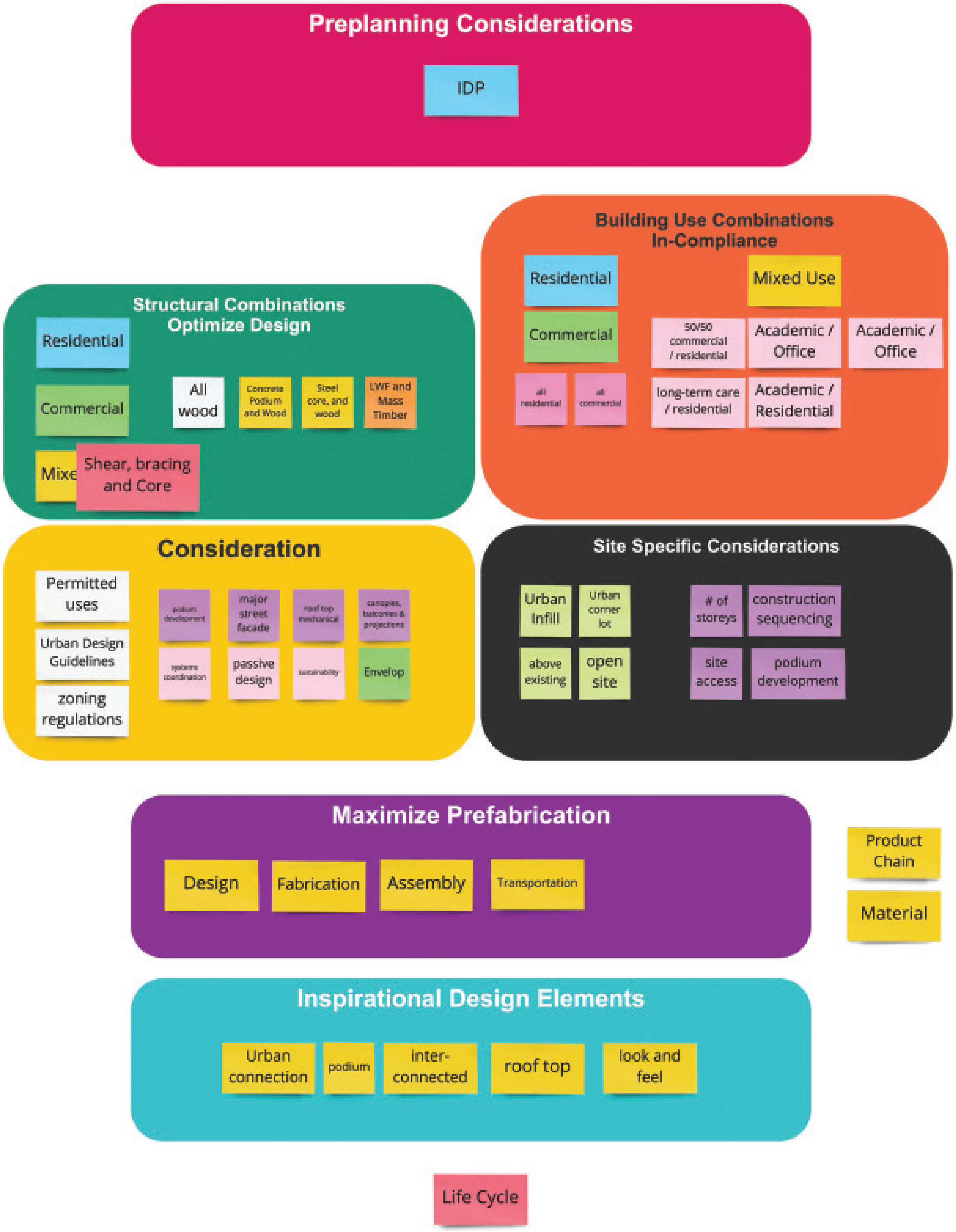


Figure 2.3: Mapping of key consideration of wood construction.

2.2 Early Considerations for Optimized Design

Designing with wood requires a different approach to the processes of planning, coordination, and construction. There are many potential advantages in developing with wood, including reducing construction time due to prefabrication, aesthetic, and environmental benefits. In designing a mid-rise wood building, many key considerations must occur early on in the planning and designing of a project to ensure optimizing design solutions for successful project delivery.

An essential part in the successful execution of a wood building includes integrated design and project delivery with various team members involved in critical decisions at the onset of a project. These early decisions are crucial when utilizing prefabrication and industrialized processes. In considering mass timber and lightweight wood-framing advancements in construction, the following key considerations will benefit the overall schedule and cost.

2.2.1 Integrated Design and Integrated Project Delivery

The importance of planning your project carefully cannot be overstressed. Thorough early planning with a design team and a qualified constructor, experienced and collaborative in nature, will deliver the project on schedule and budget.

Creating an integrated and collaborative team dynamic will enable the group to find creative solutions towards the project's success. This multidisciplinary team approach typically utilizes each other's strengths in working through the early design phase. Discuss procurement models – engage suppliers and the contractors early. This will enable developers and owners to have a clear understanding of target budgets.

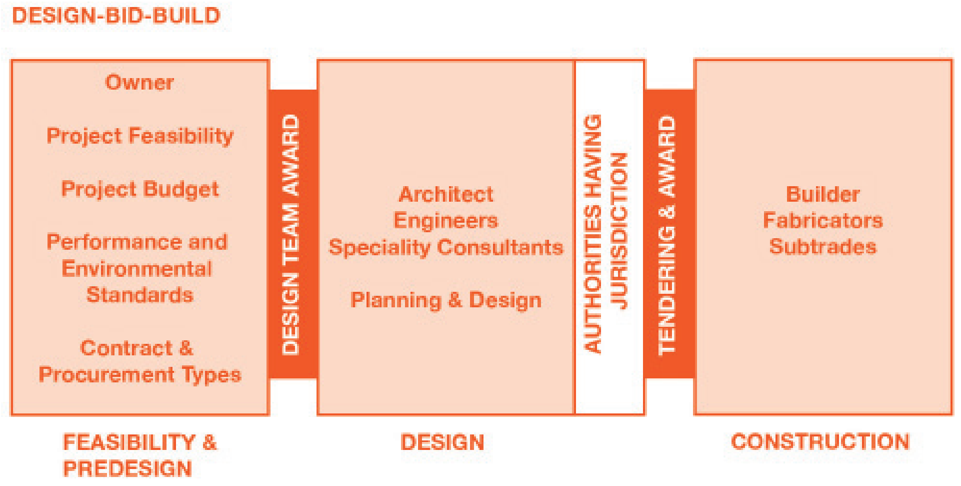


Figure 2.4: Traditional Design-Bid-Build procurement models offer little input from key experts during early stages critical in setting processes for optimizing design that can have a crucial impact on schedule and costs.

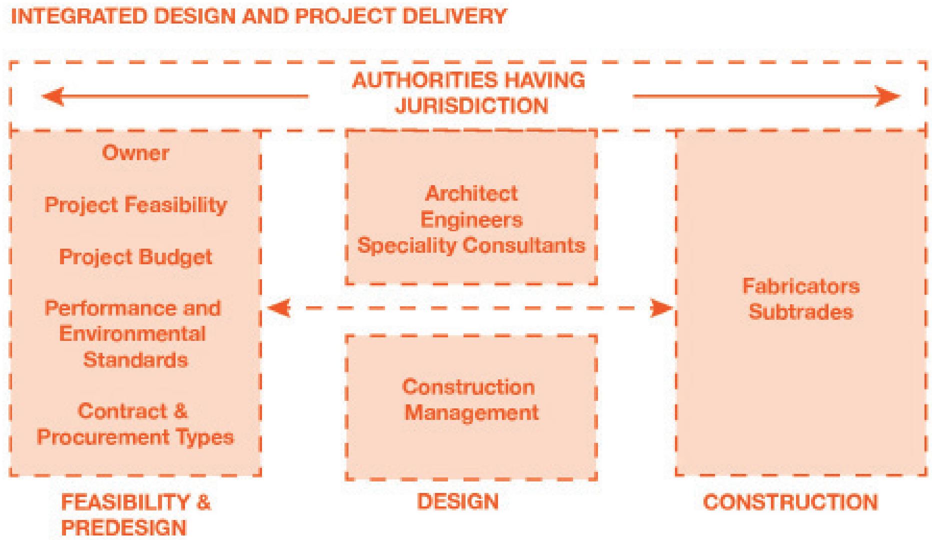


Figure 2.5: Integrated Design and Project Delivery methods allow for collaboration throughout critical times of the project. Ideally, the integrated design and construction team engage with the owner at the predesign and feasibility stage to inform overall project aspirations, methodology, schedule and costs.

The Integrated Design Process (IDP) is a multidisciplinary approach to building design that prioritizes a whole system approach. Implementing an IDP process is a critical step for achieving high-performance building design. The IDP process seeks to bring all key experts and stakeholders together to facilitate a collaborative design process. The best results are achieved when this process is implemented early on in a project and as early as the predesign stage. Ideally, the IDP process would involve the owner, architect, engineers, builders and manufacturers working together from the beginning.[2]

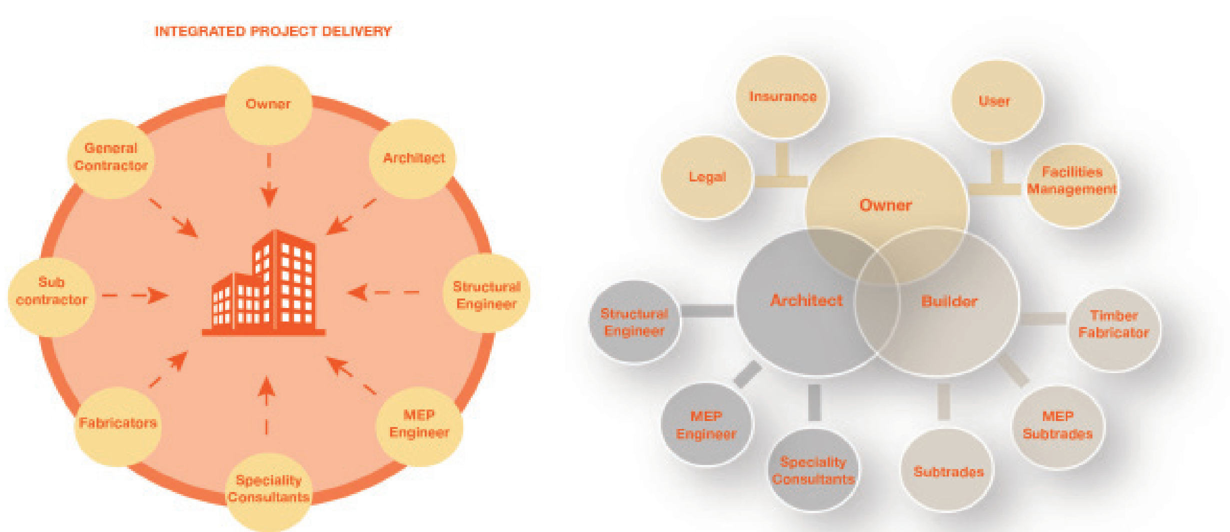


Figure 2.6: Integrated Project Delivery model and various parties involved in a building project.

2 (Busby Perkins + Will and Stantec Consulting, 2007)

Integrated Project Delivery (IPD) integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants. This delivery method can optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction.[3] The IPD process involves a multi-party contract where the Owner, Primary Designer and Primary Builder engage. The agreement includes profit at risk to partners of the agreement and shared savings if the project is delivered under budget.[4]

Conversations need to be started as early in the predesign process as possible to layout project delivery methods and models, structural systems that are being considered and key target dates in the construction process.

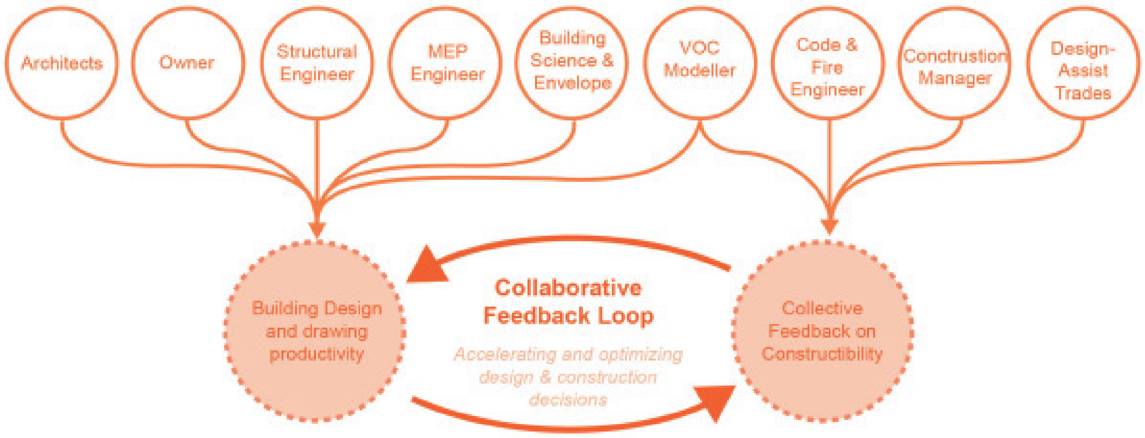


Figure 2.7: Work flow diagram of the collective feedback loop between the design and construction team. The benefits include accelerating and optimizing design and construction decisions. A similar model was used on the Brock Commons Tallwood House.

Image Source: Recreated from original by Laura Gilmore

3 (American Institute of Architects, 2007)
4 (Lean IPD, 2021)

2.2.2 Prefabrication Process

Increased industrialization and automation of the construction process have led to the increased productivity of modular construction. This increase in industrialization is shifting building activity away from the traditional on site building to off-site manufacturing. This is moving processes toward prefabricated and modular building components where it is then assembled on site.

There are varying degrees of modular construction, from kit-of-parts to three-dimensional volumetric units. The degree of modularity will depend on program requirements, site conditions, skills knowledge and manufacturer capabilities, to name a few. Developing a design that includes modular components requires a different framework for project development. Early adoption and commitment to modularity can lead to cost and schedule efficiencies and greater quality control.

As more knowledge and experience are gained in modular building products, it has been reported by McKinsey & Company that modular projects have consistently been completed 20- to 50-per-cent faster than traditional on site builds.[5]

In addition, modular construction can:

- Reduce overall build costs
- Accelerate build schedules
- Offer greater certainty on build times and costs
- Improve the quality of the building, including better energy and seismic performance

Buildings that include prefabricated systems require integrating design upfront in the planning process to ensure careful consideration of building use, site considerations, structure, systems integration, and construction sequencing. Sufficient time must be budgeted to allow extended planning time and enhanced coordination during the design and construction document stages. Many decisions must be made early on in the process, as prefabrication and detail planning are critical to be resolved before construction. This up-front planning investment can significantly reduce time during the construction phase, reduce on site time, and heighten overall quality control.

Mass timber components are mostly prefabricated off-site in a factory setting. Increasingly, lightweight wood-framing construction is also prefabricated off-site, lending greater efficiencies on site and hybrid capabilities.

5 (McKinsey & Company , 2019)

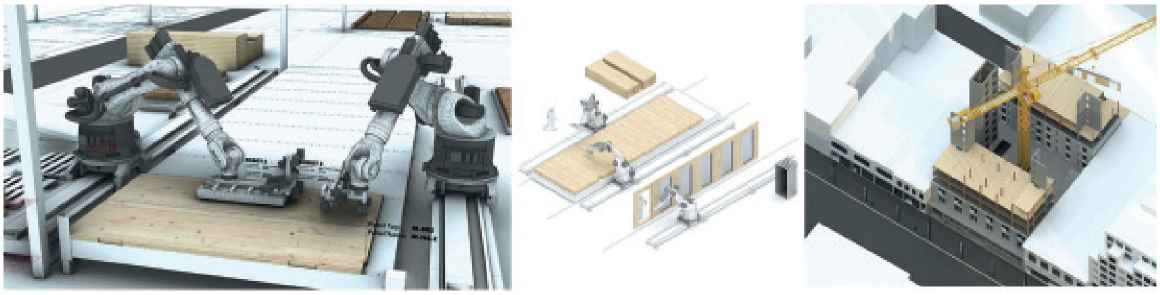


Figure 2.8: Intelligent City's software generates a detailed animation illustrating the construction process for a multi-unit building created through their system.

Source: Canadian Architect, April 1, 2020.

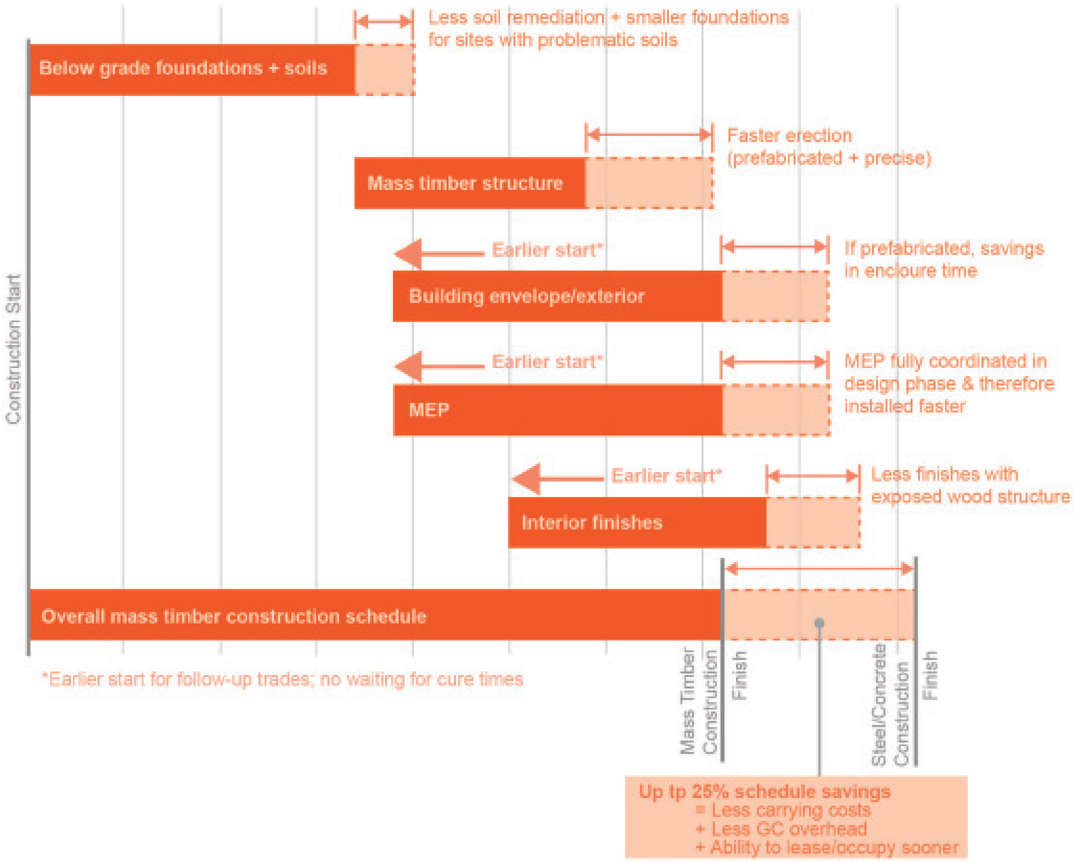


Figure 2.9: Compressing the Typical Construction Schedule with Mass Timber. Potential cost savings in comparison to steel and concrete.[6]

6 (*Wood WORKS!*, 2019)

2.2.3 Products and Supply Chain

Wood is a natural building product, and its material property can vary between species and supplier. Not only can this impact the aesthetic of the material and sizes, but product availability can also range between manufacturers. In the case of mass timber, it is essential to identify the source as early as possible to optimize and inform design opportunities.

Given that wood is a naturally harvested material, fluctuation in the supply chain can impact the availability and cost of the product. With increasing interest in wood construction, the supply chain will require adequate time and resources to develop further to meet the demand. Allowing for range and flexibility in the design to accommodate product variation from supplier to supplier can significantly impact a project's viability. To design for this level of flexibility, it is critical to do a thorough review of product and supply chain availability early on in the design process. As well, it is recommended that designers work closely with manufacturers early on to optimize solutions.

The production and fabrication of mass timber involves sophisticated presses and computer numerically controlled (CNC) machines. The use of CNC machines allows for more complicated and precise milling of wood. Each manufacturer may have specific requirements for machine capabilities, dimension and tolerances. This is another reason why early collaboration can significantly benefit design optimization.

Lightweight Wood-Framing

Lightweight wood-framing construction is made up of dimensional lumber and engineered wood products that are regularly spaced and fastened together with nails, forming the building's structure. Traditionally used in low-rise residential construction, lightweight wood-framing construction is now being used to construct a more diverse range of more extensive and taller buildings.

Mass Timber

Mass timber products consist of multiple solid wood panels nailed, glued or dowelled together, providing strength and stability in the section. It can be used as a load-bearing structure and as interior finishes.

Glulam consists of dimensional lumber pieces bonded together with adhesive. The grain of the laminations run parallel to each other, allowing for long spans and strength. Glulam is available in both standard and custom sizes with depths ranging from 6 inches to 72 inches and widths from 2.5 inches to 10.75 inches.

Common Use: Columns and Beams

Cross-Laminated Timber (CLT) panels consist of layers of dimensional lumber, usually 3, 5 or 7 lams thick, stacked crosswise at 90-degree angles and bonded with adhesive. The panel widths are typically restricted by manufacturer capability; however, the length can range and is often dictated by transportation restrictions. CLT is becoming widely used due to its strength, dimensional stability and rigidity. Although available in custom sizes, efficiency and cost-effectiveness can be achieved by designing standard and modular sizes.

Common Use: Wall and Floor Panels

Nail Laminated Timber (NLT) is a traditional method of decking that can be seen in many turn-of-the-century post-and-beam heavy timber buildings. NLT consists of dimensional lumber placed on edge with individual pieces mechanically fastened together by nails or screws. Boards are nominally 2x, 3x and 4x thick, and widths range from 4 to 12 inches. NLT does not require a dedicated manufacturing facility and can be fabricated with readily available dimensional lumber.

Common Use: Floor Deck

Dowel Laminated Timber (DLT) is similar to NLT, except it is fastened together using wood dowels rather than metal screws or nails. DLT consists of dimensional lumber placed on edge and friction-fitted together using hardwood dowels. DLT is an all-wood mass-timber product with no metal or adhesives. With advancements in CNC machinery in wood manufacturing, DLT is becoming increasingly desirable.

Common Use: Floor Deck

Mass Plywood Panel (MPP) is a veneer-based engineered panel comprised of multiple veneers pressed and adhered together in a staggered alternating grain direction for the most efficient orientations. MPP is an alternative to CLT, concrete and steel. These panels are lightweight and efficient use of material; however, they use a significant amount of glue in production.

Common Use: Wall and Floor Panels

Structural Composite Lumber (SCL), which includes Laminated Veneer Lumber (LVL), Parallel Strand Lumber (PSL), Laminated Strand Lumber (LSL) And Oriented Strand Lumber (OSL), is a family of engineered wood products created by layering dried and graded wood veneers, strands or flakes with moisture-resistant adhesive into blocks of material known as billets, which are subsequently re-sawn into specified sizes. In SCL billets, the grain of each layer of veneer or flakes runs primarily in the same direction. The resulting products out-perform conventional lumber when either face- or edge-loaded. SCL is a solid, highly predictable, and uniform engineered wood product that is sawn to consistent sizes and is virtually free from warping and splitting. Typical sizing ranges from 3/4”to 3-1/2” thick.[7]

Common Use: Rafters, Headers, Beams, Joist, Studs, Columns, and I-Joist Flange material

7 (APA – The Engineered Wood Association, n.d.)

Wood I-Joist

I-joists are strong, lightweight, "I" shaped engineered wood structural members that meet demanding performance standards. I-joists are comprised of top and bottom flanges, which resist bending, united with webs, which provide outstanding shear resistance. The flange material is typically laminated veneer lumber (LVL) or solid sawn lumber, and the web is made with plywood or OSB. The robust combination of structural characteristics results in a versatile, economical framing member that is easy to install in residential and light commercial projects.[8]

Each manufacturer produces I-joists with unique strength and stiffness characteristics. To ensure that proprietary products have been manufactured under a quality assurance program supervised by an independent third-party certification organization, manufacturers typically have their products evaluated and registered under the Canadian Construction Material Centre (CCMC).[9]

Common Depths include 9-1/2", 11-7/8", 14" and 16". Flange widths vary from 1-1/2" to 3-1/2".

Common Use: Floor and Roof Framing

Wood Open Web Joist and Truss is a lightweight system made that can offer longer span in floor and roof construction. Trusses perform a similar function to beams but offer more efficient use of materials and be much lighter than other systems for equivalent spans. They may be constructed from almost any combination of solid timber products: sawn timber, LVL or glulam.

There are various confi urations and construction types for wood joists and trusses, depending on span and use.

Trusses span longer distances and can reach spaces of 25m +.

The span to depth ratio is 12:1 for parallel chord.

Figure 2.10: Catalogue of common mass timber and lightweight wood-framing wood products.

8 (APA – The Engineered Wood Association, n.d.)
9 (Canadian Wood Council, 2021)

2.2.4 Factors in Selecting a Structural Form

Many factors are involved in selecting the buildings systems. In considering a structural system, the architect and engineer must consider many factors, including program, cost, market conditions, constructability, maintenance and long-term flexibility. In addition, height restrictions, site constraints, and building systems integration may play a significant role in deciding on the proper structural system for the project.

An architect or engineer should not make this decision alone. Early collaboration with engineers, contractors, owners, and cost consultants can ensure that the project's long-term objectives will be met.

Cost

- Cost of design
- Cost of materials
- Cost of transportation
- Cost of installation
- Cost of protection and maintenance

Schedule

- Shop drawings and approvals
- Materials acquisition
- Construction productivity

Function

- Clear span
- Program requirements and long-term fl xibility
- Depth of members and clear height
- Location of bearing walls and other supports
- Incorporation of mechanical and electrical systems
- Thermal insulation

Code Requirements

- Fire protection
- Sound transmission
- Structural capacity
- Durability

Aesthetics

- Appearance of material
- Appearance of finished system
- Architectural blend of form and function

Environmental

- Environmental impact of harvesting, mining, quarrying, and manufacturing
- Energy required to manufacture, transport, and install materials
- Thermal efficiency of building systems
- Disposal, recycle or reuse at end-of-life cycle

Figure 2.11: Factors in selecting of structural form.

Source: Canadian Wood Council Introduction to Wood Design, 2018.

Significant planning goes into designing any type of building. It must be acknowledged that interchanging structural systems, product types, and installation methods, once the design process is complete, can lead to complications during construction and performance issues later. In detailing the building, the interaction between materials is carefully considered when it comes to fire separations and designing for acoustic and building performance. Whether the construction utilizes mass timber or lightweight wood-framing construction, maintaining design integrity throughout the project's construction process can be critical in achieving the performance results required.

2.2.5 Systems Integration

Early Mechanical, Electrical, Plumbing and Fire (MEPF) system coordination can positively impact overall aesthetics, costs, and maintenance. On average, structural systems account for 20-25% of the total building costs and MEPF account for 30-35%[10]. In any project, diligent coordination of these systems can reduce undesired design outcomes and reduce extra costs during construction.

Early in the design process, engaging all members of the integrated design team in a systems workshop can avoid later coordination and interference issues. Earlier in the process, the team must review the structural and MEPF systems carefully to decide on the best approach to address the program, cost constraints, aesthetic and sustainable needs, just to name a few.

- Floor-to-floor heights
- Sustainability targets
- Program needs
- Fabrication, constructability and sequencing
- Future maintenance requirements

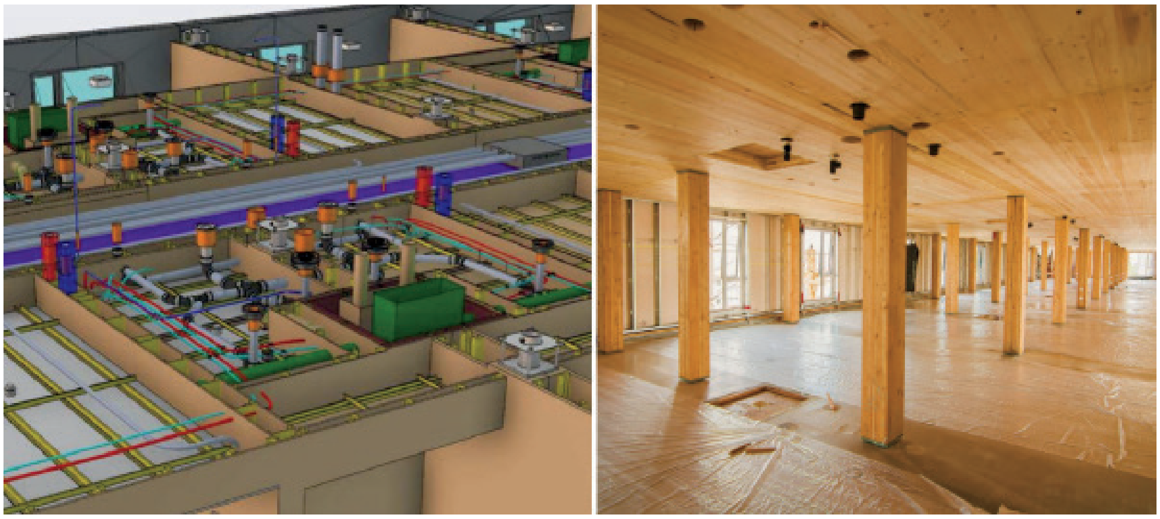


Figure 2.12: Right: Image by Cadmakers illustrating the level of detail involved in coordinating MEPF systems for fabrication. Left: Image of plumbing shelving and penetrations through CLT slab.

(Photo source: Structurlam Mass Timber Corporation).

10 (Anderson, Dawson, & Muszynski, 2021)

In mass timber buildings, there is often desire to expose the structure. Thoughtful exposure of service systems must be planned carefully. A strategy for placement of surface mounted conduit for plugs, switches, light fixtures and running of pipe and ductwork will be considered early as it will play a significant role in the overall aesthetic. Mass timber beams are often fairly deep; therefore, the route of any MEPF systems should be carefully considered to ensure the required head height is maintained.

Key considerations in MEPF coordination:

- Routing and mounting of electrical conduit for plugs, switches and lights.
- For smaller conduit, it may be possible to coordinate routing through mass timber members; however, the exact location and size must be carefully considered and designed for prior to fabrication.
- Overhead mechanical distribution, versus at floor, in a raised access floor system.
- Dropped ceiling versus exposed.
- Penetrations through structural members and floor systems.

Planning for off-site fabricated components can improve schedule and craftsmanship and reduce overall risk.[11] Involving MEPF subcontractors in the design stage can bring valuable insight into construction sequencing and installation. The use of sophisticated digital modelling programs, such as Building Information Modeling (BIM) and Virtual Design and Construction (VDC) modelling, can be an effective way to undergo this level of enhanced coordination.

This level of enhanced coordination is not typical in a traditional building project. Therefore, careful consideration must be given to the appropriate time required to perform this detailed level of design and coordination early in the design stages. This upfront planning and coordination can significantly reduce the construction schedule, extra costs and risks.

2.2.6 Fire Protection and Acoustic Strategy

Fire protection and acoustics are critical considerations in all buildings; however, both mass timber and lightweight wood-framing are strategies to consider to achieve optimal performance is a crucial consideration early in the project development. Maintaining fire protection and acoustics requires carefully considered details to ensure performance.

11 (Anderson, Dawson, & Muszynski, 2021)
12 (Tyree & Coats, 2020)

2.2.6.1 Fire Protection Strategies

Building codes require all buildings to perform to the same level of safety regardless of materials. Wood buildings can be designed to meet rigorous performance standards, which is why building codes are being modified to allow for design in wood.

When considering a fire protection strategy for any building, there are several key considerations, as listed below:

- Code requirements
- Passive fire protection strategies
- Active fire protection strategies
- Fire protection during construction

Passive fire protection is what resists a fire at its point of origin. Components and systems are intended to contain a fire or slow the spread of fires through fire-resistant building elements. The requirements for passive fire resistance strategies will be greatly dependent on the building's use and occupancy classification.[12]

- Fire-resistant rating of structure in floors
- Level of encapsulated material
- In the case of exposed mass timber, effective depth after fire and depth of char
- Fire rating of egress routes
- Fire separation requirements

Active fire protection is characterized by detection and response systems. Detection of fire through smoke or heat sensors initiates a chain reaction of events that reduces fire threat. Once a detection system is activated, a chain reaction of events will occur that may include:

- Fire dampers
- Closure of automatic doors
- Fire sprinklers activated
- Fire suppression system activated

Wood is defined as a combustible building material. Heavy timber and mass timber building components react differently when exposed to fire as compared to lightweight wood-framing

Encapsulation Mass Timber Construction (EMTC)

Encapsulation Mass Timber Construction (EMTC) refers to a construction type involving the encapsulation of the mass timber using an approved rated material, such as fire-rated gypsum board. EMTC assemblies have been tested, and incoming updates to the National Building Code are anticipated to be an acceptable method of fire protection for structures up to 12 storeys in height.

12 (Tyree & Coats, 2020)

Figure 2.13: Section detail of Brock Commons Tall House illustrating the encapsulation of the mass timber structure using fire-rated gypsum board to provide the required fire-resistance rating.
Source: Acton Ostry Architects.

Char

As timber burns, a layer of char begins to form, an insulating element that prevents an excess rise in temperature within the section.

Wood products such as the large beams used in heavy timber construction and cross-laminated timber may perform better in a fire situation than non-combustible materials. Because these products are thick and solid, they char on the outside at a slow and predictable rate while retaining strength, slowing combustion and allowing time to evacuate the building. The char protects the wood from further degradation, helping to maintain the building's structural integrity and reducing its fuel contribution to the fire, which lessens the fire's heat and flame propagation.[13]

13 (Tyree & Coats, 2020)

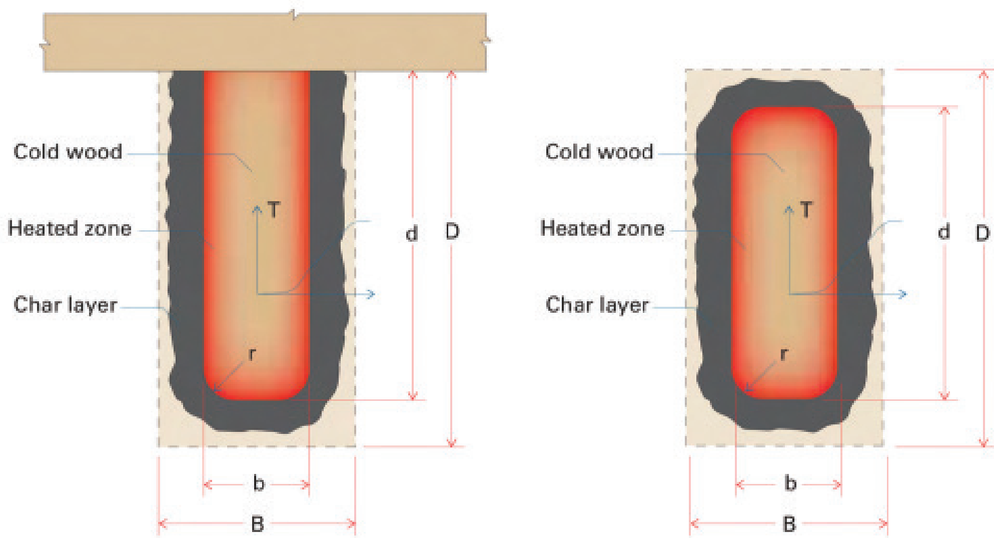


Figure 2.14: Illustration of a wood beam after the exposure to fire and the reduction of member breadth and depth over time for a mass timber section. To comply with fire safety requirements, the beam must have sufficient integrity to safely carry the structural loads after exposure to a specified duration and intensity of a fire.[14]

Fire Protection of Connections

In addition to fire-resistance rating requirements for structural wood members, connections between members must have sufficient protection to provide the same fire-resistance rating. Methods of protection include:

- Fire-rated gypsum board
- Concealed connections protected by the charring of the wood
- Other materials or methods approved by the Authorities Having Jurisdiction

2.2.6.2 Acoustic Strategy

Acoustics has a direct impact on the user experience of a building. It can impact mental health and wellbeing, in addition to maintaining privacy for the inhabitants. Acoustic control is a complex issue. Minimum requirements are prescribed by the building codes and are dependent on use; however, on site testing is an effective way to mitigate unwanted sounds in buildings. Detail execution on site can be a driving factor in failed acoustics, and quality control during construction is critical.

Due to the lightweight nature of wood, maintaining acoustic performance in either a mass timber or lightweight wood-framing must be considered carefully.

14 (American Wood Council, 2015)

In dealing with any building, there are two main acoustic concerns:

Sound Transmission Class (STC) is the airborne noise that can travel through partitions or around partitions, known as flanking.

Impact Insulation Class (IIC) is the noise that occurs through the impact on the structure that typically occurs through floors.

Because wood is a lightweight material, noise and acoustics are of particular concern as noise travels more easily through these systems. As a general rule, more mass means better noise control. Because it is lighter than concrete, lower frequency sounds transfer more easily through the wood. But that does not necessarily mean that a wood building will be noisy. With proper design, it can be as quiet as one built with concrete. This could mean incorporating a dropped ceiling below the wood structure or using a raised floor system to achieve satisfactory sound separation of floors and ceilings.[15]

There are three main ways to improve acoustic performance across an assembly:

1. Add mass
2. Add noise barriers
3. Add decouplers

Bare floor assemblies without any acoustical treatment are rarely used in wood buildings because of the inadequate acoustic control and the ability to control impact noise. Implementing acoustical mats and floor toppings provide mass that can greatly improve the conditions. Decoupling details to isolate and control flanking provide further sound performance.

Examples of Acoustically-Tested Mass Timber Panels

Mass Timber Panel	Thickness	STC Rating	IIC Rating
3-ply CLT wall[4]	3.07"	33	N/A
5-ply CLT wall[4]	6.875"	38	N/A
5-ply CLT wall[5]	5.1875"	39	22
5-ply CLT wall[4]	6.875"	41	25
7-ply CLT wall[4]	9.65"	44	30
2X4 NLT wall[6]	3-1/2" bare NLT 4-1/4" with 3/4" plywood	24 bare NLT 29 with 3/4" plywood	N/A
2X6 NLT wall[6]	5-1/2" bare NLT 6-1/4" with 3/4" plywood	22 bare NLT 31 with 3/4" plywood	N/A
2X6 NLT floor + 1/2" plywood[2]	6" with 1/2" plywood	34	33

Figure 15: Inventory of acoustically tested mass timber assemblies, provided by Wood *WORKS!*

15 (Preager, 2019)

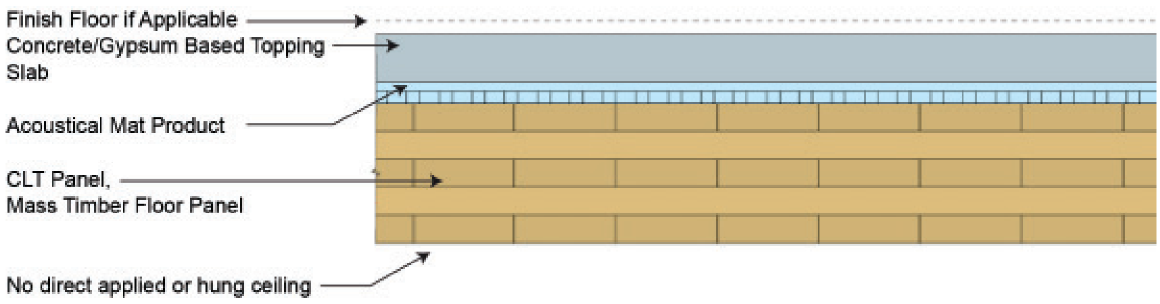


Figure 2.16: CLT floor assembly with concrete/gypsum topping, provided by Wood *WORKS!*

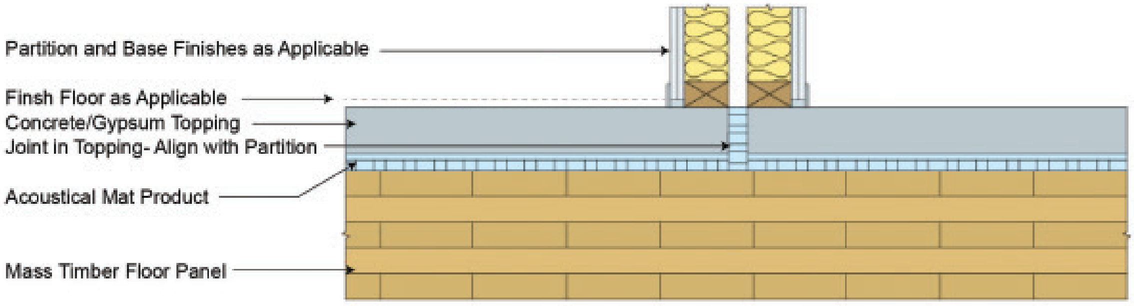


Figure 2.17: Flanking control detail at floor-wall interface.

Source: https://csengineermag.com/acoustics-and-mass-timber-room-to-room-noise-control/

2.2.7 Building Information Modeling (BIM) and Design for Manufacturing and Assembly (DfMA)

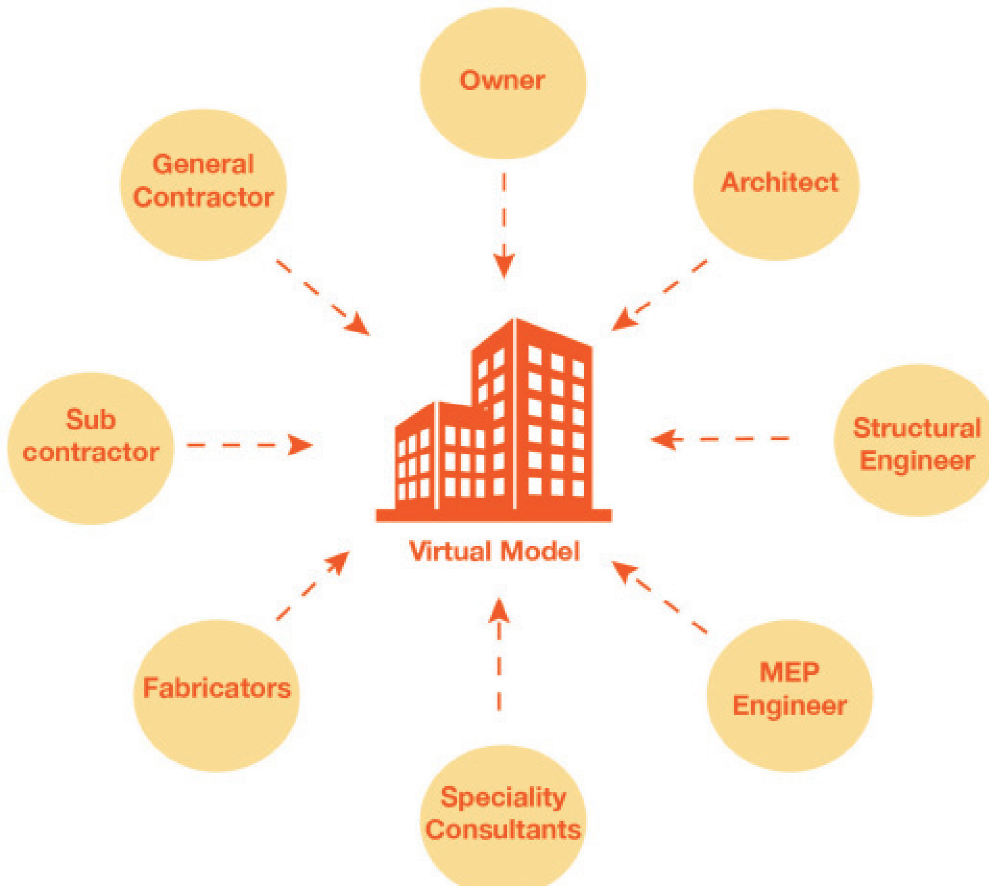


Figure 2.18: Integration of BIM amongst the owner, design and construction team.

The construction industry is increasingly adopting methods of automation and industrialization. With this, there is an increasing interest to fabricate building components off-site and growing interest in Design for Manufacturing and Assembly (DfMA) to suit modular construction. Off-site fabrication in a controlled environment can offer better quality control, reduce material waste, and potentially reduce time on site, lending to over-schedule and cost savings.

The production of engineered mass timber is a highly sophisticated process utilizing computer numerical control (CNC) equipment to precisely cut and shape the products. This precision in the construction process requires that all aspects interfacing with the mass timber structure must be fully coordinated ahead of manufacturing to avoid on site modification.

Building Information Modeling (BIM) is an intelligent 3D model-based process that gives architects and engineers, construction professionals a platform for data management and shared resources to enable efficient planning, design, construction and building management. The utilization of BIM in the development and fabrication of mass timber is critical.

Design for Manufacture and Assembly (DfMA) is a design approach that focuses on ease of manufacture and efficiency of assembly. By simplifying the design of a product it is possible to manufacture and assemble it more efficiently, in the minimum time and at a lower cost[16].

In DfMA processes, every aspect of the building is broken down into prefabricated building components like walls, columns, beams, stairs, and volumetric components, such as bathrooms. The intent is that each component's design is optimized for efficiency in manufacturing and assembly to ensure efficiency in material, cost, on site assembly, and durability. Below are the impacts that a DfMA process can have:

- Reduce cost
- Reduce schedule
- Improve site safety
- Reduce waste
- Reduce on site labour
- Higher productivity
- Improved environmental performance
- Higher quality
- Ease of reuse & deconstruction

The mass timber industry has extensively adopted the process of DfMA to enable modular and off-site construction. The use of sophisticated equipment and manufacturing processes is evolving the construction industry from on site construction to off-site, highly sophisticated, computerized manufacturing facilities.

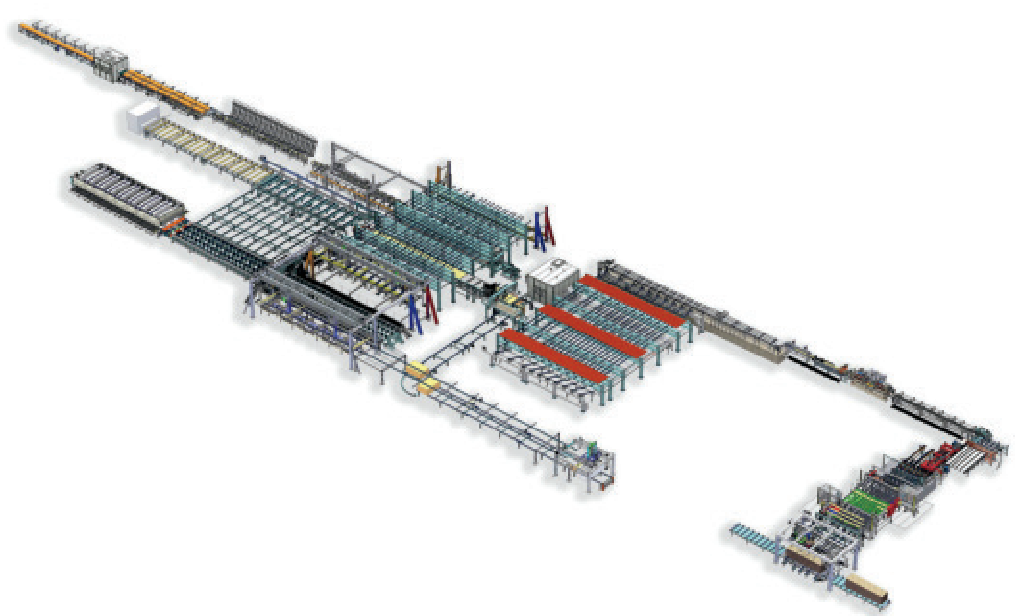


Figure 2.19: Layout of the new CLT line for Element5's new state-of-the-art mass timber facility in St. Thomas, Ontario.

Source: www.ledinek.com

16 (Design Buildings, 2020)

Figure 2.20: Image of an automated fabrication process of mass timber.

Source: Katerra.

BIM and Virtual Design and Construction (VDC) – an integrated process that contains intelligent information of a building design that aids in visualizing the construction site to optimize sequencing and schedule and DfMA processes. This can significantly reduce risk, on site change orders, allow thorough planning of safety procedures, and accelerate the construction schedule.

Figure 2.21: Brock Commons Tallwood House utilized various levels of Virtual Design and Construction Modelling throughout the design and construction process.

Source: wood-works.ca, Brock Commons Tallwood House: Construction Modeling.

2.3 Planning Considerations for Optimized Design

2.3.1 Predesign

During the predesign stage of a project, critical decisions are made regarding project procurement methods, project costs, schedule and high-level aspirations for the development. Engaging experts and consultants that can advise on the project's parameters again has tremendous benefit during the planning and execution stage.

Contractual Considerations and Assembling the Team

- Select a procurement method in the contract model that will allow integrated design activities between the design consultants, such as architects and engineers, with the builder, fabricators and subtrades.
- The design-bid-build approach will not offer input from manufacturers and builders. Other procurement types like construction management or integrated project delivery can provide the design-assist opportunities that can reduce cost and optimize design choices.
- Publicly funded projects that require competitive bidding processes may cause challenges in the early engagement of builders and manufacturers. Consider various procurement options such as construction management or integrated product delivery that can allow for a level of collaboration.
- Consider routes forward that involve reviewing structural and cost options at milestone stages to determine the best path forward

Costing Considerations

- Identifies site-related considerations such as staging and safe delivery methods that may impact the overall available buildable area and mass timber fabrication and installation requirements.

Design Goals

- Establish early processes such as building integration modelling and enhanced digital delivery that can benefit the project through design and construction.
- Establish overarching project and design goals through the development of a project charter to guide decision-making through the process of design.
- Outline project goals and value-adds.

Having early discussions with Authorities Having Jurisdiction can clarify parameters in terms of construction and design requirements and create a working relationship throughout the development of a project.

2.3.2 Design Phase

During both the schematic and design development phase of a project, set out important design goals. During the early stages of design, grid spacing, systems integration, product availability, fire, and acoustic strategies impact the overall building form and planning.

- Material optimization and repetition.
- Review with manufacturers for available sizes and consider a design solution that can accommodate multiple sources.
- Maximize modularity and panel sizes to minimize material waste that can impact the cost. Consider strategies for repetition to optimize material use and prefabricated methods and design.
- Consider the program requirements, site constraints, location of cranes and deliver strategies for prefabricated members.

MEP Systems

- Early consideration of mechanical, electrical, and plumbing systems can reduce coordination and interference later on in developing a design. Consider how the systems will be horizontally and vertically distributed to minimize interference with structure and penetrations through floor slabs. Develop strategies for delivering systems, whether that be overhead or in a raised floor system. This can impact structural coordination and overall clear height.
- Early engagement of side sub-trades and fabricators to provide design-assist services can provide valuable considerations that can positively impact efficient solutions to reduce cost and maintain the schedule.
- If exposure of wood in mass timber systems is desired, consider the distribution of electrical and sprinkler lines and how they will be incorporated. For example, surface mounted conduit may not be the desired look. Considering these details early on can have dramatic aesthetic value. There are possibilities to core in conduit into mass timber sections, carefully reviewing the structure and fire separation and rating integrity.

Structural System

- Review structural system opportunities, with the program and design objectives of the project in mind.
- Consider strategies for lateral systems and material of egress stairs and elevator shafts. Review with local authorities and provincial regulations the requirements for combustibility of exit stairs. Consider how the material of the core well impacts the sequencing of construction with wood. If materials such as concrete or steel are utilized in the core or lateral systems, develop strategies early on to consider construction sequencing and tolerances between materials.

Early Engagement with Authorities Having Jurisdiction

- Engage in early discussions with Authorities Having Jurisdiction (AHJ). In the case of mass timber, AHJs may be unfamiliar with specific mass timber systems. Early pre-application meetings can help set the expectation and overall goal for the permitting process.
- If there is a desire to go beyond the building code prescribed regulations, engage in early discussion with authorities having jurisdiction on requirements for alternative compliance solutions and any additional measures that may be implemented as a result. Also, review the process and schedule impact to determine any special conditions, such as peer review requirements during the process.

Fire and Acoustics

- Review strategies for maintaining fire separations and overall fire safety. Consider sprinklers, fire separation and fire-resistant ratings. Consider a detailed strategy for transitioning between exposed and concealed surfaces. In mass timber, overall member size may be impacted for exposed members to maintain appropriate structural integrity.
- Review strategies towards acoustic and vibration control. Additional elements such as the requirement for concrete toppings or specialty acoustic isolating mats may be required to achieve desired fire or acoustic performance.
- In lightweight wood-framing construction, consider how acoustics will be maintained between floor and demising walls. In both mass timber and lightweight wood-framing construction, consider how impact noise will be managed.

Finish Quality and Aesthetic Value

- Consider desired appearance, aesthetics and level of desired exposed wood surfaces. Review carefully with local regulations for combustibility as well as flame spread ratings.
- Consider moisture control measures during construction. In the case of mass timber and expectations for exposed finished surfaces, consider carefully moisture control and maintenance measures to reduce water staining that may require refinishing the surface to achieve the desired aesthetic.
- The aesthetic of wood will vary greatly depending on the location and type of species the manufacturer provides: review overall finish, colour tone, grade options, and finishing options.
- Review finishing options and application methods. For example, the benefits of in-shop versus on site finishing of the mass timber. Review manufacturing capabilities of in-shop finishing and its impact on costs.

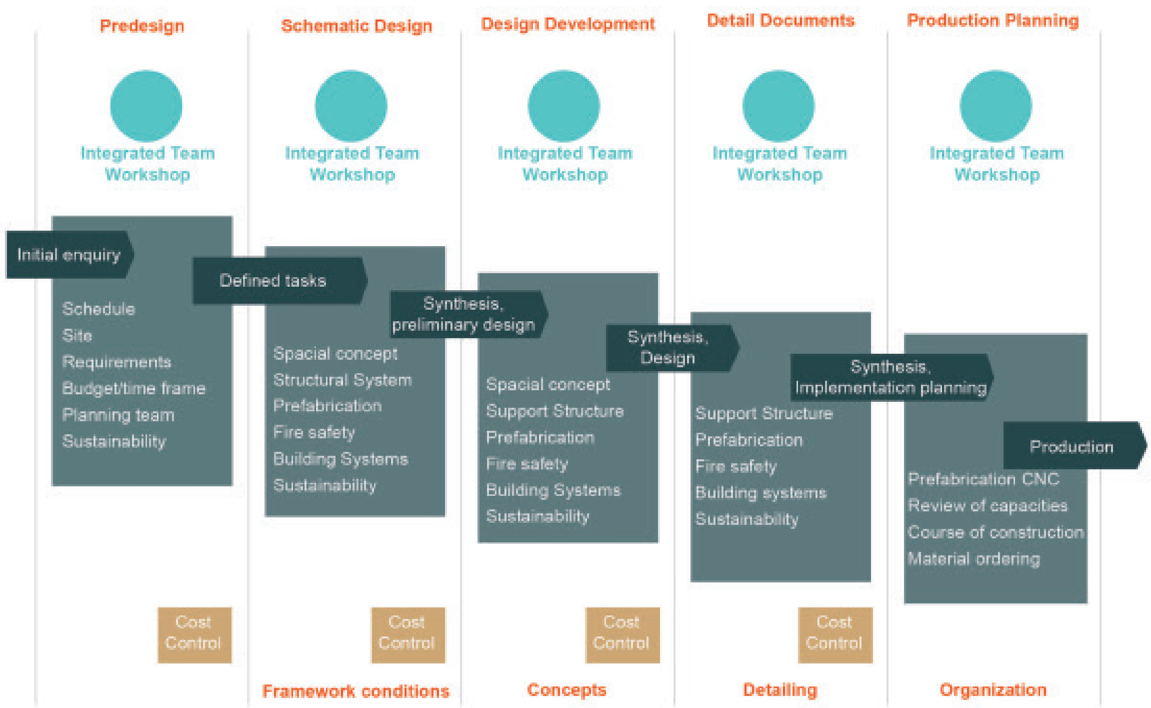
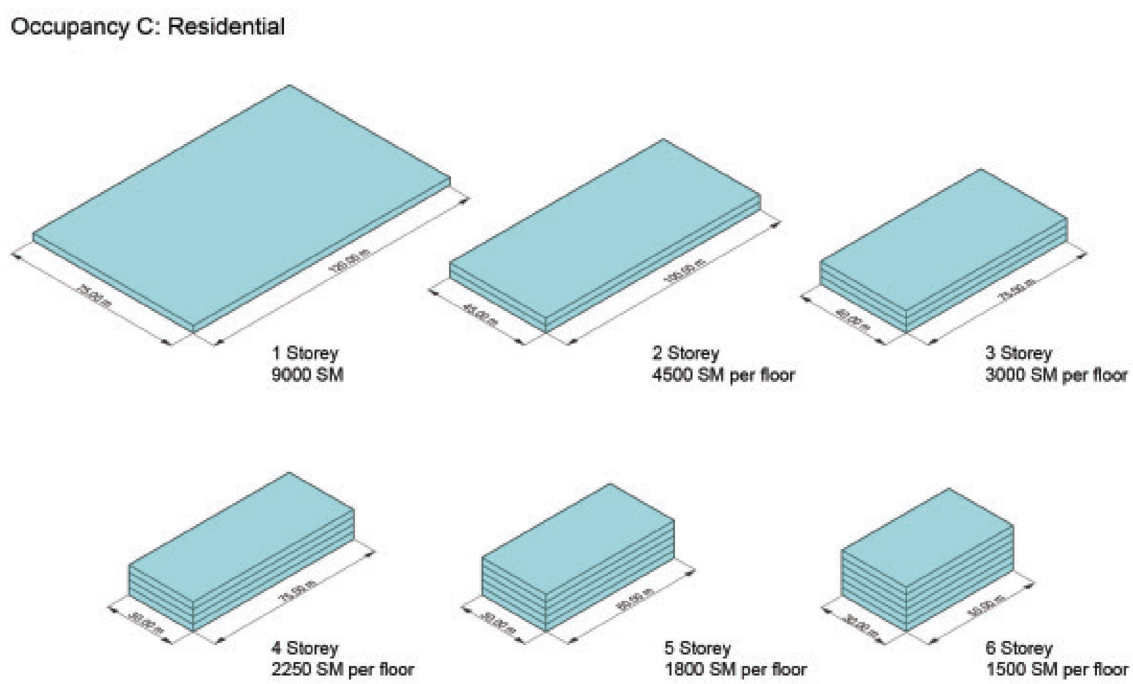


Figure 2.22: Planning and design process.

2.4 Canadian Code Provisions for Mid-Rise Wood Buildings



2.4.1 Permitted Area and Height Requirements

Figure 2.23: Group C: Residential Occupancy maximum building area per storey.

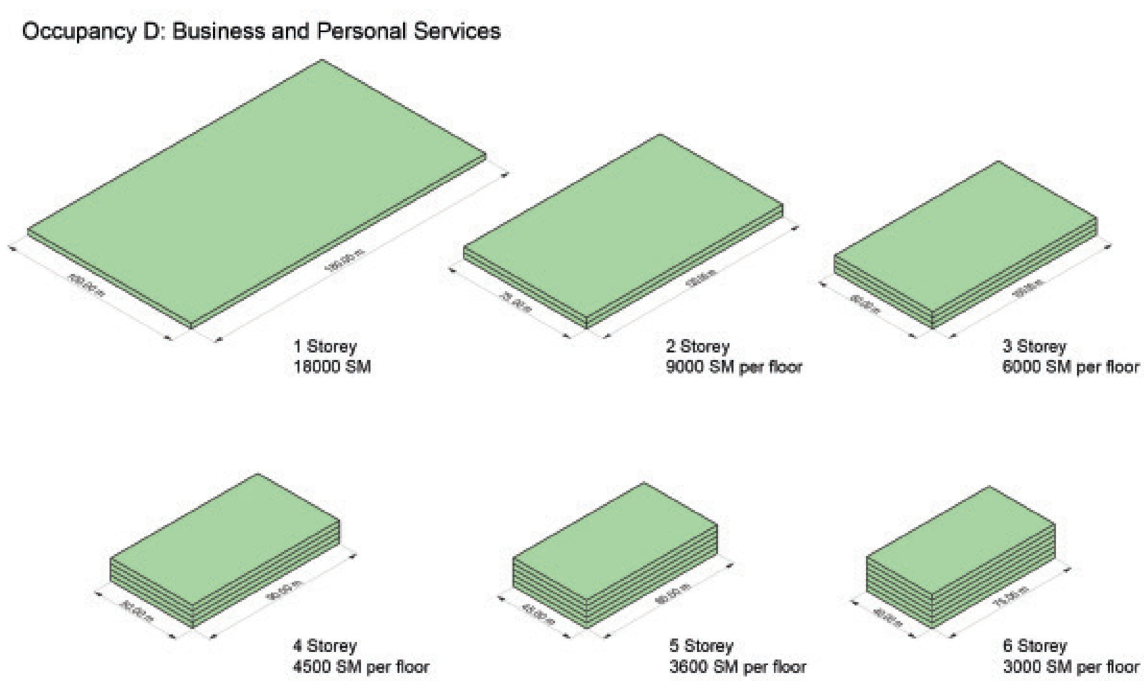


Figure 2.24: Group D: Business & Personal Service Occupancy maximum building area per storey.

Number of Floors and Physical Height Restrictions

6-storey maximum

18m from the floor of the first finished floor to the upper most floor level

25 m limit of total physical building height to peak of roof *

* Where the roof assembly has a height greater than 25 m measured from the floor of the first storey to the highest point of the roof assembly, the roof assembly shall be constructed of noncombustible construction or fire-retardant-treated wood

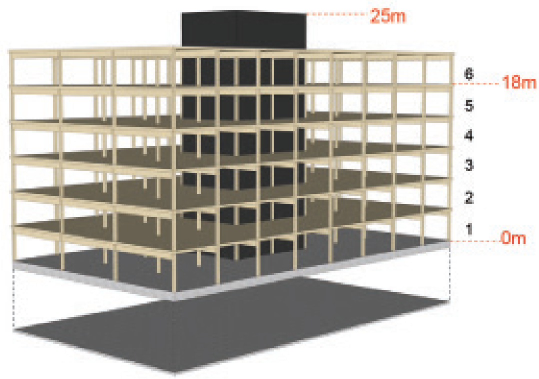


Figure 2.25: Requirement for number of floors and physical height restrictions. The uppermost floor level is determined by the last occupied level that does not serve a rooftop enclosure for elevator machinery, a stairway or a service room used only for servicing to the building. Roof terraces follow regular code requirements; however, in Quebec (QCC 2015), a roof terrace with a combustible assembly may not be more than 18m above the grade.

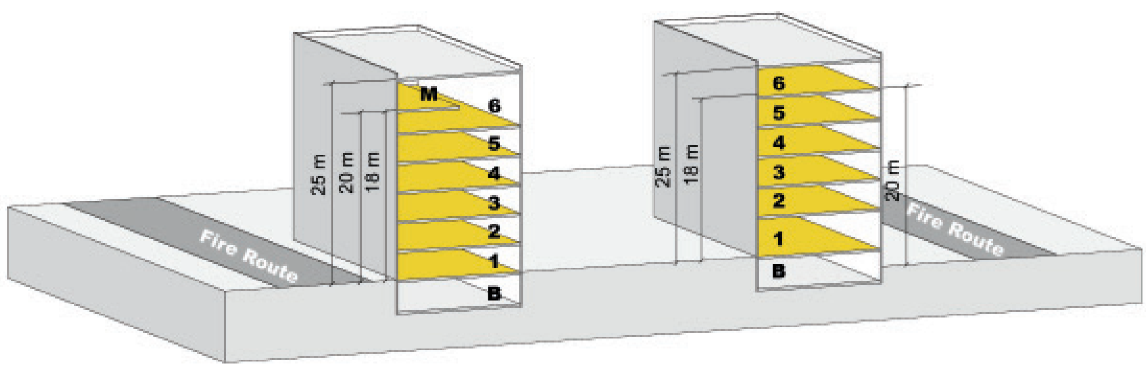


Figure 2.26: In addition to maximum height requirements, no portion of the access route shall be more than 20m below the uppermost floor. Mezzanines (M) are included in the maximum height of the uppermost floor. This requirement accommodates potential level differences between grade and the first floor. It should be noted that the maximum physical height of the building remains at 25m for combustible roof construction and includes the top of the peak of the roof and mechanical or service rooms included on the roof level. Above 25m requires non-combustible construction.

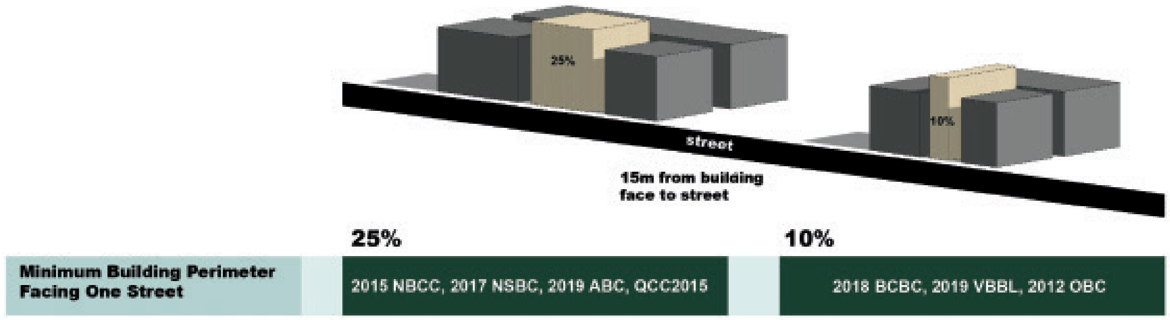


Figure 2.27: Requirements for "Facing of Streets." The illustration indicates the building is considered to face one street where not less than the percentage indicated above is located within 15m of a street or streets. Variations across Canada exist. Provinces like British Columbia and Ontario have a reduced the minimum facing percentage requirement to accommodate urban infill sites that may not have a second street access, which can be frequently seen in cities like Toronto and Vancouver.

The 2015 NBCC requirement for minimum building perimeter facing one street is that no less than 25% of the building perimeter be located within 15 metres of a street or streets. In this case, the code defines the street as a fire access route. Certain building codes such as the OBC, VBBL and BCBC reduces this requirement to 10%. This is for reasonings of urban densification where many infill sites within urban centres would not qualify for minimum building perimeter requirement. It is speculated that the 2020 NBCC will allow for a minimum of 10% of the building perimeter to be located within 15 meters of a street or streets.

Figure 2.28: Wren multi-family complex in southern California by Togawa Smith Martin.

Source: Think Wood.

2.4.2 Mixed-Use Buildings and Permitted Occupancies

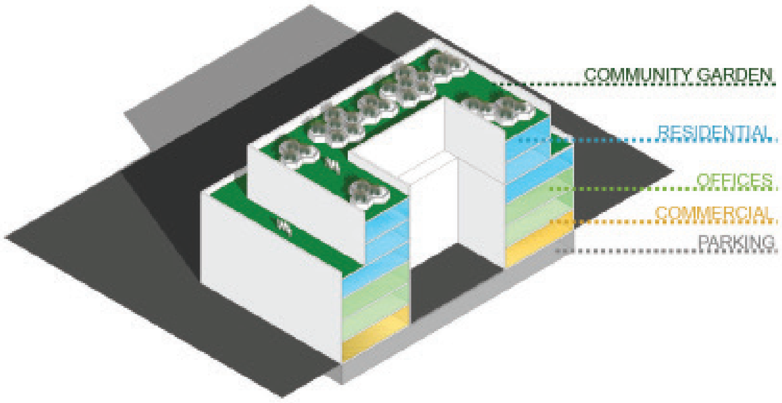
The provisions for midrise construction in the national and provincially adopted building codes allow for wood as a structural system for Group C (residential) and Group D (office) occupancies. However, the building's use is not limited to these functions as other uses can be combined under specific parameters.

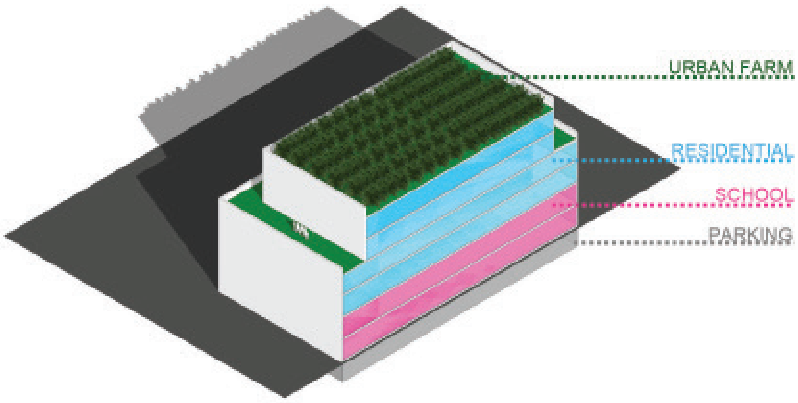
In many urban centers across Canada, the development of mixed-use buildings is encouraged. Allowing mixed-use occupancies in midrise buildings can promote diverse and sustainable communities.

Current trends in mixed-use development include:

- Post-secondary use combined with business and office can promote the integration of learning and industry
- Elementary school combined with residential uses creates holistic living environments
- Live-work spaces can promote work/life balance and flexibility
- Hotel and office use to accommodate short-term stay ventures
- Supermarkets and residential
- Places of worship and residential
- Community halls, art galleries, libraries and residential or office

An important consideration with midrise developments includes the provisions for outdoor amenity spaces. These spaces are critical to promoting physical and mental health, and support communities. These outdoor amenity spaces can consist of community gardens and urban farms that can become a food source and encourage biodiversity in communities.





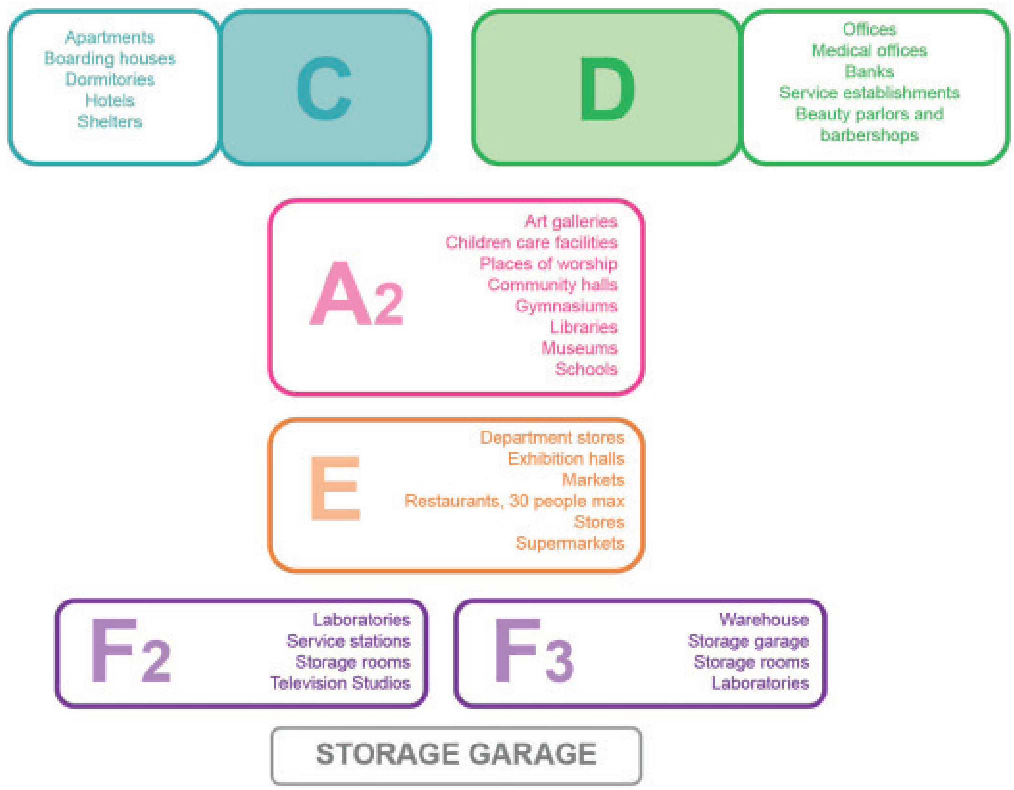


Figure 2.29: Diagram illustrating some of the mixed occupancy opportunities possible. Current trends in community development encourage mixed uses that promote activation along street edges and spaces for community functions.

Major Occupancy Group	A-2	C	D	E	F-2	F-3[a]
A-2		2h[b]	2h[b]	2h	2h	1h
C	2h[b]		1h	2h	N/A[c]	1h
D	2h[b]	1h		-[b]	-[d]	-[e]
E	2h	2h	-[b]		-	-
F-2	2h	N/A[c]	-[d]	-		-
F-3[a]	1h	1h	-[e]	-	-	

Notes:

a. Including storage garades.
b. QCC- 1.5h.
c. F-2 major occupancies are not permitted in Group C buildings of midrise combustible construction
d. F-2 major occupancies are not permitted Group D buildings of midrise combustible construction under the OBC 2012 and QCC 2015
e. F-3 major occupancies, other than storage garages, are not permitted in Group D buildings of midrise combustible construcftion under the OBC and the QCC 2015

Figure 2.30: Fire-resistance-rating requirements for fire separations required between permitted major occupancies in buildings constructed to Group C and Group D midrise combustible construction articles.

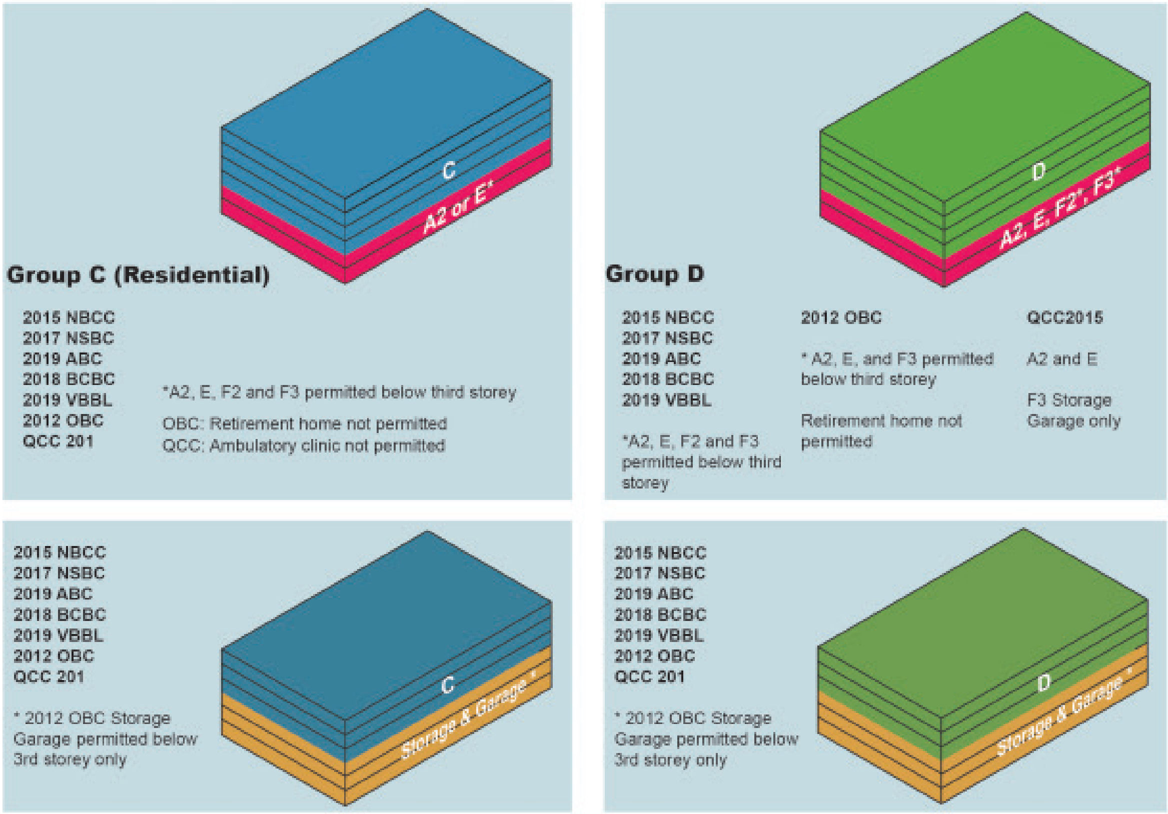


Figure 2.31: Illustration of the Mixed Major Occupancies permitted by the National Building Code and various provincial codes. The code requirements across various provinces differ and must be carefully reviewed. In addition, each municipality may have specific zoning requirements limiting types of uses in certain neighbourhoods and areas.

2.4.3 Fire Separations and Separation of Major Occupancies

Fire separation requirements will impact assembly and detail choices. Carefully reviewing the requirements for fire-separations and fire-resistant ratings are critical as they can affect the structural depth, span, requirements for encapsulation, overall building height and interior aesthetics. The code requirement for fire separation between each floor level, between major occupancies and at other critical parts of the building, such as egress stairs, varies between the National Building Code and some provincial jurisdictions.

Understanding the requirements for fire separation and fire ratings based on the provincial building code requirements becomes a critical initial step in design.

Fire Separation Between Major Occupancies

Fire resistant rating
Floor assemblies: 1-h
Roof assemblies: 1-h
Mezzanines: 1-h

Load bearing walls, columns and arches: not less than required to support assembly

2015 NBCC **2017 NSBC** **2019 ABC** **2018 BCBC** **2019 VBBL** **2012 OBC**	2-h fire-resistance rating between Group C or D and A2 or E
QCC 2015	* 1.5-h fire resistance rating between C or D and A2 or E

Group C – Within Dwelling Units

Floor: 1-hr FRR
No fire separation of floors within units required

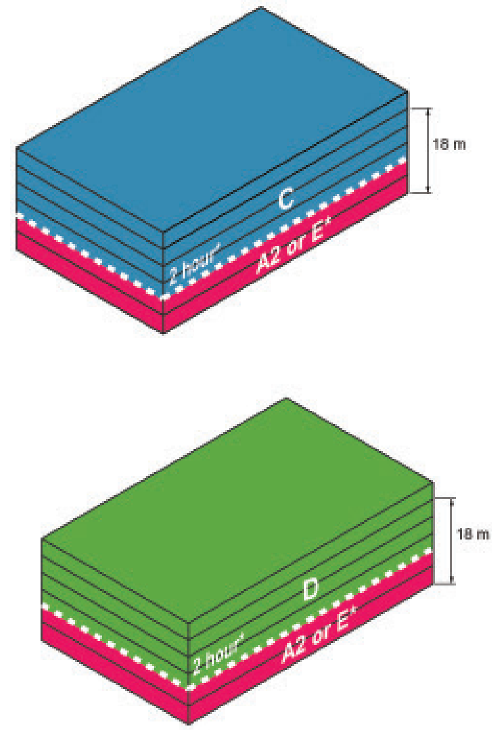


Figure 2.32: Requirements for fire separation between major occupancies.

Adjacent major occupancies in a building are required to be fire separated from each other and include the following requirements:

- A fire separation with a 2-hour fire-resistant rating is required between Group C (residential) and Group A, Division 2 (assembly) major occupancies.
- A fire separation with a 2-hour fire-resistant rating is required between Group D (office) and Group A, Division 2 (assembly) major occupancies.

This applies to all provinces except for the province of Québec (QCC 2015), where the following is required:

- A fire separation with a 1.5-hour fire resistant rating is required between Group C (residential) and Group A, Division 2 (assembly) or Group E (mercantile) major occupancies.
- A fire separation with a 1.5-hour fire resistant rating is required between Group D (office) and Group A, Division 2 (assembly) or Group E (mercantile) major occupancies.

Roof terraces: From a code perspective, regular requirements apply to roof terraces regarding fire separation requirement and egress where the assembly may be permitted to be constructed of combustible materials.

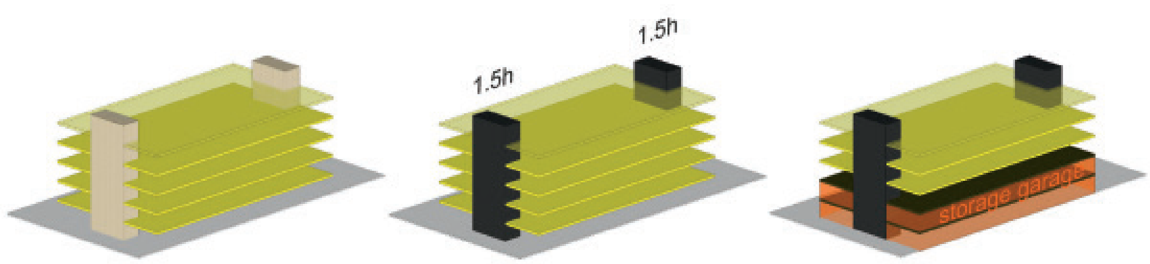
In Quebec (QCC 2015), however, the following specific requirements must be noted:

- If of combustible construction,
    - The space between the underside of the terrace floor and the roofing is not more than 150mm, and
    - The floor of the terrace is not more than 18m above the grade.

Within the mid-rise requirements, combustible construction is permitted; however, restrictions are dependent on the province. Combustible construction such as mass timber or lightweight wood-framing components can be used on the floor assemblies and structural support assemblies. In all regions except for Ontario and Québec, combustible construction with a fire separation of one hour is permitted to enclose the exit stairs.

In Ontario and Québec, the enclosure of the exit stairs must be constructed out of non-combustible material. Further, in Québec, the fire separation of the egress stair is required to be 1.5 hours. Additionally, in Québec, any floor area of a storage garage shall be of non-combustible construction. Careful review of the requirements with the Authorities Having Jurisdiction is highly encouraged early in the planning stage.

There have been examples where alternative compliance has been permitted to allow for combustible construction on the exit stairs. The potential approval for alternative compliance must be carefully reviewed and negotiated with the authorities having jurisdiction early on in the design process.



Additional Fire Separation requirements

2015 NBCC, 2017 NSBC, 2019 ABC, 2018 BCBC, 2019 VBBL	2012 OBC	QCC 2015
	Fire seperation of exits shall be of noncumbustible construction. Exits shall have a 1.5 fire seperation from remainder of building.	Fire separation of exits shall be of noncombusti-ble construction. Any area of a storage garage shall be of non-combustible construction.

General
Roof Assemblies higher than 25m requires non–combustible or fire-retardant treated wood.

Except for noncombustible roof assemblies required, if an assembly is required to be of noncombustible construction and have a fire-resistance rating, it shall be supported by noncombustible construction

Figure 2.33: Additional fire separation requirements, including variations on combustible and non-combustible egress stairs. In Ontario (OBC 2012), every exit shall be separated from the remainder of the building by a fire separation, and the fire-resistance rating of the fire separation shall not be less than 1.5 hours. In Québec (QCC 2015), exit stairwells and their rooftop enclosure extension must be of non-combustible construction in addition to any floor area of a storage garage.

Figure 2.34: Exterior cladding requirements where the exterior cladding is required to be non-combustible except for a limited amount as described above for buildings of 5 to 6 stories in height. Note that buildings of four-storeys or lower may have different requirements depending on the jurisdiction.

Figure 2.35: Catalyst Building by Michael Green Architecture.
Photo by Benjamin Benschneider.

2.5 Opportunities Created by The Code Provisions

Multiple factors will influence the choice of the structural system for a building. These include strength and stability, load capacity, program use and long-term flexibility. Also, the availability of material, construction speed, and cost are important considerations for which structural system to use.

Residential buildings will generally be more compartmentalized and may benefit from panelized or loadbearing shear walls structural systems. On the other hand, commercial and institutional buildings typically require open floor plans and flexible space, where a post and beam system would be highly appropriate.

In both instances of residential and office use, lightweight wood-framing construction is a consideration for mid-rise buildings. Lightweight wood-framing construction may be combined with timber posts and beams to achieve these longer spans in office use.

Considering the requirements of a project, there may be instances where an all-wood structural system may not be appropriate. Combining concrete to create composite floor slabs may allow for longer spans and resolve shear forces. Steel may be utilized to support heavy loads and long spans. The transitioning between wood to steel or concrete may benefit mix occupancies where various grid spans may be desired between the floors. For example, concrete may be considered for podium levels. Also, a larger structural bay size may be preferred for assembly occupancy with a tighter grid system of wood for residential use above.

Cost is a driving force in almost any building project. The cost of mass timber is significantly dependant on the price of lumber, supply chain and the volume of wood. Optimizing the structural grid to reduce volume of material will be the cost-effective route when it comes to mass timber.

Fire and acoustic requirements must be carefully considered. The use of concrete may be used in the floor construction to reduce impact noise from transferring from floor to floor. Also, concrete may be used to achieve fire separation ratings in combination or apart from the wood structure.

The use of hybrid structures may arise from the provincial codes' requirements or local authorities having jurisdiction. For example, in Ontario and Québec, combustible materials for exit stairs are not permitted. Therefore, the use of concrete or steel in these areas must be considered.

All those involved in the decision-making process of each type of structural system's opportunities and constraints must come together early on in the project. Consideration of design, structure, systems integration, construction sequencing, manufacturing, and cost must be carefully weighed at the project's onset.

2.5.1 Mass Timber Frame Systems/Post and Beam

Frame systems, which typically consist of posts and beams to carry the vertical and horizontal loads, lend themselves well to building programs that require larger spans between structural columns and flexible interior spaces. This system is ideal for office and commercial use, as well as institutional assembly occupancies.

Framed System - 9x9m GRID

Economical
Deep structure
5-stories, perhaps 6-stories depending on floor-to-floor height requirements

Girders and Purlins
Target Occupancy Type: Office
Grid Spacing: 9m x 9m

Column Size: 456 x 390 mm
Girder Size: 265 x 874 mm
Purlin Size: 215 x 570 mm

Deck:
Fire Rating = 60 minute min.
TYP. 3-ply CLT Encapsulated
TYP. 5-ply CLT Exposed

Total Structural Depth: 1013mm

Alternative Deck:
NLT / DLT / GLT

Mechanical Considerations
Underfloor air distribution
Radiant ceiling panels or chilled beams

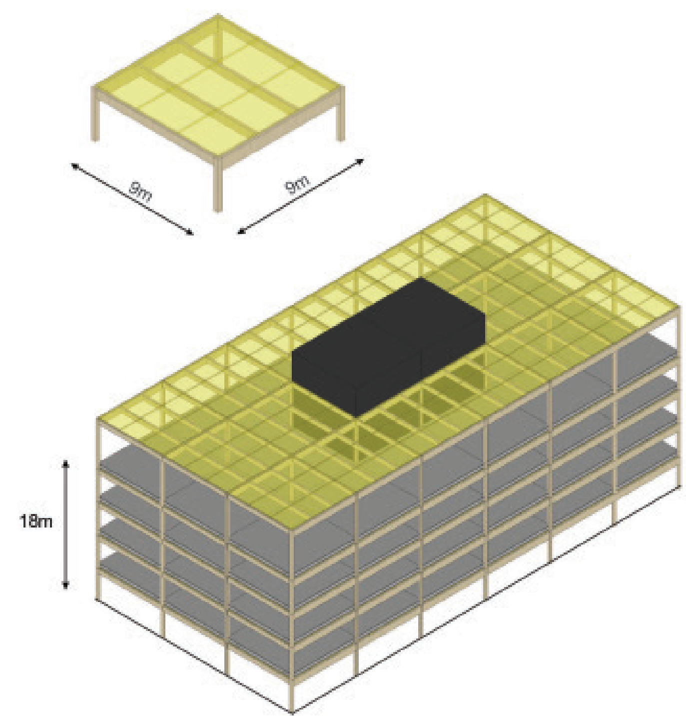


Figure 2.36: Mass timber-framed system at a 9m x 9m structural bay optimizing the efficiency and reducing the volume of the cross-laminated timber deck, making this system economical.

Figure 2.37: A proposed design for the new Ontario Secondary School Teachers' Federation architectural design by Moriyama & Teshima Architects, structural design by Fast + Epp. The building design utilizes a 9m x 9m mass timber-framed structural system consisting of deep girders in one direction and purlins in the other.

Source: Moriyama & Teshima Architects, www.mtarch.com.

Figure 2.38: Platte Fifteen in Denver is a five-storey office structure that utilizes the 30'x30' (9.1m x 9.1m) optimal bay to optimize structural spans of the mass timber component. The purlins are notched and into the girders, leaving a gap above for the running of services.

Image Source: Think Wood

10 Benefits of Using Mass Timber for Platte Fifteen

1. **Sustainability** – Wood is a sustainable, renewable material, resulting in a building with low embodied energy and light carbon footprint.
2. **Beauty** – Exposed wood provides the authentic aesthetic desired by Denver's office tenants, especially technology and creative companies wanting to attract and retain employees with appealing offices.
3. **Biophilia –** Wood's biophilic qualities promote well-being and productivity.
4. **Lower finishing costs –** Leaving wood exposed to the interior eliminates the need for additional finishes.
5. **Design flexibility –** Wood beams and panels could be configured to meet required grid spacing. Members were easily connected to the concrete podium and core using creative yet simple detailing.
6. **In-plane dimensional stability –** The cross-lamination of boards in CLT panels helps minimize in-plane dimensional change due to fluctuation in moisture content. This allowed panels to fit together precisely.
7. **Construction speed –** Mass timber members were prefabricated and installed quickly, speeding construction.
8. **Less noise and waste –** Construction was quieter, and the contractor had less on-site waste, making mass timber a good choice for Platte Fifteen's tight urban infill building site.
9. **High performance –** The mass timber system provides a good thermal and acoustic performance for Platte Fifteen's tenants.
10. **Higher returns –** Leasing premiums for the unique building outweighed extra costs of using mass timber.

Figure 2.39: Ten noted benefits of using mass timber at the Platte Fifteen development.[17]

17 (*Wood WORKS!*, 2020)

Framed System - 6x9m Grid

Economical
Open span between girders for overhead system distribution (no purlins)
Deep structure

Long Beam, Short Deck
Target Occupancy Type: Office
Grid Spacing: 9m x 6m

Column Size: 418 x 365 mm
Girder Size: 265 1178 mm

Deck:
Fire Rating = 60minute min.
235mm NLT / DLT with 5/8" plywood

Total Structural Depth: 1413 mm

Alternative Deck:
9-ply CLT or GLT

Total Structural Depth:
1531 mm

Mechanical Considerations
Overhead system distribution, distribution between girders

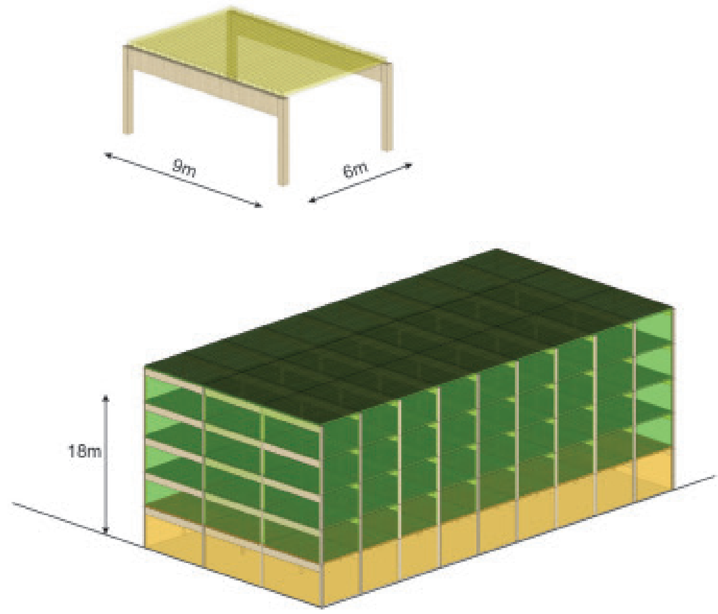


Figure 2.40: A framed system of 9m x 6m structural bay. The advantage of this system is that it eliminates a girder in one direction allowing for MEPF services.

Figure 2.41: The interior of 80 Atlantic Avenue in Toronto, Ontario. Architectural designed by BPN Quadrangle (formerly Quadrangle Architects Ltd.), structural design by RJC for Hullmark. The method utilizes a framed mass timber structure of approximately 8m x 8m consisting of deep girders in one direction and a short deck in the other, freeing the structure of intermediate purlins.

Photo credit: Doublespace Photography.

Framed System - 3x4m Grid

Economical
Shallow structure
Short bay

Short Span
Target Occupancy Type: Residential
Grid Spacing: 9 m x 9 m

Column Size: 266 x 265mm
Girder: 265 x 228 mm

Deck:
Fire Rating = 60 minute min.
5-plyCLT partially exposed

Total Structural Depth: 367 mm

Point Loaded CLT
Short Span
Occupancy Type: Residential

Grid Spacing: 4 m x 2.45 m

Deck:
Fire Rating = 60 minute min.
5-plyCLT partially exposed *

* Encapsulation may be required dependent on fire loads

Alternative Deck:
89 mm NLT / DLT or GLT

Total Structural Depth:
317 mm

Mechanical Considerations
Unit mechanical
Overhead distribution
Partial dropped ceiling or reduced head

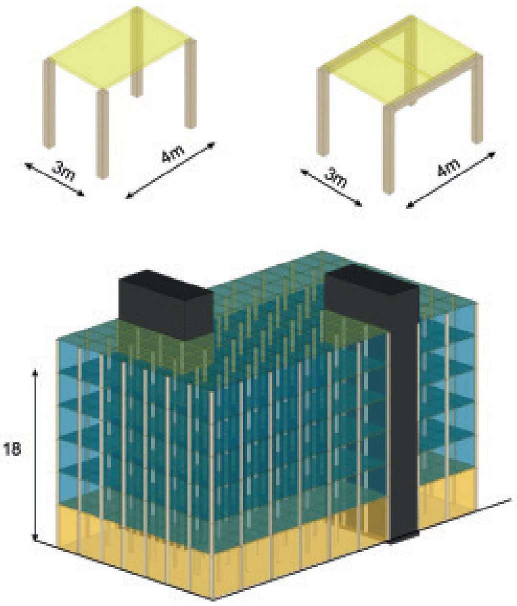


Figure 2.42: Framed system, short bay optimizes the structure as the cross-laminated timber structure is point-loaded, minimizing floor-to-floor height.

Figure 2.43: Brock Commons Tallwood House architectural design by Acton Ostry Architects, structural design by Fast+Epp illustrating a short span CLT floor structure point loaded on glulam columns.

Source: Acton Ostry Architects.

Figure 2.44: Boutique Hotel Magdalena in Austin, Texas.
Mass timber is used to provide a unique experience to its visitors.

Photo Credit: Casey Dunn

2.5.2 Mass Timber Hybrid Systems

In some cases, an all-wood structural system may not provide the most preeminent system. This may be due to structural requirements, fire requirements, design, flexibility or costs.

Hybrid systems combine various materials in structural components. The various properties of the materials can be combined to optimize the overall strategy to meet specific objectives. The combination of materials or construction methods can range significantly.

Timber and concrete can be combined at the floor slab to provide for longer spans, provide better vibration, enhance acoustics, and mitigate against deflection and sagging conditions. As well, concrete may be utilized to accommodate heavier loads. Concrete under compressive stress bonded to timber decking can create a shear-resistant action.

Timber and steel can be combined to support heavier loads and span longer distances between structural supports. Also, using steel for the horizontal load distribution can result in shallower structural depths. It may reduce overall floor-to-floor height that may be the determining factor in achieving six storeys in a long span condition.

Figure 2.45: 80 M Street in Washington D.C. is a vertical expansion of an existing building.

Source: Think Wood.

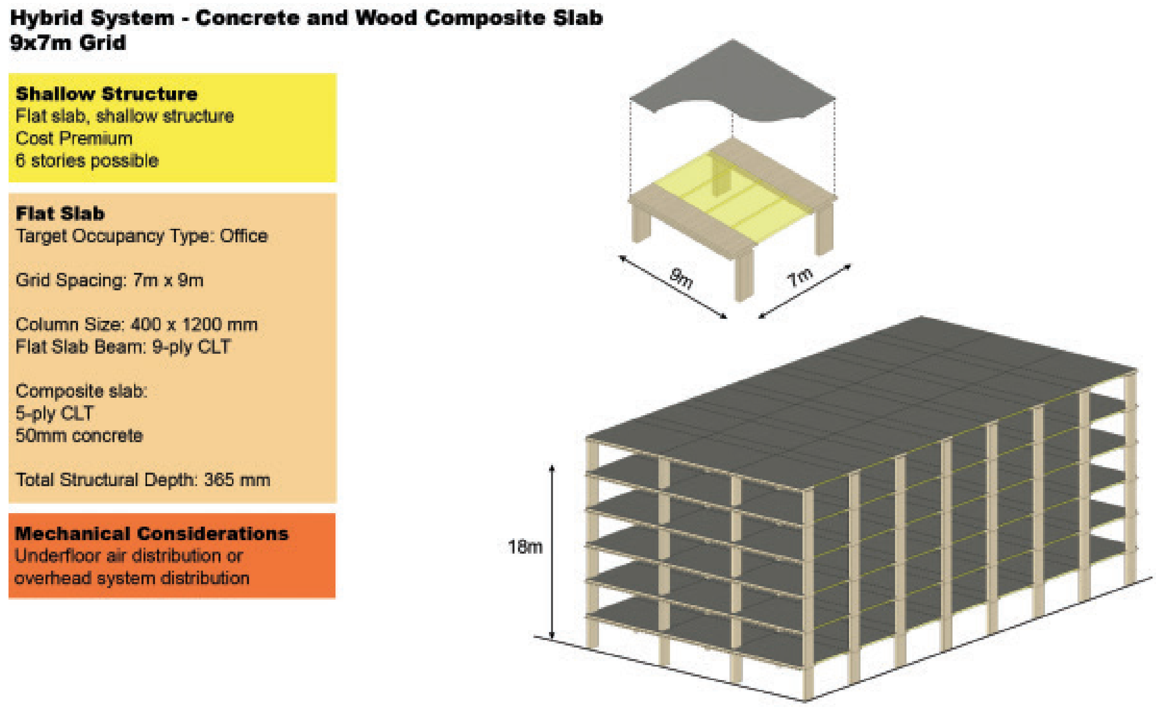


Figure 2.46: A hybrid system of composition concrete and cross-laminated timber decking to manage shear forces and minimize floor-to-floor heights.

Figure 2.47: Limberlost Place (formerly The Arbour) at George Brown College, by Moriyama & Teshima Architects and Acton Ostry Architects, structural design by Fast + Epp. The building design utilizes the flat slab band cross-laminated timber structure with localized areas of composite concrete and CLT decking to manage the shear action.

Image source: www.mtarch.com

Hybrid System - Steel Delta Beam with Wood and Concrete Composite Slab

Shallow Structure
Flat slab to minimize floor-to-floor heights
Cost Premium,
Delta Beam Propriety

Flat Slab
Target Occupancy Type: Office
Grid Spacing: 8m x 8m

Column Size: 400 x 1200 mm
Flat Slab Beam: 9-ply CLT

Composite slab:
150mm concrete on 175mm CLT

Alternative:
315mm CLT

Alternative Deck:
9-ply CLT

Total Structural Depth:
1531 mm

Mechanical Considerations
Underfloor air distribution or overhead system distribution

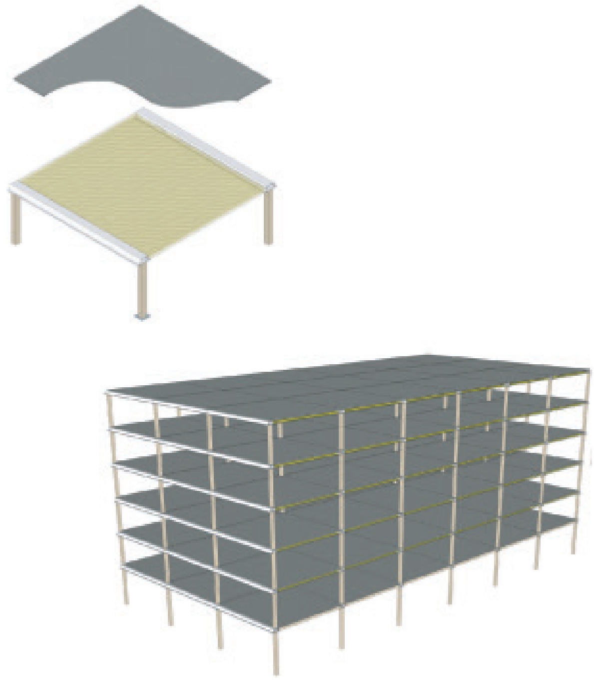


Figure 2.48: Hybrid structure utilizing concrete-filled steel beam components to maximize structural bay space and minimize floor-to-floor heights.

Figure 2.49: 77 Wade Avenue by BNKC Architecture + Urban Design utilizes the Delta Beam technology in this office building proposal in Toronto, Ontario.

Image source: BNKC Architecture + Urban Design

2.5.3 Mass Timber Panel Systems

Panel systems comprise solid wall and floor panels arranged in two directions that carry vertical and horizontal loads. Panel wall systems can be constructed out of lightweight wood-framing construction, as well as mass timber components. Cross-laminated timber has become an ideal material for the panel system due to its high strength.

The panel system can have many advantages, including acting as a loadbearing wall. The use of panel systems on exterior walls may offer benefits; however, combustible construction on exterior walls is limited in the mid-rise code requirements. Encapsulated or other fire rating strategies may be required.

Panel systems often result in a compartmentalized design that can work well with residential-type occupancies. When considering panel systems, openings must be carefully considered so as not to compromise the structural capacity.

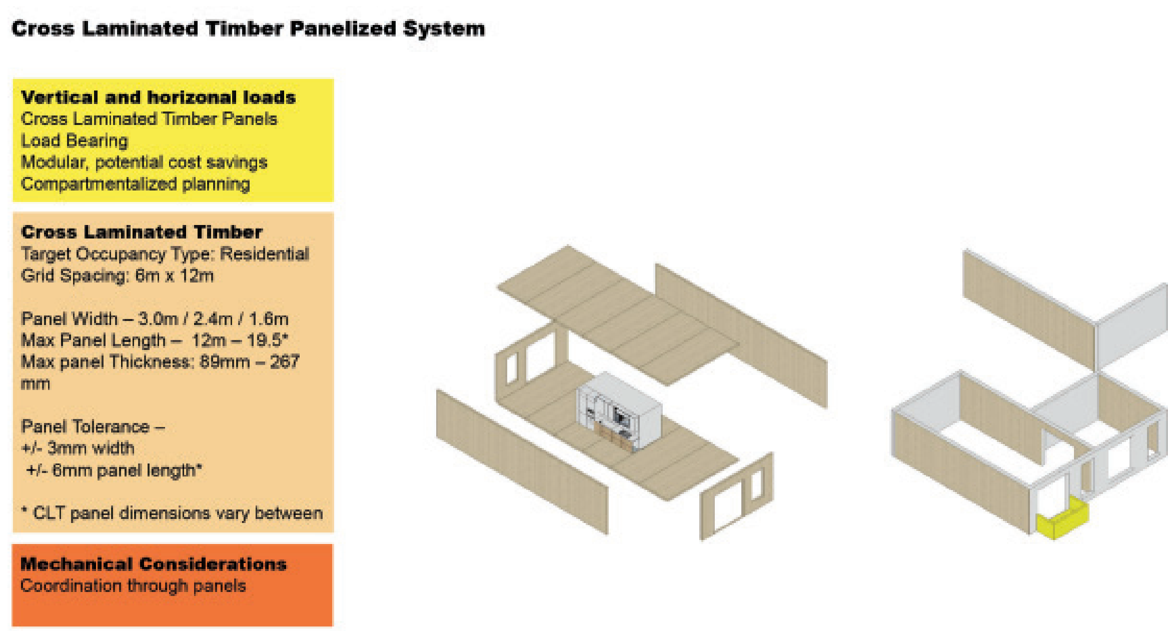


Figure 2.50: Cross-laminated timber panelized system optimizing the span capacities of the system.

Figure 2.51: The Cube in Hamburg, Germany, is constructed using CLT panels for floor and wall structure.

Photo credit: IBA Hamburg, Martin Kunze.

R-Hauz R-Town

Toronto, Ontario

Figure 2.52: Concept rendering of the front elevation along Queen Street East in Toronto, Ontario.

Image Source: www.r-hauz.ca.

Developer: R-Hauz

Architect: CMV Architects

Structural Engineer: Moses Structural Engineers

Cross-Laminated Timber Panels

Design

The R-Hauz, R-Town in Toronto, Ontario, is a multi-unit stacked townhouse complex designed using cross-laminated timber panels as the structural system on twenty-foot modules. Located at Queen St. East and Coxwell Avenue, this pilot project for R-Hauz is the first all-wood, mass timber, six-storey building in Ontario. The project utilized an all-wooden elevator shaft nd stairwell. Although it required a detailed alternative compliance approval, overall construction timelines were accelerated. The building design responded to a narrow infill site, maximizing the use of wood according to mid-rise provisions.

Figure 2.53: Concept rendering of interior space.
Image Source: www.r-hauz.ca.

Prefabrication and Integrated Design

Construction of the complex utilized the rear laneway system. Full consideration was given to the size of each CLT panel and crane size to avoid road closures when unloading and tilting into the place the prefabricated panels.

The off-site prefabrication of the mass timber structure provided a system that was less wasteful and easier to build. In addition, the prefabricated elements reduced the number of trades on site, making the onsite traffic management and coordination less onerous.

Knowledge and repeatability of the systems is key in optimizing costs in the mass timber townhouse complex. In considering the cost-efficiencies over time, an Integrated Program Delivery model was followed to benefit from inherent knowledge of the skills and trade team over time.

Flexibility

Flexibility in the aesthetic is provided by a front façade that is designed to allow adaptability and customization to the neighbourhood's character, including varying window panels, balconies and other architectural features. Lateral stability was a key consideration in accommodating the narrow building footprint and height. Cross-laminated timber was an ideal material because of its inherent rigidity.

The construction sequencing was carefully considered in the design of the building and mass timber panels. The strategy included tilting up process utilizing a hoist-crane that was located in the rear of the property. Forty feet of site area was maintained in the rear of the site to accommodate the construction process and at grade parking. The building utilized a slab-on-grade construction to prevent disruption to the streetcar system along Queen Street East. Together, these strategies added in reducing overall costs.

Figure 2.54: Aerial view during construction illustrating the construction staging off the rear laneway.

Image Source: www.ohba.ca.

Figure 2.55: View during construction from Queen Street East.

Image Source: www.ohba.ca.

YWCA Supportive Housing

Kitchener-Waterloo, Ontario

Figure 2.56: Concept rendering of the proposed exterior of the YWCA Supportive Housing.
Image Source: Edge Architects and Element5.

Architect: Edge Architects

Structural Engineer: Element5

Owners: YWKW

Developer: Melloul Blamey Construction

Mass Timber Fabricator: Element5

The YWCA project is a 41-unit supportive housing project as part of Canada's Rapid Housing Initiative. Cross-laminated timber panels are used in both the structure and the prefabricated envelope system. The CLIP envelope system provided by Element5 are cross-laminated panels in a complete envelope system, are prefabricated off-site in a controlled factory environment. The system offers shortening construction timelines, facilitating rapid building enclosure while increasing the quality and energy performance of the building envelope.

Design efficiencies are realized by working as an integrated project team, where close communication between the architect, developer and mass timber fabricator worked in establishing an efficient and cost-effective housing solution. Through close collaboration, cost savings are enabled by reducing construction time, reducing waste and optimizing the use of the CLT panels.

The mass timber will be fabricated locally by Element5's newly completed Ontario mass-timber manufacturing facility. In addition, the wood used will be supplied by Ontario forests, minimizing transportation of the product while supporting the local economy.

One of the key drivers in this cost-efficient system is the speed of construction. The CLT panels are designed to span two units, optimizing the product while reducing construction time by limiting the number of lifts – overall creating efficiency and speed in construction. The elevator and stair cores are also designed with CLT panels and are placed on the outer edge of the floor plate, simplifying the main floor plate design. The mass timber for the project will be locally supplied by Element5, including the raw materials from Ontario forests.

The speed of construction is noted to be one of the key elements in reducing overall costs. The design utilized cross-laminated timber panels for floor and wall construction. The CLT floor slab spans the distance of two units, optimizing the CLT material, while reducing construction time by reducing the number of lifts. CLT elevator and stair cores are also utilized and placed outer edge of the floor plate to increase construction time and simplify connections.

Figure 2.57: Concept rendering of the interior of a typical suite.

Image Source: Edge Architects and Element5.

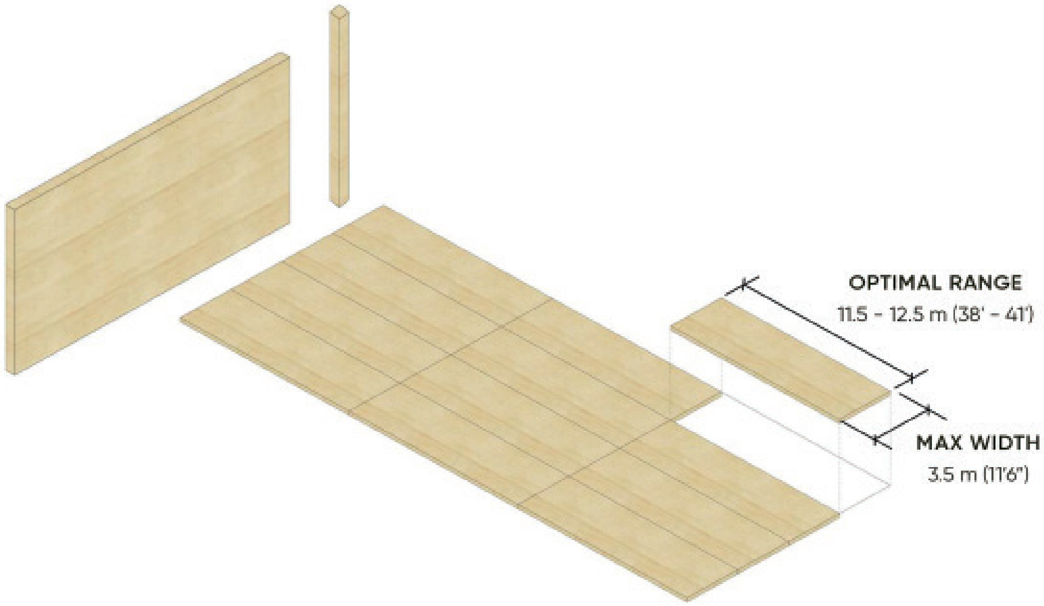
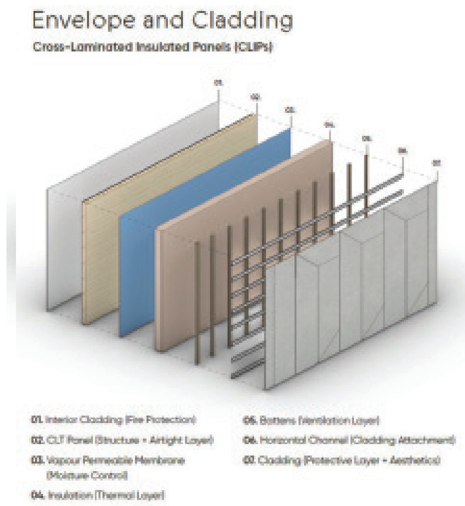


Figure 2.58: Diagram of cross-laminated timber panel distribution.

Image source: Edge Architects and Element5.

Figure 2.59: Concept rendering of the interior of the ground floor amenity space. The structural grid in this location shifts from a panelized system to a post and panel system.

Image Source: Edge Architects and Element5.



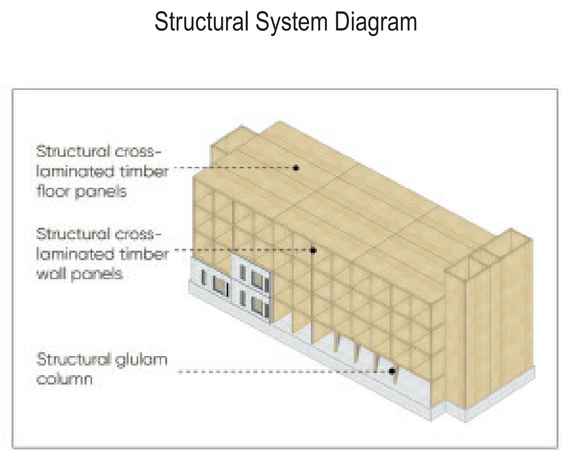


Figure 2.60: Left: Diagram of Element5's CLIP system. Right: Building diagram illustrating the prefabricated mass-timber structural system and exterior envelope components.

Image Source: Edge Architects and Element5.

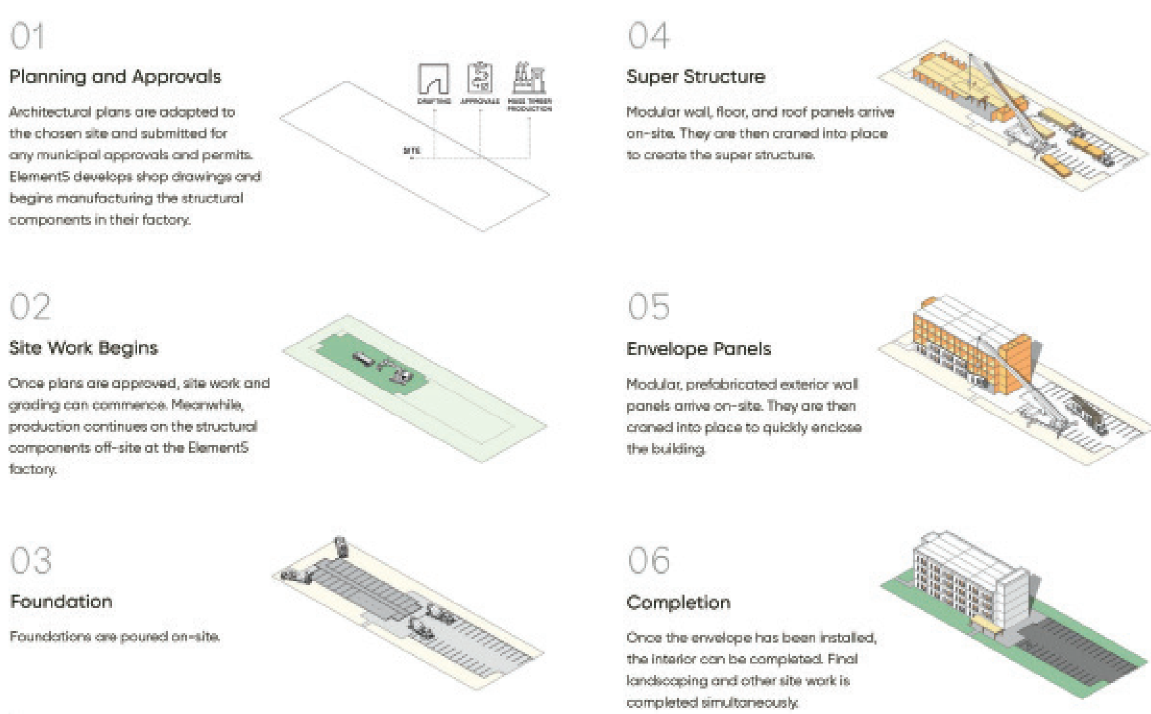


Figure 2.61: Diagram and description of the process and sequencing of construction.

Image Source: Edge Architects and Element5.

2.5.4 Lightweight Wood-Framing Systems

Lightweight wood-framing construction can also be used in the post and beam example to substitute the cross-laminated timber or the nail laminated timber deck options. This could be a cost-effective option for buildings of commercial and office occupancies, up to six storeys. Options for floor structure can include I-joists and open web trusses, depending on overall spans. However, in the open web truss condition, there may be additional fire blocking requirements. In all structural scenarios, it is essential to review fire rating and separation requirements.

The most cost-effective spans between main supports vary by joist depth, approximate ranges:

- 10'-17' for 9.5" depths
- 14'-21' for 11.875" depths
- 18'-24' for 14" depths
- 22'-28'+ for depths up to 16"-20"

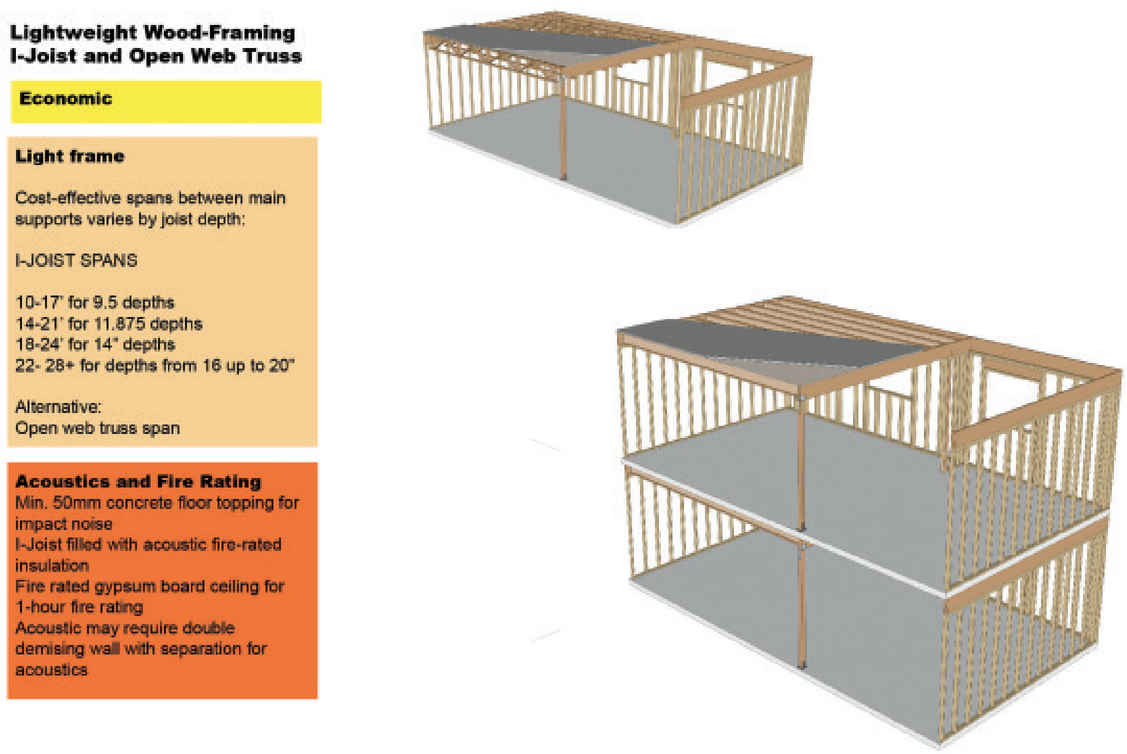


Figure 2.62: Lightweight wood-framing system utilizing an efficient 6m x 6m unit size for residential programming. As with any wood structure, careful consideration must be given to fire protection and acoustic strategies.

Balloon Framing

Balloon framing consists of continuous walls from floor to floor, and the floors are supported by steel brackets connecting to the walls. In this scenario, the CLT wall spans two to three storeys. The lightweight wood-framing floor joist is supported to the CLT continuous wall, resulting in avoiding having the compressive loading perpendicular to the grain.[18] A consideration for balloon framing is the support of the floor structure during construction. The floor structure can be prefabricated in sections and resting on a ledger to fasten to the CLT wall. The CLT acts as the shear wall, making this solution convenient for residential buildings where the floor plans are more compartmentalized.

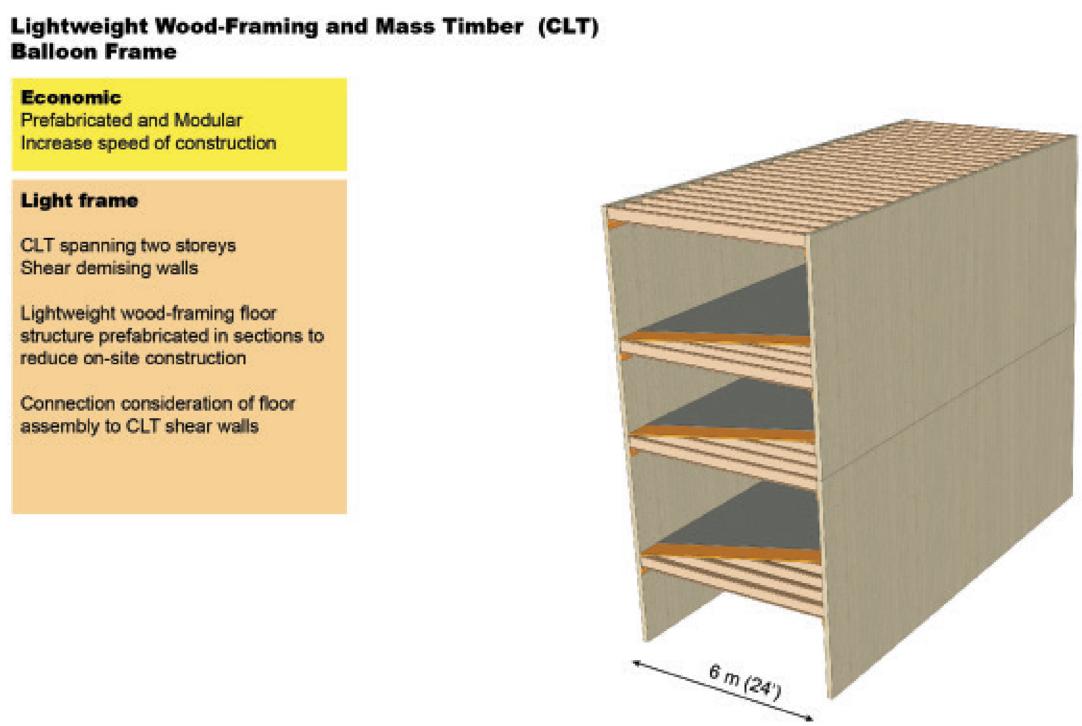


Figure 2.63: Balloon framing utilizing cross-laminated timber (CLT) and lightweight wood-framing. This system has the advantages of utilizing off-site prefabrication to reduce on site construction time.

18 (Annette, 2017)

Platform framing

This example of platform framing is constructed with cross-laminated timber at the floor levels and load-bearing lightweight wood-framing. The floor provides a platform to build the next level. As the height increases from above, this places compressive force perpendicular to the floor below. The force can be transferred to the wall or column below by utilizing self-tapping screws or other steel connectors to prevent excess deflection.[19]

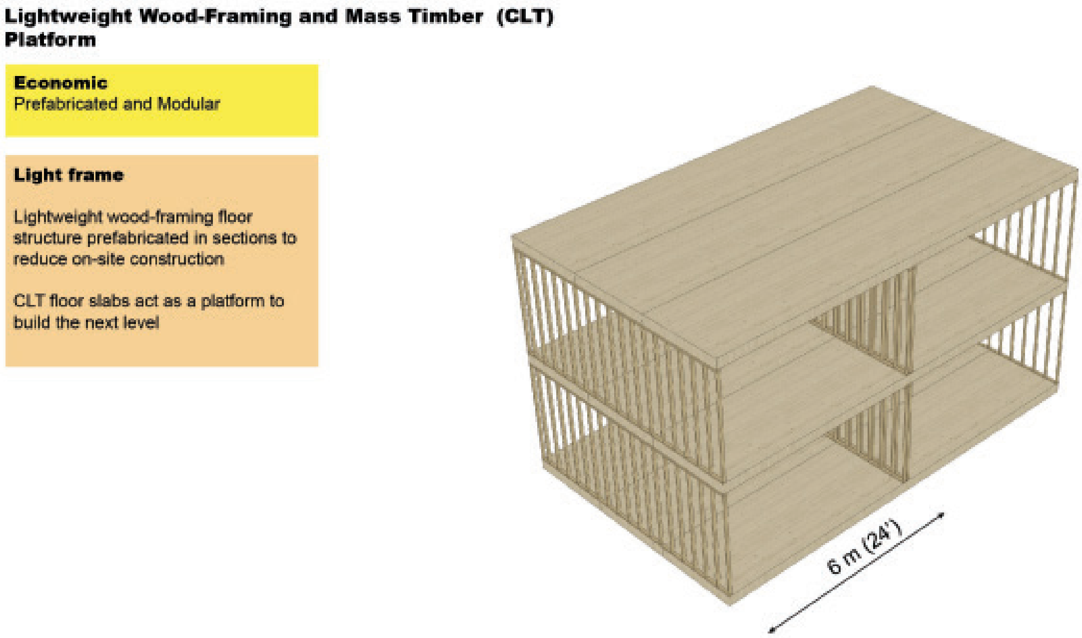


Figure 2.64: Cross-laminated timber (CLT) floor slab with lightweight wood-framing loadbearing walls. The CLT acts as a platform to build the next level.

19 (Annette, 2017)

Figure 2.65: Example of platform framing using cross-laminated timber (CLT) as the floor slab and lightweight wood-framing load-bearing walls below for a residential project. The off-site prefabrication of CLT can offer acceleration of on site construction timing.

Source: https://katerra.com/products/cross-laminated-timber/

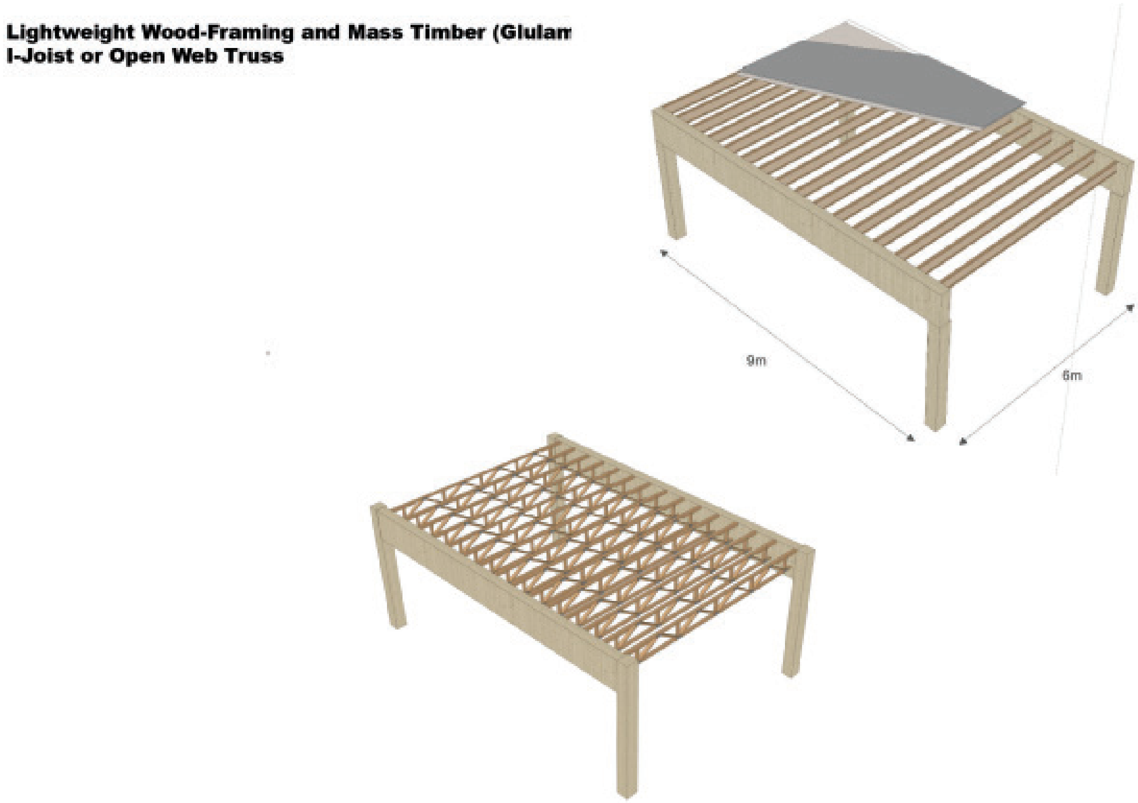


Figure 2.66: Hybrid framing structuring using mass timber glulam post and beam system to support longer bay spans with lightweight wood-framing systems.

Figure 2.67: Construction at Library Square, Kamloops, B.C.

Credit: Stephanie Tracey.

2.5.5 Podium buildings

Podium buildings are multi-storey lightweight wood-framing construction over one or two levels of concrete podium construction. The advantage of this design strategy is transferring the structural grid from a more closely spaced structural span above to a longer structural span at the podium level. This may be highly desirable in transitioning occupancies where planning requirements may require a change in structural span.

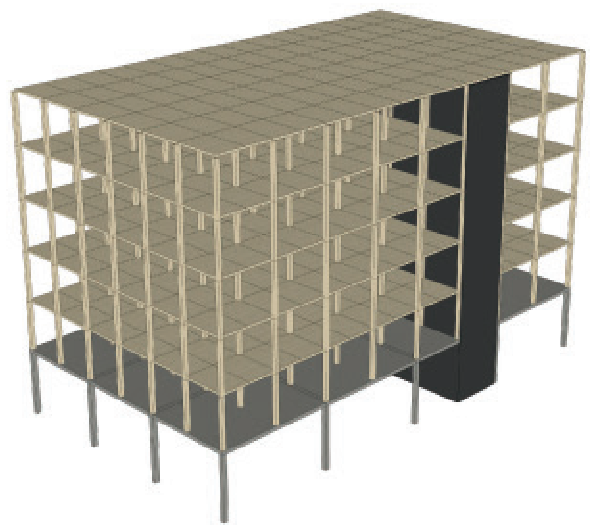


Figure 2.68: Diagram illustrating a concrete podium and mass timber structure above to transfer a short span typical in residential building to allow for more flexible space and longer spans below. This method is also compatible with lightweight wood-framing construction.

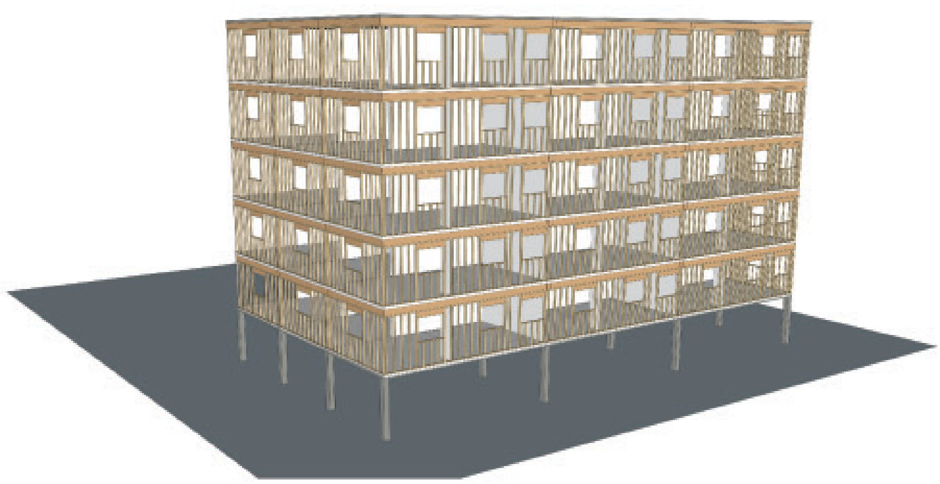


Figure 2.69: Illustration of lightweight wood-framing mid-rise framing five storeys above a concrete podium. The concrete podium offers many advantages, including transferring the load of a shorter structural span above to a larger span below to accommodate different uses.

Figure 2.70: Moto – Denver by Gensler.
Image source: www.denverinfill.com

Figure 2.71: Mid-rise wood-frame building in San Diego constructing a 5-storey lightweight wood-framed structure above the 2-storey concrete podium.

Courtesy of Brett Drury, Source: www.structuremag.org

Figure 2.72: Quatro 3 in Surrey, B.C., completed in 2012 by Cotter Architects Inc.

2.5.6 Balconies

Having access to outdoor space is critical to the overall physical and mental wellbeing of people. In the case of residential buildings, balconies and other outdoor amenity spaces are essential amenities to consider.

Balcony assemblies in both mass timber and lightweight wood-framing construction present many technical challenges that must be considered. Considerations such as structural integrity, waterproofing, continuity of building enclosure, drainage and durability are complex design concerns that must be detailed accordingly. Today, the most common balcony styles include recessed or projecting types. Selection of the most appropriate balcony type will depend on the integration with the entirety of the structural system, zoning and set back requirements, orientation for solar shading and wind protection and overall design aesthetics.

Balconies that extend further than 610mm require an automatic sprinkler system. The requirements for exterior cladding also apply to balconies, as described in Section 2.4. In addition, considerations for non-combustible finish material must be considered according to local jurisdictions.

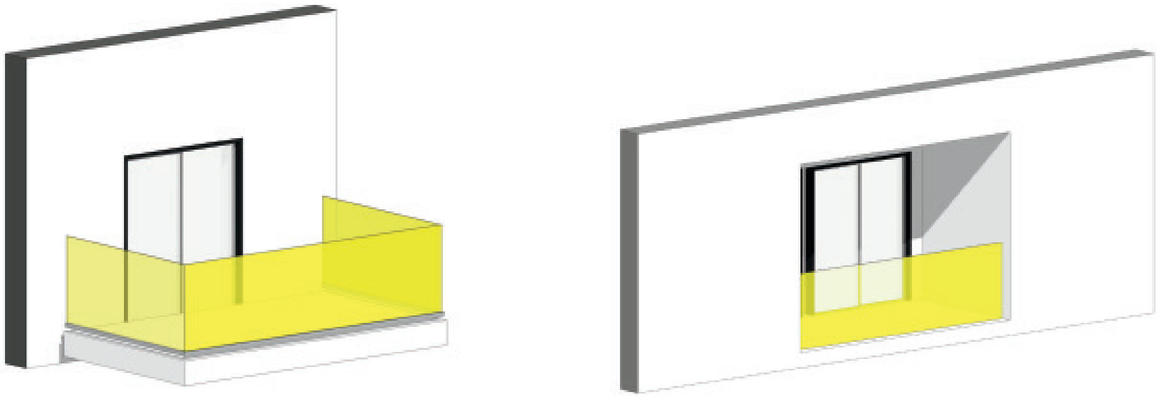


Figure 2.73: Right, illustration of projecting balcony and to the left, recessed type.

Projecting balconies extend from the building face and are often a cantilevered mass timber structure that at times, may require additional exterior support. Drainage of the balcony is less complicated than recessed, however, the structural integrity and deflection must be considered carefully. The recessed balcony allows for a more simplified approach to the detail of balcony to exterior wall, however, drainage is more complicated, especially when fully recessed.

In both scenarios, managing the height variation between the inside to outside space must be considered carefully in the structural placement and thermal and moisture protection.

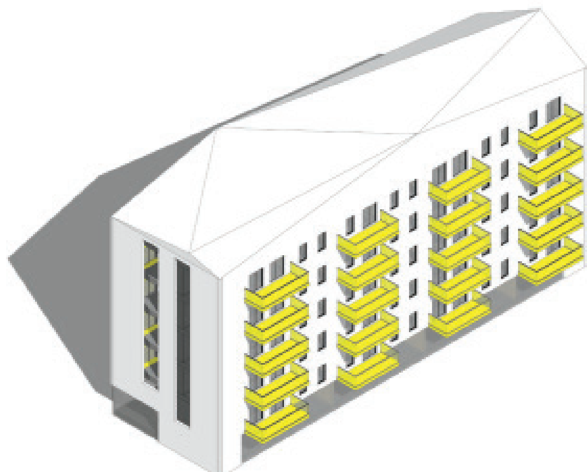


Figure 2.74: Illustration of hung balconies.

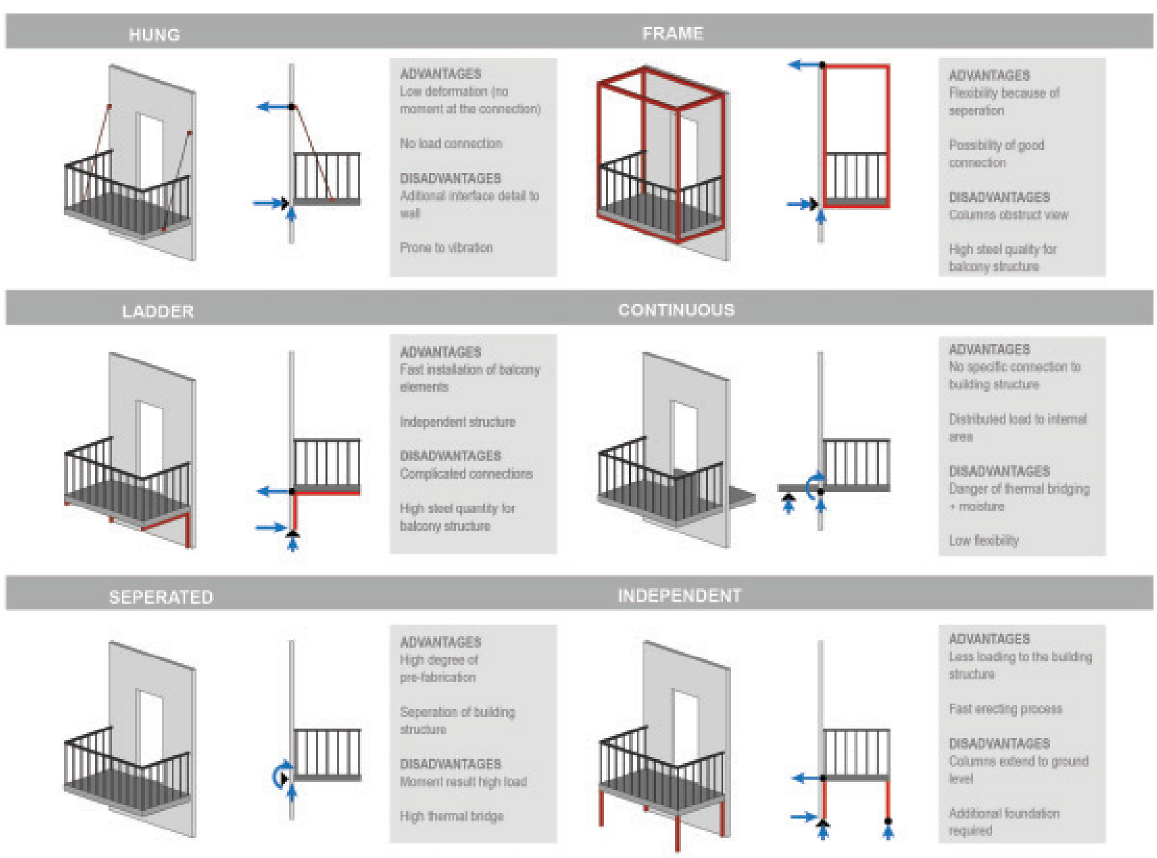


Figure 2.75: Various balcony types and description of advantages and disadvantage of each.[20]

20 (Eurban, n.d.)

2.5.7 Adding Storey to Existing Buildings

Currently, the need for housing is a priority, and as we move into the future and the world's population continues to increase, urban densification will be critical in addressing population growth. Across Canada, three to four-storey buildings can be commonly seen on main streets. Adding storeys to existing buildings can be an essential method of adaptive reuse of existing buildings and increasing density in cities and towns.

Wood construction offers an advantage in that it is lightweight, and in the case of mass timber and some lightweight wood-framing systems, prefabricated. In some cases, this can reduce the need for reinforcement of existing structures and foundations to accommodate additional storeys. In addition, considering modular and kit-of-parts components can lend itself well to constricted urban sites. This can potentially reduce adverse effects during construction to the lower storeys and neighbours as prefabricated buildings tend to be constructed quicker, reducing construction time, and are often less noisy than other traditional building materials.

Figure 2.76: Illustration representing design opportunities with adding storeys to an existing building.

Concept rendering by Studio Veronica Madonna Architect.

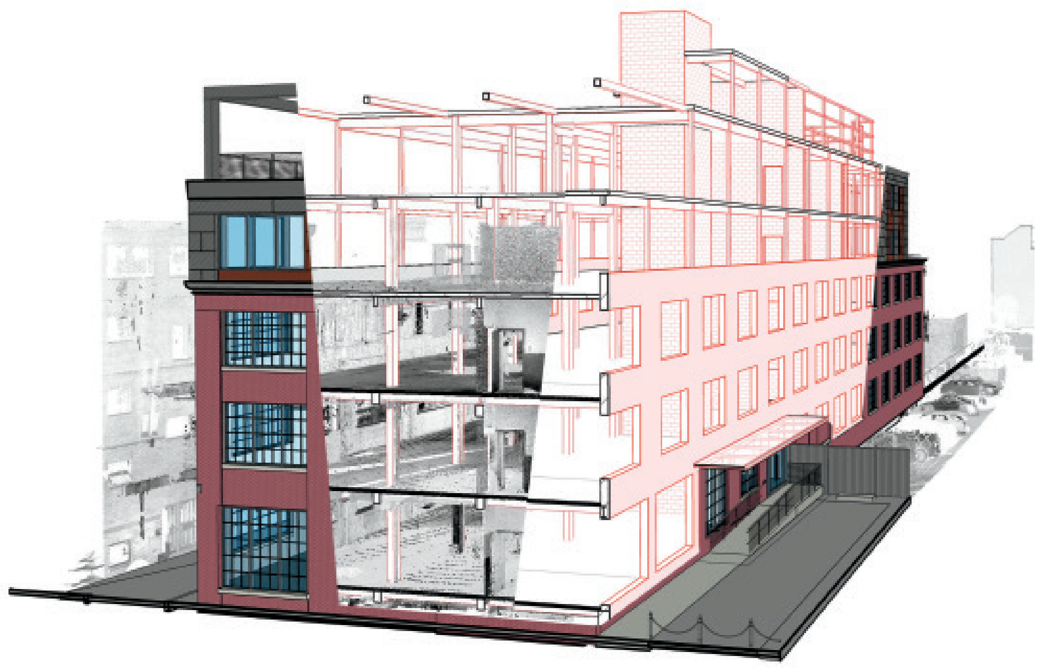


Figure 2.77: South Boston Rivet Factory. This 120-year-old masonry and heavy timber structure underwent a two-storey addition using cross-laminated timber (CLT). The lightweight nature of mass timber eliminated the need to reinforce the existing foundations to support the addition. As well, the prefabricated kit-of-parts approach to the new mass timber building structure lent itself well to the constricted urban site. Challenges included that the existing structure was not plumb, and careful consideration was required to tie in the fairly precise CLT members with the irregularities of the existing structure. To navigate this issue, a concrete spandrel beam was installed at the perimeter of the existing structure for the CLT structure to be placed on top. The mass timber structure of the proposed addition was erected in six days.

Image courtesy: Project architects margulies perruzzi and CIEE building owner

When working with existing buildings, there are many complex issues to consider, including;

- Strategies for managing the variations that exist with older buildings against the precision of mass timber members must be carefully planned out early on in the design process.
- Managing aesthetic of new construction with existing.
- When heritage resources are involved, carefully considering the attributes of the heritage resource and working closely with Authorities Having Jurisdiction.
- Adequate protection of existing structures during construction and managing water and thermal barriers to minimize water penetration.
- Carefully considering thermal and moisture transition details between old to new.
- Structural capacities of existing structure and foundation to manage additional loads.

Figure 2.78: Illustration representing design opportunities with adding storeys to an existing building.
Concept rendering by Studio Veronica Madonna Architect.

2.6 Zoning

In addition to the building codes, there are other requirements such as zoning regulations and urban design guidelines that must be considered in mid-rise buildings. Each municipality may have restrictions in height, density, exposure, form and use that must be considered early in the design process. These regulations can impact overall building height and number of storeys and must be considered carefully at the beginning of a project.

In Toronto, the objectives of the city's Performance Standards for Mid-Rise Buildings is to create healthy, livable and vibrant main streets and guides density to support sensitive neighbourhoods. This standard's key recommendations include a tall ground floor for the animated ground floor, street wall, and maximum height.

Regulations of floor heights found in the zoning regulations can impact the building's structural system and design strategy. For example, maintaining a tall ground floor may restrict achieving six storeys due to the system's structural depth. The regulations for minimum ground floor height can also be seen in other cities.

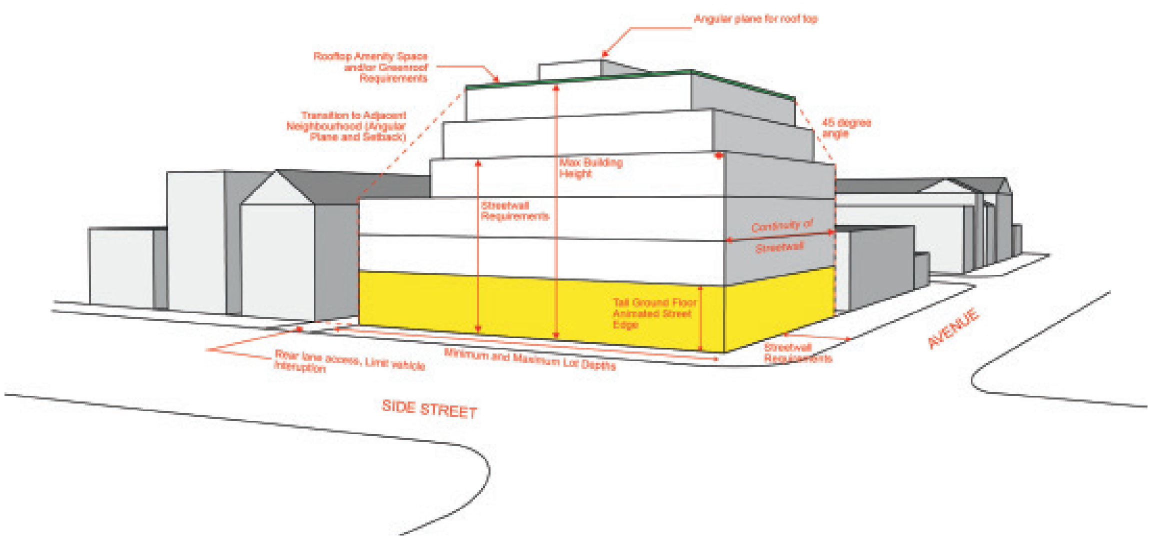


Figure 2.79: Example of zoning complexity that may vary in various municipalities. Above is the City of Toronto Performance Standards for Mid-Rise Buildings illustrating requirements for the street wall, animated and tall ground floor and height transitions. Prior to beginning any building project, it is imperative to understand the zoning requirements in the local municipality.

The requirement for regulating the street wall height is also an important consideration. The maximum height before stepping back in the building form may be controlled. For example, in Halifax, there is a maximum building height of 18.5 metres along the street wall, in which case the building must step back above this point. Also, some neighbourhoods may restrict maximum building height. Maximum height requirements may vary from neighbourhood to neighbourhood, so detailed zoning analysis must be done at the beginning of a project.

Street wall requirements in certain zoning areas of Edmonton require that buildings that are over 10 metres in height, be set back a distance from the setbacks and lot lines. These setbacks require careful consideration when planning the structural system to accommodate vertical load transfers of the structural members.

Cities across Canada are recognizing the importance in encouraging mid-rise construction. Vancouver has recently passed new zoning regulations in areas were previously not permitted, to allow for six-storey residential buildings as a means to increase housing. In addition, 35% of the homes are to be sized for larger families with two or more bedrooms along with high sustainability standards.

Edmonton's development of the "Missing Middle" is a strategic planning initiative geared to promote multi-unit housing that falls between single detached homes and tall apartment buildings. This strategy includes multi-unit mid-rise developments.

As well, recent projects such as Toronto's R-Hauz multi-unit mid-rise development, is a built example of a mass timber infill project demonstrating design and construction innovation. New Brunswick recently adopted the 2015 National Building Code allowing for mid-rise construction opening the doors for more density and housing supply.

Other cities like Montreal, have been promoting mid-rise development for many years now and, in fact, has the least amount of land coverage by single-family houses in favour of multi-unit developments.

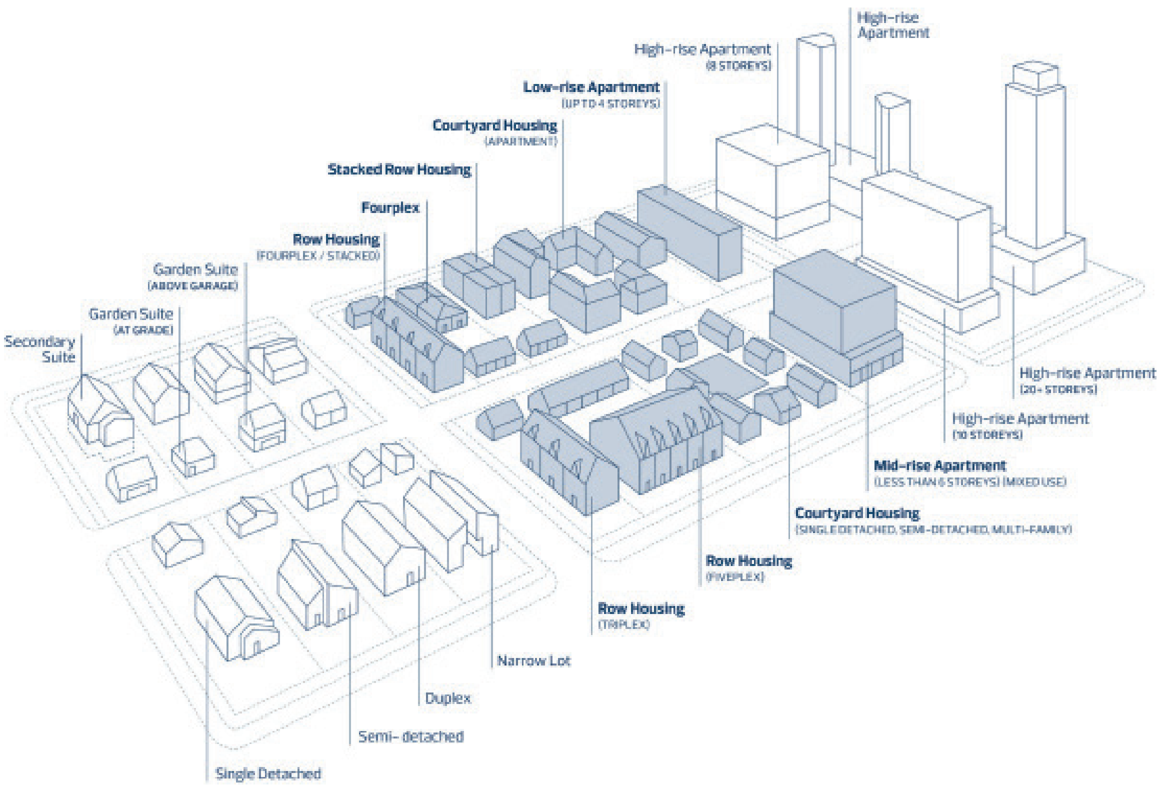


Figure 2.80: City of Edmonton's diagram of the "Missing Middle".

Source: https://www.edmonton.ca/city_government/urban_planning_and_design/missing-middle-housing.aspx

2.7 Design Prototypes

Residential Infill

Figure 2.81: Rendering of a multi-unit residential prototype building.
Concept Rendering by Studio Veronica Madonna Architect.

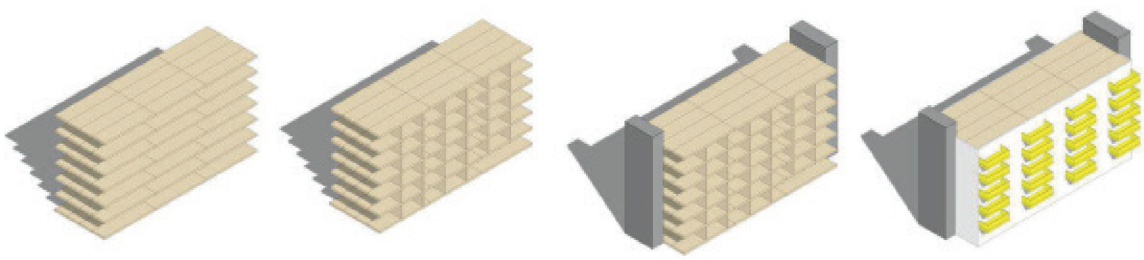


Figure 2.82: Concept illustration of a 6-storey mid-rise multi-unit residential building utilizing a CLT panelized structural system.

Figure 2.83: Concept floor plan of a CLT multi-storey residential building illustrating a flexible unit design using a modular approach. The plan accommodates one-, two- and three-bedroom suite layouts with consideration of adaptability over time.

Floor plan design by Studio Veronica Madonna Architect.

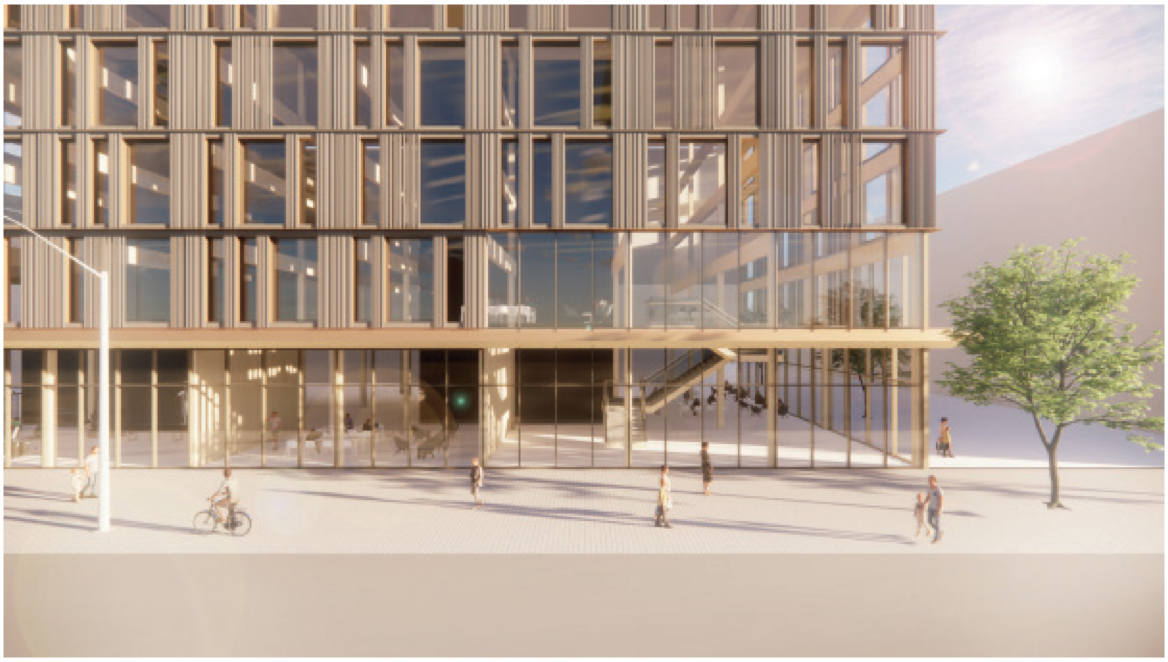


Figure 2.84: Rendering of an office prototype building.
Concept design by Studio Veronica Madonna Architect.

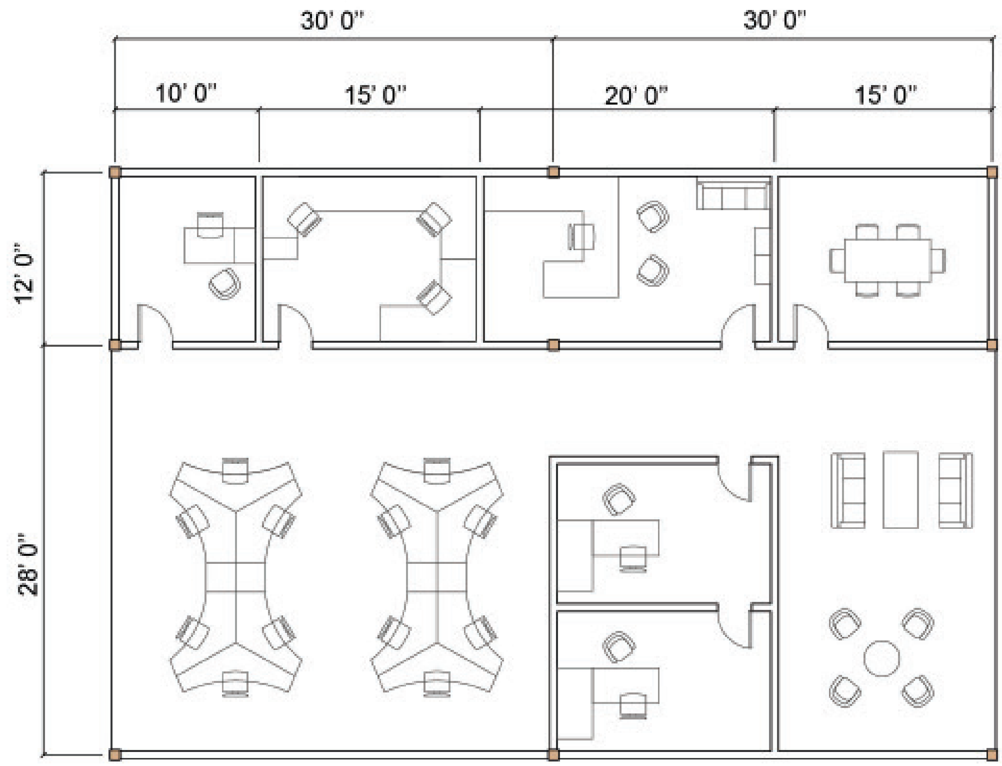


Figure 2.85: Plan illustration of a typical office plan layout utilizing a 30' x 30' (9.1m x 9.1m) mass timber framed system.

Floor plan design by Studio Veronica Madonna Architect.

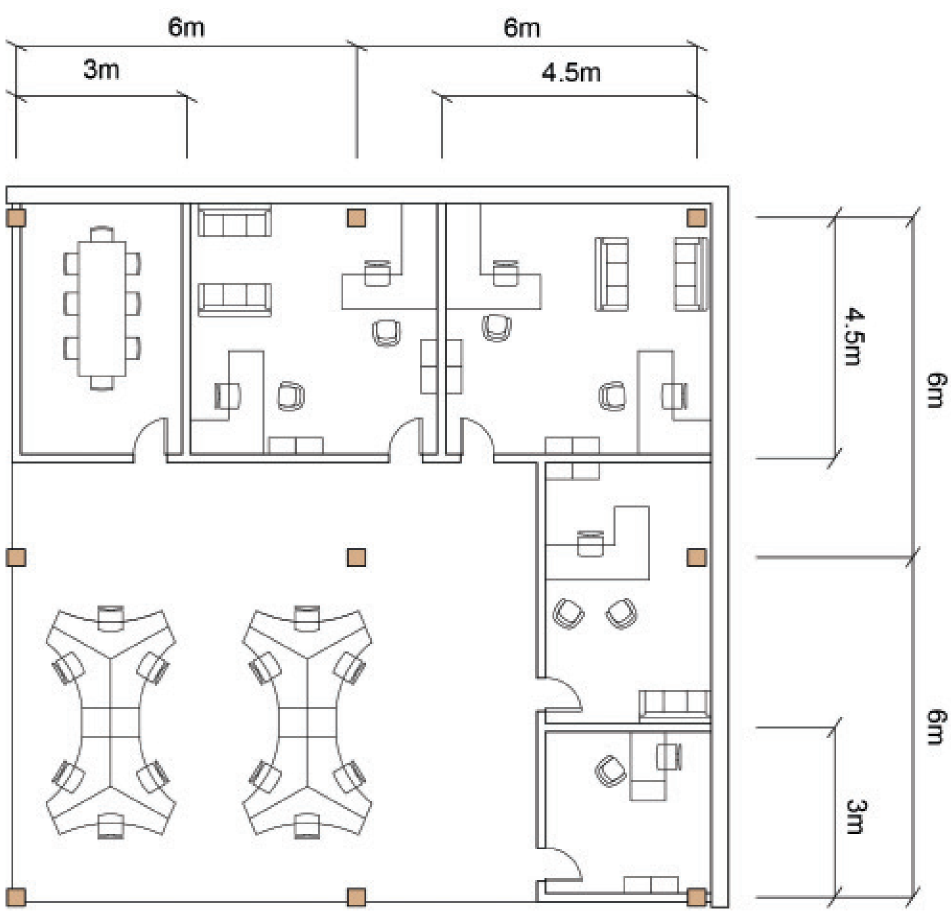
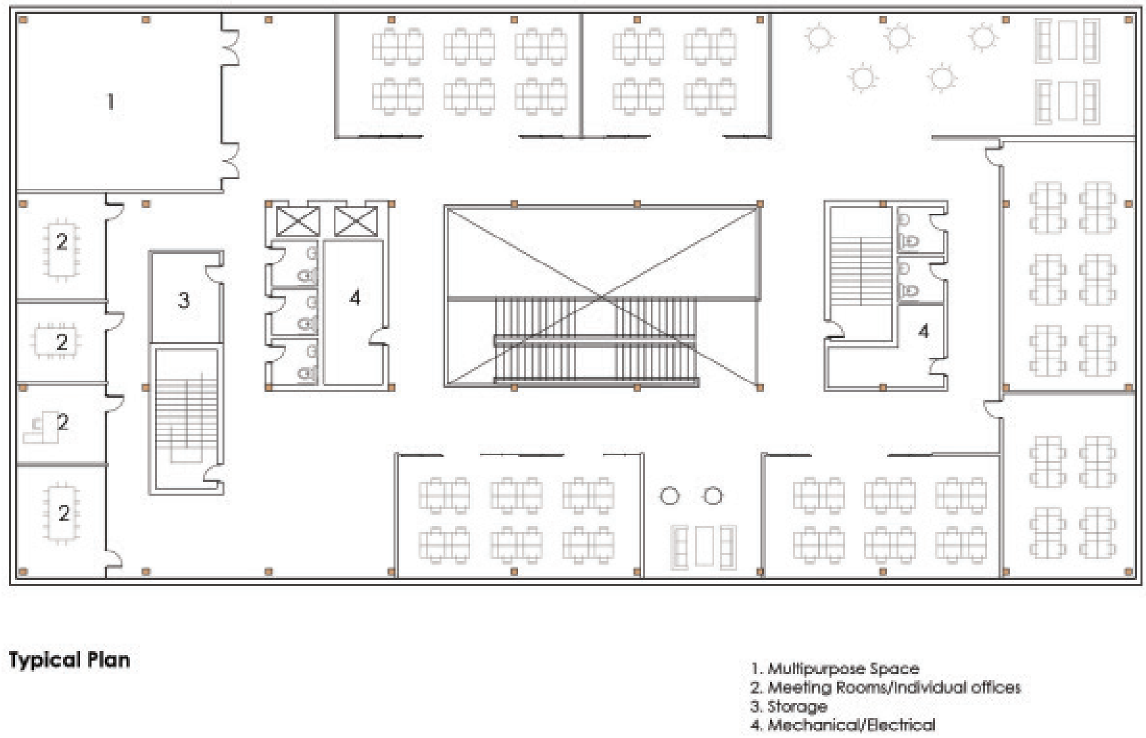


Figure 2.86: Plan illustration of a typical office plan layout utilizing a 6m x 6m (19'-8" x 19'-8") mass timber framed system.

Floor plan design by Studio Veronica Madonna Architect.



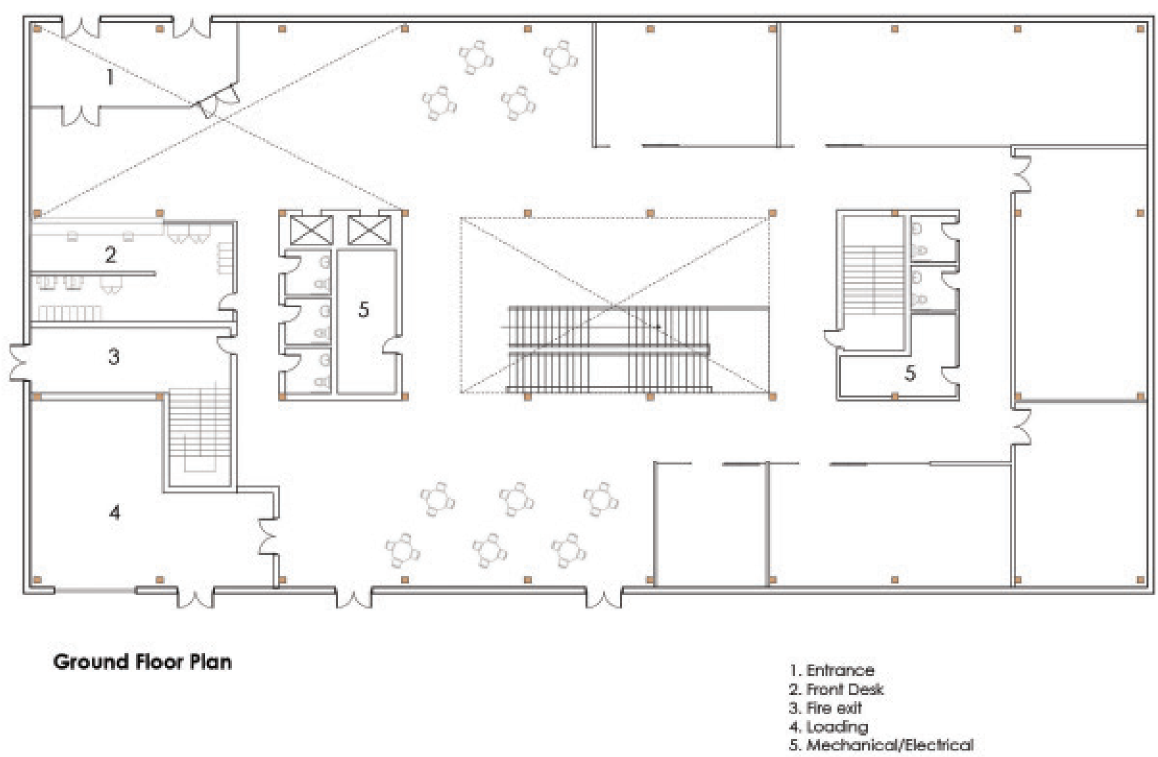


Figure 2.87: Typical office building floor plan, with a 9m x 6m structural bay size.

Floor plan design by Studio Veronica Madonna Architect.

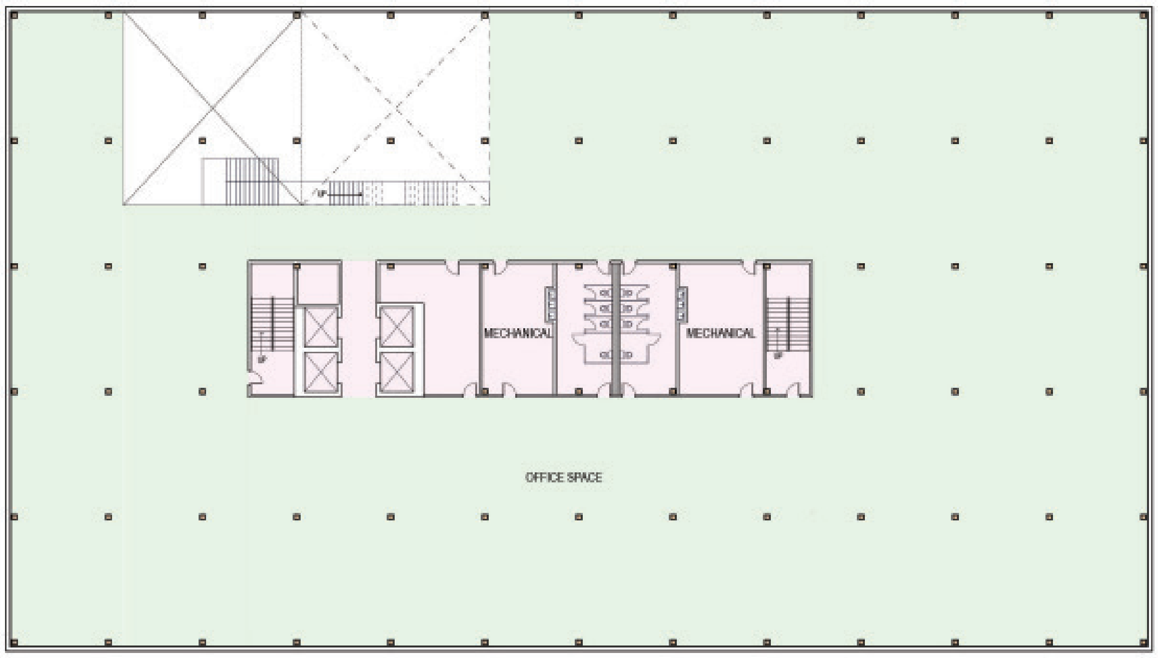


Figure 2.88: Typical office building floor plan, with an 8m x 6m structural bay size.
Floor plan design by Studio Veronica Madonna Architect.

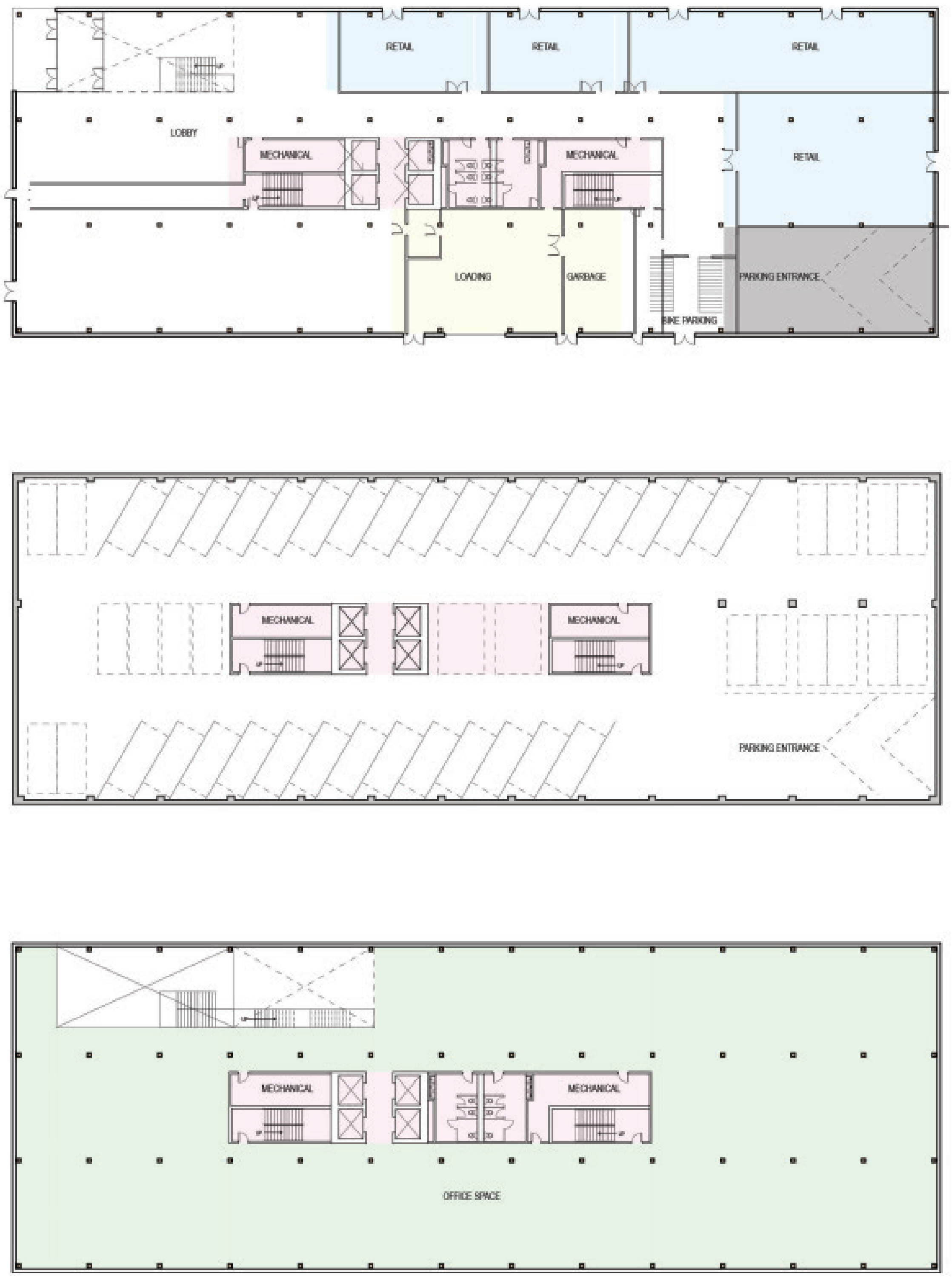


Figure 2.89: Typical office building floor plan, with a 9m x 6m structural bay size.
Floor plan design by Studio Veronica Madonna Architect.

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3 Defini g the Business Case

3.1 Value

Across Canada, population growth is expected to rapidly grow in the next five to twenty years. Most of that growth will be absorbed by provinces and will be centred in existing urban areas. A scarcity of developable land will face planners, as suburbs reach their outer limits. The influx of people will create considerable demand on existing infrastructure in urban centres but gives us the opportunity to rethink how we live and use spaces. Creating healthy and affordable housing options and business and work opportunities, will play a key part of how urban planners will create the capacity for a city to absorb this growth. Strategies around affordable housing, greater intensification and density, and healthy and vibrant liveable and walkable neighbourhoods, will all be important parts of the solution to the opportunities that will follow. Building professionals, including city planners and designers, all have a responsibility to optimize their processes in favour of decarbonization. Sustainability should be a factor in all building decisions being made, from design to product selection.

Mid-rise building, as we have shown, can provide part of that solution towards managing our population growth projections. Human-scale development, mixed-use buildings provide high quality, and highly sophisticated solutions that achieve greater density, create vibrant local economies and communities, and can be centred around existing infrastructure like public transportation, community services and schools.

Throughout **Section 2**, the factors that affect a project's overall budget have been illustrated. Early design considerations should focus on design optimization of structural systems, understanding the supply and procurement channels, utilizing repetition, efficient connection design and constructability of the building.

3.1.2 Carbon, Sustainable and Green Construction Goals

Using wood as a construction material leads to the development of greener more environmentally-friendly buildings. The negative impacts of carbon emissions are becoming more mainstream and understood. Builders and developers are realizing that their clients, potential buyers or renters, are thinking about healthier and greener ways to live and work. Cost-effective solutions to this opportunity and responsibility can be realized with wood construction. Wood products and systems lower the carbon footprint of buildings and turn buildings into carbon sinks by storing captured carbon for the life of the building.

Embodied carbon is the amount of carbon found in the extraction, manufacturing, and processing stages of building materials, including the deconstruction and disposal at the end of life of the building.

Operational carbon is the amount of carbon emitted during the operational or in-use phase of a building. This includes the use, management, and maintenance of a product or structure.

Humans naturally respond to the environment created by building with wood. Natural materials greatly effect overall health and well-being, reducing stress related health issues. The ability to create well thought out environments for living and workspaces that mandate ecological design is a significant opportunity for the construction industry.

Architects and design teams will be taking up the challenge of greener and higher sustainability targets that building owners will set out as their desired result. Jurisdictions will be mandating conformance and adoption of higher design and performance standards like Net-Zero, PassivHaus, LEED and the Living Building Challenge, to name a few. Materials will come from natural sources and be renewable in nature. These will be coupled with stricter energy requirements, utilizing energy that comes from renewable sources.

An example of this in practice currently is seen in Toronto. In 2010, the City of Toronto implemented the Toronto Green Standards (TGS) as a basis for the Climate Change Action Plan, which is an environmental framework aimed at reducing the city's greenhouse gas emissions by 80% by 2050. The TGS targets five categories of performances including:

- Air quality and reducing the urban heat island effect.
- Energy efficiency, GHG emissions reduction and resilience to power disruptions with a focus on renewable, greener energy.
- Water balance, quality and efficiency for stormwater management.
- Ecology: protection and enhancement.
- Solid waste reduction

The city of Vancouver has set a target of reducing embodied emissions by 40% by 2030, as part of the city's declaration of a climate emergency. This ambitious target will encourage innovation in all types of construction materials. Focusing on building design and engineering, and helping to position local industries as leaders in low-carbon construction.

The following strategies that have been discussed throughout this document, form part an integral part of the design process, and help to reduce embodied carbon in buildings:

Efficiency: Sustainable building design can form part of the early planning and concept design for any project well before construction starts. Carbon emissions can be understood with material selection in mind. Constructability goals can be understood by discussions early on with factory and prefabricated systems in mind, and the entire life cycle of materials being considered. Designing with efficiency and sustainability in mind can greatly reduce a building's carbon footprint. A client may have set targets for minimizing the impact of the building (3.1 Value). These goals can form the discussions around optimization of grid spacings and material sizes – part of greater design and material efficiency. Thinking about supply, products and build sequencing as early as possible will optimize success.

Less material: The less material required for a project, the lower the environmental impact. This may result in a more efficient, compact building form, which can reduce a building's total embodied carbon. Considering wood building systems results in a decrease in embodied carbon. Off-site and modular construction should be considered early in planning and design. Simplicity and repetition is a major factor in project cost reduction. Duplication of simple structural systems, as we have seen in the earlier architectural section, allows fabrication processes to optimize efficiency. This becomes more attractive and important as larger, more repetitive project types start using this methodology.

Less waste: Utilizing the factory-built environment and supply will lead to significant waste reduction on site, and is a key consideration that should be explored and discussed at design concept. There must be collaboration between designers, suppliers, and contractors to specify procedures that minimize waste. Waste is cut down on site, as prefabricated systems have optimized material use in the factory, and site waste is minimized.

Longevity: Consider entire life-cycle cost of materials. Durable products help prolong the life of the building and will prolong the carbon capture benefits of the wood building materials. Design with deconstruction and material reuse in mind. Materials with the ability to be disassembled and be reused help decrease the impacts of waste.

The value proposition that green building offers is becoming something of high value and growing interest to investors. Many investors and investment groups are applying ESG metrics as part of their analysis process – identifying material risk and growth opportunities. Development companies that understand how valuable sustainable and green buildings are should use some of the illustrated ESG trends that are emerging, covering climate change to social unrest to attract investment. Most recently the COVID-19 pandemic, in particular, has intensified discussions about the interconnectedness of sustainability and the financial system. This is definitely an area of tremendous growth and business opportunities, focused on materials mattering in their selection and use on a project, and the types of communities that will be created by the development.

Figure 3.1: Environmental Social and Governance are the three main factors that socially responsible investors measure when deciding whether to invest in a company. It is a generic term used in capital markets.

Courtesy Market Business News.

Environmental criteria: examines how a business performs as a steward of our natural environment, focusing on: waste and pollution, resource depletion, greenhouse gas emission, deforestation, climate change

Social criteria: looks at how the company treats people, and concentrates on: employee relations and diversity, working conditions, including child labour and slavery and local communities and seeks explicitly to fund projects or institutions that will serve poor and underserved communities globally, health and safety, and conflict

Governance criteria: examines how a corporation polices itself , how the company is governed, and focuses on: tax strategy, executive remuneration, donations and political lobbying, corruption and bribery, board diversity and structure.

3.1.3 Business Case Benefits of Wood Construction Systems

Building with factory produced light-framed systems and mass timber systems allows for rapid building. By the reduction of on-site installation and build schedule, the benefits of time savings in erection time and the impact on the build schedule, allows developers and builders to see substantial cost savings associated with carrying costs for a project. Cutting unnecessary site waste and dumping fees, impacts construction costs and the projects overall budget.

Several factors typically delay construction and build process performance, including weather, material supply, site trade coordination, design and change orders, sub-contractor performance and cash flow, to name a few. Approaching the project with an industrialized approach could result in a more efficient project.

Utilizing Efficiency

Projects that utilize the concept of efficiency from early planning and concept stages, have the ability to carry it through the entire design and project build.

- Detailed planning and scheduling coordination can set an aggressive schedule that will fully utilize off-site building technologies and greatly reduce on-site erection and assembly.
- Material optimization, repetition of assemblies and connections.
- Construction management processes will see sequencing improve and will utilize just-in-time delivery of components to rapidly progress the build. Communication of all parties improves, leading to fewer change orders that typical impact profitability.
- The precision and quality of prefabricated components is high, industrialized, off-site manufacturing processes in a controlled environment can incorporate automated or semi-automated ideologies. Utilizing quality control procedures in-house to maintain quality and performance of wood systems.
- Production of structural wood systems and components runs parallel with site clearing, excavation and foundation work, rather than a linear timeline seen on a project using traditional methods of construction.
- Follow-on trades can start rough in immediately, as there is no formwork to strip or shoring and curing time required. Floor decks and platforms are typically stable and load bearing.
- Budgets and costs are met by incorporating this approach- site and time wastage is minimised, installation on site is optimized.

Materials & Labour

Designing projects with materials and systems that are readily available in the existing marketplace will help with procurement and sourcing strategies. Delivery times need to be understood in early schedule development.

- More locally sourced materials may form part of the green strategy that the project utilizes. Discussions on systems needs to start early in the process.
- Qualified labour and skilled trade shortages is a growing concern to builders, so approaching large-scale projects should incorporate discussions on installation and erection of the building as part of the industrial approach. Think about the construction phase: are the trades needed available locally?
- More remote project locations or those being planned in smaller communities will have a smaller labour pool. Are the necessary skills and knowledge available?
- Structural system manufacturers and material suppliers can provide highly skilled installation teams that are well versed in craning techniques, health and safety protocols, on-site installation of wood products, systems and assemblies. A benefit to this type of installation method consideration is the speed and efficiency it creates.
- Labour organizations are regularly updating their members on the newest material systems, fastening techniques, connections, and installation procedures. Wood assemblies on larger and taller wood projects need a high degree of skill and precision. Having a resource of labour and installation teams with the necessary qualifications and certification is very important.

Site works

- Building weight: Wood is lighter than other materials. The reduction in the mass of the buildings has advantages, typically by reducing the necessary lateral system designed, the size of footings and foundation decreases. Less reinforced concrete is needed for the same sized structure. This can be of significant advantage for wood buildings, especially if poor soil conditions are present. Higher unit volumes are possible on the same site footprint.
- Wood projects typically see a reduction off ite infrastructure such as scaffolding, formwork and pumping equipment. The installation of formwork adds not only cost, but also time to assemble and remove.
- Health and safety advantages of using off-site prefabrication. Less time spent on site by erectors.
- Crane costs: Lifting is quicker and can be achieved with smaller cranes and/or shorter equipment rental times and related costs.
- The building is closed in and watertight sooner.
- Fewer site deliveries and traffic disruptions. Just-in-time delivery optimization.
- Less dust, noise and impacts to established neighbourhoods during build phase.

Overhead

- Rapid erection and greater productivity of workers on site can have significant impact on lowering a project's overhead costs.

Value

- Construction duration reduced in terms of time and total site time.
- Reduction in Course of Construction Insurance duration by shortening project timelines.
- Loan rates and financial carrying costs can be reduced by the expediting of the build schedule. A time savings of two to three months off he build schedule will have significant financial impact to the bottom line for of any project, for example.
- The leasability of premium office space: Faster leasing, and longer leasing tenants are attracted, as architecture plays a significant role in client retention. Contract periods can be extended and premium lease rates achieved.
  - Buildings with clean air, plenty of natural sunlight, and other tenants of good health have become increasingly important for companies bidding to pull people back into the office after the pandemic. Healthy buildings with low embodied carbon materials and a focus on biophilic design have the potential to attract premium tenants.
- A premium is realized for space created with exposed structures. See the case study from USWW: – https://www.woodworks.org/wp-content/uploads/case_study-MT-Office-Case-Studies.pdf
- Value at sale time: Exposed timber buildings command a premium in markets where high quality architecture is prized.
- Market differentiation: Wood buildings give clients something different.

3.2 Sustainability

Life-Cycle Assessment

The choice of construction products has a significant impact on the environment. Although still at an early stage of market adoption, the life cycle environmental costs (impacts) that occur outside of direct building operations are increasingly being factored into project decision-making.

Life cycle assessment (LCA) is a universally accepted science-based method to evaluate the environmental impacts of products and services that go into buildings, as well as the buildings themselves over their entire life cycle, i.e from raw materials extraction to final disposal. LCA is finding its way into green building rating systems and in procurement models in Europe.

Using LCA, the project team can evaluate a broad range of environmental considerations (such as embodied energy, global warming potential, impacts on water quality, impacts on human health, etc.) against explicitly declared criteria and give a summary of environmental performance. Such assessments can be used for benchmarking performance and monitoring progress towards improvement of performance. LCA is a powerful way to inform owners and the project team of the impacts associated with a material, product or entire building and also provides a basis for demonstrating and communicating the result of efforts to improve environmental performance in construction works (assemblies, structures, civil infrastructure, etc.).

LCA largely addresses the non-financial impacts of buildings and is, therefore, not considered in life-cycle costing in current practice. However, as owners begin to integrate the economic, social and environmental goals into a triple-bottom line procurement model, LCA will become increasingly important.

Owners can ask for LCA to be conducted on the proposed building (or any portion) to determine the lowest environmental footprint for specific factors such as embodied energy, carbon and more. To meaningfully inform decision-making, LCA should be undertaken early in the design process.

Source: Procuring Innovation British Columbia Construction Association

4 Insurance

4.1 Course of Construction Insurance

Course of Construction Insurance, also known as Builders Risk Insurance, is a type of property insurance designed to provide temporary coverage against damage or loss during the course of construction. Course of Construction Insurance can cover the structure only, or can be expanded to include building materials on the job site and in transit coverage.

Course of Construction Insurance can be purchased for new construction and renovation projects and protects against damage done to the insured structure from a variety of events. Most insurance policies cover against property damage from fire, wind, theft, explosion, and vandalism, generally for losses that might occur from operations related to construction. Additional coverage may have to be added for flood and earthquake coverage as these are not generally included in basic policy coverage. This is generally dependent on where the project is located and may have to be considered.

Course of Construction policies are usually written in three-, six- or twelve-month terms. If the construction project is not completed by the end of the initial policy term, a policy may be extended. Builders Risk Insurance is not usually an option on construction projects, especially for new construction. A valid Certificate of Insurance is a requirement of the municipality for construction to start. Coverage is intended to terminate when the work has been completed and the property is ready for use or occupancy. The new owner should then commence permanent property insurance on the building such as a homeowner's policy or a commercial property policy.

Insurance costs generally run between one and four per cent of the construction cost, depending upon the type of insurance purchased and exclusions from coverage.

Insurance policies that are intended to cover financial losses of larger buildings are considered higher risk for insurers. There are fewer insurance carriers that underwrite builders risk policies, compared with other types of property insurance. However, there are many markets offering builders risk insurance. Insurance companies look at a number of factors in order to offer their best rates and conditions of insurance for the building.

4.2 Selecting the Right Broker

Selecting the right insurance broker and company is important. Finding a broker that understands the materials, applications and approach to a mid-rise wood project is important. As outlined throughout this document, communication is a necessity in all aspects of the design phase. Building good insurer relations is a key step and a good opportunity for education on the rapidly innovative construction practices, materials and methods that are taking place for wood projects.

In selecting a suitable broker, they need to be experienced and knowledgeable in handling similar types of business. Your broker will know what information is required by the insurance companies to get the best premium rates and have the right insurance companies at hand to approach. Preparation is vital. Know your project, know your approach to the build, know your materials and their applications, and know your approach to risk management. Pass this knowledge along to the broker in order for them to assist in finding the right insurer. More mid-rise wood opportunities will be coming as growth plans become more of a focus and priority for municipalities. Build the broker relationship and carry it into the next projects.

The brokerage should be large enough to have contact with a number of leading insurance providers to write the course of construction business. The broker will manage rate comparisons and know which company is the best fit in terms of staff xperience, in-house knowledge, handling of claims and legal resources.

The Canadian Wood Council continues to engage with the insurance industry, identifying knowledgeable brokers that are familiar with wood construction.

4.3 Factors that Impact Insurance Policy Costs

A number of factors impact the rates that determine the total premium costs quoted by the insurer. The developer and the design team generally have little impact or influence on what the insurer uses to set as the base rate. The base rates are assigned on general industry experience, typically looking at loss history of that particular building type and sector of the construction industry. Loss history is tracked by area and province, and type of construction (use and size).

Generally, the broker will assist in helping develop base rate modifiers. These are factors that build a level of comfort with the insurers to show that risk factors on site are carefully managed, and previous experience and knowledge that has been acquired by the builder has built a safety conscious and risk adverse approach to projects. Rate modifiers can include:

- Obtaining certificates of insurance from project sub-contractors limits the risk exposure to any loss that maybe of fault of the sub-contractor.
- Project architects and designers who are on the project that carry Errors and Omissions (E&O) Professional Liability Insurance reduces Course of Construction risk.
- Higher deductibles. The insured is willing to share more responsibility in case of a loss or claim.
- Compliance with loss-control and underwriting recommendations builds trust working towards improving the risk.
- Outlining site policy and procedures related to material storage, waste handling, and sources of ignition (site hot work protocols).
- Site security and fire safety planning.
- Details of past claims-free experience with similar projects.
- Previous insurers.

4.4 Insurance Warranties

Warranties are special conditions that are included in a policy that can restrict or deny insurance coverage if the special conditions are not followed. The importance in adhering to warranty special conditions is amplified during hard market conditions or when the frequency and cost of losses increases.

During a hard market, insurance companies tend to enforce these warranties without exception, conducting site inspections and audits of construction sites that focus on compliance with warranty.

Tying back to how the broker and builder have modified rates to reduce premiums, due diligence by the builder is required. A risk management programme should be developed, specific to the project site and build, containing insurance warranty requirements. Risk management is normally the site superintendent's responsibility for implementation and enforcement. Therefore, they must be aware of warranty requirements that have been signed and agreed to by project management, as failure to comply can invalidate the projects insurance coverage.

4.5 Site Risk Control Guidelines

Developing a site-specific risk management programme helps control site specific hazards and reduces accidental losses.

Implementation of developed guidelines can be managed by creating daily or weekly logs or checklists, helping to monitor compliance and hazard control. These protocols can include:

- Access for firefighting and emergency services.
- Ensuring an adequate and reliable water supply is available.
- Coordinating operational fire protection equipment like standpipes, hose stations, and temporary sprinkler systems (when possible), providing active fire control in synch with the development progression.
- Separation walls and fire barriers completed as development progresses.
- Implement a site specific "Hot Work Permit System."
- No-smoking policy enforced on site.
- Site security procedures. Site monitoring, security fencing and hoarding (after hours security and lighting). Motion-activated cameras and site surveillance.
- A fire safety plan containing all emergency procedures, roles and responsibilities of key site personnel, training of site personnel, posting site emergency procedures, fire extinguisher training and accessibility.
- Portable heaters procedures: Type, required procedures for permits and monitoring.
- Development of a safe work plan.
- Waste management procedures.
- Material storage of combustible materials.
- Storage of highly flammable fuel sources in a fenced storage compound.

Daily or weekly logs should be recorded and kept, noting dates of inspections, review of protocols and regular training given to personnel. Records may have to be submitted to validate warranty compliance and during site inspections by the insurer.
(Section 5.8 Construction Site Best Practices)

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5 Technical Design Considerations for 5- and 6-storey Wood Buildings

5.1 Introduction

Th ***Technical Design Considerations for 5- and 6-storey Wood Buildings*** section is intended as a technical supplement, designed to help designers better understand some of the practical considerations needed for the construction and design of mid-rise wood buildings. It is written for design professionals in the construction industry, and builders with the necessary skills to approach taller wood buildings. None of the elements presented in this guide shall be interpreted as contradicting existing regulations. This guide refers to the National Building Code of Canada 2015 (NBC 2015) and Provincial Building Codes for combustible construction that are contained in the code matrixes in **Section 1**, 5- and 6-storey residential occupancies (Group C), business and personal services occupancies (Group D), and some mixed major occupancies.

An objective of this guide is to ensure that 5- and 6-storey wood buildings perform well and successfully meet structural, architectural, safety and comfort requirements while taking building durability, cost efficiency and their environmental footprint into consideration. It presents specific considerations for these buildings while examining requirements related to the structure, fire prevention, building mechanics, architecture, prefabricated structural elements and best practices for the construction site.

Section 5 was prepared by the inspiration and guidance garnered from translating the **(Cecobois 2016) Guide technique sur la conception de bâtiments de 5 ou 6 étages à ossature légère en bois.**

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5.1.1 Considerations for 5- and 6-storey Wood Buildings

Several factors need to be considered when designing and constructing a 5- and 6-storey wood building. The level of complexity increases for wood buildings higher than 4-storeys. The primary structural system, the types of materials, specified assemblies, how gravity loading affects wood behaviour, dimensional changes in wood, types of connections, fastenings, and tie-down systems, must be carefully studied and understood. Review and attention is required for building envelope design, fire protection and life safety requirements. **Table 5.1** summarizes some important points that need to be considered when designing mid-rise wood buildings. The issues presented in the following table are discussed in the various sections within this chapter of the guide.

Table 5.1 Specific considerations for 5- and 6-storey wood buildings

Category	Element	Issues & Recommended Solutions
Structural Design *(Section 5.3)*	Mid-rise light wood-frame structures	Prescriptive detailing and/or practices that are commonly used in designing small light wood-frame buildings are not acceptable for mid-rise buildings. They must be designed based on engineering principles.
	Loadbearing walls	Studs in loadbearing walls, particularly in the lower floor le els of mid-rise buildings, will be supporting significa t loads, which may require the use of closer stud spacing, doubled-up or built-up studs. Higher grades of wood, different species, or even an engineered wood stud may be required.
		Quality control is critical. Prefabricated walls can offer a solution with several advantages: compliance with prescribed wood grades and reduced moisture content, material tolerances used in manufacturing, and a reduction in total construction time on site.
	Top and bottom plates	It is important to consider constraints related to bending, shear, and compression perpendicular to grain. Top and bottom plates contribute significa tly to vertical movement, the type of material used, and moisture content (MC) is very important.
	Vertical movement	Vertical movement must be calculated and clearly indicated on structural plans to ensure that the building's architectural and mechanical elements are designed with this movement in mind. All members must comply with the moisture content specified y the structural engineer.
	Floor joists	Prefabricated floor trusses or I-joists a e one solution for light-frame wood construction with lower moisture content (MC). Double rim joists may be required to avoid load transfer issues on lower storeys.
	Beams and lintels	Support reactions in beams and lintels accumulate toward lower storeys and require increasingly large bearing surfaces to prevent crushing. Engineered wood members may be required to accommodate higher bearing loads. MC is typically lower, potentially reducing the shrinkage effects.

Category	Element	Issues & Recommended Solutions
	Lateral loads	Defle tions in the lateral force resisting system are critical and must be calculated. To ensure the system is installed properly, the location and composition of the shearwalls, and location of hold-downs and anchors, must be clearly indicated on structural drawings.
		To ensure the correct functioning of the lateral force resisting system for a mid-rise wood building, hold-downs with shrinkage compensators are typically used, a system providing equivalent performance, detailed by the structural engineer.
Fire safety ***(Section 5.4)***	Fire-resistance	60-minute fi e-resistance rating (FRR) is required for floo , wall, column, and roof structural assemblies.
	Sprinkler protection	5- and 6-storey buildings are required to be sprinklered throughout, with a system designed in conformance with NFPA 13.
	Concealed spaces	Depending on the arrangement, many combustible concealed spaces (e.g., floor or oof assemblies) must be sprinklered in accordance with NFPA 13. There are exceptions, such as those spaces containing non-combustible insulation or spaces with all surfaces having a flam -spread rating of 25 or less. Particular attention is necessary for unheated spaces that are subject to freezing.
	Exterior cladding	Not less than 90% of the exterior cladding on each exterior wall shall consist of noncombustible cladding; or, a wall assembly that satisfies the ode criteria when tested in conformance with CAN/ULC-S134
Prefabrication ***(Section 5.7)***	For prefabricated panel systems	Particular attention is required for connection detailing between prefabricated systems (walls, floor , roof).
	For modular construction	Special attention by building designers must be given to the intersections and connection to adjacent modules to limit the building vertical movement.
Good jobsite practices ***(Section 5.8)***	Fire protection	During construction, wood construction assemblies are most vulnerable to fi e as fi e safety systems are incomplete. Fire safety planning measures must be implemented, controlling sources of ignition and fuel, and full-time site security and monitoring is suggested.
	Weather protection	Using prefabricated framing systems and components ensures closer control of wood moisture content. Wood products and systems should be protected from adverse weather effects until the building is fully enclosed, maintaining the lower moisture levels required in the design.
	Lateral restraints for loadbearing walls and temporary bracing	5- and 6-storey buildings have significa t vertical load transfer through the lower storeys. Temporary lateral restraints must be planned as necessary for the studs of loadbearing walls until the gypsum board or wood panels have all been installed.

5.2 Communication Between Professionals

When designing a 5- or 6-storey wood building, there are some specific considerations that will help ensure the project's success. **Table 5.1** provides a summary of some important points that should be discussed. This following section covers communication between design professionals and constructors and focuses on the roles and information exchange that assists in the design process proceeding successfully.

Section 2.2 deals with early approaches that help to optimize design. A key component for this to be successful and for the process of Integrated Project Delivery and Integrated Design to work successfully (**Section 2.2.1**), is a good communication strategy. Projects benefit from constructive and clear communication strategies between everyone involved in the design and planning process and should begin as early as possible. The project team can discuss managing any environmental and performance targets, procurement strategies and procedures, project management, building a schedule and the projects constructability. All of these areas affect the project budget, and optimizing cost-efficiencies is a key benefit to this approach.

Many design elements are interconnected, from the primary structural system concept, the buildings layout, created spaces and aesthetics, fire safety, vertical movement management and mitigation, acoustical performance, building envelope, wood systems and structural components, installation methods and logistics. All parties benefit from early interaction with each other, creating a collaborative design environment from the beginning.

Early coordination and interaction with material suppliers and installers, means that light-framing components and/or mass timber elements can be optimized. Different occupancy types and building uses require different design approaches that an architect and structural engineer will need to consider. Understanding the available supply channels is part of the procurement process. Achieving time savings during the build phase may require developing an understanding of production run times, order timelines, material availability, costing and estimated delivery times; considerations that an architect and structural engineer will have to carefully balance.

5.2.1 Architect

Architects have the big-picture view of any project, allowing them to observe how the different constraints of a project affect each other. Throughout the design development and construction planning phase, early decisions on structural systems and materials ensure optimal design. Interacting with the structural engineer ensures that the structural systems are integrated into the overall building aesthetic and expression early on. The structural system defines layouts of grids and bearings that create the interior spaces, ceiling lines and aesthetics. The orientation and length of joists, beams and roof trusses determines the location of walls or supports forming interior and exterior loadbearing. External wall elevations may have locations of door and window openings affected by the structural system layout as load paths are considered. Each storey of light wood-frame construction contains shearwalls, long enough to provide the necessary lateral load resisting system (for wind and earthquake loads), but continuity must be maintained from one storey to the next. If planned without openings, a review is required of unit and suite layouts.

Mechanical system (MEP) integration is important to consider, as are fire safety systems, building envelope and air barrier details, and how the project will be supplied and built, as materials selection determines how the structure incorporates mechanical systems.

Good coordination between all stakeholders is essential towards achieving the desired acoustic performance for the building (**Section 6 Architectural Considerations**). The composition of floor assemblies, including the addition of concrete topping, influences the loads that must considered during the structural design. Wall assemblies stud framing can be linear, alternating, or in some load cases doubled, based on the calculated design loads, and has a direct affect on how connections of different structural elements are detailed. The mechanical, plumbing and electrical system runs benefit greatly from some preliminary understanding of the wall types and layouts. Chases and duct runs might have to re-routed if expected acoustic performance is compromised.

The building envelope is an essential design and technical consideration for an architect. The overall thickness of the assemblies, materials used, thermal performance, aesthetics, and related construction sequencing of the building envelope, are important considerations that must be thought out and discussed. Lightweight wood-framing and mass timber platforms often can incorporate a prefabricated envelope system and becomes an efficient solution in managing moisture during the construction phase from the effects of rain and snow. Having a clear strategy for the building envelope may allow system assemblies to be integrated and determine whether mock-ups are needed for more complex systems to be tested for constructability and performance.

5.2.2 Structural Engineer

Structural engineers are responsible for the structural integrity of the primary structural systems of a building and integration of gravity and lateral load-resisting systems. The structural elements and concepts should be determined in collaboration with the project architect, fire safety professional, mechanical engineer, and project members that maybe involved in the design.

Structural engineers provide details for lateral resisting systems such as location of shearwalls in light wood-frame buildings, and shear transfer detailing with opening locations. This provides the necessary specifications for sheathing panels, lumber grade and species, fastening details, connections and hold-down locations and type. Concept checks early in design assist in an efficiently designed structure, ensuring that adequate bearing is acceptable from an architectural standpoint. Thought should be given to mechanical system layouts within the structure and units.

The structural grid layout and direction of floor joists, beams and roof trusses, determines the location of loadbearing walls on the exterior and interior of the building. Interior loadbearing walls are generally located between units or suites and along corridor locations. Alignment of loadbearing walls with the support of the concrete columns in a parking garage scenario is beneficial, as load transfer directly impacts design of the concrete transfer slab at the ground level.

Wall framing can be linear, alternating, or doubled up, based on loading, location and application. This may affect acoustic design and performance and should be reviewed. Lower storey exterior wall stud spacing may affect thermal resistance performance of the building envelope.

Structural engineers evaluate expected vertical differential movement and horizontal deflection. Drawings should show the expected shrinkage. Mechanical system designers, elevator designers require the expected vertical movement and material shrinkage predictions for design.

Plans must clearly indicate gravity and lateral load resisting system details, including the placement of hold-downs. Temporary bracing, including the lateral restraint of studs necessary prior to the installation of structural panels or gypsum board, must also be clearly communicated.

Using prefabricated structural assemblies and components provides a solution when building larger and taller wood projects. Full integration of prefabricated components requires good coordination and communication between the component manufacturer and the structural engineer. By reviewing shop drawings, the structural engineer can confirm that the manufacturer has fully integrated the requirements indicated on the structural drawings (**Section 5.7 Off Site Prefabrication**).

Site inspection and installation review is the responsibility of the structural engineer.

5.2.3 Mechanical Engineer

The mechanical engineer is responsible for the planning and design of the mechanical, electrical, plumbing, ventilation and automatic sprinkler systems. As designs and methods of building change, incorporation of an Integrated Design Process is beneficial to all parties. Choosing the right mechanical system early allows for integration with the project's structural and architectural design. The structural system plays a role in influencing the integration of the mechanical systems. Grid spacings, structural layouts of floor and wall assemblies, material types and architectural finishes desired by the client, play a role in choosing the right mechanical system for the correct application. Designing mechanical systems for 5- and 6-storey wood buildings, rigid conduit, plumbing systems and ducting must be designed to accommodate expected vertical differential movement. All 5- and 6-storey wood buildings are required to be sprinklered in conformance with NFPA 13. Early coordination on fire safety with the architect, structural engineer, and fire protection engineer, as applicable, is strongly encouraged and beneficial.

5.2.4 Fire Protection Engineer

The mechanical engineer is typically responsible for designing the building's sprinkler system (**5.4.2 Sprinklers and Standpipe Systems**), and the electrical engineer will design the fire alarm system, but other aspects of fire safety may require an engineer with more specialized knowledge in this area. A fire protection engineer (FPE) can serve as a consultant for the architect, owner, and other project engineers, providing directions and suggestions regarding various elements including the selection of fire-rated assemblies needed in the project design, detailing of fire safety systems and application of required code provisions. They may also play a critical lead role in facilitating discussions with the Authorities Having Jurisdiction if an alternative solution is needed as part of the project requirements for submission. An FPE provides direction in understanding the effects of vertical shrinkage and how it can impact the connections between the wood assemblies, masonry or concrete firewalls, elevator shafts or other stiffer noncombustible elements.

Fire protection engineers can detail firestopping requirements concerning service penetrations, concealed spaces, fire suppression systems, mechanical, electrical and plumbing systems, and detail drawings with this important information.

Section 2.2.6 discusses Fire Protection Strategies. This helps in understanding passive and active fire protection strategies and helps in risk mitigation by providing suggestions for fire protection during the construction phase (**Section 5.8 Construction Site Best Practices**).

5.2.5 Builder/Contractor

Owner-builders and general contractors should be aware of the specific characteristics presented in **Table 5.1**, and how important it is to have experience, knowledge and understanding in constructing 5- and 6-storey wood buildings. General contractor or project builder's involvement early in the project planning has value, enabling input on the feasibility of the project, procurement involvement, constructability strategies, scheduling, and sequencing, all impacting the project budget. Incorporating innovative structural systems and materials into designs may require this approach.

Maintaining acceptable levels of health and safety procedures throughout the construction and installation stages is part of risk management and experience with 5- and 6-storey wood buildings is an asset (**Section 5.8 Construction Site Best Practices**).

Moisture content is a factor carefully considered throughout the design of the building; it is important for structural members to remain as dry as possible during the construction phase. (**Section 5.8 Best Practices for Construction Sites**).

5.2.6 Structural Component Engineer

Prefabricated structural components (**Section 5.7 Off site Prefabrication**) can provide several advantages, including precise manufactured assembly, materials built with monitored moisture content and quality control procedures. Roof and floor truss engineers can be involved and responsible for designing prefabricated components. The design requirements on the structural engineer's drawings require shop drawings to incorporate all of the material grades and specifications that form the design. Coordination is particularly important when shearwalls are to be prefabricated in multiple segments. Attention is required in the detailing, ensuring that all shear forces are transferred, and that no gaps between the wall panels impede load transfer.

Permanent bracing of roof and floor trusses, and hold-down design are part of the building's permanent bracing and anchoring system and fall under the responsibility of the structural engineer to design. Component manufacturers may be required to produce certification that indicates that the manufacturing of components is in conformance with the specification details indicated on the structural engineer's plans. Review of shop drawings is typical.

5.2.7 Site Supervision

The planning of site services and supervision is strongly recommended. A keen and active knowledge and understanding of mid-rise wood buildings, dimensional lumber, engineered wood, panel products and mass timber components is an essential part of successful project delivery. Wood buildings can be complicated, so experience with wood framing and structural systems, assembly installation and sequencing is required. Strong attention to detail will result in the performance that is designed into the building by the project team. Failure to adequately supervise the installation of systems correctly could have a negative effect on the building performance after the construction phase is completed.

Maintaining quality control procedures during the project build is essential. If construction of the wood elements takes place on site, it is important to ensure that all wood assemblies are built as tight as possible, thereby minimizing gaps. This is an important step in reducing one of the effects of vertical movement. This tightening accumulates through all the assemblies once the building is erected. It protects materials from the effects of moisture. Moisture content should be monitored throughout the build and is important to manage in wood products. Installing windows and doors early provides added site security and moisture protection

Best practices in risk management on site concerning worker health and safety, fire, water and moisture management planning, should form a part of worker orientation and training, prior to work commencing (**Section 5.8 Best Practices for Construction Sites**).

There are many benefits in familiarizing site workers and installers with methods and material types that will be utilized during the build. This is essential as construction starts to move forward. Buildings are more complex, working as a complete system, and continuous learning and knowledge transfer is important.

Professional site supervision ensures that worker health and safety is mandated, and risk exposure is managed and minimized. Successful project management is based on sequencing, scheduling and quality control measures being in place and fully understood, preventing costly change orders and schedule delays, which affect the total project budget.

5.3 Structural Design

The following section provides information on some of the structural requirements to consider when designing mid-rise wood buildings. In **Section 1**, Canadian code provisions were used to illustrate some creative building typologies that optimize different types of structural systems. These were identified and presented as some possible solutions and opportunities for different types of wood buildings to be realized. This section will outline special design considerations related to the code requirements in Canada and provide some general information and recommendations on detailing, design solutions and areas that need some attention when designing.

5.3.1 Wood Structural Systems

Different structural systems can be used to construct wood building up to six-storeys in height. Light-wood frame, post and beam, and mass timber construction are three primary building systems. It is possible to combine these systems in certain configurations to provide hybrid solutions that best meets the project requirement for the client. For example, light frame floor panel assembles can be supported with glue-laminated posts and beams, or a building can strategically use mass timber elements as floors, walls, or elevator shafts in certain sections. It is important to ensure compatibility between the systems, particularly with regards to load transfer and vertical and lateral diffe ential movement.

In Canada, the current code edition for structural design is the National Building Code of Canada 2015 (NBC). The design basis for wood is referenced in Section 4.3.1.1., of the NBC 2015. (*See Figure 3.01*)

4.3.1. Wood

4.3.1.1. Design Basis for Wood

1) *Buildings* and their structural members made of wood shall conform to CSA OS6. "Engineering Design in Wood"

Figure 3.01: Design Basis for Wood.
Image courtesy of NBC 2015.

The current referenced edition for the CSA standard is CSA O86-19 as per Table 1.3.1.2, Documents Referenced in the National Building Code of Canada 2015. A recent update to the CSA standard (CSA O86-19) has been approved and published in preparation of the release of NBC 2020 code and can be used as a referenced document.

In general, the code requirements in the NBC 2015 and CSA O86-19 apply to wood frame construction regardless of the number of storeys. To ensure that the same level of safety as existing 4-storey wood-framed buildings is achieved, additional provisions are provided for 5- and 6-storeys buildings of wood construction which will be outlined in this section.

Provinces in Canada either adopt the NBC or adapt the NBC, in some cases publishing their own provincial codes. Provincial codes have adopted the same structural/seismic provisions that the NBC has published.

5.3.2 Load Requirements

All building codes and project specifications require that that the building and all structural elements have sufficient strength to resist the imposed loads. Of equal importance to design strength is the design requirement that a building be functional as stipulated by the serviceability considerations. Serviceability requirements are generally given as allowable or permissible maximum deflection and vibration limits, either vertical or horizontal, or both.

5.3.2.1 Gravity Loads

Before initiating a building design, engineers must become familiar with the load requirements of the local building code. Dead, live and snow loads are considered vertical loads and generally are specified as force per unit area in kPa (lb/ft^2). These loads are often referred to as gravity loads. In some cases, concentrated dead or live loads also must be considered.

Live Loads

The specified live load on an area of floor or roof depends on the intended use and occupancy. As shown in Chapter 2, the building use and occupancy can vary from level to level for these possible building types.

Section 4.1.5. NBC 2015 provides guidance for the live loads due to use and occupancy. The uniformly distributed live load is based on use and occupancy and is provided in Table 4.1.2.1. It is applied uniformly over the entire area or on any portions of the area, whichever produces the most critical effect in the structural member concerned.

In Canada, ground snow loads are used as a basis for the determination of roof snow loads. They form part of the basic climatic information needed for building design. This information is presented in NBC 2015 Table C-2, Climatic Design Data for Selected Locations in Canada, in Appendix C of Division B. Ground snow loads consist of two loads: Ss which is a snow load, and Sr, which is due to the associated rain that may fall into the snow cover.

Projections such as parapet walls, penthouses or mechanical rooms on flat roofs will collect snow drifts that must be analyzed. Other significant vertical roof projections, such as an elevator shaft   r HVAC equipment will create snow drift oads across the roof. Structural design information for snow loads can be found in the Structural Commentaries (User's Guide – NBC 2015: Part 4 of Division B), Commentary G: Snow Load.

Since gravity loads accumulate from the upper storey to the lower storey on mid-rise wood construction, this load analysis is especially important in the selection of the structural members.

Dead Loads

The uniformly distributed dead load includes the weight of the member itself, the weight of all material of construction incorporated into the building to be supported permanently by the member, the weight of partitions and the weight of permanent equipment. Section 4.1.4 NBC 2015 provides additional information on dead loads.

Table 5.2 shows an example of calculating the dead load for a floor assembly, which includes the addition of 38 mm (1-½") of lightweight concrete topping and regular concrete topping.

Strength calculations for wood structures include an adjustment factor related to the load duration (KD). If the long-term load (such as dead load) is greater than the standard term load (such as live load), the resistance is required to be reduced based on an equation involving the ratio of the long-term load to standard term load, to a minimum of 65% of the resistance when the load is of standard term duration.

(CSA O86-19, Clause 5.3.2.3). For instance, for the dead load indicated in Table 5.2 and a live load of 1.9 kPa (residential areas), a KD factor between 0.91 and 0.93 is obtained based on the type of concrete topping used. Where the live load is higher than the dead load, the KD factor for calculating the resistance of loadbearing components of these floor areas would be 1.0.

Table 5.2 The impact of concrete topping weight on load duration factor

Material	Lightweight Concrete Topping (kPa)	Regular Concrete Topping (kPa)
Wood Flooring	0.15	0.15
38 mm (1.5 in.) concrete topping	0.72	0.89
18.3 mm (23/32 in.) OSB subfloor	0.13	0.13
356 mm I-joist @ 400 mm (16" o.c.) (4 x 2 flange)	0.14	0.14
Insulation and resilient channel	0.18	0.18
2 layers 16 mm (5/8 in) Type X gypsum board	0.25	0.25
Partition loads as per (NBC 4.1.4.1 (3))	1.00	1.00
Additional dead loads	0.10	0.10
Total dead loads	2.67	2.84
K_D =	**0.93**	**0.91**

5.3.2.2 Wind Loads

Wind loads are assumed to act normal to building surfaces and are expressed as pressure in kPa (lb/ft^2). Depending on the direction of the wind and the geometry of the structure, wind loads may exert either a positive or negative pressure on a building surface.

There are three procedures outlined in sentence 4.1.7.2(2) NBC 2015 for determining wind load on the structure. The most common analysis for wood frame buildings up to six storeys is the static analysis. The static procedure is described in Structural Commentaries (User's Guide – NBC 2015: Part 4 of Division B), Commentary I: Wind Loads. Where the building height is greater than four times its minimum effective width, the dynamic effect on the building should also be checked. Empirical formulas for estimating peak acceleration and information on acceleration limits used to control wind inducted vibrations are provided in the Structural Commentary I.

Even when the shear wall design is controlled by seismic loads, designers are required to analyse the shear wall deflection under wind loads to ensure that the deflection does not exceed the limits set in Sentence 4.1.3.5(3) NBC 2015.

5.3.2.3 Seismic Loads

Seismic loads for wood-frame buildings may be determined using the equivalent static force procedure (Sentence 4.1.8.7 NBC 2015). Previous editions of the NBC and provincial codes had limits for combustible construction up to four storeys in height; therefore, it was not common for designers to perform deflection calculations or to check storey drift, as they were generally assumed to be acceptable. With the changes to allow combustible construction of up to six storeys in the NBC 2015, it has become important that designers consider more sophisticated methods, such as linear dynamic analysis, for the design of wood-based shear walls. The use of linear dynamic analysis may provide a more realistic representation of force distribution, higher mode effects and torsional effects. This method may also be better for analysing hybrid systems, such as podium structures in which the vertical variation of RdRo exists between the upper wood-frame and the podium.

CLT buildings can be constructed using two types of construction: platform and balloon-type framing. In the platform-type construction, the floor platform of each storey is used as a base for erecting the CLT walls of the next storey. The height of the CLT walls is equal to the height of the storey and the CLT walls transfer the gravity loads from the storey above to the CLT floor panels underneath. This type of construction has a large number of walls that can also be used to resist seismic loads, thus allowing for high redundancy.

In balloon-type CLT structures, CLT walls are erected along the entire height of the building, and the floor panels are attached (suspended) to the walls at each storey. Currently CSA O86-14 and -19 only have provisions for CLT structures that are constructed using platform-type construction.

5.3.3 Gravity Load Resisting System

5.3.3.1 Maximum Spans

For 5- and 6-storey buildings, span selection is more often influenced by the compressive resistance perpendicular to the grain of the top and bottom plates of the loadbearing walls than by the maximum spans that the floor joists can cover. The longer the spans, the greater the loads supported by the loadbearing walls on the lower storeys, which can lead to crushing perpendicular to the grain of the top and bottom plates. As an example, **Table 5.3** shows maximum spans calculated based on the crushing capacity of the top and bottom plates using MSR 2100Fb-1.8E, with a loadbearing wall on the ground floor supporting five floor levels, but no load from the roof. Double walls can take increased spans because they halve the vertical loads to be supported.

Table 5.3 Spacing of loadbearing walls calculated based on the crushing capacity of the bottom plates.

	Stud spacing	Maximum spacing between loadbearing walls[1]	
		2x4 (38 x 89 mm) studs	**2x6 (38 x 140 mm) studs**
Single wall			
Single studs	400 mm (16 in.)	1.8 m	2.8 m
Single studs	300 mm (12 in.)	2.4 m	3.7 m
Double studs	400 mm (16 in.)	3.2 m	5.1 m
Double wall			
Single studs	400 mm (16 in.)	3.6 m	5.6 m
Single studs	300 mm (12 in.)	4.8 m	7.5 m
Double studs	400 mm (16 in.)	6.5 m	10.2 m

[1] The calculation is based on a specified floor dead load of 2.85 kPa, a specified live load of 1.9 kPa, and top and bottom plates composed of SPF MSR 2100Fb-1.8E. Bearing is calculated using the compressive resistance perpendicular to grain equations in CSA O86-19: 6.5.6.2 and 6.5.6.3.1, where KD = 0.91 (see page 21), KB = 1.17 to 1.25 (depending on Ab' vs Ab, respectively), and KZcp = 1.15.

The wall supports a floor tributary width equal to the stud spacing x 5 floors. For the double wall, each half of the wall supports a tributary width equal to half of the spacing.

5.3.3.2 Orientation of Loadbearing Systems

Selecting the orientation for floor and roof systems can help determine the optimal configuration for structural framework. The floor and roof systems act as the diaphragm which transfer lateral loads to the shear walls. In light frame multi-family buildings, party walls between dwelling units are generally double walls due to their superior acoustic performance. Floor systems arranged parallel to longitudinal corridor walls are therefore supported by these double walls between the dwelling units. These party walls often serve as shear walls to resist lateral loads because they are long wall segments without openings. This type of floor system configuration supports more gravity loads on the party walls to counter overturning forces caused by lateral loads. Where underground parking spaces are planned, this orientation of floor systems also helps distribute forces in the ground floor concrete transfer slab.

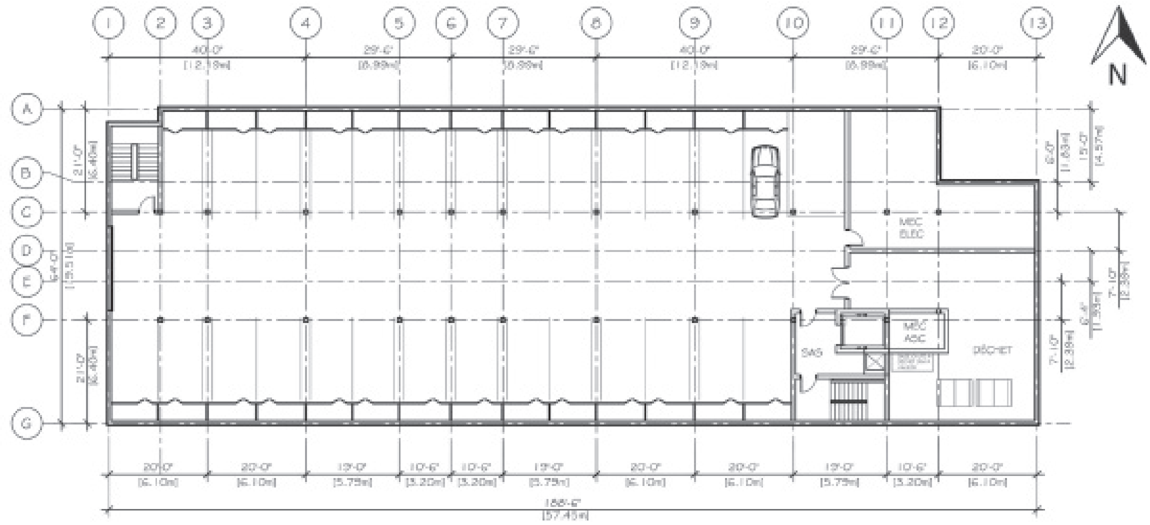
If maximum floor joist spans are not long enough to reach party walls, intermediate loadbearing beams or walls can be added.

5.3.3.3 Alignment of Loadbearing Walls/Columns

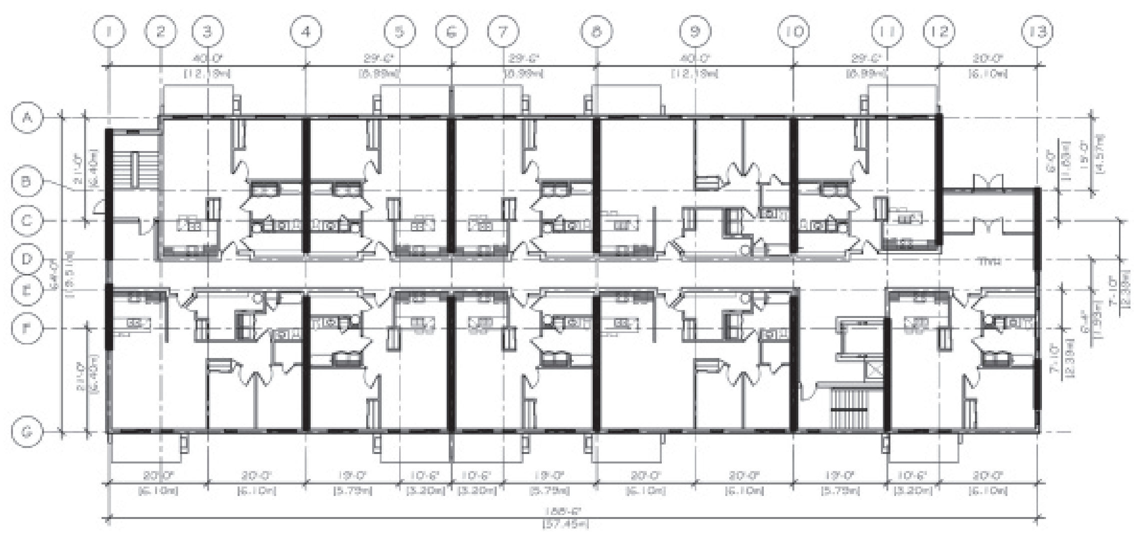
Typically, light wood-frame and mass timber buildings require that all load paths be vertically and uniformly aligned throughout all storeys of the structure. Aligning loadbearing walls and columns from one storey to the next in the same vertical plane throughout the building ensures a continuous load path. This may be a requirement in moderate to high seismic zones (Sentence 4.1.8.10 (4) NBC 2015). It helps prevent an additional bending moment in the floor structure while transferring shear forces between the shear walls from one storey to another. Wood structures with the load paths that are not aligned will require transfer beams to support the loads. These types of designs are typically less cost-effective and should be avoided if possible.

It may also be beneficial to align loadbearing walls with the columns supporting the ground floor concrete transfer slab. Alignment can reduce the forces transferred to the transfer slab, leading to structural efficiency and cost savings. For an underground parking garage, columns are generally spaced 6 m (two parking spaces) or 8.7 m (three parking spaces) apart. Although a span of 8.7 m can be achieved with a deep floor system (I-joist or open web), a 6-m spacing of loadbearing walls is encouraged, because it enables optimal floor depth height and reasonable loads on ground floor walls (*Figure 3.02*).

For greater flexibility in living area layouts, it is possible to use an intermediary post-and-beam system to support floor joists between loadbearing walls. However, it is important to thoroughly study the transfer of the vertical loads to the supports of these columns. Alignment with the columns supporting the ground floor concrete transfer slab is recommended to enable the transfer of these large, concentrated vertical loads.



Plan view of underground parking



Plan view of an upper storey

Figure 3.02: Structural framework for a span of approximately 6 m, or two parking spaces.
Courtesy: Bourassa Maillé Architects.

When there is no underground parking garage that defines the structural grid above, it is worth considering designs using shorter spans and smaller grid spacings (4 to 6 m), using intermediate loadbearing supports. This may increase foundation costs, but shorter spans enable the use of shallower floor depths, making the floor systems more cost efficient, and reducing the total height of the building.

5.3.3.4 Temporary Lateral Restraints

It is important to plan temporary lateral restraints for loadbearing wall studs that have not yet been covered in wood structural panels or gypsum board during the duration of construction. During construction there may be considerable vertical dead loads applied on the lower storeys in 5- and 6-storey wood frame construction.

Wood structural panels (OSB or plywood) can also be planned for all loadbearing walls to avoid using temporary lateral restraints. This option also enables designers to include loadbearing walls in the lateral load resisting system.

5.3.4 Lateral Load Resisting System

5- and 6-storey wood buildings are subjected to greater gravity, wind, and seismic loading than lower wood buildings.

5.3.4.1 Selecting a Lateral Load Resisting System (LLRS)

Different lateral load resisting systems can be used for 5- and 6-storey light wood-frame buildings:

- Light-frame shear walls and floor/roof diaphragms.
- CLT panels in platform-type or balloon-type systems.
- CLT panels and other mass timber elements.
- Cores or walls composed of structural composite lumber, such as laminated strand lumber (LSL).
- Concrete core, CMU, or steel-based system.

Light-frame shearwall and diaphragm systems are high-performing and cost-effective systems ideal for multi-storey residential buildings. Buildings using this type of system must be configured with long wall segments that can be used effectively as shear walls.

CLT panels can be used in a wide variety of structural applications in either all wood or wood hybrid buildings. In all wood buildings, CLT panels can be used in platform or balloon-type applications, or in buildings designed to use CLT in combination with other mass timber elements. The post and platform system is a common type of mass timber structural system made up of CLT floor panels resting directly on Glulam or SCL columns. Systems like this are ideal for either multi-storey residential, offices or commercial buildings.

CLT, LSL or concrete wall segments or cores, are another option for designers where light-frame shear walls are not structurally adequate. These types of solutions could lead to differential shrinkage between the main structure and the lateral load resisting system, so careful attention to this shrinkage must be considered. When designers are required to use shear walls or reinforced concrete cores to brace the building, particular attention must be paid to the connections between the two structural systems, particularly with regards to vertical movement.

Before beginning the design process, it is best to discuss each option to determine which one is best for the project.

5.3.4.2 Shearwall Layout

One advantage of light wood-frame shearwalls is controlling differential movement between the main structure and the lateral load resisting system. However, to perform well, this lateral load resisting system must have sufficiently long wall segments.

Using shorter length wall segments significantly increases the number of hold-downs necessary, because they must be installed at the ends of each segment. Hold-downs and the associated installation costs can add up quickly, particularly because hold-downs with continuous rods and shrinkage compensators are generally required for 5- to 6-storey wood buildings (Section 3.4.5). In addition, a wall segment that is too short in length, is much more flexible and likely will not meet the deflection criteria set by the NBC 2015.

It is therefore essential that the architect and structural engineer work closely together to ensure that the available wall lengths are sufficient to accommodate an effective and economical lateral load resisting system. Shearwalls located inside the building can be advantageous compared to exterior walls. Party walls between units, and corridor walls, are suitable options because they are made up of long segments with few or no openings. They are therefore much more resistant to overturning and deflection.
(*Figure 3.03*).

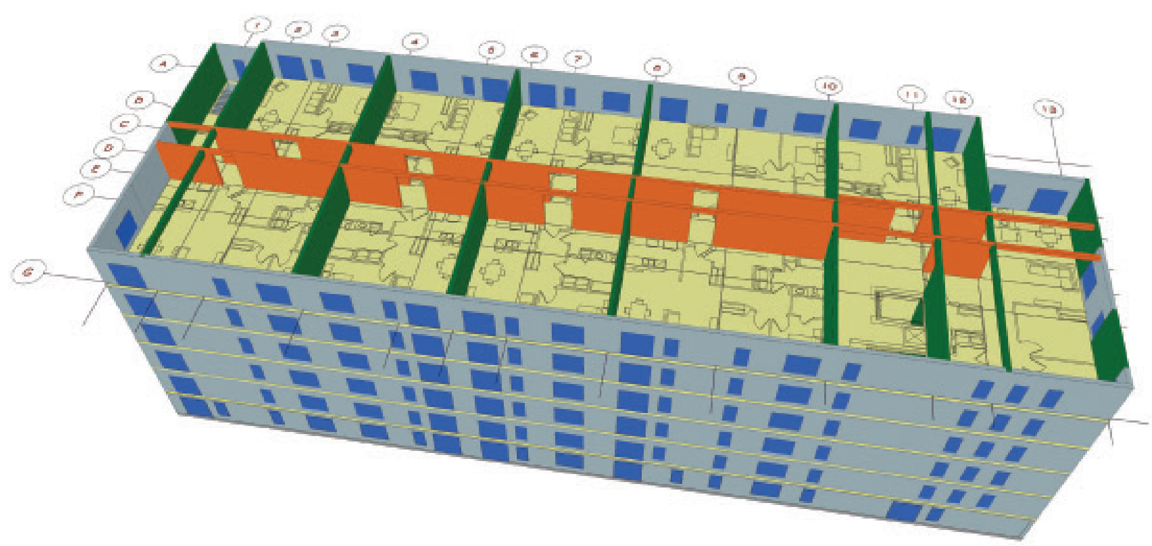


Figure 3.03: Party walls of dwelling units and corridor walls used as shear walls (in green and orange).

5.3.4.3 Calculating the Lateral Load Resisting System (LLRS)

The lateral resistance of light wood-frame and CLT diaphragm and shearwalls are required to be calculated in conformance with Cause 11 of CSA O86-19, Engineering Design in Wood. The provisions in this clause should be used in conjunction with the CWC Commentary on CSA O86.

5.3.4.3.1 Light Wood-Frame Construction

To offer designers more flexibility, a mechanics-based methodology was adopted in the CSA O86-14 and O86-19 editions for light-frame diaphragm and shearwall design. In accordance with this methodology, the factored shear resistance of wood diaphragms and shearwalls constructed with wood-based structural panels is governed by the lowest resistance of the sheathing-to-framing connection and sheathing panel buckling. For seismic design, restrictions apply. Buckling is not permitted to govern, and the sheathing-to-framing connection must be governed by a ductile yield mode.

Since the lateral resistance of a shear wall is based on the sheathing-to-framing connection or sheathing buckling, the stud species, sheathing species and thickness, and nail length and diameter are all important variables. To reduce the shrinkage that contributes to the building's vertical movement, top and bottom plates composed of a structural composite lumber such as LSL can be used. However, a wall constructed with SPF studs, and LSL top and bottom plates, is required to be calculated using the lowest density of the two to determine the shear resistance of the shear wall. Shearwalls may also be constructed with multiple layers:

- Wood-based panels on both sides.
- Gypsum panels on both sides; or
- Wood-based panels on one side and gypsum panels on the opposite sides.

The factored shear resistance of the panels on both sides of the same shearwall may be added together. Where wood structural panels are applied over 12.7-mm- or 15.9-mm-thick gypsum wallboard, the shear resistance of the wood-based panel may be considered in the shearwall design provided the minimum nail penetration requirements are met. In all other cases with multiple layers of panels on the same side of the shearwall, only the shear resistance of the panel closest to the studs is considered in design.

Research has been carried out to investigate alternative shearwalls that have higher lateral load-carrying capacities than standard shear walls. The design of mid-panel shearwalls *(Figure 3.04)* was implemented in the CSA O86-19 edition and reference to construction and detailing of this type of shearwall can found in Clause 11.3.2.3. Selection tables for the factored shear resistance of mid-panel shearwalls is also available in the Wood Design Manual 2020 (CWC)

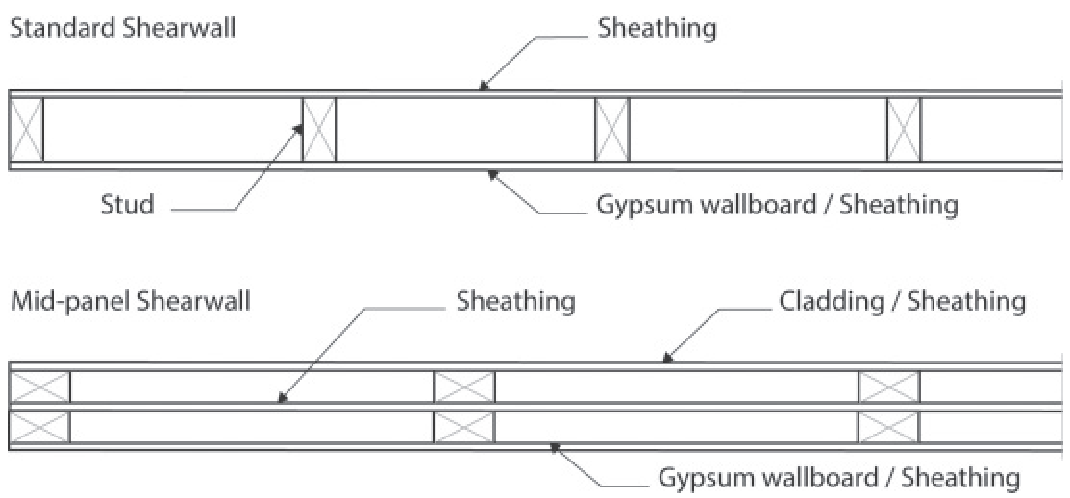


Figure 3.04: Mid-panel shearwall.

Where shearwalls have openings for windows and doors, only the full height shearwall segments between the openings and at the ends of shearwalls are considered in the shearwall design. For blocked shearwalls, when the height of the shearwall segment, Hs, measured from the bottom of the bottom plate to top of the top plate within the storey, is greater than 3.5 times the length of the shearwall segment, Ls, the segment is not included in the resistance calculation. For unblocked shearwalls, where Hs is greater than 2Ls, the segment is not included in the resistance calculation.

A shearwall is designed to resist the accumulated shear forces from the upper storey shearwalls and diaphragm in wood-frame construction. Different methods can be used to distribute the shear force on a shearline to each of the shearwall segments. The distribution of lateral forces to the shearwall segments may be based on the relative strength of the segments. Distributing forces by relative strength of the segments is improved when the segments of shearwalls have similar configuration and are of similar construction. This approach may be less accurate than distributing forces based on relative stiffness of the segments.

A more rigorous approach is to distribute the forces based on relative stiffness of each segment using the shearwall deflection equations to determine the stiffness of each segment. This requires an iterative approach towards arriving at a solution where all the segments in the shearwall have the same displacement at the load level being considered.

Additional design requirements specific to mid-rise wood construction are referenced in CSA O86-19 are:

1. Requirements for calculation of deflection for multi-storey shearwalls (Clause 11.7.1): *It is required that in the calculation of deflection for multi-storey shearwalls, multi-storey effects shall be considered. A methodology using a purely mechanics-based approach is given in Clause A.11.7.1.*
2. Requirements for shearwalls using gypsum wallboard (Clause 11.8.8 and 11.8.9): *It is specified in Clause 11.8.8 that gypsum wallboard shall not be considered to provide lateral resistance when the inter-storey drift atio exceeds 1%, and that for mid-rise wood frame construction the gypsum wallboard shall not be accounted for in seismic resistance.*
   It is specified in Clause 11.8.9 that for load bearing walls constructed with gypsum wallboard only, when the inter-storey drift atio due to seismic loading exceeds 1% the design shall be based on the assumption that the gypsum wallboard provides no lateral support to the studs. Alternatively, a secondary blocking system shall be used.

Several examples can be found in the Wood Design Manual 2020 (CWC) in Chapter 8. In this chapter, light-frame wood lateral force resisting systems can be found in Section 8.1, General Information, Section 8.2, Light-Frame Diaphragm Design, Section 8.3, Light-Frame Shearwall Design, and Section 8.4., Seismic Design Considerations for Shearwalls and Diaphragms.

Additional seismic design requirements for continuous wood construction more than 4 storeys can be found in the new updated version of the NBC 2020.

- Restriction on irregularities (NBC 2020, Sentence 4.1.8.10.(5)):

  For buildings constructed with more than 4 storeys of continuous wood construction and where the Seismic Category is SC3 or SC4, timber SFRS consisting of shear walls with wood-based panels or of braced or moment-resisting frames as defined in Table 4.1.8.9. within the continuous wood construction shall not have Type 4 or Type 5 irregularities as described in Table 4.1.8.6. (See Note A4.1.8.10.(4) and (5).)

- Requirements for the static design force level (NBC 2020 Sentence 4.1.8.11.(12)):

  Where the fundamental lateral period, Ta, is determined in accordance with Clause (3)(d) and the building is constructed with more than 4 storeys of continuous wood construction and has a timber SFRS consisting of shear walls with wood-based panels or of braced or moment-resisting frames as defined in Table 4.1.8.9., the lateral earthquake force, V, as defined in accordance with Sentence (2) shall be multiplied by 1.2 but need not exceed the value determined by using Clause (2)(c). (See Note A-4.1.8.10. (4) and (5).)

- Requirements for dynamic design force level (NBC 2020, Sentence 4.1.8.12.(12)):

  For buildings constructed with more than 4 storeys of continuous wood construction, having a timber SDRS consisting of shear walls with wood-based panels or braced or moment-resisting frames as defined in Table 4.1.8.9., and whose fundamental lateral period, Ta, is determined in accordance with Clause 4.1.8.11. (3)(d), the design shear, Vd, shall be taken as the larger value of Vd determined in accordance with Sentence (7) and 100% of V. (See Note A-4.1.8.10. (4) and (5).)

Seismic design force for shearwalls and diaphragms shall be determined using appropriate procedures specified in the NBC 2020. Clause 11.8 of CSA O86-19 provides additional information for designers. The corresponding ductility-related seismic force modification factor, Rd, and system related force modification factor, Ro, for shearwalls are given in Table 11.8.1., providing failure is governed by sheathing-to-framing connection. The sheathing-to-framing connection shall be designed to yield in mode (c), (d), (e) or (g) shown in Clause 12.9.4.2 for nails to ensure sufficient ductility in the shearwall and diaphragm. Clauses 11.8.2 to 11.8.6 apply to structures where the Seismic Category of the building is SC3 or SC4. Clause 11.8.7 applies to structures where the Seismic Category of the buildings is SC1 and SC2. The Seismic Category of buildings is determined in accordance with the NBC, Subclause 4.1.8.5 on the basis of IES(0.2) and IES(1.0) irrespective of the fundamental lateral period of the building Ta.

5.3.4.3.2 CLT Panel Construction

In platform-type CLT construction, the floor platform of each storey is used for erecting the CLT walls for the next storey. The CLT floor of each storey (including the roof) act as diaphragms, which collect the lateral loads and transfer them to CLT shear walls below. This type of construction usually involves many CLT walls that can be used to resist lateral loads.

Clause 11.9 of CSA O86-19 provides design information for CLT shearwalls and diaphragms. Clause 11.9 applies to platform-type construction, where the lateral-load-resisting system consists of CLT shearwalls. The CLT shearwalls are placed on a platform of CLT panels, or a concrete podium or concrete foundation at the lowest level. Alternative systems are required to be designed in accordance with Clause 4.3.2 of CSA O86-19 and Clauses 1.2.1.1.1 (b) (Division A) and 4.1.8 (Division B) of NBC 2020.

The height of the CLT Seismic-Force-Resisting System (SFRS) cannot exceed 30 metres where the Seismic Category determined in accordance with the NBC is SC1, SC2, or SC3 (Clause 11.9.3.2.3.1). For Seismic Category, SC4, the height cannot exceed 20 m (Clause 11.9.3.2.3.2).

The connections between CLT wall panels and surrounding elements are the main contributors to shearwall strengths and deformation, as the CLT panels behave mostly as rigid bodies. Similarly, the shear resistance of a diaphragm is governed by the properties of connection between the CLT diaphragm panels and to the supporting structure. The provisions in CSA O86-19 require that the shear resistance of CLT shearwalls and diaphragms are governed by connections, using the assumption that each individual panel acts as a rigid body and is analyzed using a suitable method of mechanics.

The design of CLT structures to resist seismic loads relies on capacity design principles and requires moderate- or high-ductility connections for energy dissipation at specified locations. All other connections are designed with sufficient over-strength and are considered non-dissipative connections. The CLT shearwalls are expected to act in rocking.

CLT platform-type SFRS constructed with more than four storeys, and where the Seismic Category of the building is SC3 or SC4, cannot contain irregularities prohibited in NBC Article 4.1.8.10.

Examples can be found in the Wood Design Manual 2020 (CWC) in Chapter 8, Section 8.5, Lateral Load Design of cross-laminated timber in Platform-type Constructions.

5.3.4.4 Connection Details

Connections play an important role in maintaining the integrity of the wood structure and in providing strength, stiffness, and stability. The structural efficiency of the floor/roof system acting as a diaphragm and the wall system acting to resist the lateral loads depend on the efficiency of the connection details used to interconnect the panels and assemblies together.

5.3.4.4.1 Wall-to-Floor Connections

Light Wood-Frame Construction

Connections in light wood-frame systems are required to transfer the vertical and lateral loads from the upper storeys to the lower storeys at each wall-to-floor connection. The rim board size (thickness and type) is determined for the cumulative amount of vertical load at each level. *Figure 3.05* show a common detail for light wood-frame construction. To satisfy the lateral requirement at each level, metal connectors *(Figure 3.06)* are typically added to increase the shear transfer as the cumulative lateral load exceeds the common nailing requirements for 5- or 6-storey wood-frame construction.

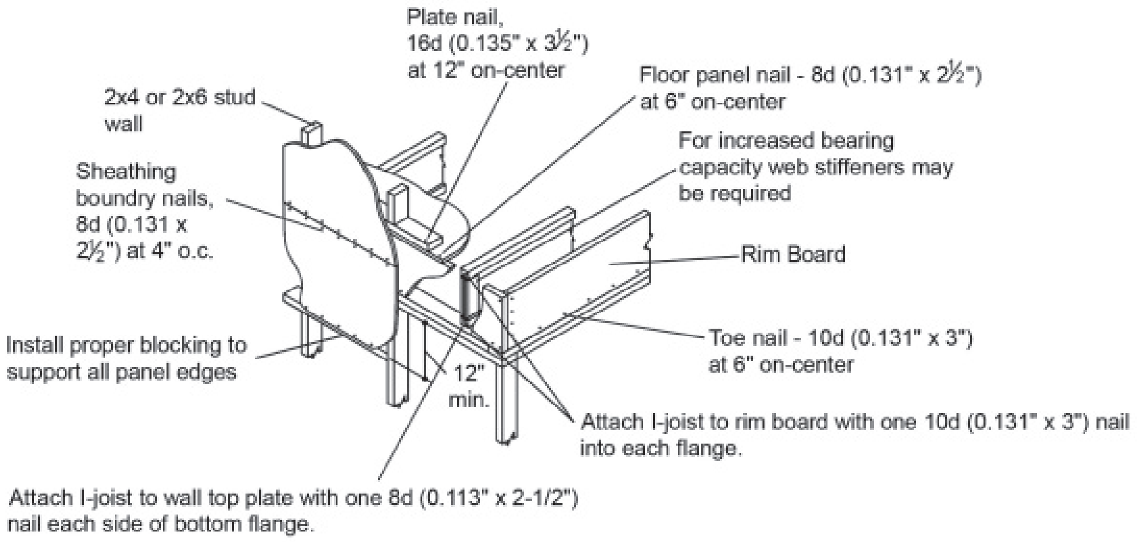


Figure 3.05: Typical Light Wood-Frame Connection Detail.

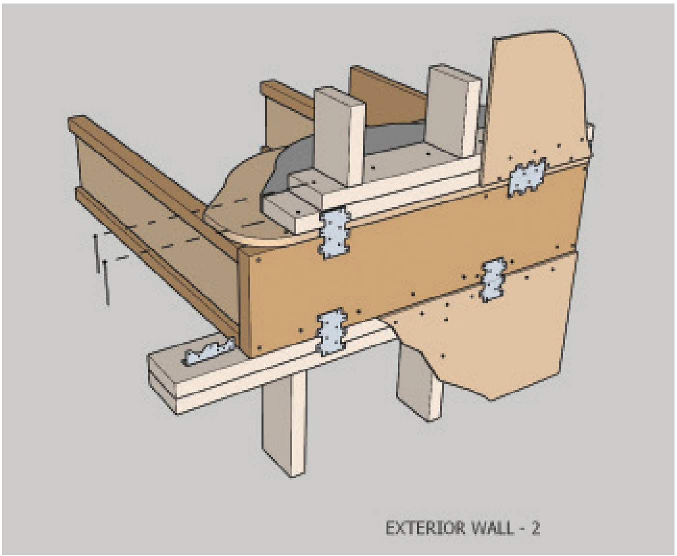


Figure 3.06: Metal connectors transferring shear forces between rim joist and wall.

Another possible connection detail is to use top-mount hangers to support trusses or I-joists directly on top of the top plate of the wall *(Figure 3.07)*. The bottom plate of the upper wall is connected directly to the top plate of the lower wall with nails or screws. Connecting the bottom plate directly to the top plate is good for the accumulated shear forces, and the plywood subfloor into the top plate is to transfer that particular floor level's shear forces. The number of perpendicular-to-grain wood components is limited to one bottom plate and two top plates – 114 mm of horizontally oriented wood. A fire block may also be required in the wall at the ceiling level, to maintain the fire-resistance rating.

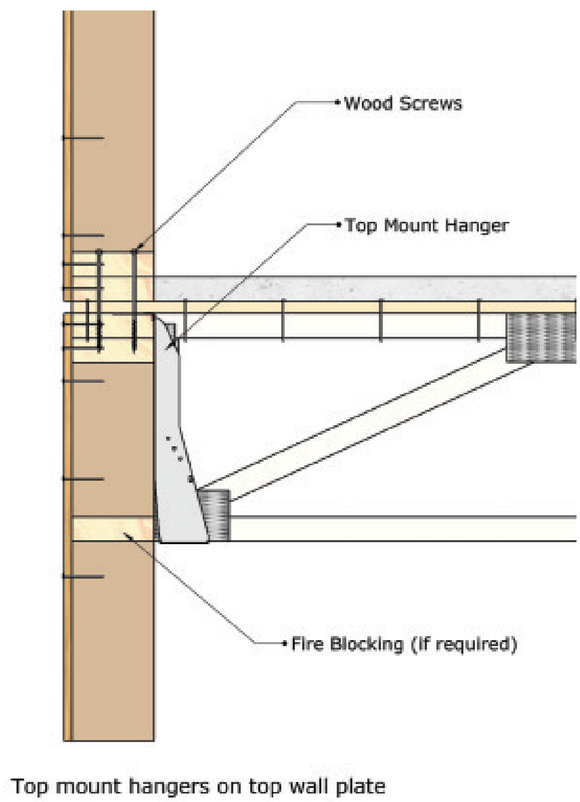


Figure 3.07: Top mount hangers on top wall plate.

Lastly, it is also possible to install floor joists in face-mount hangers, fastened to an engineered wood beam and installed on the top of the wall *(Figure 3.08)*. The beam transfers vertical loads, as well as inter-storey shear forces. The bottom plate of the upper wall is therefore connected to the beam, which is fastened to the top plate of the lower wall using screws or other fasteners.

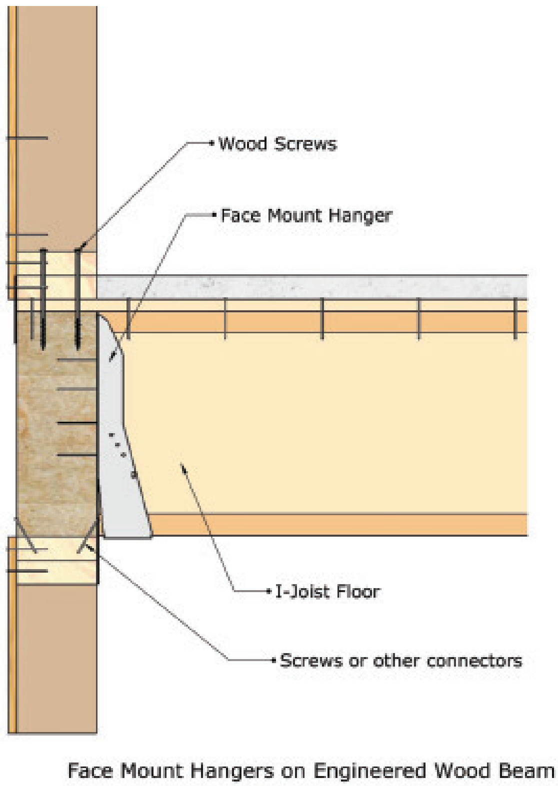


Figure 3.08: Face-mount hangers on wood beam.

CLT Panel Construction

Connections in CLT panel construction are required to transfer the vertical and lateral loads from the upper storeys to the lower storeys at each wall-to-floor/roof panel connections and between panel-to-panel connections.

Floor-to-floor connections are mainly designed to transfer in-plane shear forces, with the panels acting as diaphragms. Several joint types are offered by CLT manufacturers providing differences in application, capacity, and ease of installation. The three most common types of details for floor-to-floor connection are as follows:

- Butt Joint Connection
  The butt joint is the simplest connection type from a fabrication point of view, as the panels are simply cut straight at the edges. There is less machining time, and less material is lost during fabrication. This connection is one of most cost-effective methods of transferring in-plane shear between CLT panels. Screws are installed at a 45-degree angle to the edge face. *(Figure 3.09)*

Figure 3.09: Typical CLT butt joint connection.

- Lap Joint Connection

  Lap joints require more prefabrication than butt joints. During fabrication, part of the CLT panel width is removed to create a lap joint. The lap joint is connected in shear with vertical or inclined screws. *(Figure 3.10)*

Figure 3.10: Typical CLT lap joint connection.

- Surface Spline Connection

  Spline joints are similar to the butt joints. Surface spline connections are made using standard plywood placed into a routed section on the panel surface across the joint. The surface spline is then fastened with screws to the CLT panels. *(Figure 3.11)*

Figure 3.11: Typical CLT spline connection.

To connect a CLT floor or roof panel to a CLT wall panel below, the simplest method is to use long self-tapping screws driven from above directly into the wall edge, as shown in *Figure 3.12*. The same principle can be applied to connecting walls above to floors below, where self-tapping screws are driven at angle into the wall and floor intersection. The designer should allocate special attention to ensure minimum end and edge distance requirement for the narrow edge of CLT are satisfied with these types of connections.

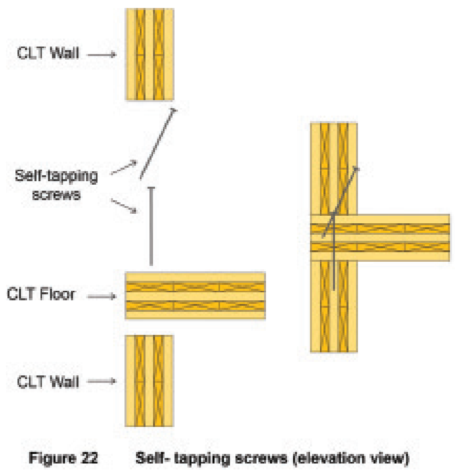


Figure 3.12: Platform floor-to-wall connection with self-tapping screws.

Alternatively, metal brackets can be used to connect floor to walls above and below. Self-tapping screws, nails and wood screws can be used to attach the metal brackets to the CLT panels. There are many innovative proprietary fastenings and systems on the market, and it is best to contact these sources along with your CLT manufacturer to optimize the connections for your project.

Partially threaded screws can be used to transfer shear forces and close gaps between the CLT floor/roof panels and glulam beams. The partially threaded self-tapping screws are installed from the top surface of the panel to transfer shear and uplift orces. *(Figure 3.13)*

Figure 3.13: CLT panel fastened to glulam beam.

CLT floor or roof panels can be supported by light-frame walls below and be connected using self-tapping screws installed from the installed from the top of the panel or bottom screwed as shown in *Figure 3.14*.

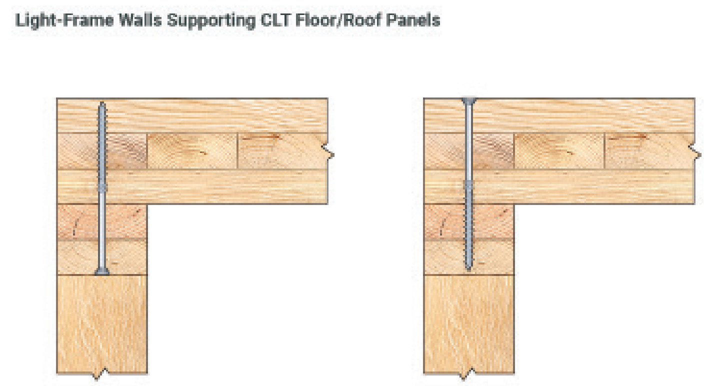


Figure 3.14: Light-frame walls supporting CLT floor/roof panels.

A typical detail used in balloon framing is the structural ledger. Most ledgers used in construction with CLT are typically glulam and structural composite lumber (SCL) products. Using a steel ledger is also an option. In this application, connections will exhibit perpendicular-to-grain loading in the side member while parallel-to-grain loading in the CLT wall. When a different material is used for the ledger, or for the floor slab, the relative density of different material must be used in the design. For this connection, the connection strength and stiffness are assumed to come entirely from the inclined screw. The shear screws installed at 90-degree angle are used during installation to ensure proper placement between the side and main member *(Figure 3.15)*. Other details are possible for this type of balloon framing; therefore, consultation with the CLT manufacturer and supplier of the screws is recommended to optimize the connections.

Figure 3.15: CLT balloon framing with structural ledger.

5.3.4.4.2 Prefabricated Shear Wall Segment Connections

Prefabricated shear walls are strongly recommended for 5 to 6-storey wood frame buildings. The manufacturing process enables greater precision, better quality control, faster on-site installation, and a lower risk of weather exposure. When using prefabricated components, however, the connection details need to maintain continuity and transfer forces between different shear wall segments. Some manufacturers can produce wall panels in a single piece in length of 9.8 m (32 ft.), if plate material can be sourced in that length from their suppliers.

If a shear wall segment needs to be manufactured in several sections, it is best to place the connections in areas with the lowest loads to transfer. Moreover, vertical connection details need to adequately join the different sections placed side to side to form a single shear wall. Vertical connections are required to be designed to transfer maximum shear forces that act on the shear wall *(Figure 3.16)*. The connection needs to be specified by the structural engineer and be coordinated with the manufacturer, site super and framing contractor so that the proper connection is achieved on the construction site.

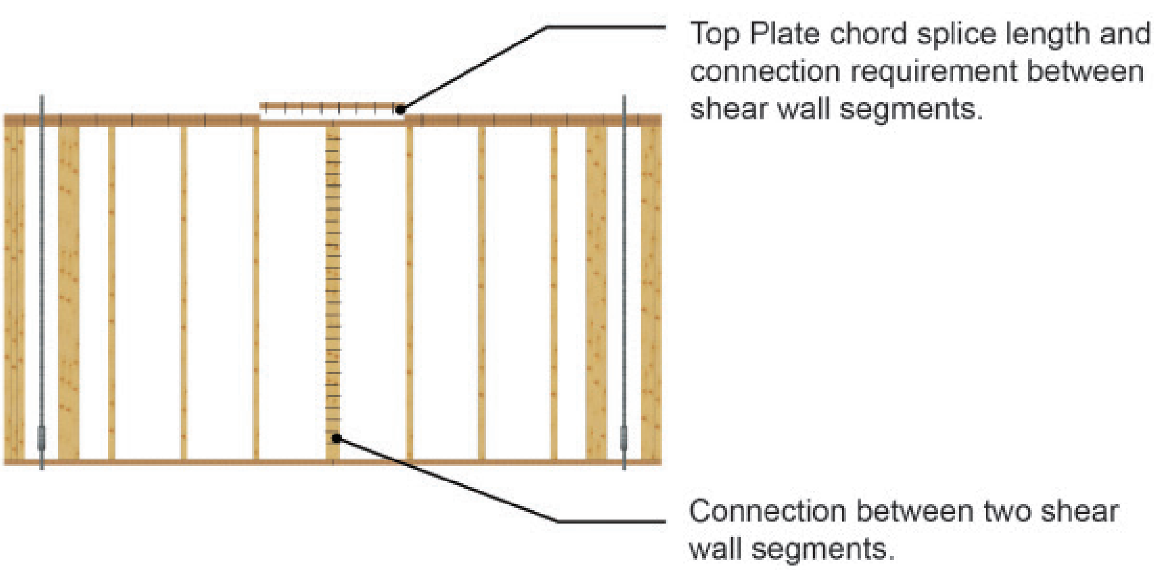


Figure 3.16: shear segment connection detail.

The floor or roof diaphragms span between the shear walls. Wall top plates typically function as the diaphragm chords, and they must be continuous along the full length of the diaphragm to transfer the shear forces to the shear walls. When double top plates are used, the splices must overlap along a wide enough area to leave enough space for the number of nails required for the force transfer *(Figure 3.16)*.

5.3.4.5 Nails and Spikes

Nails and spikes are the most used fasteners in light wood-frame construction. In prefabricated and job-site construction, builders almost exclusively use nails designed for pneumatic nailing guns. Design information is provided in CSA O86-19, Clause 12.9.1, and apply to common round steel nails and spikes and common spiral nails spiraled to head as defined in CSA B111 or ASTM F1667, including power-tool-driven common nails. See Table A.21 and A.22 in CSA O86-19 for commonly available nail and spike sizes. The ASTM F1667 Standard Specification for Driven Fasteners: Nails, Spikes and Staples, is a widely accepted standard.

Engineers must clearly indicate the length and diameter of nails used in their design of the shearwalls and diaphragms as this is the only allowable connection as per CSA O86-19. Clause 12, Connections, specifies criteria for engineering design for both light wood-frame, CLT and mass timber wood buildings.

5.3.4.6 Wood Screws

Wood screws are manufactured in many different sizes and styles. Design information in CSA O86-19, Clause 12.11 is only applicable for wood screws that meet the requirements of ASME B18.6.1. Design provisions are limited to 6-, 8-, 10- and 12-gauge screws. Nominal diameters and minimum design yield strengths are given in CSA O86-19, Clause 12.11, Table 12.27. Wood screws are not permitted for seismic resistance in light wood-frame construction.

There are several manufacturers who produce fasteners designed for light wood-frame, CLT and mass timber construction, providing a wide array of screws with different lengths and diameters. Screws are usually specified by the gauge number, length, head style, material, and finish.

Proprietary wood screws are also available from various manufacturers; thus, they should be contacted directly for design capacities and installation instructions. Typically, these manufacturers have there own CCMC Evaluation Report providing assurances that they meet the intent of NBC 2015 and CSA O86-19.

5.3.4.7 Hold-Downs

In light wood-frame construction, hold-downs are usually required to prevent overturning in shear walls due to lateral loads. For buildings less than 4 storeys tall, hold-downs are fastened to built-up studs at the ends of the shearwalls and transfer forces directly to the built-up studs of the shearwall below, or to the concrete foundation. These are fastened with screws or bolts at the top and bottom of built-up posts at the ends of shear wall segments and continue up, vertically connected at each level. *(Figure 3.17)*.

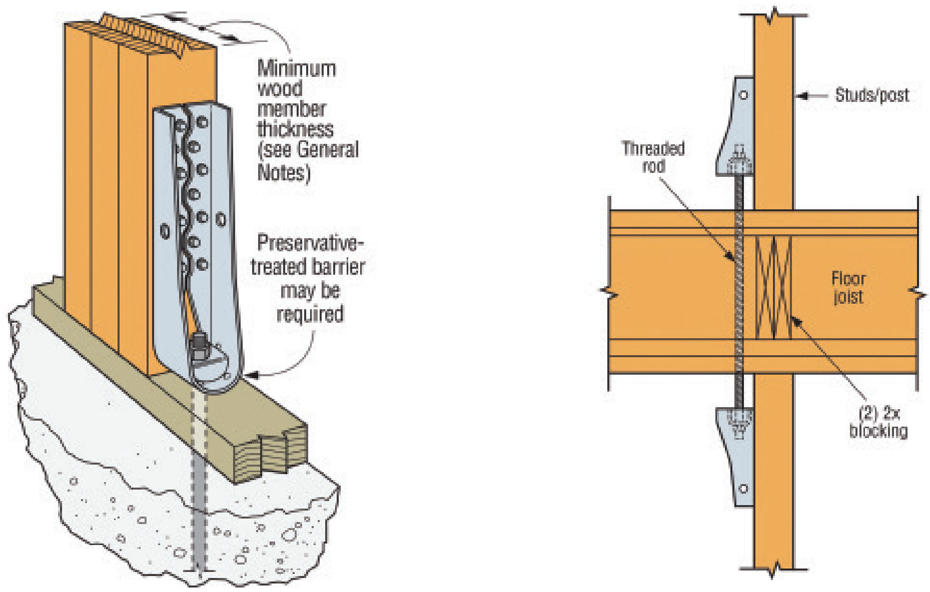


Figure 3.17: Conventional hold-downs.

Images courtesy of Simpson Strong-Tie®.

In 5- and 6-storey wood- frame buildings, greater hold-down strength is necessary to resist shear wall overturning forces, particularly in the building's lower storeys. Conventional type hold-downs are typically insufficient to resist these loads. Cumulative vertical movement in the building over 5 or 6 storeys may lead to gaps in the hold-downs, which could increase a building's lateral deflection. Therefore, an alternate system must be used.

This system uses continuous steel rods through all floors of a building combined with shrinkage compensators to eliminate gaps in connections as shrinkage occurs. The steel rods are placed at each end of shear wall segments, between built-up studs that form posts. The steel rod is designed to resist tension forces, while the multiple studs are designed to resist compression forces *(Figure 3.18)*. For these shrinkage-compensating tie-downs, the diameter of the steel rod can vary at each storey based on the anchoring forces.

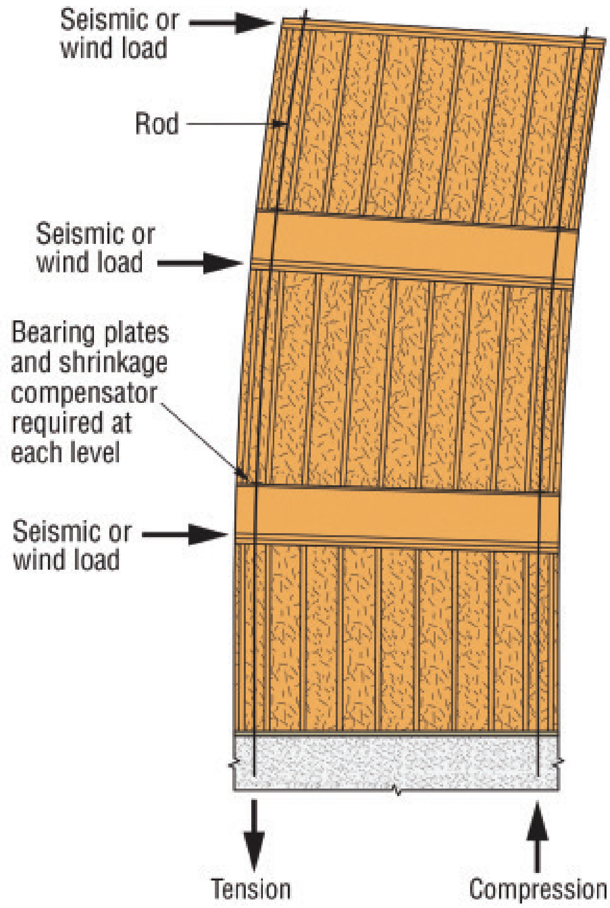


Figure 3.18: Continuous steel rod tie-down system.

Image courtesy of Simpson Strong-Tie®.

These tie-downs systems need to be installed at the end of each shear wall segment; therefore, using long shear wall segments reduces the numbers of tie-downs necessary. The same tie-systems can be used when CLT floor or roof panels are supported with light-frame wall panels.

Prefabricating shear wall panels means that overturning resisting systems such as hold-downs and tie-downs can be accurately modelled in the 3-D modeling software. However, panel manufacturers must create temporary openings in the prefabricated wall panels to accommodate the connection and anchoring details to be completed on the job site.

Various fastenings for CLT wall panels, such as metal plates and brackets, are available in the market (*Figure 3.19*). These metal plates and brackets are used to connect the CLT wall panels to the concrete foundation and podiums. The placement depends on the required load capacity and ductility. When the CLT wall is designed as a shearwall, then hold-downs specifically designed by the project engineer will be specified on the structural drawings.

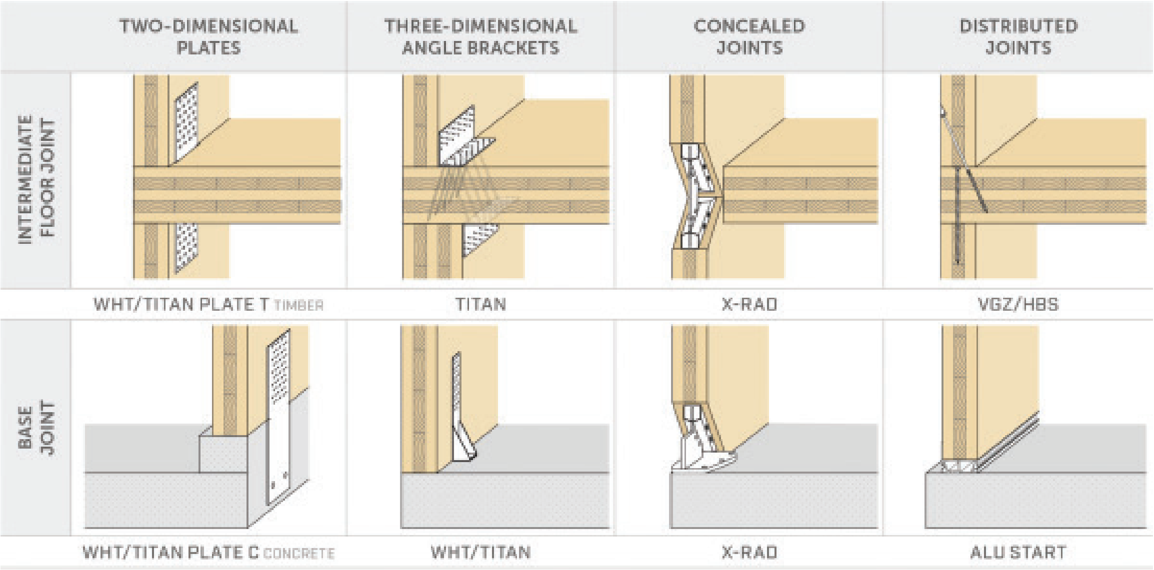


Figure 3.19: Different type of CLT metal plates and brackets.

Image courtesy of Rothoblaas Canada.

Many variables impact anchorage design, such as foundation type, slab thickness, concrete strength, anchor embedment and edge distances. The lateral loads from the structure above will produce large tensile overturning forces. It is a critical step to ensure that the slab thickness is sufficient for the anchor placement and the geometry of the anchor bolts are not too close to the foundation wall. The concrete contractor will need to locate these anchor bolts and use a template or other method to set the anchor bolt prior to pouring concrete.

5.3.5 Serviceability Limit States

Serviceability limit states do not compromise the safety of a building for its occupants. Designers must nevertheless take them into account to restrict damage that could occur to the structure or non-structural elements, and to ensure occupant comfort. Serviceability limit states essentially relate to temporary and permanent deformation and vibrations (Article 4.1.3.4, NBC 2015). For wood buildings, vertical movement – primarily from shrinkage – must also be considered.

5.3.5.1 Deflection

Deflection occurs when structural elements are affected by different loads. Deflection falls into two categories: temporary deflection or permanent deformation. Structural engineers must verify the magnitude of the deflection of structural elements under live loads, but also under total loads. Allowable deflection criteria are provided in the NBC 2015, or in the various Canadian wood design standards. These criteria vary depending on the type of structural elements, the type of loads, and the types of finishes used.

5.3.5.1.1 Temporary Defl ction

Temporary deflection, also known as elastic deflection, occurs temporarily when a load is applied to a structural element. It is reversible, in that the deformed element will return to its initial shape when the load is removed. There are two criteria of temporary deflection that must be verified: deflection under the total load, and deflection from live loads only.

The various elastic deflection criteria can be found in Commentary D of the User's Guide – NBC 2015: Structural Commentaries (NRCC, 2015), in CSA O86-16 (Article 5.4), and in the Wood Design Manual (Table 2.1, CWC 2017). **Table 5.4** provides a summary of the elastic deformation criteria under total loads and live loads for different types of wood structural elements.

Where lintels support loads over openings in light wood-frame loadbearing walls, it is better not to limit the deflection to a fraction of the span, but rather to ensure that the absolute value of the deformation is low enough to prevent impairing the doors and windows, or damaging interior or exterior finishes.

Table 5.4 Summary of elastic deformation criteria

Components	Defle tion under total loads (Δ_T)		Defle tion under live loads (Δ_L)	
	Gypsum or plaster ceiling	Other ceiling	Gypsum or plaster ceiling	Other ceiling
Roof members in heavy timber (rafters, joists, beams)	L/360[3]	L/180[1]	L/360[2]	L/240[2,3]
Roof members in engineered wood (trusses, beams, joists)	L/240[4]	L/180[1]	L/360[2,3]	L/240[2,3]
Floor members in heavy timber (joists, beams)	L/360[3,5]	L/180[1] or L/360[5]	L/360[2,3]	L/360[2,3]
Floor members in engineered wood (joists, trusses, beams)	L/240[4] or L/360[5]	L/180[1] or L/360[5]	L/360[2,3] or L/480[4]	L/360[2,3] or L/480[4]
	With masonry veneer	Without masonry veneer	With masonry veneer	Without masonry veneer
Light-frame wall studs [1]	L/360	L/180	L/360	L/180
Columns [1,3]	L/360	L/180	L/360	L/180

Notes:
(1) User's Guide – NBC 2015: Structural Commentaries (Commentary D, Table D-1).
(2) National Building Code 2015 (Division B, Part 9, Table 9.4.3.1).
(3) Wood Design Manual 2017(Table 2.1).
(4) Common practice by manufacturers of engineered wood members.
(5) For members supporting floors covered in a concrete topping, L/360 is recommended as the criterion for deflection under total load (Wood Design Manual 2017, Table 2.1).

5.3.5.1.2 Permanent Deformation

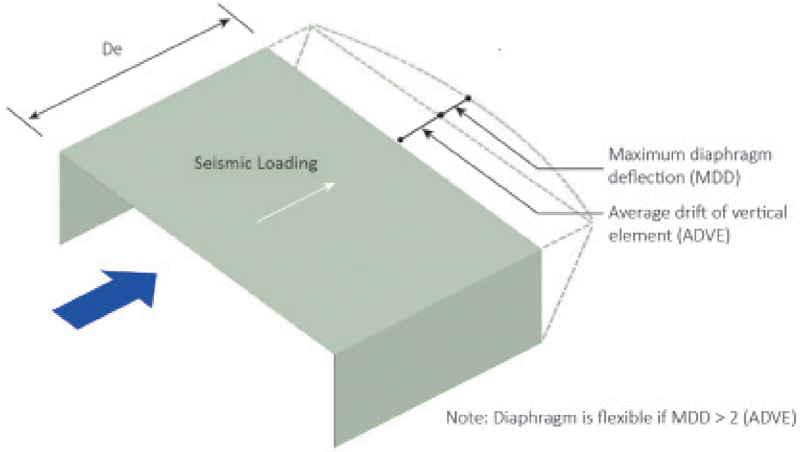
Dead loads, which continuously affect framing elements, can lead to permanent deformations in the long term, known as creep. These deformations depend primarily on the magnitude of the dead loads applied to the structure. Unlike elastic deflection, creep is an irreversible phenomenon.

Canadian standards and codes contain little information on calculating creep for wood-frame members, or guidance for limits to consider for this deformation. CSA O86-14 (Clause 5.4.3) mentions that deflection is to be limited to L/360 under dead loads when these dead loads are more than 50% of the load combinations for serviceability limit states.

More elaborate design methods for evaluating creep in wood-frame elements can be found in the American National Design Specification (NDS, 2018) and in the European standard Eurocode 5 (CEN, 2009).

5.3.5.1.3 Deflection from Lateral Loads

Buildings can be subjected to two types of lateral loads: wind loads and earthquake loads. The NBC requires that deflection from lateral loads on a building be restricted in order to limit damage to the structure or non-structural elements. Total deflection from lateral loads includes the deflection of the diaphragm and vertical lateral load resisting systems *(Figure 3.20)*.



Sentence 4.1.3.5 (3) of the NBC 2015 limits inter-storey deflection under wind loads to h/500, where h represents the storey height, with some exceptions for certain building uses and occupancies. It also permits the use of other limits from Canadian material design standards. Article 4.1.8.13 of the NBC limits inter-storey deflections under earthquake loads to h/40, except for post-disaster buildings or high importance category buildings such as schools, where the limit is more stringent. The NBC indicates that deflection values for earthquake loads determined by elastic linear analysis are to be multiplied by RdRo/IE for more realistic deflection results. This is because the design loads are first multiplied by IE/RdRo.

Although wind deflection criterion seems more restrictive, it is associated with a wind service load corresponding to a frequent event while the seismic deflection criterion is associated with a seismic design load corresponding to an extremely rare event. In other words, wind deflection criterion is meant to prevent damage while seismic deflection criterion is meant to limit damage.

5.3.5.2 Vibration

Vibration is a serviceability limit state that applies primarily to floors. It does not generally cause damage to a building's structure or non-structural elements, but it can lead to discomfort for the occupants. Article 4.1.3.6 of the NBC 2015 provides limit requirements for floor vibration.

In light wood-frame structures, floor vibration depends on the overall composition of the floor system. There are many factors that influence the stiffness of a floor assembly, and consequently its susceptibility to vibration, including the type and thickness of structural sheathing, fastening method, any bridging system, and the direct attachment of gypsum ceiling on the underside.

There are two types of structural members that can be used in a light wood-frame floor assembly: dimensional lumber joists and engineered wood joists (open-web trusses or I-joists). The NBC 2015 provides a numerical method in Appendix A-9.23.4.2. (2) of Division B for checking the vibration behaviour of a floor assembly containing dimensional lumber joists. The static analysis method is based on calculating the deflection under a concentrated midpoint load.

For engineered wood joists, the Canadian Construction Materials Centre (CCMC) has developed a method that also checks the deflection under a concentrated midpoint load. This dynamic method considers the floor system as a whole and not just one individual joist. The recommended design methods are provided in CSA O86-19, Clause A.5.4.5. Engineered wood joist manufacturers publish vibration-controlled span tables and have software available that complies with the CCMC's vibration criterion.

Vibration performance of CLT floors is also required and a suitable design method is provided in CSA-086-19, Clause A.8.5.3. The calculation procedure given in this Clause for single span systems may be applied to individual spans in a multiple span system, with adjustment, if appropriate. The Canadian CLT Handbook, 2019 Edition provides additional information on vibration in Chapter 7. It also may be prudent to contact the CLT manufacturer to get guidance on allowable spans for vibration

5.3.5.3 Vertical Movement

Vertical movement is a serviceability limit state that must be checked to restrict damage to a building's structure or non-structural elements. In wood-frame buildings, the total vertical movement comes from a combination of four factors: shrinkage from varied moisture levels in the wood, elastic deflection under gravity loads, creep caused by dead loads, and settlement caused by imprecise construction or gaps in connections. Section 3.6 takes a more detailed look at vertical movement in light wood-frame buildings and mass timber buildings.

5.3.6 Vertical Building Movement

Vertical movement is an important consideration in building design, so that proper detailing can be planned to ensure good serviceability of the building's architectural finishes and equipment. Moreover, differential vertical movement can occur between structural elements in buildings where materials with different properties are used. For example, there are specific design considerations when using a wood structure adjacent to a concrete stair shaft.

The NBC and CSA O86 do not provide any maximum deformation criteria associated with vertical movement. However, structural engineers can calculate the total value of this movement and share it with other consultants working on the project to avoid unwanted consequences such as:

- Poor door and window operation.
- Changes to slopes of plumbing system pipes.
- Stretching or jamming of electrical wires.
- Changes to slopes of roof or balcony drainage.
- Discontinuity or crushing of exterior cladding.

Vertical movement in wood buildings can be caused by:

- Shrinkage due to variation in moisture content between installation and service equilibrium.
- Elastic deformation of structural elements from gravity loads.
- Creep of structural elements from gravity loads.
- Settlement caused by gaps and clearance between structural elements during installation.

This section provides designers with information about these effects so they can estimate the total vertical movement of a wood-frame building, along with some solutions for reducing this vertical movement.

5.3.6.1 Shrinkage

Wood shrinkage is a cause for vertical movement in wood-frame construction. Predicting wood shrinkage is mostly dependent on the ability to correctly estimate the start and end moisture condition for a wood member, and the accuracy of the shrinkage coefficient. It is possible to limit shrinkage by paying close attention to the moisture content of the various structural members when they are installed and detailing proper accommodations.

The shrinkage of solid sawn lumber and glued-laminated timbers can be estimated using the equation:

$$S = D \times M \times C$$

Where:

S = shrinkage (mm)

D = actual dimension (thickness or width or length, mm)

M = percentage of MC change below 28% (fibre saturation point)

C = shrinkage coefficient

= 0.002 for shrinkage perpendicular to grain

= 0.00005 for shrinkage parallel to the grain

In certain regions of Canada, it is possible to use an estimated minimum moisture content of 8% in the winter for heated buildings and 10% for unheated spaces. The initial moisture content for wood members at the time of installation depends on the material. **Table 5.5** shows moisture content for different wood materials at the time of manufacturing.

Table 5.5

Material	Moisture Content
S-Dry Lumber	19% – maximum
KD Lumber	19% – maximum
Glued-laminated timber	11 to 15% – average
Plywood/OSB	6 to 12% – average
LSL, LVL and PSL	6 to 12% – average
Laminated Finger-Jointed Lumber	8 to 12% depending on M.C. requested
Cross-laminated timber (CLT)	11 to 15% – average

Differential movement is typically a larger concern for platform frame construction due to the used of stacked members, such as wall plates, than for post and beam and mass timber construction.

If we look at a CLT platform structure *(Figure 3.21)*, the dimensional changes in the thickness direction of the CLT floor would be larger than the in-plane changes.

Other than deformation or creep caused by the gravity load, the CLT floor panel would shrink when the wood dries from construction into service. The load from the CLT Wall on this CLT floor will also cause some deformation due to crushing. The CLT Wall is highly dimensionally stable due to cross laminations with the wood in the longitudinal direction and shrinkage would be minimal like wall studs in light wood-frame construction.

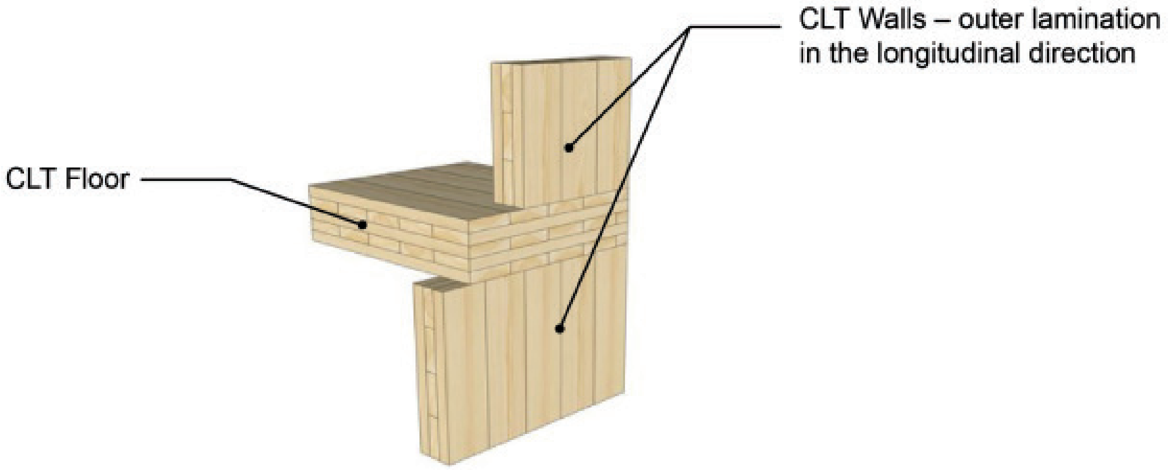


Figure 3.21: CLT Platform Construction.

The shrinkage of the CLT floor can be estimated using a regular shrinkage calculation formula,

$$S = D \times M \times C$$

Where:

S = shrinkage amount (mm)

D = actual dimension of wood members (mm)

M = percentage of MC change (%), i.e., the difference between the initial MC (typically 15% for CLT, depending on climate and exposure to rain/humidity during construction) and the service EMC (depending on climate and building operation)

C = shrinkage coefficient of wood members (percentage per 1% change in MC), which is typically 0.2-0.25% per 1% change in MC for transverse direction (cross section) of wood

A recent FP Innovations publication titled, "*Field Measurement of Vertical Movement and Roof Moisture Performance of the Wood Innovation and Design Centre,*" reported on the moisture performance of a mass timber building in Prince George, B.C. This report covers vertical movement and roof moisture performance for about three-and-a-half years, with sensors installed during construction.

It is possible to reduce the amount of shrinkage that may occur in mid-rise wood buildings by using engineered wood products. **Section 5.3.6.5** provides relevant solutions for the construction of light wood-frame buildings. Structural engineers, architects, and mechanical engineers must work closely together to set acceptable limits for vertical building movement and select construction details and materials that meet these objectives.

5.3.6.2 Elastic Deformation of Structural Members

Predicting the amount of elastic deformation of each structural member can be estimated based on engineering principles. It may be impossible to precisely calculate the elastic deformation of wood, particularity for horizontal members due to large variations in MOE perpendicular-to-grain and effective bearing length. The deformation is cumulative from the upper storeys to the lower storeys, just like the predicting shrinkage.

This vertical deformation of wood frame structures (e.g., studs, plates, and headers of floor joists) can be estimated using the following formula:

$$\Delta_{elastic} = P \times L / (A \times E)$$

Δ elastic = estimated elastic deformation (mm)

P = specified load (N)

L = actual dimension of the wood member in the load direction (mm)

A = cross-section of the wood member (mm^2)

E = modulus of elasticity (MPa)

The MOE and other wood strengths will vary with wood species, density, grain orientation, and moisture content. CSA O86-19 and other wood standards specifies the modulus of elasticity parallel to the grain of the wood members, However, for horizontal elements such as top plates, bottom plates, joists and rafters, the modulus of elasticity perpendicular to the grain (E_{perp}) is not provided by CSA O86-19. According to the "*Wood Handbook – Wood as an Engineering Material*" (US FPL, 2010), E_{perp} can vary between 1/10 and 1/30 of the modulus of elasticity parallel to the grain.

Several case studies of this procedure have been presented in Section 5.3.3, "*Mid-Rise Wood-Frame Construction Handbook*, First Edition 2015" (FP Innovations). The E_{perp} was assumed to be 1/30 of the modulus of elasticity parallel to the grain in the analyses on these case studies.

The FP Innovations document entitled, "*Vertical Movement in Wood Platform Frame Structures: Movement Prediction,*" (CWC/FPInnovations, 2013) suggests a different procedure and only considers the dead load in the formula for analysis.

5.3.6.3 Creep in Structural Members

Creep is a permanent deformation caused by sustained load applied to structural wood members. It is affected by the length of time the load is applied, by the load's intensity, and by the wood's moisture content. CSA O86 does not provide information on calculating the creep value. Based on European references, the document, "*Vertical Movement in Wood Platform Frame Structures*,"(CWC/FPInnovations, 2013) suggests estimating long term creep as 0.60 times the instantaneous dead load deformation for wood. This value applies to structures in typical indoor conditions, with an average temperature of 20°C, and relative humidity of the surrounding air only exceeding 65% for a few weeks per year.

5.3.6.4 Movement Due to Closing of Gaps Between Members (settlement)

The amount of settlement caused by gaps and clearance between structural members from installation depends on manufacturing precision and the quality of the wood pieces. The document "*Vertical Movement in Wood Platform Frame Structures: Movement Prediction*" (CWC, 2013) suggests accounting for 2 mm of settlement for each storey to compensate for gaps between structural members during installation. However, the use of prefabricated components, such as prefabricated floors and walls, will likely reduce settlement to less than 2 mm per storey. Settlement is rarely considered in vertical building movement calculations for architectural tolerances because it occurs directly under dead loads as the building is being constructed.

5.3.6.5 Strategies for Limiting Vertical Movement

As mentioned previously, shrinkage is the most significant factor when calculating the total vertical movement for a building using a wood platform frame structure, followed by the elastic deflection of structural elements on lower storeys. The best strategies for limiting shrinkage involve selecting materials with low moisture content and good strength, using fewer horizontal elements contributing to shrinkage, and opting for prefabricated assemblies and components.

5.3.6.5.1 Using Materials with Low Moisture Content

As discussed in **Section 5.3.6.1**, shrinkage is caused by the reduction in (MC) between installation and service equilibrium. The initial moisture content for wood members at the time of installation depends on the material. Since the average equilibrium moisture content inside heated buildings in most regions of Canada is around 8%, using materials with a moisture content close to this value during construction limits vertical movement due to shrinkage.

5.3.6.5.2 Limiting the Contribution of Horizontal Members to Shrinkage

The shrinkage coefficient perpendicular to the wood grain is 40 times greater than the coefficient parallel to the grain. For this reason, particular attention must be paid to details using horizontal structural members, such as the connections between wall and floor assemblies. Since the modulus of elasticity perpendicular to the wood grain is about 20 times lower than the modulus parallel to the grain, these horizontal elements also cause greater elastic deformation in the structure.

Top and Bottom Plates

In light-frame wood construction, a large portion of total shrinkage is caused by the shrinkage of top and bottom plates. In a 6-storey building, which has a lightweight gypsum concrete layer, there are generally two top plates and two bottom plates per storey, for a total of 24 plates or 912 mm of horizontally-oriented wood. **Table 5.6** shows the expected shrinkage at equilibrium based on the type of material used for these top and bottom plates. The type of material used for top and bottom plates and its moisture content at time of installation will therefore have a significant impact on the calculation of the building's vertical movement.

Table 5.6 Total shrinkage of top and bottom plates for a 6-storey light-frame wood building

Top and bottom plates	Manufacturing M.C.	Average E.M.C.[1]	Cumulative height of top and bottom plates	Expected shrinkage
SPF	19%	8%	912 mm	20 mm
LSL	8%	8%	912 mm	0 mm

1 The average equilibrium moisture content can vary based on conditions; an average equilibrium M.C. of 8% is an approximate value for a heated building in Canada.

Wall-to-Floor Connections

Rim boards play several roles in light wood-frame platform construction (*Figure 3.22*). In addition to providing lateral support for floor joists and connecting diaphragms to shear walls, rim boards are also used to transfer gravity loads between the walls located above and below floor intersections. Rim boards are generally made of engineered wood and are manufactured in different thickness. The wider rim boards can support greater gravity and lateral loads and must be sized accordingly for the project.

Engineered wood rim boards (LSL, LVL or OSB) add little overall shrinkage to the structure, because they are manufactured with an M.C. lower than 8%, and generally reach an equilibrium M.C. of 8% when in service. On the other hand, their elastic and creep deflection can also contribute to a building's total vertical movement.

Figure 3.22: Wall-floor connection with rim board.

When a CLT panel is supported with a post and beam structure, it is best to use details that directly transfer the compression loads from the posts from the upper storeys to lower storeys. This eliminates the load transfer on the CLT floor panel as the compression load is mechanically transferred to posts below.

Floor Joists

Dimensional lumber floor joists, such as those measuring 38 x 235 mm (2 x 10 in.) or 38 x 286 mm (2 x 12 in.), cause significant shrinkage and are not recommended for 5- and 6- storey mid-rise light-framed wood buildings. Prefabricated I-joists or trusses are better solutions. The flanges of these joists may be made of structural composite lumber or sawn lumber with a maximum M.C. of 19% (KD-HT wood). Although squash blocks can be used to increase the load transfer capacity *(Figure 3.23)*, the squash block's shrinkage value is very low because it is parallel to the wood grain. For example, the shrinkage of a 406 mm long SPF #2 block is 0.2 mm (406 mm x 0.00005 x (19-8)).

Figure 3.23: Squash block with rim board detail.

Use of CLT panels and other mass timber components also provides different solutions for wall and floor connections, as previously discussed.

5.3.6.5.3 Using Prefabricated Components

Section 7 discusses using prefabricated assemblies that incorporate greater precision, which may help control settlement. Shop drawings also allow structural engineers to check the exact specification of material and associated details. Prefabricated panels and systems are manufactured in a controlled environment under a quality control plan and installed more quickly on the jobsite. Therefore, there is much less risk of exposure to weather at the job site, which could increase their moisture content before the building is closed in.

5.3.6.5.3 Strategy Summary

Table 5.7 provides a summary of the different strategies for reducing total vertical movement and maintaining good serviceability in 5- and 6-storey wood buildings. It also presents recommendations for wood products that could be used as structural members to minimize a building's total shrinkage. Engineered wood can also be used for top and bottom plates, or other horizontal elements. The use of engineered wood products, CLT and mass timber elements with high-performing connection details also ensure good serviceability.

As explained previously, a building's total vertical movement also includes elastic deflection, creep, and settlement of the structure, which depend on the applied loads and must be added to the shrinkage.

Table 5.7 Strategies for reducing total vertical movement in 5- and 6-storey wood buildings.

Strategy		Comments
Using materials with low moisture content and good strength		
Top and bottom plates	LSL, LVL, or glued-laminated timber	Top and bottom plates composed of traditional lumber (with 19% moisture content) can cause over 50% of a structure's overall shrinkage.
Framing in loadbearing and non-loadbearing walls	KD-HT lumber LSL, LVL, glued-laminated timber, CLT wall panels	Longitudinal shrinkage of studs is not the most significa t factor. However, KD-HT lumber could be used, if necessary.
Beams and lintels	LSL, LVL, PSL or glued-laminated timber	Like top and bottom plates, beams and lintels are horizontal members with significa t shrinkage that can influen e the total vertical movement of a building. Engineered wood is recommended, because it undergoes less shrinkage and provides better perpendicular compression resistance than sawn wood.
Columns not in loadbearing walls	LSL, LVL, PSL or glued-laminated timber	For uniform shrinkage, the general recommendation is to use columns with the same M.C. as the wall studs. However, the shrinkage will affect longitudinal members less, so it is better to use engineered wood columns in one piece, because the compression resistance parallel to the grain is much weaker in a composite member not retained laterally.
Floor joists	Prefabricated I-joists or trusses, CLT floo panels	Sawn lumber joists undergo quite a bit of shrinkage. Not recommended.
Roofin	Prefabricated trusses in KD-HT lumber, CLT roof panels	Like floor member , roof framing must contain dry wood to limit their contribution to shrinkage.
Minimize the number of horizontal elements that contribute to shrinkage		
Using prefabricated components		
Use prefabricated walls, fl or, and roofs panels for all loadbearing elements		Prefabrication takes place in a controlled indoor environment. Quick installation greatly reduces the risk of exposure to weather during building construction. Manufacturing precision limits the settlement factor in the calculation of vertical movement.

5.3.6.6 Specific Considerations for Balcony Design

Since balconies are floors built outside the main building envelope, they must always have a drainage slope toward the outside to prevent water ingress inside the building. Differential vertical movement between the building structure and the balcony could change the drainage slope. Possible solutions are covered in **Section 5.6.5.**

5.4 Fire Safety

Building fire safety is a very important topic. It ensures an acceptable level of safety for occupants and emergency responders located within or near a building in the case of a fire, and also ensures a level of protection against building damage from such an event. Prescriptive requirements for building fire safety can be found in Division B, Part 3 of the National Building Code of Canada (NBC, 2020), as well as in the National Fire Code of Canada (NFC, 2020).

Prescriptive fire safety requirements in Division B, Part 3 for mid-rise wood buildings of primarily residential and business and personal services occupancies (i.e., 5- and 6-storeys, in addition to larger buildings of 1, 2, 3 and 4-storeys) were first published in the 2015 edition of the NBC (NBC 2015). The 2015 NBC provisions, as well as various province-specific versions, are now in effect across most of Canada. Revisions were made to the requirements in the 2020 NBC.

This section provides an overview of the fire safety requirements of the NBC for mid-rise wood buildings. The information herein provides guidance for designers. Building designs and details are the responsibility of the designer and are subject to the approval of the Authority Having Jurisdiction (AHJ).

Table 5.8 presents a summary of the primary fire safety requirements in the 2015 NBC documents for 5- and 6-storey wood buildings.

	NBC 2015	
	Residential Occupancies (Group C)	Business and Personal Services Occupancies (Group D)
Major Occupancies and Maximum Areas	– 1 storey = 9 000 m^2 – 2 storeys = 4 500 m^2 – 3 storeys = 3 000 m^2 – 4 storeys = 2 250 m^2 – 5 storeys = 1 800 m^2 – 6 storeys = 1 500 m^2	– 1 storey = 18 000 m^2 – 2 storeys = 9 000 m^2 – 3 storeys = 6 000 m^2 – 4 storeys = 4 500 m^2 – 5 storeys = 3 600 m^2 – 6 storeys = 3 000 m^2
Other Occupancies Permitted in Building (using same construction type)	– Assembly (Group A Division 2) and mercantile (Group E) major occupancies on first wo storeys; – Storage garage on the first th ee storeys.	– Assembly (Group A Division 2), mercantile (Group E), and low- and medium-hazard industrial (Group F Divisions 2 and 3) major occupancies on first wo storeys; – Storage garage on the first th ee storeys.
Maximum Heights	– Up to 18 m between floor of first orey and the uppermost floor le el	
Automatic Sprinkler Protection	In conformance with NFPA 13, except that if the building is 4 storeys or less NFPA 13R is permitted to be used;	In conformance with NFPA 13;
	– Sprinklers shall be provided for balconies and decks exceeding 610 mm in depth measured perpendicular to the exterior wall.	
Fire-Resistance Ratings (FRR)	– Floors: fi e separation having a 1-h FRR; – Roof: 1-h FRR; – Mezzanines: 1-h FRR; – Loadbearing walls, columns and arches: 1-h FRR.	
Fire Separations Between Major Occupancies	Between Group C and: – Group A-2: 2-h FRR; – Group D: 1-h FRR; – Group E: 2-h FRR; – a storage garage: 1.5-h FRR.	Between Group D and: – Group A-2: 2-h FRR; – Group C: 1-h FRR; – Group E: none; – a storage garage: 1.5-h FRR.
Horizontal Concealed Spaces	Depending upon the arrangement, many combustible concealed spaces (e.g., floo or roof assemblies) must be sprinklered in accordance with NFPA 13. There are exceptions, such as those spaces containing non-combustible insulation or spaces with all surfaces having a flame sp ead rating of 25 or less.	
Cladding	Not less than 90% of the exterior cladding on each exterior wall shall consist of: – non-combustible cladding; – or, a wall assembly that satisfies the ode criteria when tested in conformance with CAN/ULC-S134.	
Roof	– Where the roof assembly has a height greater than 25 m measured from the floo of the first s orey to the highest point of the roof assembly, the roof assembly shall be constructed of non-combustible construction or fi e-retardant-treated wood conforming to Article 3.1.4.5. – Where the roof height is greater than 25 m measured from the floor of th first s orey to the highest point of the roof, roof coverings shall have a Class A classific tion.	
Accessibility	– Not less than 25% of the building perimeter shall be located within 15 m of a street;* – No portion of the access route shall be more than 20 m below the uppermost floo level.	
Emergency Power Supply	Shall be operational for a period of: – 1 h for emergency lighting; – 1 h for fi e alarm systems.	
Other Material Combustibility Requirements	– Considered as buildings of combustible construction.	

* Note: The percentage of building perimeter has been revised in the 2020 NBC to 10%.

This section provides information on specific fire safety requirements to consider when designing 5- and 6-storey lightweight wood-frame buildings and offers potential solutions for meeting these requirements. However, designers are responsible for ensuring compliance with all fire safety requirements in accordance with applicable local regulations.

This section presents the requirements associated with the type of construction required for the different elements forming 5- and 6-storey wood buildings, along with the requirements for automatic sprinklers and standpipe systems, required fire-resistance ratings (FRRs), fire separations, fire containment in concealed spaces, elevator shafts and exit stairs, as well as interior and exterior finishes.

5.4.1 Combustible and Non-combustible Construction

First, it is important to provide a definition for non-combustible and combustible materials. According to the NBC, a non-combustible material passes the criteria when tested in conformance with CAN/ULC-S114, *Test for Determination of Non-Combustibility in Building Materials*, while, in contrast, a combustible material is one that does not pass the criteria when tested in conformance with this standard (NBC, 2020). Organic materials such as wood fall into the second category. Contrary to popular belief, treating or adding fire-retardant products does not change the combustible nature of materials such as wood; they simply delay the combustion process.

The ype of construction, combustible or non-combustible, is one of the fire safety strategies that appears in the acceptable solutions of Division B of the NBC to characterize a building's structure as a whole, or certain elements in particular. The NBC defines non-combustible construction as "*that type of construction in which a degree of fire safety is attained by the use of non-combustible materials for structural members and other building assemblies*," while combustible construction is simply "*that type of construction that does not meet the requirements for non-combustible construction*." The latter may therefore be built with "combustible" structural components. However, some specific combustible components are permitted in non-combustible construction. The NBC's various requirements on combustible construction appear in Subsection 3.1.4. and those on non-combustible construction in Subsection 3.1.5. In the various Articles of Subsection 3.2.2., the NBC indicates whether a building is permitted to be of combustible construction, or if non-combustible construction is required, based on specific parameters including the building's major occupancy, its area, its number of storeys and whether or not it has an automatic sprinkler system (NBC, 2020).

The 2015 and 2020 editions of the NBC authorize the use of combustible construction for 5- and 6-storey residential or office buildings (in conformance with the provisions of Subsection 3.1.4). The provisions also allow certain other major occupancies on the lower storeys of these buildings (see Table 5.8). The only portion of these buildings that may be required to be of non-combustible construction is the roof assembly, and only if any portion of it is higher than 25 m, measured from the floor of the first storey to the highest point of the roof assembly. Even in that instance, fire-retardant-treated wood construction is permitted.

Finally, it is important to keep in mind that although the 2015 and 2020 NBC permit the use of wood structures for 5- and 6-storey residential or business buildings, the requirements in Subsection 3.2.3. on spatial separation and exposure protection may necessitate the use of non-combustible construction for one or several of the exterior walls of a building, depending on limiting distances and percentage of area of unprotected openings.

5.4.2 Sprinklers and Standpipe Systems

5.4.2.1 Automatic Sprinkler Systems

Automatic sprinkler systems are known to be one of the most effective methods for controlling fires in buildings, thereby reducing occupant fatalities and injuries as well as reducing damage to the building due to fire. Although they provide some of the best fire protection in buildings, sprinklers are not generally designed to put out a fire entirely. In the event of a fire, the sprinklers lower the fire's temperature, controlling the fire until firefighters arrive, and, in some cases, completely extinguish the fire (CWC, 1997).

As is the case with most other buildings over four storeys in height, the NBC requires that 5- and 6-storey buildings of wood construction containing residential occupancies (Group C) and business and personal services occupancies (Group D) be equipped with an automatic sprinkler system throughout in conformance with Sentence 3.2.5.12.(1). Sprinkler systems are to be designed, constructed, installed, and tested in conformance with NFPA 13, *Standard for the Installation of Sprinkler Systems* (NFPA 13).

However, the mid-rise combustible construction Articles might also be used for large low-rise buildings of wood construction for residential occupancy that are 1-, 2-, 3-, or 4-storeys in height, in order to permit larger building areas compared to those permitted for other low-rise residential wood buildings. In this case, the NBC permits the residential occupancy to be sprinklered throughout in conformance with NFPA 13R, *Standard for the Installation of Sprinkler Systems in Low-Rise Residential Occupancies* (NFPA 13R).

NFPA 13 is generally intended for mechanical engineers who are responsible for designing sprinkler systems. It includes the minimum requirements for selecting a type of automatic sprinkler system, piping, fittings, valves, sprinkler locations, hanging methods, and necessary design discharge densities and total water supply required. However, any professional who is involved in designing light wood-frame buildings of up to 6-storeys should be aware of this standard's specific requirements, because the requirements are closely tied to various structural and architectural elements, and for a sprinkler system to comply with NFPA 13 there are additional considerations than those in NFPA 13R. These include protecting concealed spaces, horizontal exterior projections, vertical shafts, electrical equipment rooms, bathrooms, closets and compartments, as well as pipe bracing fastened to structural members.

Types of Piping

The network of pipes in an automatic sprinkler system designed in compliance with NFPA 13 may be made up of metal pipes and fittings or non-metal pipes and fittings (e.g., CPVC). Whether metal or non-metal, piping shall comply with the various requirements of Section 7.3 of NFPA 13 (2019). Article 3.2.5.13. of the NBC also provides specific requirements for the use of combustible piping in sprinkler systems.

Protection of Concealed Spaces

In general, NFPA 13 requires all concealed spaces that are entirely or partially formed by exposed combustible materials to be protected by automatic sprinklers in order to limit fire spread within the spaces. In particular, this includes concealed spaces for floor and wall assemblies, attics or roof spaces, mechanical ducts, concealed spaces in drop ceilings, bulkheads and concealed spaces under stairs. However, in the section entitled, "Concealed Spaces Not Requiring Sprinkler Protection," NFPA 13 indicates special situations in which concealed spaces need not be protected with sprinklers. For example, in cases where the space is filled with non-combustible insulation (including air gap), where all rigid surfaces in the space have a flame-spread rating of 25 or less, where there is not enough physical space to install sprinklers, or where the concealed spaces are sufficiently fire-blocked in small volumes to limit fire spread within the spaces.

Of the situations in which automatic sprinklers may be omitted from concealed spaces, the following apply more specifically to lightweight wood-frame construction (NFPA 13, 2019):

a) Concealed spaces formed by solid-sawn lumber studs or joists with less than 152 mm (6 in.) between their inside edges: This is particularly the case for concealed spaces formed by double-row light-framed walls (*Figure 4.01*).

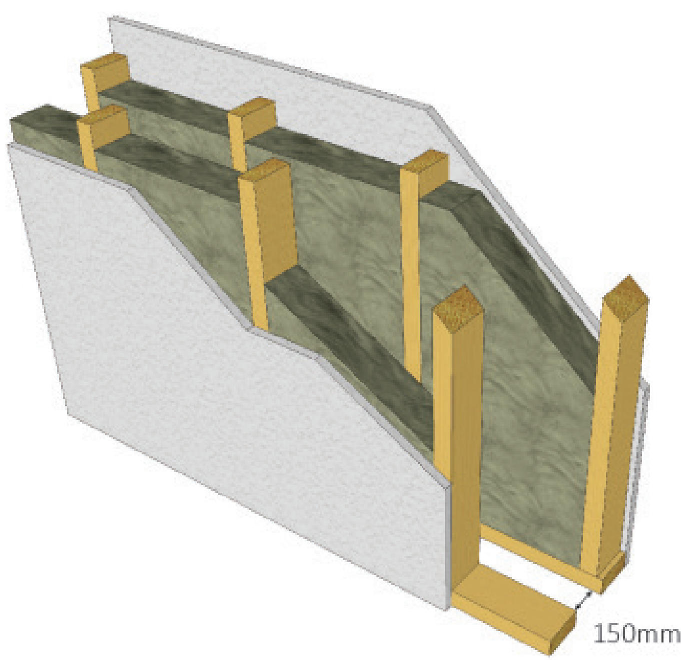


Figure 4.01: Example of concealed space where the distance between the inside edges of the elements is less than 152 mm (6 in.).

b) Concealed spaces formed by ceilings attached directly or within 152 mm (6 in.) of solid-sawn lumber or similar engineered solid wood joist construction (e.g., structural composite lumber). These must be solid joists with a maximum height of 356 mm (14 in.) and in which there are no openings (*Figure 4.02*). Engineered wood I-joists or wood trusses do not comply with this exception.

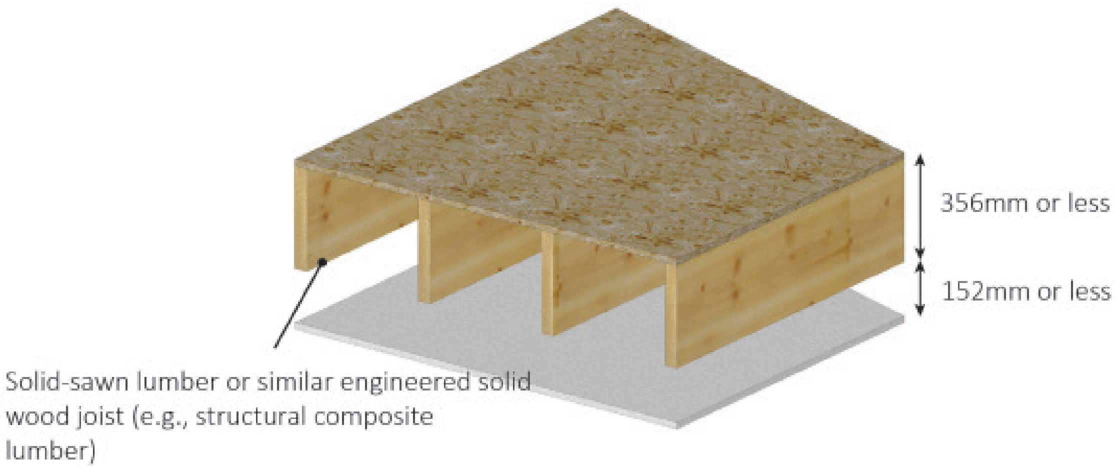


Figure 4.02: Concealed spaces formed by a ceiling attached beneath solid-sawn lumber or similar engineered solid wood joist construction (e.g., structural composite lumber). Adapted from NFPA 13, 2019.

c) Concealed spaces formed by ceilings attached to wood I-joist construction either directly or by metal channels not exceeding 25.4 mm (1 in.) in depth. However, the concealed spaces shall be separated into volumes not exceeding 4.53 m^3 (160 ft^3) using materials equivalent to the web construction. The volume of the joist space is calculated based on the length and width of the joist channel and the depth of the space within the channel measured from the top of the insulation to the underside of the subfloor. Additionally, at least 90 mm (3½ in.) of batt insulation shall be installed at the bottom of the joist channels when the ceiling is attached utilizing metal channels (*Figure 4.03*).

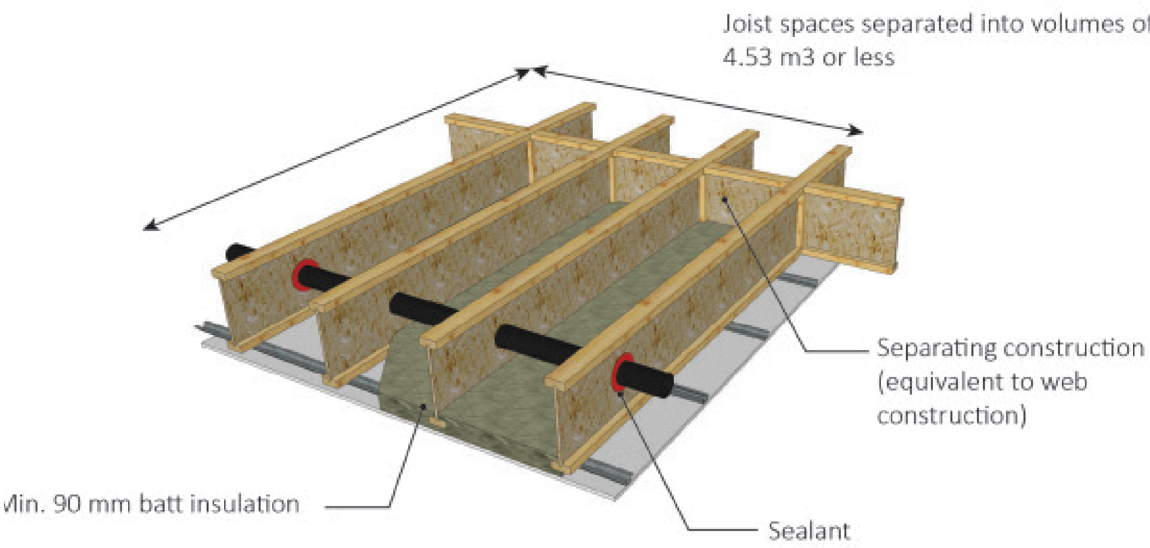
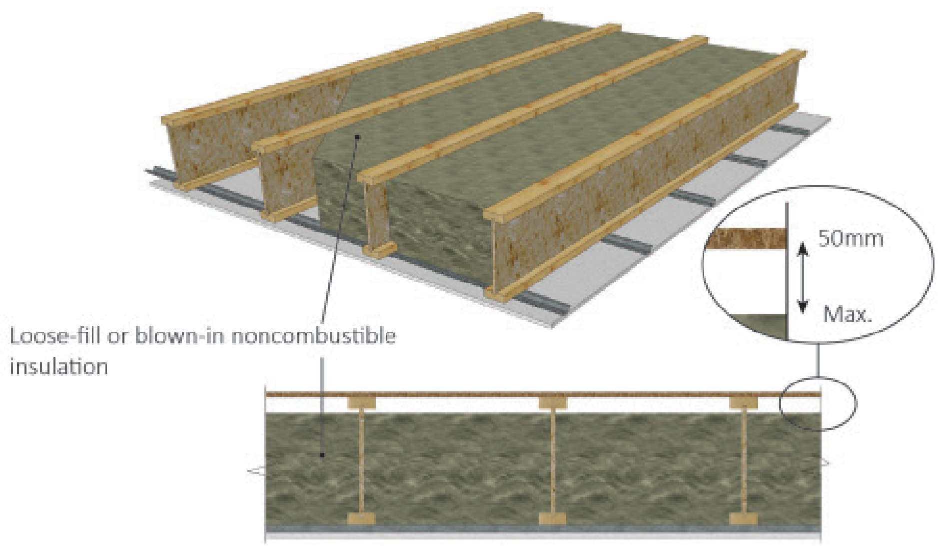


Figure 4.05: Concealed spaces formed by a ceiling membrane fastened at a certain distance under the bottom flange of floor joists or beams (adapted from NFPA 13).

d) Concealed spaces filled entirely with non-combustible insulation. A maximum 50 mm (2 in.) air gap is permitted at the top of the space (*Figure 4.04*). A non-combustible insulation shall comply with the requirements of CAN/ULC-S114, Standard Method of Test for Determination of Non-Combustibility in Building Materials (ULC-S114, 2005). In particular, this includes basalt-based rock or slag fibre and glass fibre insulations. These two types of insulation are available in loose-fill or blown-in form. In some situations, it may be more cost-effective to fill the cavities with non-combustible insulation rather than to install automatic sprinklers. Adding insulation also usually improves the building's acoustic (sound) transmission performance.



Note: the scenario depicted may also qualify as not requiring sprinklering based on volume of the joist spaces. This figure depicts an example of the cavity space being filled with non-combustible insulation.

Figure 4.04: Concealed spaces under a floor filled with non-combustible insulation (adapted from NFPA 13, 2019).

e) The spaces formed by wood I-joists and a ceiling membrane fastened at a certain distance to the bottom flange, provided that the cavity between the ceiling and bottom flanges of the joists are filled with a non-combustible insulation and the spaces formed by the beams are separated into volumes each not exceeding 4.53 m3 (160 ft3) using materials equivalent to the web construction (*Figure 4.05*). See paragraph (d) above for more information on non-combustible insulation.

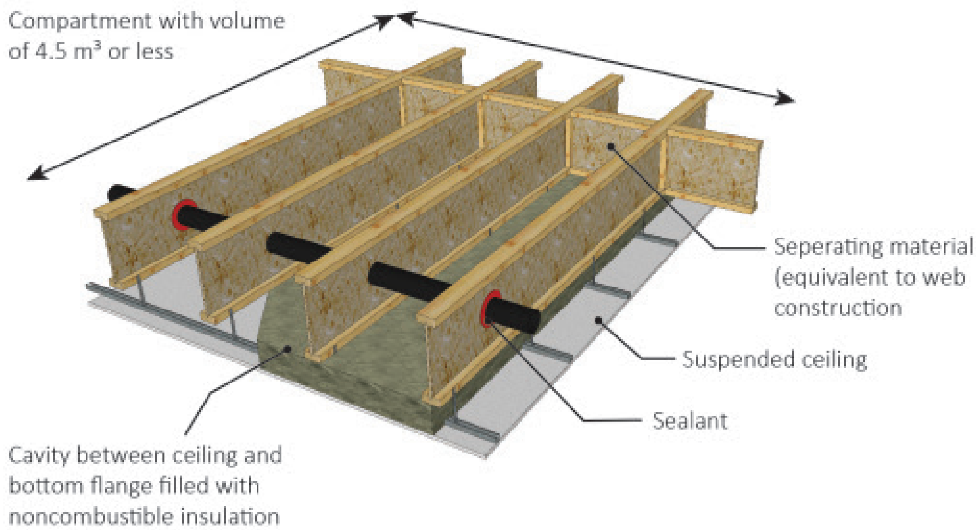


Figure 4.05: Concealed spaces formed by a ceiling membrane fastened at a certain distance under the bottom flange of floor joists or beams (adapted from NFPA 13).

f) Concealed spaces where rigid materials are used, and the exposed surfaces have a flame-spread rating of not more than 25 when the material is tested for flame spread for an additional 20 minutes, (for a test lasting 30 minutes total). Some fire-retardant coatings and other products such as oriented strand board (OSB) panels coated in a thin layer of a proprietary non-combustible material for wood products may be considered (by some AHJ's) as meeting these criteria.

g) Concealed spaces in which the exposed materials are constructed entirely of fire-retardant-treated wood as defined in NFPA 703 (2018). This wood is required to be pressure treated with fire-retardant chemicals and has a flame-spread rating of not more than 25 when tested in conformance with ASTM E 84 (2016). They also shall have been subjected to this flame-spread test for an additional 20 minutes. In Canada, the NBC requires that fire-retardant-treated structural wood products comply with CSA O80 (2008) and that their flame-spread rating be not more than 25, when tested in conformance with CAN/ULC-S102 (2010). However, the NBC does not require that flame-spread tests on fire-retardant-treated wood last for an additional 20 minutes, as required by the American standard. Since most of the available products have both the American and Canadian certifications, the difference between these certifications does not generally pose a challenge to designers. However, it is not currently common practice in Canada to build structural assemblies, such as walls or floors, using fire-retardant-treated wood. Consequently, designers should contact manufacturers to see if the necessary fire-retardant-treated wood products are available, as well as checking the cost and turnaround time for this option. Finally, it is important to mention that the wood's strength is affected by the fire-retardant pressure treatment. Engineers should take this into consideration when calculating the structural capacity of loadbearing fire-retardant-treated structural members, by using the treatment factor (KT) provided by the manufacturer of the fire-retardant product.

h) Vertical pipe chases with an area under 0.9 m2 (10 ft2). These cavities are generally located in the bathrooms or kitchens of residential buildings, and the lack of space makes it practically impossible to install automatic sprinklers in them. These spaces shall have fire blocks at each floor, pipe penetrations in fire blocks shall be properly sealed by an appropriate fire-stop system, and pipe chases shall contain no sources of ignition.

Other situations in which automatic sprinklers may be omitted from concealed spaces are presented in Section 9.2.1 of NFPA 13.

It is important to mention that applying some of the exceptions listed above to avoid installing sprinklers in concealed spaces may necessitate an increased design area to be applied for the sprinkler system protecting areas adjacent to these spaces, in conformance with NFPA 13 (2019), 19.3.3.1.5. This may necessitate a greater total water supply/flow pressure for the system to protect these areas.

Finally, for horizontal combustible concealed spaces that must be equipped with automatic sprinklers, and with a height less than 914 mm (36 in.), a slope not exceeding 2:12, and that contains a combustible upper surface, such as concealed spaces under floors, sprinklers listed for this application are required. Similarly, NFPA 13 contains requirements for installation of sprinklers in sloped concealed spaces, such as peaked roofs and ceilings.

Protection of Horizontal Exterior Projections

Along with the other requirements in NFPA 13, automatic sprinklers shall be installed below all horizontal exterior projections greater than 1.2 m (4 ft.) in width, in conformance with Section 9.2.3. This includes elements such as roof overhangs, canopies, porte-cochères, balconies and decks. However, Section 9.2.3.2 permits sprinklers to be omitted where the exterior projections are constructed with non-combustible materials or fire-retardant-treated wood. Section 9.2.3.3 of the standard also permits sprinklers to be omitted from below the exterior projections of combustible construction, provided the exposed finish materials are non-combustible or fire-retardant-treated wood, and the concealed spaces are equipped with sprinklers or meet one of the following criteria (NFPA 13):

- The concealed spaces are filled entirely with non-combustible insulation;
- A non-combustible or gypsum board ceiling is directly attached to sawn lumber joists, creating enclosed joist spaces of 4.5 m3 (160 ft3) or less in volume; or,
- The exterior projection does not exceed 5.1 m2 (55 ft2) in area.

Horizontal exterior projections less than 1.2 m (4 ft.) in depth measured perpendicular to the wall do not generally require automatic sprinkler protection below the projection, unless combustible materials are stored beneath them, as indicated in NFPA 13, 9.2.3.5. In such cases, the standard requires that sprinklers be installed below any projections greater than 0.6 m (2 ft.) in depth measured perpendicularly to the wall. Outdoor furniture and accessories commonly found on apartment balconies such as chairs, tables, cushions or planters are not considered storage of combustible materials. However, automatic sprinklers may be appropriate when sources of ignition such as barbecues or patio heaters are present on balconies. This is why, in spite of the above-listed provisions of NFPA 13, Sentence 3.2.5.12.(7) of the NBC, it is required that all balconies in wood 5- and 6-storey buildings be sprinklered when they are of combustible construction and when their depth measured perpendicularly to the exterior wall is greater than 0.61 m (2 ft.).

Protection of Unheated Areas

When automatic sprinklers are installed in unheated areas where the temperature cannot be maintained above 4°C, such as horizontal exterior projections or attics, the pipes are subject to freezing. In such cases, a dry pipe system or other methods to prevent freezing such as those indicated in Section 16.4.1 of NFPA 13 (2019), and Article 3.2.5.17. of the NBC, are required.

Protection of Vertical Shafts

Vertical mechanical, ventilation or electrical shafts shall be sprinklered in conformance with Section 9.3.3 of NFPA 13 (2019). In particular, this means that where vertical shafts are composed of combustible surfaces, a sprinkler shall be installed at the top of each shaft, as well as at each alternate floor level, alternating their position, if possible. The requirements for elevator and stair shafts are explained in Section 4.6 of this chapter.

Protection of Electrical Equipment Rooms

Electrical equipment rooms shall also be equipped with automatic sprinklers in conformance with NFPA 13. However, recognizing the potential safety hazards and the costs associated with equipment damage if the sprinkler system is accidentally discharged over operational electrical equipment, Section 9.2.6 permits sprinklers to be omitted in electrical rooms as long as the following four conditions are met (NFPA 13, 2019):

a) The room is dedicated to electrical equipment only;
b) Only dry-type electrical equipment or liquid-type with listed K-class fluid is used, which means that transformers containing coolant or other similar equipment are not permitted under this exemption;
c) The room is separated from the rest of the building by two-hour fire-rated fire separations, and penetrations in the separations are sealed using appropriate fire-stop systems;
d) No materials shall be stored inside the room.

With regard to requirement c), although NFPA 13 permits two-hour fire-rated fire separations of any type, Sentence 3.6.2.7.(2) of the NBC requires fire separations of solid masonry or concrete construction having a FRR of two-hours when the room is protected by an automatic sprinkler system and 3 hours when it is not (NBC, 2020).

Protection of Bathrooms, Closets and Compartments

According to Article 9.2.4.1 of NFPA 13, bathrooms in dwelling units that meet specific requirements are permitted to not be sprinklered. Otherwise, they are to be protected by an automatic sprinkler system. Readers may consult the standard for more information (NFPA 13, 2019).

NFPA 13 requires that all closets and compartments be sprinklered, no matter their dimensions. This includes closets housing clothes or mechanical equipment such as washers, dryers, furnaces, water heaters, or other. The only exception to this rule relates to hotels and motels, since their closets are less likely to contain large amounts of combustible materials. Regarding the number of sprinklers required in closets and similar compartments, Article 9.5.5.4 of the standard indicates that one sprinkler on the ceiling is sufficient, provided that the volume of the compartment is less than 11.3 m3 (400 ft3).

Note that Sentence 3.2.5.12.(6) of the NBC requires that sprinklers be installed in all closets and rooms in the storey immediately below a roof assembly (NBC, 2020).

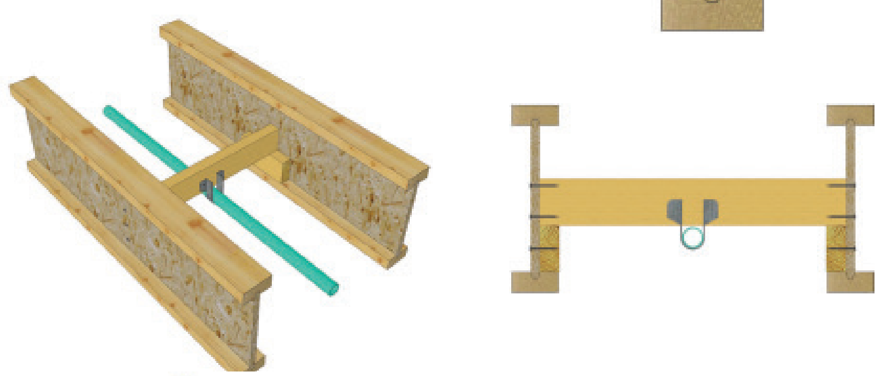
Installation of Automatic Sprinkler System Piping

The hangers and bracing for automatic sprinkler system piping should be designed by an engineer in such a manner as to support the weight of the system in a gravitational orientation as well as a lateral orientation. The connections used to fasten the sprinkler system to the structure shall resist the weight of the piping and seismic forces, in conformance with the requirements of Article 4.1.8.18. of the NBC and Section 18.1 of NFPA 13. Guidelines for using fasteners in structural wood elements are provided in Subsection 17.2.4, NFPA 13. There are many details available illustrating how to fasten a sprinkler system to a wood structure. *Figure 4.06* contains several details for fastening the system in a gravitational orientation, and *Figure 4.07* shows details for a lateral orientation. Other resources may also be consulted for examples of devices and sprinkler pipe installation on wood structures. In particular, these include "Sprinkler Pipe Installation for APA Performance Rated I-Joists (Number J745)" (APA, 2009) as well as technical literature from various engineered wood joist manufacturers (e.g., BCEWP, 2014 and TrusJoist, 2014).

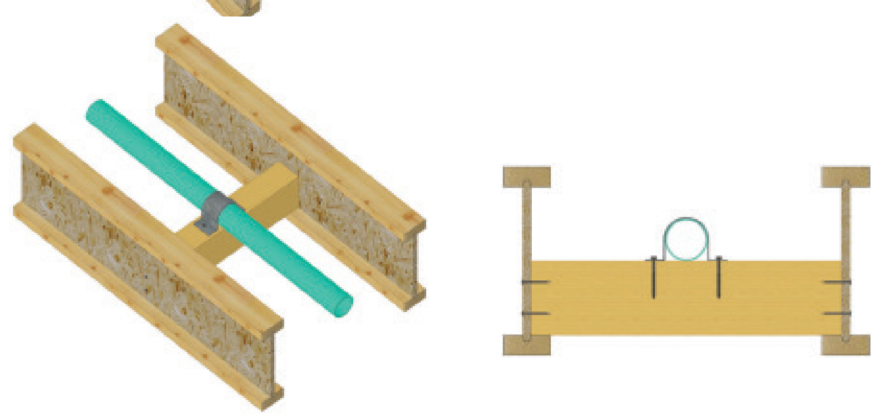
When installing sprinkler piping that requires holes to be drilled within wood I-joists, these holes need to be made in the appropriate places, and in conformance with manufacturer instructions to avoid compromising the strength of the joists.

Detail A

Detail B



Detail C



Detail D

Detail E

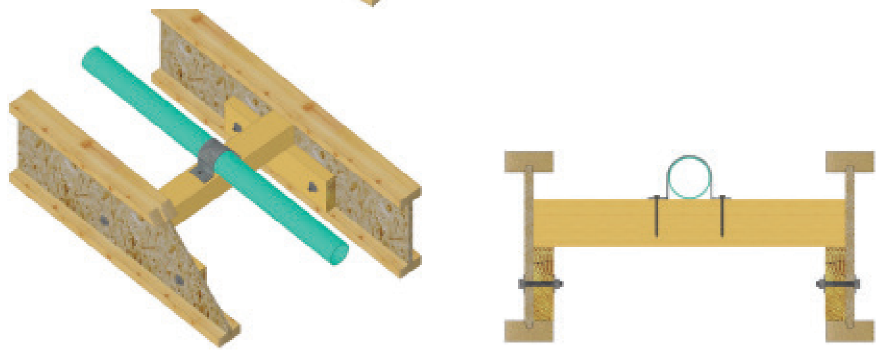
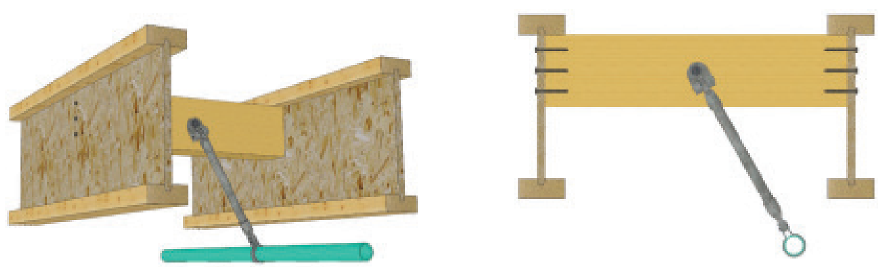


Figure 4.06: Examples of installing sprinkler systems in a gravitational orientation (adapted from APA 2009 and BCEWP 2014) Details A-E.

Detail A



Detail B

Detail C

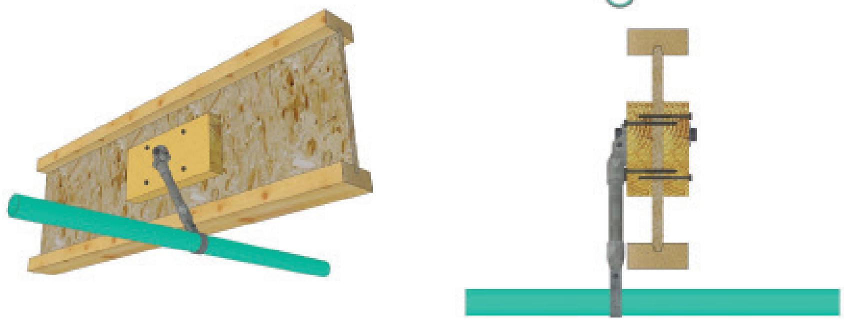


Figure 4.07: Examples of installing sprinkler systems in a lateral orientation (adapted from APA 2009 and BCEWP 2014) Details A-C.

5.4.2.2 Standpipe Systems

A standpipe system is a system of piping, valves, and hose connections in a building used to provide a water supply for firefighting throughout the building. Upon arrival on the scene of a fire, fire services can connect hoses to the hose connections in order to suppress the fire.

Buildings of residential (Group C) or business and personal services (Group D) occupancy, 4-, 5- and 6-storeys in height, whether of combustible or non-combustible construction, shall be equipped with standpipe systems in conformance with Articles 3.2.5.8. and 3.2.5.9. of the NBC. These systems shall be designed, constructed, installed and tested in conformance with NFPA 14, Standard for the Installation of Standpipe and Hose Systems (NFPA 14, 2019). Additionally, according to Article 3.2.5.15. of the NBC, each standpipe shall contain a fire department connection located within 45 metres of a hydrant so that municipal fire departments can connect to it in emergency situations (NBC, 2020).

5.4.3 Fire Resistance

Fire resistance is the ability of a structural member or construction assembly to withstand the effects of a fire. This is not a property that is intrinsic to a material; rather, it is a level of performance that a building's structural members or construction assemblies must meet in a fire situation. There is no direct relationship between a material's combustibility and its fire resistance (Cecobois, 2012a).

A fire-resistance rating (FRR) is a rating system used to quantify an element or assembly's fire- resistance in order to be able to compare the performance of one element or assembly to another. It is defined as the time, in minutes or hours, during which a material or assembly continues to maintain its structural and/or separating function by preventing the passage of flames and transmission of heat, under specific test conditions. FRR evaluation of a structural member or assembly is based on three performance criteria during a standard fire exposure:

- Structural stability;
- Integrity (flame passage);
- Insulation (heat transmission).

The relevance of these criteria depends on the type of element tested, whether it is a simple structural member or a separating element such as a wall or floor assembly. More information on fire resistance can be found in the CWC Fire Fact Sheet "Fire Separations and Fire-resistance Ratings" (CWC, 2020). The fire-resistance rating requirements for 5- and 6-storey timber buildings in the NBC 2020 stipulate that:

Floor assemblies shall be fire separations with a FRR of not less than one hour. However, floor assemblies located inside a dwelling unit that has more than one storey need not be constructed as fire separations, if:

- The FRR of loadbearing walls, columns and arches shall be not less than one hour;
- The FRR of roof assemblies shall be not less than one hour;
- The FRR of mezzanines shall be not less than one hour.

Note that fire separations can have multiple functions, such as a floor assembly and a separation between major occupancies in a building. In this case, the highest FRR will apply, which may require certain fire separations to be upgraded a higher FRR.

The NBC currently provides designers with two methods for determining the FRR of structural members or assemblies of buildings governed by Division B, Part 3. In Article 3.1.7.1., the NBC requires that the FRR of a structural member or assembly of materials to be determined either:

- On the basis of the results of tests conducted in conformance with CAN/ULC-S101, Fire Endurance Tests of Building Construction and Materials (CAN/ULC-S101, 2014), or
- Based the methods presented in Appendix D, Division B of the NBC.

Although they are not considered acceptable solutions in the NBC, there are other methods for determining the FRR of structural members made of wood that can be used as alternative solutions. Some of them are briefly presented in Subsection 4.3.2 of this chapter.

The subsections below contain explanations and examples of ways to achieve a one-hour FRR for light wood-frame assemblies such as floors, walls and roofs, as well as for simple structural elements such as solid wood beams and columns.

5.4.3.1 FRR of Light-Frame Structural Systems

For light wood-frame assemblies such as floors, roofs and loadbearing walls, the FRR of the assemblies may be determined using the component-additive method presented in Division B, Appendix D-2.3., of the NBC (2020), by viewing proprietary test reports from material manufacturers, or by using design listings from third-party certification organizations.

The fire-resistance of light-frame assemblies primarily comes from protective membranes such as Type X or other special types of fire-resistant (e.g., Type C) gypsum board. It is therefore important to follow membrane fastening directions to ensure the required system performance. Fastening instructions are presented in Article D-2.3.9. of the NBC (2020) for the component additive method presented in Appendix D, or they can be found directly in the applicable fire-resistance test reports or design listings.

Component-Additive Method (Appendix D-2.3. of the NBC)

As mentioned previously, the FRR of light wood-frame assemblies can be determined using the component-additive method, presented in Appendix D-2.3. Division B of the NBC (2020). This method consists of adding the assigned fire-resistance values of each component of an assembly.

It applies to loadbearing and non-loadbearing walls using wood studs, as well as to floor and roof assemblies composed of solid-sawn lumber joists, wood I-joists, metal-plate-connected wood-frame trusses, metal-web wood trusses and finger-jointed wood trusses. It is valid for FRRs up to a maximum of 90 minutes.

For light wood-frame walls, a FRR of one hour can be achieved by pairing several materials following the calculation method presented in Appendix D-2.3. of the NBC (2020). The method in Appendix D-2.3. was considerably improved in the 2015 edition of the NBC, and now provides more possible combinations than previously. In particular, it allows for resilient channels to be used in wood-frame wall assemblies. **Table 5.9** provides a summary of the different possible combinations for achieving a FRR of one hour.

Proprietary test reports and design listings are also an option for wall assembly designs with better acoustic ratings.

Previously, the only way a one-hour FRR could be achieved for floor and roof assemblies using the method in Appendix D-2.3. of the NBC (2010) was to follow Article D-2.3.12., which only considers the contribution of the ceiling membrane in obtaining the FRR. The membrane must be formed with two layers of 15.9-mm-thick Type X gypsum board. However, for this to be a valid approach, the ceiling membrane cannot have any duct openings.

The revisions made to Appendix D-2.3. in the 2015 NBC added many new designs for floor assemblies providing a one-hour FRR. **Table 5.10** provides a summary of the added possible designs for a one-hour FRR floor assembly.

The NBC does allow penetrations into and through the wall, floor and roof assemblies designed using Appendix D-2.3., provided that the penetration is sealed by a fire stop system with an appropriate rating. More information on penetrations in fire-resistance-rated assemblies, as well as fire stops, is available at the end of Subsection 4.3.1 and in Subsection 4.4.3 of this chapter. If designers opt to use Appendix D-2.3. of the NBC, they must make sure to meet all of the method's conditions and requirements, in particular as relates to the sizes and spacing of components, the type of insulation or furring allowed, and membrane fastening instructions.

Fire-Resistance Test Reports

Many construction material manufacturers have conducted fire-resistance tests in conformance with CAN/ULC-S101 (2014) on assemblies using their products. The results from these tests are published in proprietary test reports. This is particularly applicable to companies that manufacture engineered wood products, gypsum board products, and underlayment products. These proprietary test reports are generally available for free from different manufacturers, or in the online directories of design listings of the product certification agencies, who often also conducted the tests.

Wall Assemblies

For light-frame wall assemblies in sawn lumber, in addition to the testing performed by the National Research Council of Canada (NRC) that has been used to expand the component additive method in Division B, Appendix D-2.3. of the NBC (NRC, 2002; NRC, 2014a; NRC, 2014a; and, NRC, 2019), reports from tests conducted in conformance with CAN/ULC-S101 (2014) may be obtained directly from manufacturers, because the structural materials are typically generic. Most test reports or design listings can be viewed in the online directories of the product certification agencies, which often also conducted the tests, such as Underwriters Laboratories of Canada (ULC) and Intertek.

For wall assemblies, there are two categories of test reports: those that apply to interior walls, and those that apply to exterior walls. Loadbearing and non-loadbearing interior walls are tested for fire exposure on each side, while exterior walls are evaluated for fire exposure on the inside only. Test reports for exterior wall designs must therefore only be used for this application. **Table 5.9** lists some interior and exterior wall assemblies that achieve the minimum one-hour FRR for mid-rise wood buildings.

In 5- and 6-storey light wood-frame residential buildings, corridor walls and party walls between dwelling units often serve as interior loadbearing walls to resist the lateral loads that influence these buildings, because they are generally long wall segments without openings. Therefore, these walls must be covered in structural wood panels on one or both sides of the studs. However, fire-resistance test reports for wall compositions with structural wood panels are primarily available for exterior walls. There are a few test reports for interior wall assemblies containing structural wood panels, but they are more difficult to find. Research in this field has nevertheless produced some general rules on fire-resistance for assemblies. One such rule stipulates that the fire-resistance of an assembly does not decrease with the addition of further layers (Harmathy, 1965). This rule is subject to certain conditions, but it means that adding one layer of structural wood panelling below a gypsum board membrane in a wall assembly, tested for one hour of fire-resistance, will not reduce the fire-resistance rating of the assembly. On the contrary, it will increase the FRR, even if this increase cannot be quantified. However, longer fasteners must be used in the gypsum board to ensure that they maintain the same penetration into structural members. Additionally, if the gypsum board needs to be fastened using resilient channels for acoustic reasons, these channels should not be installed between a structural wood panel and gypsum board. This configuration would significantly reduce the assembly's acoustic performance. Wood panels and gypsum board should only be used together without resilient channels on that side of the wall (*Figure 4.08*).

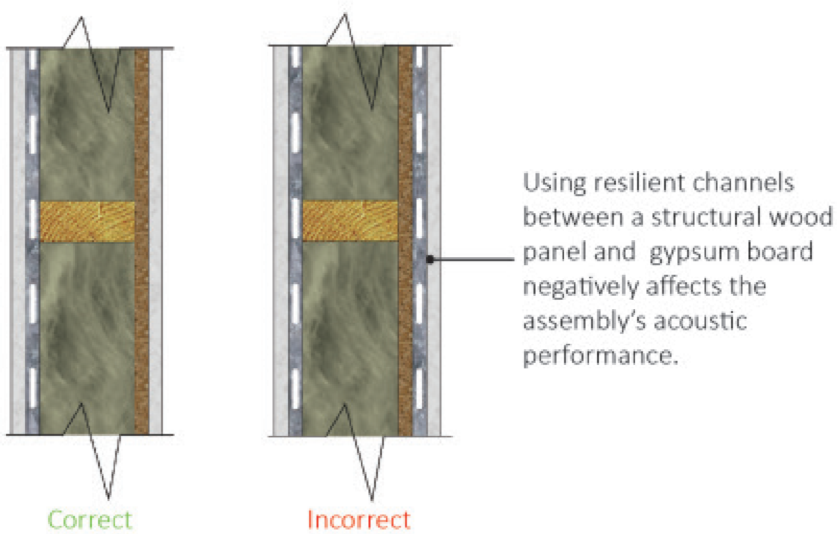


Figure 4.08: Use of resilient channels on a light-frame wall covered in structural wood panels.

Table 5.9 One-Hour Fire-Rated Light Wood-Frame Wall Assemblies

Illustration	Description[1,4,5]	FRR (minutes)	STC	References[2,3]
Interior Loadbearing Walls[7]				
	- 1 layer of 15.9 mm (5/8 in.) thick Type X gypsum board - 38 x 89 mm (2x4) studs @ 406 mm (16 in.) o.c. - 89 mm (3-1/2 in.) glass fib e or rock or slag fib e insulation batts - 1 layer of 15.9 mm (5/8 in.) thick Type X gypsum board	60	34	FRR: NBC, D-2.3. ULC-W313 STC: IRC-IR-761
	- 1 layer of 15.9 mm (5/8 in.) thick Type X gypsum board - 38 x 89 mm (2x4) studs @ 406 mm (16 in.) o.c. - 1 layer of 15.9 mm (5/8 in.) thick Type X gypsum board	60	32	FRR: NBC, D-2.3. STC: NBC, W1d
	- 1 layer of 15.9 mm (5/8 in.) thick Type X gypsum board - 38 x 89 mm (2x4) studs @ 610 mm (24 in.) o.c. - 89 mm (3-1/2 in.) rock or slag fib e insulation batts - 1 layer of 15.9 mm (5/8 in.) thick Type X gypsum board	70	36	FRR: NBC, D-2.3. STC: NBC, W1a
	- 2 layers of 15.9 mm (5/8 in.) thick Type X gypsum board - 38 x 89 mm (2x4) studs @ 406 mm (16 in.) o.c. - 76 mm (3 in.) glass fib e or rock or slag fib e batts - 0.5 mm resilient channels @ 610 mm (24 in.) o.c. - 1 layer of 15.9 mm (5/8 in.) thick Type X gypsum board	60	53	FRR: UL-U305 UL-U309 UL-U327 STC: IRC-IR-761

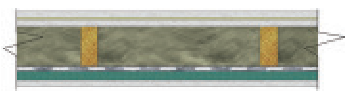
Illustration	Description[1,4,5]	FRR (minutes)	STC	References[2,3]
	- 1 layer of 15.9 mm (5/8 in.) thick Type X gypsum board - Thermoacoustic membrane - 1 layer of 15.9 mm (5/8 in.) thick Type X gypsum board - 38 x 89 mm (2x4) studs @ 406 mm (16 in.) o.c. - 89 mm (3-1/2 in.) glass fib e or rock or slag fib e batts - 0.5 mm resilient channels @ 610 mm (24 in.) o.c. - 19 mm (3/4 in.) sound-absorbing panel - 1 layer of 15.9 mm (5/8 in.) thick Type X gypsum board	60	55	FRR: ULC-W301 UL-U309 UL-U314 STC: MSL
	- 2 layers of 15.9 mm (5/8 in.) thick Type X gypsum board - 38 x 89 mm (2x4) studs @ 406 mm (16 in.) o.c. - 76 mm (3 in.) glass fib e or rock or slag fib e batts - 0.5 mm resilient channels @ 610 mm (24 in.) - 2 layers of 15.9 mm (5/8 in.) thick Type X gypsum board	60	59	FRR: UL-U305 UL-U309 UL-U327 STC: IRC-IR-761

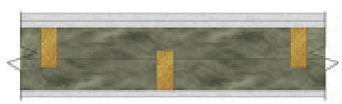
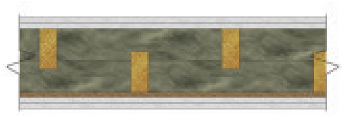
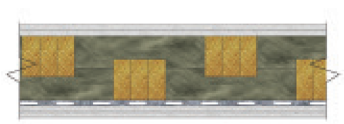
Illustration	Description[1,4,5]	FRR (minutes)	STC	References[2,3]
	- 2 layers of 15.9 mm (5/8 in.) thick Type X gypsum board - 2 rows of 38 x 89 mm (2x4) studs @ 610 mm (24 in.) o.c., staggered on a single 38 x 140 mm (2x6) plate - 89 mm (3-1/2 in.) glass fib e or rock or slag fib e batts - 1 layer of 15.9 mm (5/8 in.) thick Type X gypsum board	60	52	FRR: ULC-W313 UL-U340 STC: IRC-IR-761
	- 2 layers of 12.7 mm (1/2 in.) thick Type X gypsum board - 2 rows of 38 x 89 mm (2x4) studs @ 406 mm (16 in.) o.c., staggered on a single 38 x 140 mm (2x6) plate - 89 mm (3-1/2 in.) glass fib e or rock or slag fib e batts - 11 mm (7/16 in.) plywood or OSB - 2 layers of 12.7 mm (1/2 in.) thick Type X gypsum board	92	51	FRR: Midrise #1 STC: Midrise 3WN & 4WS
	- 2 layers of 12.7 mm (1/2 in.) thick Type X gypsum board - 2 rows of triple 38 x 89 mm (2x4) studs @ 406 mm (16 in.) o.c., staggered on a single 38 x 140 mm (2x6) plate - 89 mm (3-1/2 in.) glass fib e or rock or slag fib e batts - 0.5 mm resilient channels @ 610 mm (24 in.) - 2 layers of 12.7 mm (1/2 in.) thick Type X gypsum board	90	56	FRR: Midrise #2 STC: Midrise 12WS

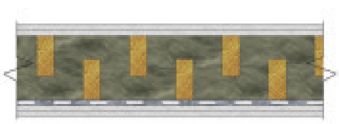
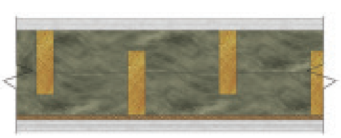
Illustration	Description[1,4,5]	FRR (minutes)	STC	References[2,3]
	- 2 layers of 12.7 mm (1/2 in.) thick Type X gypsum board - 2 rows of 38 x 89 mm (2x4) studs @ 100 mm (4 in.) o.c., staggered on a single 38 x 140 mm (2x6) plate - 89 mm (3-1/2 in.) glass fib e or rock or slag fib e batts - 0.5 mm resilient channels @ 610 mm (24 in.) - 2 layers of 12.7 mm (1/2 in.) thick Type X gypsum board	75	50	FRR: Midrise #3 STC: Midrise 14WS
	- 2 layers of 12.7 mm (1/2 in.) thick Type X gypsum board - 2 rows of 38 x 140 mm (2x6) studs with spacing of 406 mm (16 in.) o.c., staggered on a single 38 x 184 mm (2x8) plate - 140 mm (5-1/2 in.) glass fib e or rock or slag fib e batts - 11 mm (7/16 in.) plywood or OSB - 2 layers of 12.7 mm (1/2 in.) thick Type X gypsum board	81 or 98[6]	51	FRR: Midrise #5&6 STC: Midrise 22WN
	- 2 layers of 12.7 mm (1/2 in.) thick Type X gypsum board - 38 x 89 mm (2x4) studs with spacing of 610 mm (24 in.) o.c., - 2 layers of 12.7 mm (1/2 in.) thick Type X gypsum board	65	35	FRR: NBC, D-2.3 STC: NBC, W2e

Illustration	Description[145]	FRR (minutes)	STC	References [23]
	- 2 layers of 12.7 mm (1/2 in.) thick Type X gypsum board - 38 x 89 mm (2x4) studs with spacing of 610 mm (24 in.) o.c., - Resilient metal channels @ 406 mm (16 in.) o.c. - 2 layers of 12.7 mm (1/2 in.) thick Type X gypsum board	65	46	FRR: NBC, D-2.3 STC: NBC, W6j
	- 1 layer of 12.7 mm (1/2 in.) thick Type X gypsum board - 38 x 89 mm (2x4) studs with spacing of 406 mm (16 in.) o.c., - 89 mm (3-1/2 in.) rock or slag fib e batts - 1 layer of 12.7 mm (1/2 in.) thick Type X gypsum board	60	34	FRR: NBC, D-2.3 STC: NBC, W1b
	- 1 layer of 15.9 mm (5/8 in.) thick Type X gypsum board - 38 x 89 mm (2x4) studs @ 610 mm (24 in.) o.c. - 89 mm (3-1/2 in.) glass fib e batts - 25 mm (1 in.) gap - 89 mm (3-1/2 in.) glass fib e or rock or slag fib e batts - 38 x 89 mm (2x4) studs @ 610 mm (24 in.) - 1 layer of 15.9 mm (5/8 in.) thick Type X gypsum board	60	59	FRR: ULC-W313 UL-U376 STC: IRC-IR-761

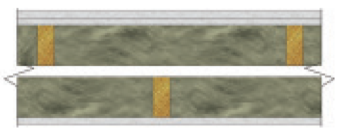
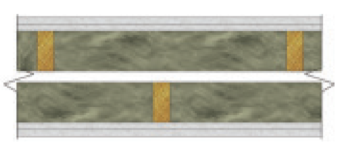
Illustration	Description[1,4,5]	FRR (minutes)	STC	References [2,3]
	- 2 layers of 15.9 mm (5/8 in.) thick Type X gypsum board - 38 x 89 mm (2x4) studs @ 610 mm (24 in.) o.c. - 89 mm (3-1/2 in.) glass fib e batts - 25 mm (1 in.) gap - 89 mm (3-1/2 in.) glass fib e or rock or slag fib e batts - 38 x 89 mm (2x4) studs @ 610 mm (24 in.) - 1 layer of 15.9 mm (5/8 in.) thick Type X gypsum board	60	62	FRR: ULC-W313 UL-U376 STC: IRC-IR-761
	- 2 layers of 15.9 mm (5/8 in.) thick Type X gypsum board - 38 x 89 mm (2x4) studs @ 610 mm (24 in.) o.c. - 89 mm (3-1/2 in.) glass fib e batts - 25 mm (1 in.) gap - 89 mm (3-1/2 in.) glass fib e or rock or slag fib e insulation batts - 38 x 89 mm (2x4) studs @ 610 mm (24 in.) - 2 layers of 15.9 mm (5/8 in.) thick Type X gypsum board	60	69	FRR: ULC-W313 UL-U376 STC: IRC-IR-761

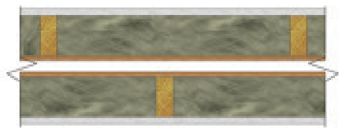
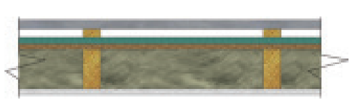
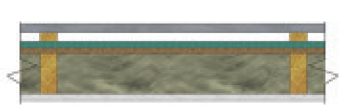
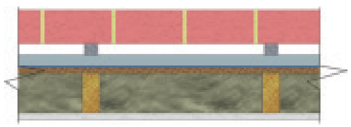
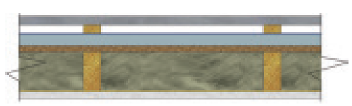
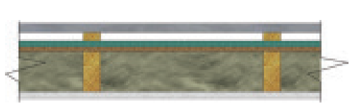
Illustration	Description[1 4 5]	FRR (minutes)	STC	References [2 3]
	- 1 layer of 15.9 mm (5/8 in.) thick Type X gypsum board - 38 x 89 mm (2x4) studs @ 610 mm (24 in.) o.c. - 89 mm (3-1/2 in.) glass fib e or rock or slag fib e insulation batts - 11 mm (7/16 in.) plywood or OSB - 25 mm (1 in.) gap - 11 mm (7/16 in.) plywood or OSB - 89 mm (3-1/2 in.) glass fib e batts - 38 x 89 mm (2x4) studs @ 610 mm (24 in.) o.c. - 1 layer of 15.9 mm (5/8 in.) thick Type X gypsum board	60	unavailable	FRR: UL-U341
Exterior Loadbearing Walls[7]				
	- Cladding - Plywood, OSB, or gypsum sheathing - 38 x 89 mm (2x4) studs @ 406 mm (16 in.) o.c. - 89 mm (3-1/2 in.) rock or slag fib e batts - 1 layer of 12.7 mm (1/2 in.) thick Type X gypsum board	60	n/a	FRR: NBC, D-2.3
	- Cladding - Plywood, OSB, or gypsum sheathing - 38 x 89 mm (2x4) studs @ 610 mm (24 in.) o.c. - 89 mm (3-1/2 in.) rock or slag fib e batts - 1 layer of 15.9 mm (5/8 in.) thick Type X gypsum board	60	n/a	FRR: NBC, D-2.3

Illustration	Description[1,4,5]	FRR (minutes)	STC	References[2,3]
	- 100 mm (4 in.) brick cladding - Min. 25 mm (1 in.) gap - Rigid extruded polystyrene insulation - Fluid-applied air barrier - 12.5 mm (1/2 in.) plywood or OSB - 38 x 89 mm (2x4) studs @ 406 mm (16 in.) o.c. - 89 mm (3 1/2) glass fib e batts - 1 layer of 15.9 mm (5/8 in.) thick Type X gypsum board	60	n/a	FRR: UL-V317
	- Cladding - Rainscreen - Rigid 25 mm (1 in.) thick polystyrene insulation - 12.5 mm (1/2 in.) plywood or OSB - 38 x 89 mm (2x4) studs @ 406 mm (16 in.) - 89 mm (3 1/2) kraft paper faced glass fib e insulation - 1 layer of 15.9 mm (5/8 in.) thick Type X gypsum board	60	n/a	FRR: UL-U326
	- Cladding - 12.5 mm (1/2 in.) fib eboard - 11 mm (7/16 in.) plywood or OSB - 38 x 89 mm (2x4) studs @ 406 mm (16 in.) o.c. - 89 mm (3 1/2) glass fib e or rock or slag fib e batts - 1 layer of 15.9 mm (5/8 in.) thick Type X gypsum board	60	n/a	FRR: UL-U356

Notes:

1. The descriptions in the above table are simplifications of specific fire-resistance-rated assemblies. Designers shall consult the various test reports from certification agencies for comprehensive information on these assemblies.
2. References for fire-resistance rating (FRR) values:
– *National Building Code* – Canada 2020 (NBC, 2020), Division B, Appendix D
– Underwriters Laboratories of Canada (ULC)
– Underwriters Laboratories (UL)
– *Solution for mid-rise wood construction: full-scale standard fire resistance tests of wall assemblies for use in lower storeys of mid-rise buildings (Report to research consortium for wood and wood-hybrid mid-rise buildings),* by P.-S. Lafrance, R. Berzins, P. Leroux, J.Z. Su, G.D. Lougheed and N. Bénichou, National Research Council of Canada (NRCC, 2014a)
3. References for sound transmission class (STC) values:
– *Gypsum Board Walls: Transmission Loss Data*, by R.E. Halliwell, T.R.T. Nightingale, A.C.C. Warnock, J.A. Birta, IRC-IR-761, National Research Council of Canada (NRCC)
– *Acoustics: sound insulation in mid-rise wood buildings (Report to Research Consortium for wood and wood-hybrid mid-rise buildings),* by S. Schoenwald, B. Zeitler, F. King, I. Sabourin, National Research Council of Canada (NRCC, 2014b)
– Matériaux Spécialisés Louiseville (MSL), SONOpan II Appendix
– *National Building Code* – Canada 2020 (NBC, 2020), Division B, Table 9.10.3.1.-A Fire and Sound Resistance of Walls.
4. Dimensions listed for studs, structural wood panels, gypsum board and insulation panels are minimum values.
5. Spacings listed for studs and resilient channels are maximum values for FRR values and minimum values for STC values.
6. Value obtained with horizontal blocking at mid-height to limit deformation of the studs.
7. Non-loadbearing walls would get at least the same FRR as the same configuration in a loadbearing wall.

Floor and Roof Assemblies

In addition to the testing performed by the National Research Council of Canada (NRC) that have been used to expand the component additive method in Appendix D-2.3. of Division B of the NBC (NRC, 1998 and NRC, 2005), for floor or roof assemblies composed of engineered wood joists, such as wood I-joists, metal-plate-connected trusses, metal-web trusses and wood trusses with finger-jointed glued connections, reports from tests conducted in conformance with CAN/ULC-S101 (2014) may be obtained directly from manufacturers.

For proprietary structural products, such as wood I-joists or wood trusses with glued, finger-jointed connections, each manufacturer has reports from fire-resistance tests that indicate the FRR values for assemblies with their products. The assemblies and their respective fire-resistance ratings are generally published on the product manufacturer's website in their technical documentation. FRR test reports and design listings can also be viewed in the online directories of the product certification agencies, which often also conducted the tests, such as the Underwriters Laboratories of Canada (ULC), Intertek and APA – The Engineered Wood Association. Fire-resistance test reports for wood trusses with metal plate connectors or metal webs are provided by the manufacturers of the metal plate connectors or metal webs rather than by the truss manufacturers themselves. Trusses with either metal plate connectors or metal webs are both generic and proprietary products because they contain conventional sawn lumber, but also perforated metal connector plates or metal webs, which are proprietary products. Perforated metal plate manufacturers and metal web manufacturers therefore typically provide the reports for the fire-resistance tests conducted with their products.

Other fire-resistance test reports for assemblies containing engineered wood girders come from the gypsum board producers, or manufacturers of different types of construction materials.

For floor or roof assemblies containing traditional sawn lumber joists, in addition to the testing performed by the National Research Council of Canada (NRC) that have been used to expand the component additive method in Appendix D-2.3. of Division B of the NBC (NRC, 1998 and NRC, 2005), most additional fire-resistance test reports come from gypsum board or subfloor product producers, because the structural material is generic. These test reports can be viewed in the online directories of the product certification agencies, which often also conducted the tests, such as the Underwriters Laboratories of Canada (ULC) or Intertek.

Table 5.10 contains examples of assemblies that achieve a one-hour FRR for floor assemblies containing I-joists, trusses, or solid wood joists.

Most fire-resistance test reports for assemblies formed by engineered wood or solid wood joists are available for floor assemblies, but some reports are also available for roof assemblies. They are different reports and are generally identified as such.

Table 5.10 Examples of One-Hour Fire-Rated Light Wood-Frame Floor Assemblies

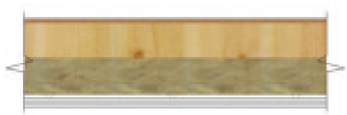
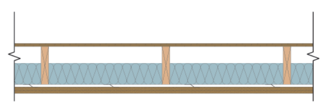
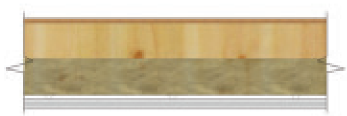
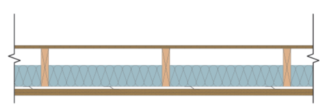
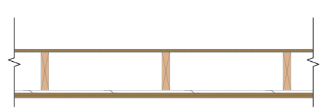
Illustration	Description[1,4,5]	FRR (minutes)	STC[10]	References[2,3]
Sawn Lumber Joists				
 	- 15.9 mm (5/8 in.) plywood - 38 x 184 mm (2x8) joists @ 610 mm (24 in.) o.c. - Glass fib e or rock or slag fib e batts - 0.5 mm thick resilient channels @ 406 mm (16 in.) o.c. - 2 layers of 15.9 mm (5/8 in.) thick Type X gypsum board	60[6]	52	FRR: NBC, D-2.3.12 STC: NBC, F9c
 	- 15.5 mm (5/8 in.) plywood or OSB - 38 x 184 mm (2x8) joists @ 610 mm (24 in.) o.c. - rock or slag fib e batts - Resilient metal channels @ 610 mm (24 in.) o.c. - 2 layers of 12.7 mm (1/2 in.) thick Type X gypsum board	60	53	FRR: NBC, D-2.3 STC: NBC, F9h
	- 15.5 mm (5/8 in.) plywood or OSB - 38 x 184 mm (2x8) joists @ 610 mm (24 in.) o.c. - Resilient metal channels @ 406 mm (16 in.) o.c. (optional) - 2 layers of 12.7 mm (1/2 in.) thick Type X gypsum board	60	43	FRR: NBC, D-2.3 STC: NBC, F9i

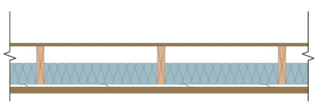
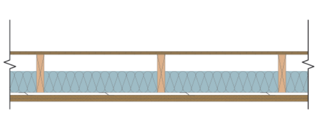
Illustration	Description[1,4,5]	FRR (minutes)	STC[10]	References[2,3]
 	- 25 mm topping (proprietary mix) - 15.9 mm (5/8 in.) plywood - 38 x 235 mm (1.5 in. x 9.25 in.). joists @ 406 mm (16 in.) o.c. - Glass fib e batts (optional) - 0.5 mm thick resilient channels @ 610 mm (24 in.) o.c. - 1 layer of 12.7 mm (1/2 in.) thick Type C gypsum board - Note: a second layer of gypsum board is required for use with insulation.[7]	60	63[9]	FRR: ULC-M501 ULC-M509 STC: NBC, F15i
Many UL reports for the L500 series can also be viewed for sawn lumber joist assemblies, gypsum board, suspended ceiling systems, or ventilation system components.				
I-Joists				
	- 15.9 mm (5/8 in.) plywood - Wood I-joists 241 mm (9-1/2 in) deep with 38 mm x 38 mm (1-1/2 in. x 1-1/2 in.) flanges an 9.5 mm (3/8 in.) OSB or plywood web @ 610 mm (24 in.) o.c. - 0.5 mm thick resilient channels @ 406 mm (16 in.) o.c. - 2 layers of 15.9 mm (5/8 in.) thick Type X gypsum board	60[6]	45	FRR: NBC, D-2.3.12 STC: NBC, F9a

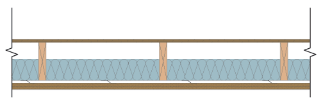
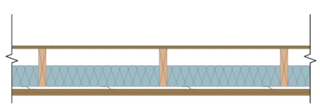
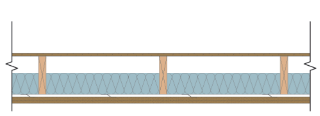
Illustration	Description[1,4,5]	FRR (minutes)	STC[10]	References[2,3]
	- 15.5 mm (5/8 in.) plywood or OSB - Wood I-joists 241 mm (9-1/2 in) deep with 38 mm x 38 mm (1-1/2 in. x 1-1/2 in.) flanges an 9.5 mm (3/8 in.) OSB or plywood web @ 610 mm (24 in.) o.c. - rock or slag fib e batts - Resilient metal channels @ 610 mm (24 in.) o.c. (optional) - 2 layers of 12.7 mm (1/2 in.) thick Type X gypsum board	60	53	FRR: NBC, D-2.3 STC: NBC, F9h
	- 15.5 mm (5/8 in.) plywood or OSB - Wood I-joists 241 mm (9-1/2 in) deep with 38 mm x 38 mm (1-1/2 x 1-1/2 in.) flanges an 9.5 mm (3/8 in.) OSB or plywood web @ 610 mm (24 in.) o.c. - Resilient metal channels @ 406 mm (16 in.) o.c. - 2 layers of 12.7 mm (1/2 in.) thick Type X gypsum board	60	44	FRR: NBC, D-2.3 STC: NBC, F9e
	- Lightweight concrete topping (optional) - 15.9 mm (5/8 in.) plywood or OSB - 241 mm (9-1/2 in.) deep I-joists @ 610 (24 in.) o.c. - 38 mm (1-1/2 in.) rock or slag fib e batts - 0.5 mm thick resilient channels @ 406 mm (16 in.) o.c. - 1 layer of 15.9 mm (5/8 in.) thick Type C gypsum board	60	638	FRR: APA PR-S201-FR6 APA PR-S205-IB. P60.1 APA PR-S274-NEW. P60.1 ITS WNR/ FCA 60-07 STC: NBC, F20c

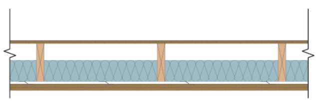
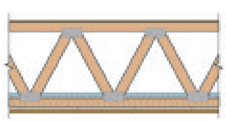
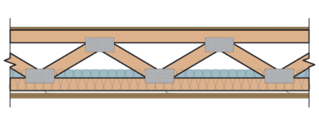
Illustration	Description[1,4,5]	FRR (minutes)	STC[10]	References[2,3]
	– Lightweight concrete topping (optional) – 15.9 mm (5/8 in.) plywood or OSB – 241 mm (9-1/2 in.) deep I-joists @ 610 (24 in.) o.c. – 89 mm (3-1/2 in.) glass fib e batts (optional) – 0.5 mm thick resilient channels @ 406 mm (16 in.) o.c. – 2 layers of 12.7 mm 1/2 in.) thick Type X gypsum board	60	66[8]	FRR: APA PR-S205-IB. P60.2 APA PR-S274-NEW. P60.2 ITS LP/FCA 60-01 ITS WNR/ FCA 60-01 STC: NBC, F21i
Trusses				
	– 15.9 mm (5/8 in.) plywood – Metal-plate-connected trusses @ 610 mm (24 in.) o.c. – Glass fib e or rock or slag fib e batts (optional) – 0.5 mm thick resilient channels @ 406 mm (16 in.) o.c. – 2 layers of 15.9 mm (5/8 in.) thick Type X gypsum board	60[6]	54	FRR: NBC, D-2.3.12 STC: NBC, F28c
	– 15.5 mm (5/8 in.) plywood or OSB – 305 mm (12 in.) deep metal-plate-connected trusses with minimum 38 mm x 64 mm (1-1/2 x 2-1/2 in.) framing members @ 610 mm (24 in.) o.c. – rock or slag fib e batts – Resilient metal channels @ 610 mm (24 in.) o.c. – 2 layers of 12.7 mm (1/2 in.) thick Type X gypsum board	60	53	FRR: NBC, D-2.3 STC: NBC, F28h

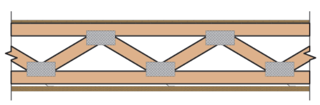
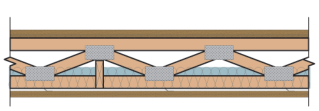
Illustration	Description[1,4,5]	FRR (minutes)	STC[10]	References[2,3]
	- 15.5 mm (5/8 in.) plywood or OSB - 305 mm (12 in.) deep metal-plate-connected trusses with minimum 38 mm x 64 mm (1-1/2 x 2-1/2 in.) framing members @ 610 mm (24 in.) o.c. - Resilient metal channels @ 406 mm (16 in.) o.c. - 2 layers of 12.7 mm (1/2 in.) thick Type X gypsum board	60	44	FRR: NBC, D-2.3 STC: NBC, F28e
	- Lightweight concrete topping (optional) - 15.9 mm (5/8 in.) plywood or OSB - 254 mm (10 in.) deep metal-plate-connected trusses @ 610 mm (24 in.) o.c. - 38 x 140 mm (1-1/2 in. x 5-1/2 in.) SPF #2 continuous strongback @ 2.1 m (7 ft.) o.c. - 89 mm (3-1/2 in.) glass fib e batts (optional) - 0.5 mm thick resilient channels @ 610 mm (24 in.) o.c. - 1 layer of 15.9 mm (5/8 in.) thick Type C gypsum board - or - 2 layers of 12.7 mm (1/2 in.) thick Type X gypsum board	60	668 or 698	FRR: ITS MCI/FCA 60-02 ITS ITW/FCA 60-02 ITS ITW/FCA 60-10 STC: NBC, F37d NBC, F38h

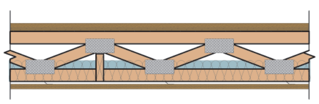
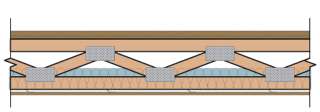
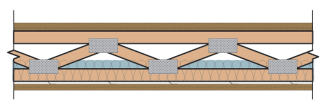
Illustration	Description[1,4,5]	FRR (minutes)	STC[10]	References [2,3]
	- Lightweight concrete topping (optional) - 15.9 mm (5/8 in.) plywood or OSB - 254 mm (10 in.) deep metal-plate-connected trusses @ 610 mm (24 in.) o.c. - 38 x 140 mm (1-1/2 in. x 5-1/2 in.) SPF #2 continuous bracing @ 2.1 m (7 ft.) o.c. - 89 mm (3-1/2 in.) glass fib e batts (optional) - 0.5 mm thick resilient channels @ 610 mm (24 in.) o.c. - 2 layers of 15.9 mm (5/8 in.) thick Type X gypsum board	90	708	FRR: ITS MCI/FCA 90-02 ITS ITW/FCA 90-02 STC: NBC, F38d
	- Lightweight concrete topping (optional) - 15.9 mm (5/8 in.) plywood or OSB - 241 mm (9-1/2 in.) deep wood truss with glued chords @ 610 mm (24 in.) o.c. - Min. 38 mm (1-1/2 in.) rock or slag fib e batts - 0.5 mm thick resilient channels @ 406 mm (16 in.) o.c. - 1 layer of 15.9 mm (5/8 in.) Type C gypsum board - or - 2 layers of 12.7 mm (1/2 in.) thick Type X gypsum board	60	638 or 678	FRR: ITS BS/SFWT 60-01 ITS BS/SFWT 60-02 STC: NBC, F37c NBC, F38g

Illustration	Description[1 4 5]	FRR (minutes)	STC[10]	References [2 3]
	- Lightweight concrete topping (optional) - 15.9 mm (5/8 in.) plywood or OSB - 241 mm (9-1/2 in.) deep wood truss with glued chords @ 610 mm (24 in.) o.c. - Min. 38 mm (1-1/2 in.) rock or slag fib e batts - 0.5 mm thick resilient channels @ 305 mm (12 in.) o.c. - 2 layers of 15.9 mm (5/8 in.) thick Type C gypsum board	90	688	FRR ITS BS/SFWT 90-01 STC: NBC, F38c

Notes:

1. The descriptions in the above table are simplifications of specific fire-resistance-rated assemblies. Designers shall consult the various test reports from certification agencies to obtain comprehensive information on these assemblies.
2. References for the fire-resistance rating (FRR) values:
   – *National Building Code – Canada 2015* (NBC, 2020), Division B, Appendix D
   – Underwriters Laboratories of Canada (ULC)
   – Underwriters Laboratories (UL)
   – APA Product Reports, S series
   – Intertek Testing Services (ITS)
3. References for sound transmission class (STC) values: *National Building Code – Canada 2020* (NBC, 2020), Division B, Table 9.10.3.1.-B Fire and Sound Resistance of Floors, Ceilings and Roofs.
4. Dimensions listed for joists, trusses, structural wood panels, and gypsum board are minimum values.
5. Spacings listed for joists, trusses and resilient channels are maximum values for FRR values and minimum values for STC values.
6. The fire-resistance rating (FRR) is guaranteed only by the gypsum board ceiling membrane.
7. Refer to Section III.17 of the BXUV guide from the Underwriters Laboratories (UL) certification agency for more details.
8. Applicable value when a 38 mm (1-1/2 in.) thick lightweight concrete topping is used.
9. Applicable value for minimum 38 x 184 mm (1.5 x 7.25 in.) joists.
10. Applicable values when 150 mm of insulation is used.

When a roof is composed of metal-plate-connected light wood-frame trusses, the wood members are typically set on edge rather than flatwise, particularly in pitched roof trusses. Proprietary reports from metal-plate connector manufacturers do not generally apply to these situations, because they cover situations where wood is used in flat applications, i.e., parallel-chord floor trusses. However, gypsum board or ventilation product manufacturers provide some proprietary test reports that apply to roofs composed of metal-plate-connected light-frame trusses. Many of these reports are available in the online directory of the Underwriters Laboratories (UL) certification agency. Designers may also refer to *Fire Resistance Rated Truss Assemblies*, a document published by the Structural Building Components Association (SBCA, 2015), and *Fire Resistance Design Manual* (GA 600, 2012) produced by the Gypsum Association, a North American organization for gypsum manufacturers, for more examples of roof assemblies and their corresponding FRRs. Table 5.11 provides an overview of some roof assemblies that achieve a one-hour FRR.

Table 5.11 One-Hour Fire-Rated Light Wood-Frame Roof Assemblies

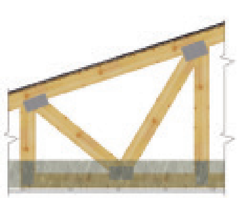
Illustration	Description[1 3 4]	FRR (minutes	References[2]
Metal-Plate-Connected Light-Frame Trusses (Pitched or Parallel-chord)			
	– Class A, B or C roof covering – 12.5 mm (1/2 in.) plywood5 – Light-frame trusses @ 610 mm (24 in.) o.c. – Glass fib e or rock or slag fib e batts (optional) – 0.5 mm thick resilient channels @ 406 mm (12 in.) o.c. – 2 layers of 15.9 mm (5/8 in.) thick Type X gypsum board	605	NBC, D-2.3.12.
	– Class A, B or C roof covering – 12 mm (15/32 in.) plywood or OSB5 – Light-frame trusses @ 610 mm (24 in.) o.c. – Glass fib e batts (optional) – 0.5 mm thick resilient channels @ 305 mm (12 in.) o.c. – 1 layer of 15.9 mm (5/8 in.) thick Type C gypsum board	60	UL: P522, P531, P533, P538, P544, P545, P547, P549, P552, P554, P556, P559

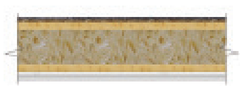
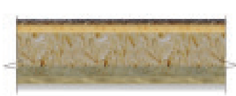
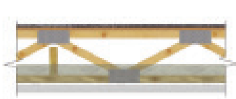
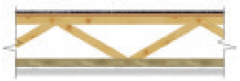
Illustration	Description[1 3 4]	FRR (minutes	References[2]
I-Joists			
	– Class A, B or C roof covering – 12.7 mm (1/2 in.) plywood5 – 241 mm (9-1/2 in.) deep I-joists @ 610 mm (24 in.) o.c. – Min. 38 mm (1-1/2) rock or slag fib e batts – 0.5 mm thick resilient channels @ 406 mm (16 in.) o.c. – 1 layer of 15.9 mm (5/8 in.) thick Type C gypsum board	60	APA PR-S201-FR6 APA PR-S205-IB. P60.4 APA PR-S274-NEW. P60.4
	– Class A, B or C roof covering – 12.7 mm (1/2 in.) plywood or OSB5 – 241 mm (9-1/2 in.) deep I-joists @ 610 mm (24 in.) o.c. – 0.5 mm thick resilient channels @ 610 mm (24 in.) o.c. – 2 layers of 12.7 mm (1/2 in.) thick Type X gypsum board	60	ITS WNR/RCA 60-01
	– Class A, B or C roof covering – 15.9 mm (5/8 in.) plywood or OSB5 – 286 mm (11 1/4 in.) deep I-joists @ 610 mm (24 in.) o.c. – Glass fib e batts – 2 layers of 12.7 mm (1/2 in.) thick Type X gypsum board	60	ITS LP/RCA 60-01
Parallel-chord Trusses			
	– Class A, B or C roof covering – 12.5 mm (1/2 in.) plywood5 – Metal-plate-connected trusses @ 610 mm (24 in.) o.c. – Glass fib e or rock or slag fib e batts (optional) – 0.5 mm thick resilient channels @ 406 mm (16 in.) o.c. – 2 layers of 15.9 mm (5/8 in.) thick Type X gypsum board	606	NBC, D-2.3.12.

Illustration	Description[1 3 4]	FRR (minutes	References[2]
	– Class A, B or C roof covering – 12.7 mm (1/2 in.) plywood or OSB[5] – Finger-jointed wood truss min. 241 mm (9-1/2 in.) deep @ 610 mm (24 in.) o.c. – Min. 38 mm (1-1/2 in.) glass fib e or rock or slag fib e batts – 0.5 mm thick resilient channels @ 406 mm (16 in.) o.c. – 1 layer of 15.9 mm (5/8 in.) thick Type C gypsum board – or – 2 layers of 12.7 mm (1/2 in.) thick Type X gypsum board	60	ITS BS/SFWT 60-01 ITS BS/SFWT 60-02
There are also many UL reports of the L500 series available for assemblies composed of metal-plate-connected trusses, gypsum board, suspended ceilings and ventilation system components. These assemblies must have a UL-certified Class A, B or C oof covering.[6]			

Notes:

1. The descriptions in the above table are simplifications of specific fire-resistance-rated assemblies. Designers shall consult the various test reports from certification agencies to obtain comprehensive information on these assemblies.
2. References for the fire-resistance rating (FRR) values:
   – National Building Code – Canada 2020 (NBC, 2020), Division B, Appendix D
   – Underwriters Laboratories (UL)
   – APA Product Reports, S series
   – Intertek Testing Services (ITS)
3. Dimensions listed for trusses, joists, structural wood panels, and gypsum board are minimum values. Thicker structural wood panels than those listed may be required depending on the spacing of trusses or joists and the loads to support.
4. Spacings listed for trusses, joists, structural wood panels and resilient channels are maximum values.
5. The fire-resistance rating (FRR) is guaranteed only by the gypsum board ceiling membrane.
6. Refer to Section III.19 of the BXUV guide from the Underwriters Laboratories (UL) certification agency for more details.

Test Report Sources

Proprietary test reports are available for free from different manufacturers, or in the online directories of some certification agencies for products certified by the Standards Council of Canada (SCC), such as the Underwriters Laboratories of Canada (ULC), Intertek Testing Services (ITS), APA – The Engineered Wood Association, etc. Here are a few links to online agency directories:

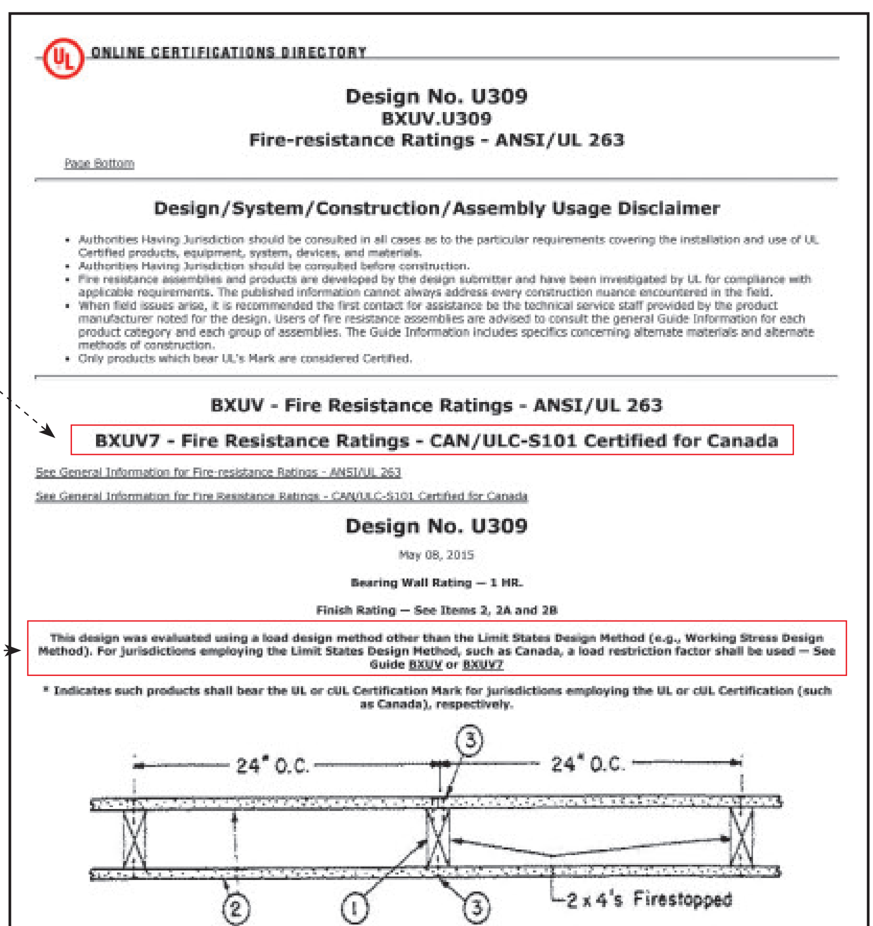
- ULC/UL: https://iq2.ulprospector.com/session/new
- Intertek: https://bpdirectory.intertek.com/Pages/DLP_Search.aspx
- APA: https://www.apawood.org/product-reports

In Canada, it is common practice to refer to test reports published by the Underwriters Laboratories of Canada (ULC) certification organization to ensure that the reports meet Canadian standards. However, many UL-certified test reports are also intended for use in Canada, subject to certain restrictions. UL reports that can be used in Canada bear the following note: "Fire Resistance Ratings – CAN/ULC- S101 Certified for Canada" *(Figure 4.09)*. Most of these reports contain a restriction on design loads, which means that the load applied to the assembly during the fire-resistance test was smaller than the load normally required in Canada in conformance with CAN/ULC-S101. This means that for reports that mention a load restriction, a load-restricted factor shall be applied to the factored resistance of the structural members of the assembly to take this restriction into account. For a UL- or ULC-certified assembly with this identification, the project designer shall notify the structural engineer or manufacturer of the structure so that they can apply the strength reduction factor when designing the applicable fire-resistance-rated assemblies. The same applies for when using any FRR design listing or test report that lists a load restriction.

Applicable for use in Canada

Restriction on design loads applicable for use in Canada:

"This design was evaluated using a load design method other than the Limit States Design (e.g., Working Stress Design). For jurisdictions employing the Limit States Design Method, such as Canada, a load restriction factor shall be used. See Guide BXUV or BXUV7."


ONLINE CERTIFICATIONS DIRECTORY

Design No. U309
BXUV.U309
Fire-resistance Ratings - ANSI/UL 263

Page Bottom

Design/System/Construction/Assembly Usage Disclaimer

- Authorities Having Jurisdiction should be consulted in all cases as to the particular requirements covering the installation and use of UL Certified products, equipment, system, devices, and materials.
- Authorities Having Jurisdiction should be consulted before construction.
- Fire resistance assemblies and products are developed by the design submitter and have been investigated by UL for compliance with applicable requirements. The published information cannot always address every construction nuance encountered in the field.
- When field issues arise, it is recommended the first contact for assistance be the technical service staff provided by the product manufacturer noted for the design. Users of fire resistance assemblies are advised to consult the general Guide Information for each product category and each group of assemblies. The Guide Information includes specifics concerning alternate materials and alternate methods of construction.
- Only products which bear UL's Mark are considered Certified.

BXUV - Fire Resistance Ratings - ANSI/UL 263

BXUV7 - Fire Resistance Ratings - CAN/ULC-S101 Certified for Canada

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

See General Information for Fire Resistance Ratings - CAN/ULC-S101 Certified for Canada

Design No. U309

May 08, 2015

Bearing Wall Rating — 1 HR.

Finish Rating — See Items 2, 2A and 2B

This design was evaluated using a load design method other than the Limit States Design Method (e.g., Working Stress Design Method). For jurisdictions employing the Limit States Design Method, such as Canada, a load restriction factor shall be used — See Guide BXUV or BXUV7

*** Indicates such products shall bear the UL or cUL Certification Mark for jurisdictions employing the UL or cUL Certification (such as Canada), respectively.**

Figure 4.09: Excerpt from a UL-listed test report applicable in Canada (Source: UL).

Designers do not always know which product manufacturers will be selected for a project in advance. If this is the case, it is possible to refer to lists with the FRRs for generic wall or floor assemblies. Tables 9.10.3.1.-A and 9.10.3.1.-B of the NBC are examples of generic assemblies, but the tables are only permitted to be applied to buildings subject to Division B, Part 9 of the NBC. However, the NRC tests that the tables are based on are applicable to Part 3 buildings, including 5- and 6-storey wood buildings, as well as Part 9 buildings (NRC, 1998; NRC, 2002; NRC, 2005; NRC, 2014a; NRC, 2014a; and, NRC, 2019). For Part 3 buildings, the designer must find a different way to justify the design other than the Part 9 tables (such as directly referencing the test reports). Using this approach, or the method in NBC Appendix D, the assemblies are not subject to the load restrictions applicable in certain listings (as discussed above).

Fire-Rated Systems, a document from APA – The Engineered Wood Association, and *Fire Resistance Design Manual*, produced by the Gypsum Association, a North American association for gypsum board manufacturers, also contain many generic assemblies (APA, 2005 and GA 600, 2012).

Openings and Penetrations in Fire-Resistance-Rated Assemblies

Fire-resistance-rated floor, roof and wall assemblies sometimes need openings or penetrations to enable vents, plumbing or electrical services to pass through. These services can pass through the assemblies completely, or simply penetrate one membrane of the assembly. These openings and penetrations require particular care to maintain the integrity of fire separations that require an FRR. Commonly used protections for penetrations of fire separations, such as fire stops, are also required for when penetrating the membrane of assemblies that have an FRR but do not form a fire separation. For example, this is the case for light wood-frame floor assemblies located inside a dwelling unit that has more than one storey, or loadbearing wall assemblies located inside a dwelling.

Subsection 3.1.9. of the NBC presents the different requirements for penetrations in fire-resistance-rated assemblies. In particular, the NBC requires the use of fire-stop systems certified by CAN/ULC-S115 (2011) to seal penetrations. When a ventilation and recovery ducting system is installed level with the ceiling membrane, fire-stop flaps generally need to be installed to ensure the integrity of the assembly. Where a floor or roof assembly of combustible construction is assigned an FRR on the basis of Appendix D-2.3. of the NBC, the requirements for that type of opening can be found in Appendix D-2.3.10. If, on the other hand, the fire-resistance rating of a floor or roof assembly is assigned on the basis of proprietary fire-resistance test reports, the protective device for the membrane opening (fire-stop flap) should be included in the assembly test report. Subsection 4.4.3 of this chapter provides further explanations on the different openings and penetrations in fire separations and fire-resistance-rated assemblies.

5.4.3.2 FRR for Beams, Columns and Solid-Wood Panels

FRRs for exposed solid-wood structural members with a large cross section, such as solid-sawn timber or engineered wood beams and columns and cross-laminated timber (CLT) panels are assigned using design methods based on the charring rate of wood members. Since the different methods available involve load and strength calculations for the structural members, a structural engineer generally ensures that the FRRs of the solid-wood structural members meet the requirements.

Solid-Sawn Timber, Glued-Laminated Timber and Structural Composite Lumber

Method A of Appendix D-2.11. of the NBC contains a simplified method for calculating the FRR of glued-laminated timber beams and columns. This method applies to glued-laminated timber, but it may also be valid for other products such as structural composite lumber, provided that their product evaluation report from the Canadian Construction Materials Centre (CCMC) mentions the compliance.

A new Canadian design method for FRRs of mass timber elements, including solid-wood beams and columns, that has been available in Annex B of CSA O86, E*ngineering Design In Wood* (CSA O86, 2019) has been added to Appendix D-2.11. as Method B. This method applies to large cross-section wood elements in solid-sawn timber, glued-laminated timber, and structural composite lumber. *The ood Design Manual* (CWC, 2021) provides an explanation of the method, as well as selection tables for typical scenarios for beams and columns.

There are other methods for determining FRRs for solid-sawn timber or engineered wood beams and columns. In particular, this includes the *American National Design Specification for Wood Construction* (NDS, 2012) and the method used in Europe, Eurocode 5 (Part 1-2) (CEN, 2009).

Only results from fire tests conducted in conformance with CAN/ULC-S101 (2007) and the methods presented in Appendix D of the NBC are currently recognized by the NBC as methods for determining FRRs. In order to use any other method, designers must first request authorization from the relevant authority via an alternative solution.

Solid-Wood Panels, Including Cross-Laminated Timber (CLT)

Appendix D-2.4. of the NBC provides generic, prescriptive, FRR information related to traditionally constructed solid wood walls, floors and roofs, with ratings from 30 minutes to 1.5 hours based on the minimum thickness of the construction, using splined or tongued-and-grooved planking or nail-laminated dimensional lumber (NBC, 2015).

The design method for FRRs of mass timber elements that has been available in Annex B of CSA O86, *Engineering Design In Wood* (CSA O86, 2019) and has been added to Appendix D-2.11. as Method B, also is applicable to CLT. *The ood Design Manual* (CWC, 2021) provides selection tables for typical scenarios for CLT walls, floors and roofs.

Connections

The connections between various structural members, such as beams and columns, shall also be designed to achieve the structure's required FRR so that they do not become the weak point in a fire. However, no calculation method for determining the FRR of connections for mass timber currently exists in the NBC or the CSA O86 standard. Designers can therefore refer to non-Canadian methods such as those in the American and European standards mentioned above. One of the most common methods involves concealing the metal connections inside the wood members to protect them from extreme fire temperatures *(Figure 4.10)*. For exposed metal connections such as steel plates or hangers, designers can use intumescent coatings certified in conformance with CAN/ULC-S101 (2014) to protect them from the intense heat of a fire.

Figure 4.10: Example of metal connections concealed inside wood members.

(Photo: Cecobois)

Additional Contribution of Gypsum Board

Lastly, when using the Appendix D-2.11. Method B, the FRRs of solid-wood structural elements, such as solid-sawn timber or engineered wood beams and columns, and (CLT) panels, can be increased by fastening one or several layers of gypsum board directly to the structural wood members. The times listed in **Table 5.12** can be added to the fire-resistance rating assigned using the methods described above for unprotected mass timber structural members. Values from **Table 5.12** are taken from Clause B.8.1 of Annex B of CSA O86 (2019).

Table 5.12 Additional Contribution of Protective Membranes to FRR

Protective membrane	Contribution to FRR (min)
One layer of 12.7 mm (1/2 in.) thick Type X gypsum board	15
One layer of 15.9 mm (5/8 in.) thick Type X gypsum board	30
Two layers of 12.7 mm (1/2 in.) thick Type X gypsum board on CLT	60
Two layers of 15.9 mm (5/8 in.) thick Type X gypsum board	60

For the times listed in **Table 5.12** to be valid, the following installation conditions must be met:

- The fasteners used to directly attach the gypsum board shall penetrate the wood element a minimum of 25 mm. If steel or wood furring providing a gap between the gypsum board and wood member is used, the fasteners used to attach the furring shall penetrate the wood structural elements a minimum of 25 mm.
- The screws shall be spaced at no more than 300 mm (12 in.) on the perimeter and in the field of the boards.
- Each length of gypsum board is to be attached by a minimum of two rows of fasteners that are offset by half the fastener spacing if row spacing is less than 300 mm.
- When there is more than one layer of gypsum board, the joints between boards in one layer shall be offset from those in the other layer.
- When a single layer of gypsum board is used, the joints shall be coated with tape and joint compound.
- When two layers of gypsum board are used, the joints of the exposed layer shall be covered with tape and joint compound.
- In all cases, screw heads on exposed boards shall be covered in a joint compound.

Fasteners should be located at least 38 mm (1-1/2 in.) from the board edges.

Fire Separations

As defined in the National Building Code of Canada (NBC,2020), a fire separation is a construction assembly that acts as a barrier against the spread of fire. Even when a fire separation is not required to have a FRR, it is expected to act as a barrier to the spread of smoke and fire until some type of response is initiated (e.g., automatic fire sprinklers are activated). It is important not to confuse fire separations with firewalls. A firewall is a specific type of fire separation of non-combustible construction that subdivides a building into separate buildings, or separates adjoining buildings, to resist the spread of fire from one building to another. Fire separations, on the other hand, subdivide a building into several compartments that serve to restrict fire spread by confining it as much as possible to its place of origin. For this reason, fire separations must be constructed as whole, continuous elements. They may be of combustible or non-combustible construction and may or may not have an FRR required. This section describes the fire separation requirements for mid-rise wood buildings and provides some details for maintaining their continuity and integrity.

5.4.4.1 Fire Separation Requirements

In conformance with the 2020 edition of the NBC, floors assemblies in 5 or 6-storey wood buildings shall be fire separations with an FRR not less than one hour. In a building that contains dwelling units that have more than one storey, the floor assemblies need not be constructed as fire separations. However, their FRR shall not be less than one hour.

Note that fire separations can have multiple functions, such as a floor assembly and a separation between major occupancies in a building. In this case, the highest FRR will apply, which may require certain fire separations to be upgraded a higher FRR. Fire separations for major occupancies are located in Subsection 3.1.3. of the NBC.

Moreover, Sentence 3.3.4.2.(1) of the NBC requires that suites of residential occupancy be separated from each other and the remainder of the building by a fire separation having an FRR not less than one hour (NBC, 2020). In particular, this means that party walls located between different dwelling units and walls that separate dwelling units from public corridors shall be fire separations having an FRR not less than one hour, whether the walls are loadbearing or non-loadbearing. A storage room provided for the use of tenants in a residential occupancy within a floor area but not contained within a suite shall also be separated from the remainder of the building by a fire separation having an FRR not less than one hour, as indicated in Article 3.3.4.3. of the NBC.

Suites of business and personal services (Group D) occupancy that are sprinklered throughout are not required to be separated from one another by vertical fire separations if they are served by public corridors. Walls of public corridors shall be fire separations, but they need not have an FRR when the building is sprinklered. However, there are specific cases when the walls of public corridors need not be fire separations. Refer to Subsection 3.3.1. of the NBC for more details on these cases.

In buildings with a storage garage, the garage shall be separated from the remainder of the building by a fire separation with an FRR not less than 1.5 hours, in conformance with Article 3.3.5.6. Moreover, for the storage garage to be considered as a separate building for the purposes of applying Subsection 3.2.2. of the NBC, the fire separation shall be of non-combustible construction and have an FRR of not less than two hours to meet the requirements of Article 3.2.1.2. of the NBC (2020). Other requirements also apply.

Vertical service spaces, such as shafts for vents, plumbing or electrical services, shall also be constructed as fire separations having a specific FRR. The related requirements are presented in Article 3.6.3.1. of the NBC, and they are based on the FRR requirements for the floor assemblies (NBC, 2020). In 5 to 6-storey wood buildings, vertical service spaces shall be separated by a fire separation with an FRR of at least 45 minutes, in conformance with Table 3.6.3.1. Specific requirements apply to vertical service spaces for linen and refuse chutes. For these requirements, refer to Article 3.6.3.3. of the NBC.

Service rooms containing equipment such as heating or air-conditioning appliances or electrical equipment shall also be separated from the rest of the building by fire separations in conformance with the requirements presented in Subsection 3.6.2. of the NBC.

Elevator hoistways and stairways shall also be separated by fire separations with an FRR in conformance with NBC requirements. As with vertical service spaces, FRR requirements are based on the FRR required for the building's floor assemblies. In 5 to 6-storey wood buildings, the fire separations for elevator hoistways and stairways shall have an FRR of at least one hour. Applicable requirements are presented in NBC Subsection 3.5.3. for elevator hoistways and Subsection 3.4.4. for stairways (NBC, 2020). Section 4.6 of this chapter looks at elevator hoistways and stairways in more detail.

5.4.4.2 Continuity of Fire Separations

To make sure they fulfill their fire containment purpose, wall and floor assemblies constructed as fire separations shall be constructed so as to be continuous and smoke-tight. In the NBC, Sentences (2) and (3) of Article 3.1.8.3. indicate that a vertical fire separation shall terminate so that smoke-tight joints are provided where it abuts on or intersects a floor or a roof. Moreover, Sentence (4) of the same Article indicates that the continuity of a fire separation shall be maintained where it abuts another fire separation, a floor, a ceiling, a roof, or an exterior wall assembly (NBC, 2020). While the NBC does not provide explicit methods for ensuring continuity and smoke-tight construction for fire separations at construction joints, Appendix A-3.1.8.3.(4) specifies that continuity can be maintained by filling all openings at the juncture of the assemblies with a material that will ensure the integrity of the fire separation at these locations. There are, therefore, different ways to achieve continuity and smoke-tight construction in fire separations at construction joints, such as using sealing materials like a fire-stop sealant or arranging materials in an appropriate way at these joints.

The platform system used in light wood-frame construction leads to a number of interruptions or discontinuities in fire separations. It is important to pay particular attention to the intersections between two wall assemblies, and to the top and bottom of wall assemblies to prevent the passage of flames and smoke.

Wall-to-Wall and Wall-to-Ceiling Joints

Where two gypsum board membranes intersect, such as at wall-to-wall or wall-to-ceiling joints, fire separation continuity can be maintained through the installation of tape and joint compound, where the intersection between the gypsum boards is backed by a framing member to prevent fire and smoke spread (NRCC, 2007). Adequate overlapping of gypsum board is also important in these types of joints.

Figure 4.11 and *Figure 4.12* provide examples of these concepts. *Figure 4.11* provides a detailed example of how to ensure integrity where two adjacent fire separations meet, or where a vertical fire separation meets a partition. This occurs, for instance, when an interior partition or party wall meets a corridor wall or exterior wall. *Figure 4.12* shows a detail for configuring gypsum board to maintain continuity of a horizontal fire separation where it abuts a loadbearing wall. When a horizontal fire separation meets a non-loadbearing partition, builders are strongly encouraged to install the gypsum board membrane before the wall is constructed, so that the membrane is continuous above it.

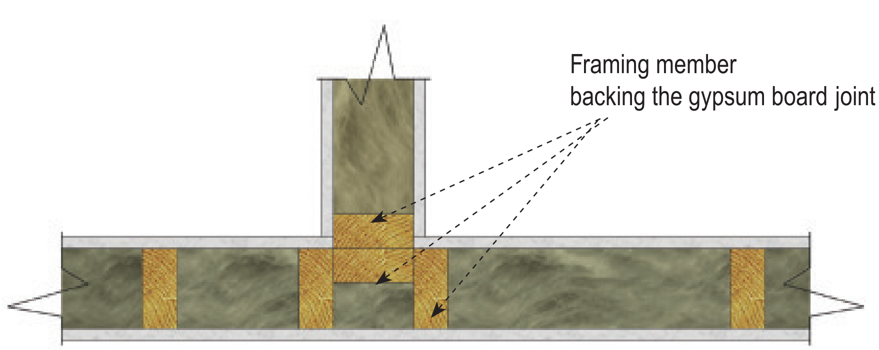


Figure 4.11: Continuity at the joint between two vertical fire separations.

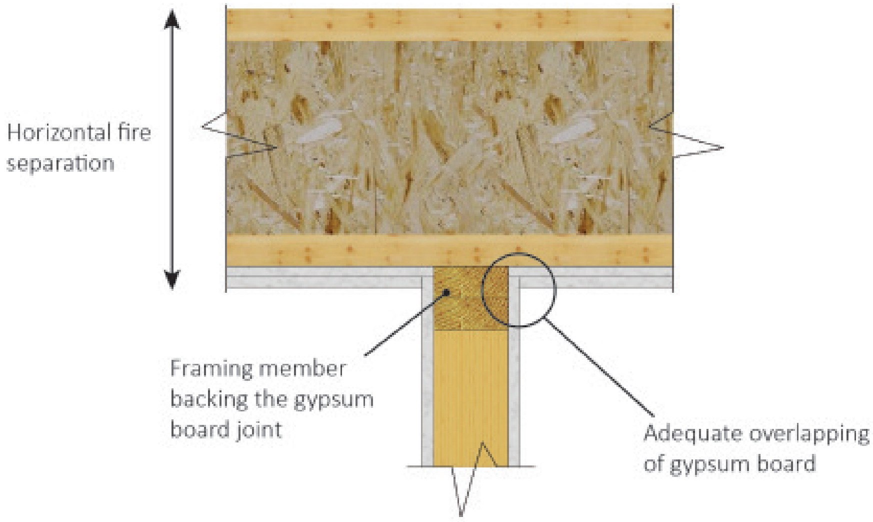


Figure 4.12: Continuity at the joint between a horizontal fire separation and a loadbearing wall.

Wall-to-Floor Joints

The bottoms of walls are another place where vertical fire separations are interrupted. The joint between the bottom wall plate in a framed wall and the structural wood panel subfloor can be sealed using an acoustical sealant or a listed fire-stop sealant (NRCC, 2007). *Figure 4.13* shows an example of this type of detail.

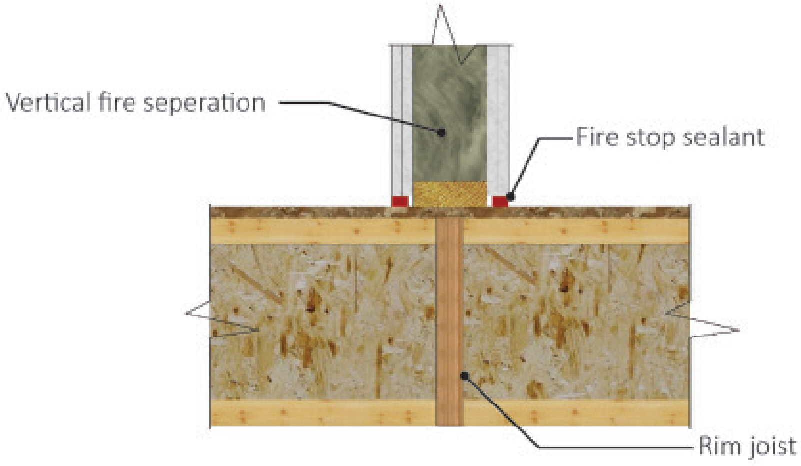


Figure 4.13: Joint between a vertical fire separation and a floor assembly.

Continuity of Fire Separations into Concealed Spaces

A horizontal service space or other concealed space located above a required vertical fire separation shall be divided at the fire separation by an equivalent fire separation within the horizontal service space, as stipulated in Sentence 3.1.8.3.(1) of the NBC. For example, a light wood-framed wall required to be a vertical fire separation should generally be continued up at the fire separation by an equivalent fire separation within the concealed space in the floor above it to meet this requirement (*Figure 4.14*).

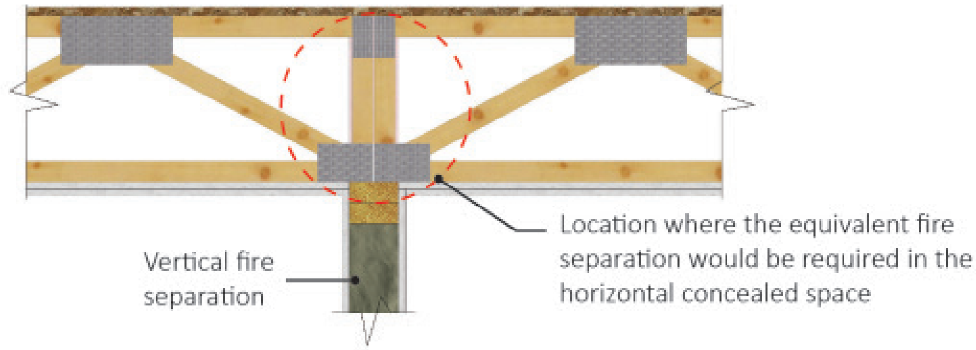
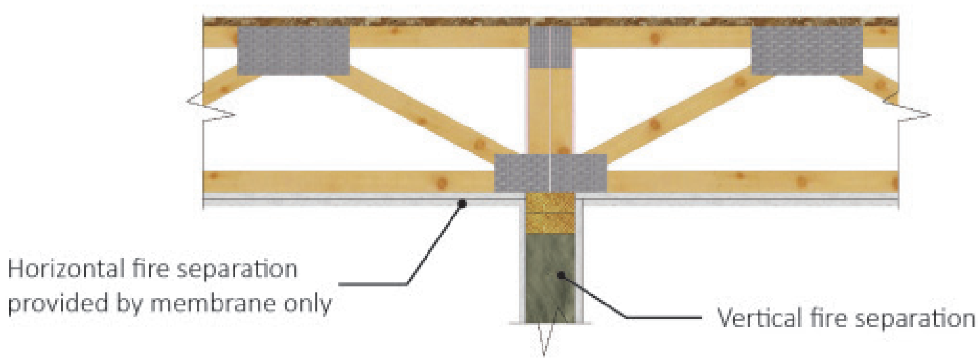


Figure 4.14: Required equivalent fire separation of a vertical fire separation in a horizontal concealed space (adapted from RBQ 2008).

However, the NBC mentions in Sentence 3.6.4.2.(2) that a horizontal service space or other concealed space located above a vertical fire separation need not be divided at the fire separation by an equivalent fire separation, provided the construction between this space and the space below is a fire separation with an FRR equivalent to that required for the vertical fire separation (NBC, 2020). *Figure 4.15* illustrates this situation. Take note that this exception does not apply to the vertical fire separations required for vertical service spaces and stairways. These separations must always be continuous through the horizontal concealed spaces. *Figure 4.59* in Section 4.6 of this chapter provides some detailed examples of continuity in wood elevator shafts and stairways. The option presented by the NBC applies to interior walls that form vertical fire separations, such as party walls between dwelling units, or public corridor walls.



Equivalent fire separation **not required** in the horizontal concealed space above a vertical fire separation provided the FRR of the horizontal fire separation is equal to that of the vertical fire separation and the space is not a vertical shaft or a stairway

Figure 4.15: Vertical fire separation that does not require an equivalent fire separation in the above horizontal concealed space.

However, it is important to note that applying this exception means that the FRR of the horizontal fire separation can only be provided by the membrane separating the horizontal concealed space from the room below. In the illustrated example of a light wood-frame construction in *Figure 4.15*, the FRR is provided only by the gypsum board ceiling membrane, and not by the floor assembly as a whole, as is usually the case. The gypsum board membrane therefore needs to meet all three FRR evaluation criteria on its own for the required period: structural stability, integrity (passage of flames), and insulation (heat transmission). Thus, it is necessary to refer to fire test reports for which the FRR is determined on the basis of the membrane only and not of the complete assembly.

The component-additive method presented in Appendix D-2.3. of the NBC, and Article D-2.3.12. specifically, provides the FRR of floor or roof assemblies based only on the contribution of the ceiling membrane (NBC, 2020). Subsection 4.3.1 of this chapter has more information on this method for determining the FRR. However, for this approach to be valid, the ceiling membrane cannot have any vent openings. In Sentence 3.1.9.1.(3), the NBC permits certain penetrations in the ceiling membrane provided that the penetration is sealed by a fire stop with an appropriate FT rating, which has more stringent requirements than most fire-stop systems in a building due to the addition of the “T”, or temperature, rating. In particular, this could be applied to electrical boxes for light fixtures.

In the platform frame systems commonly used in light wood-frame construction, it can be difficult to maintain continuity of loadbearing wall fire separations into the horizontal concealed spaces formed by floor joists or roof trusses. However, some details of junctions between loadbearing walls and floor joists can be used to maintain continuity in the vertical fire separations. For instance, for I-joists supported on the wall by the lower flange, there are junctions consisting of an engineered wood rim joist, used alone or in combination with a strip of Type X gypsum board, which are listed for one- or two-hour FRRs in conformance with CAN/ULC-S101 (2014). *Figure 4.16* shows an example junction for a one-hour FRR in a single-wall configuration and a double-wall configuration. Whether or not you need to install a strip of gypsum board on the rim joist depends on the rim joist’s thickness and the type of ceiling membrane used. The various junction details may be viewed in technical literature from I-joist manufacturers, or in the APA Rim Board in Fire Rated Assemblies should be italicized published by the APA – The Engineered Wood Association (APA, 2015).

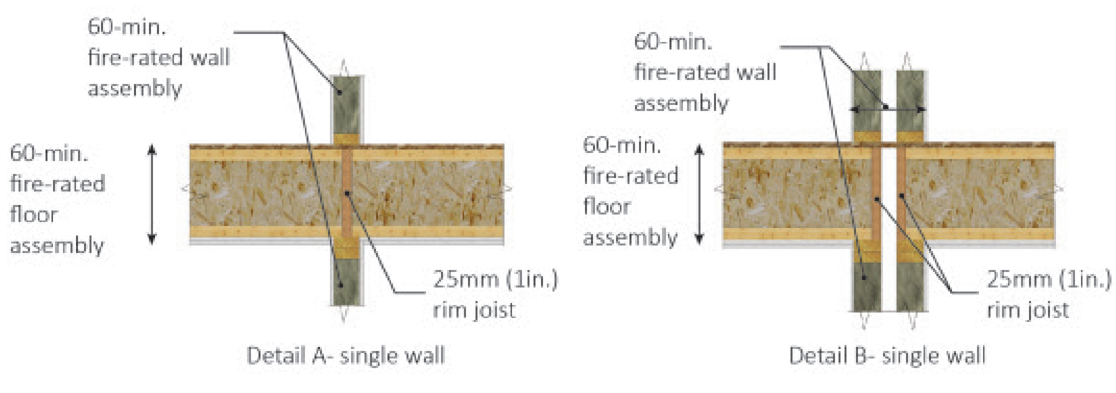


Figure 4.16: Wall-to-floor juncture with one-hour fire-rated rim joist (adapted from APA 2015).

It is also possible to use top chord bearing trusses with metal plate connectors. For this type of truss, the most recent edition of TPIC (2014) (the standard governing light-frame truss and metal-plate-connected truss design) authorizes a distance between the face of the loadbearing wall and the face of the truss of up to 89 mm (3-1/2 in.) based on the support reaction of the truss. This spacing enables the gypsum board covering the wall face to be extended up to the top plate, thus, which maintains the continuity of the vertical fire separation inside the floor assembly concealed space. However, filler blocks are required above the top plate to fill the spaces between the trusses. *Figure 4.17* illustrates this situation.

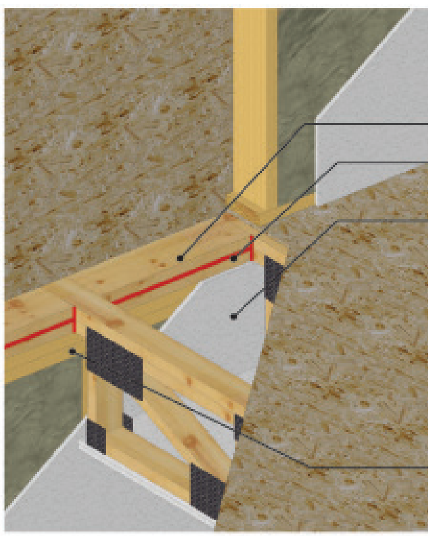


Figure 4.17: Details of top chord bearing trusses to extend the wall's gypsum board membrane.

Another similar option consists of supporting the I-joists or trusses on the loadbearing wall with top-mount or face-mount metal hangers designed specifically for installation on top of gypsum board. As with top chord bearing metal-plate-connected trusses, this configuration allows for the gypsum board to extend up to the top plate of the loadbearing wall without requiring filler blocks. For top-mount hangers, the flanges supporting the hangers are only partially supported on the top plate of the wall due to the thickness of the gypsum board *(Figure 4.18a)*. As such, hanger capacity, as published in connector manufacturer documentation, is lower than that normally obtained with hangers bearing entirely on the top plate. Moreover, these hangers can only be installed on one single layer of 15.9 mm (5/8 in.) thick gypsum board. There are, however, face-mount hangers that can be installed above a maximum of two layers of 15.9 mm (5/8 in.) thick gypsum board. These hangers are fastened through the gypsum board into the top plate of the wall *(Figure 4.18b)*. On their websites, metal hanger manufacturers publish documentation on the capacities for these different products. However, these types of hangers are more expensive than more commonly used hangers and require that the gypsum board in wall assemblies be installed early on – i.e., before the building is totally closed up and weather-tight. Additional precautions are therefore necessary to protect the gypsum board from the weather. Another solution for extending the vertical fire separation is to support I-joists or trusses using face-mount hangers fastened to an engineered solid wood beam (e.g., of structural composite lumber) bearing on the top of the wall. *Figure 4.19* illustrates this example.

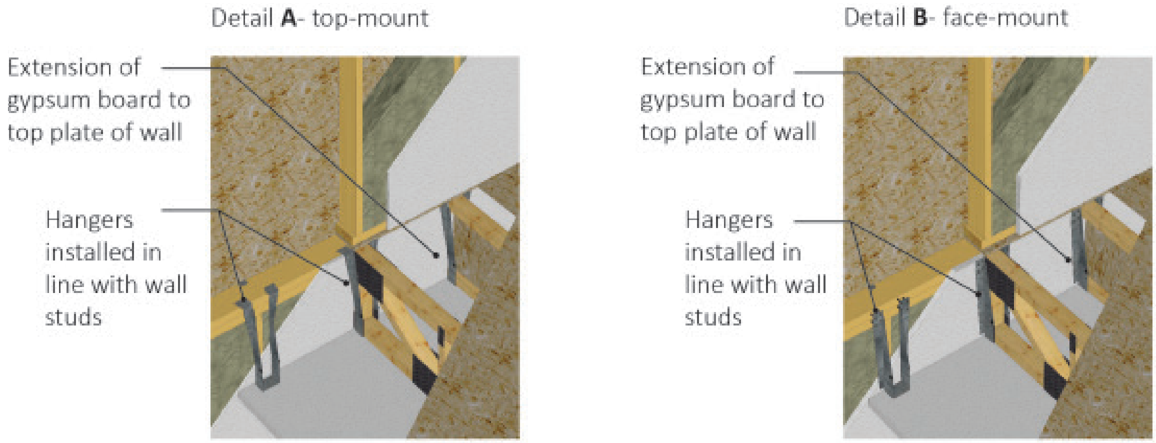


Figure 4.18: Metal hangers that can be installed on top of a gypsum board membrane.

For non-loadbearing wall assemblies that are vertical fire separations, it is much easier to maintain the required continuity in the above horizontal concealed spaces. *Figure 4.19* presents a few examples of details that maintain this continuity for vertical fire separations having an FRR not less than one hour. In Details A and B, whether or not you need to install a strip of gypsum board on the rim joist depends on the rim joist's thickness and the type of ceiling membrane used.

Sawn lumber joists can be beneficial when used as structural elements in corridor floor assemblies in light wood-frame multi-storey buildings. Spans are shorter in corridors, which means that joists that are less deep can be used compared to the engineered joists used in floor assemblies for suites. This difference in depth of floor enables the building's equipment to pass through the corridor ceiling assemblies in the different storeys. As mentioned previously, corridor walls are vertical fire separations that require specific details to maintain continuity at their intersection with floor assemblies. *Figure 4.20* illustrates examples of this type of junction. Depending on the thickness of the rim joist, two layers of gypsum board may be necessary on the corridor side of the wall to protect the rim joist and achieve the required fire rating at the junction (APA, 2015).

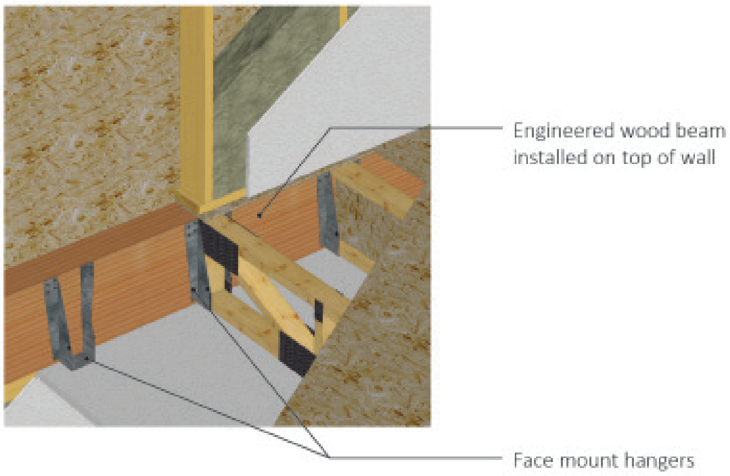


Figure 4.19: Details of joists bearing on an engineered wood beam using face-mount hangers.

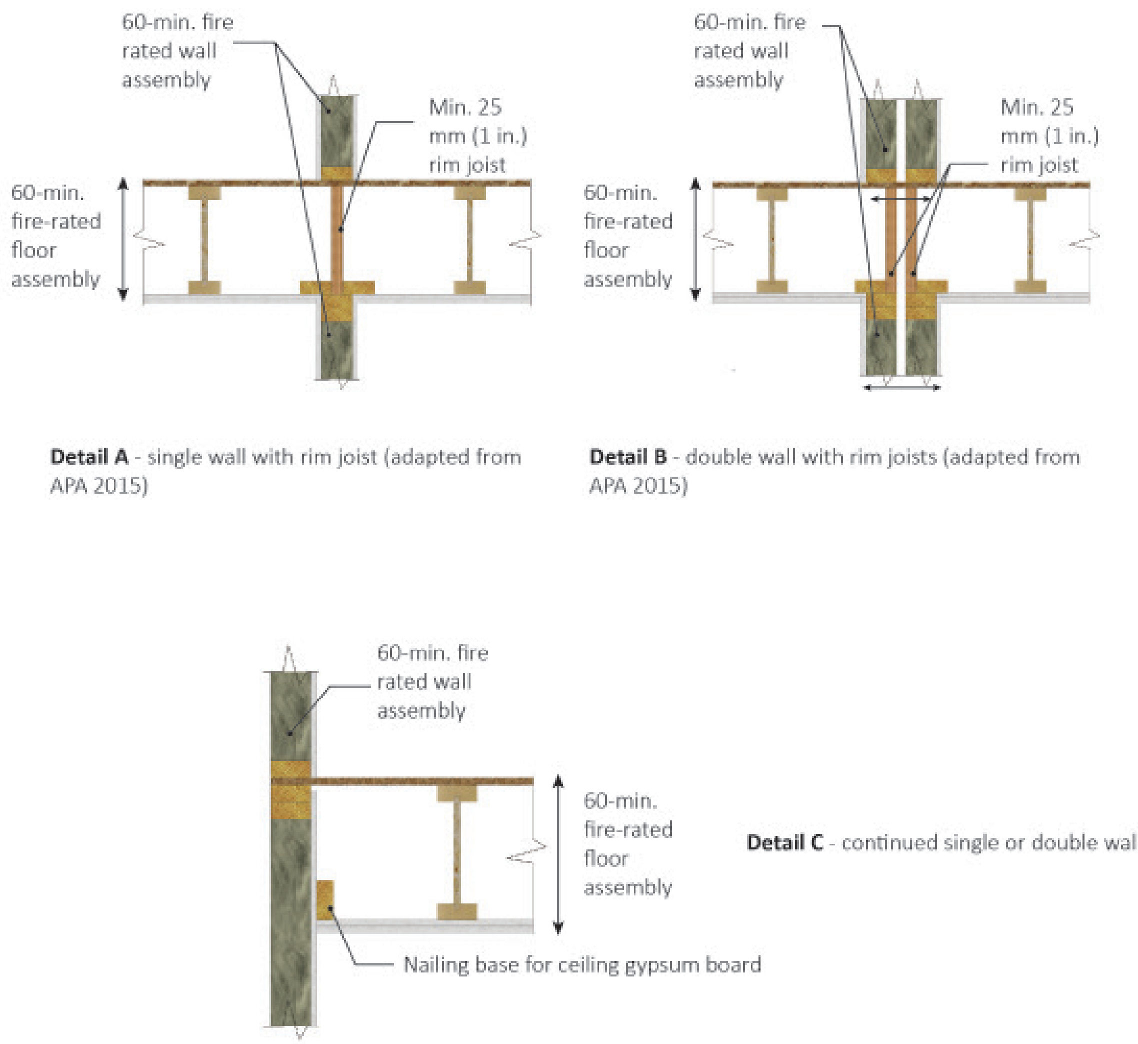
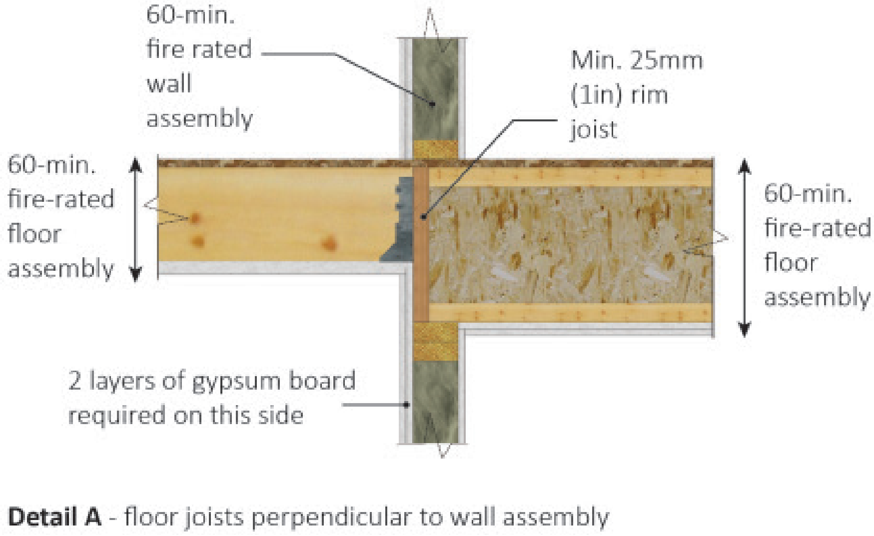


Figure 4.20: Intersection of a floor assembly and one-hour fire-rated non-loadbearing vertical fire separations.



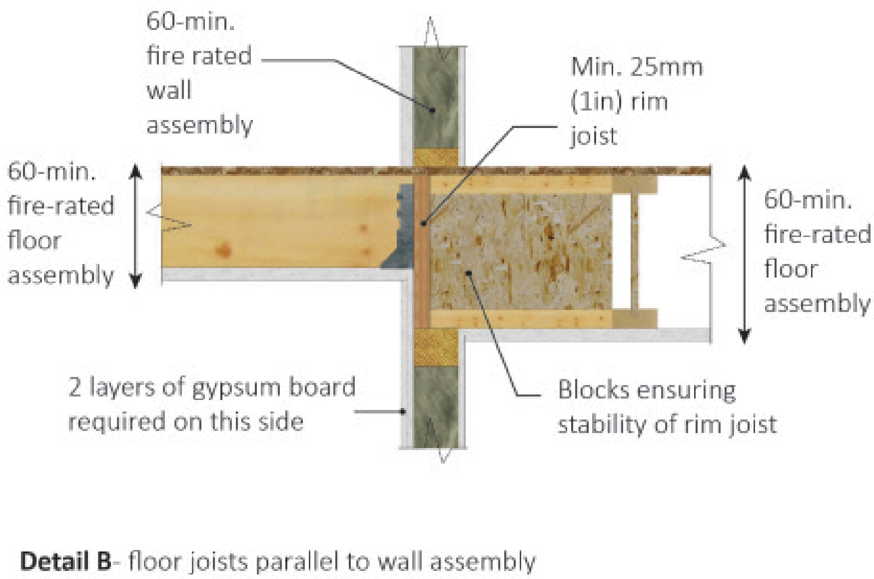


Figure 4.21: Intersection between floor and corridor wall assemblies for a one-hour FRR (adapted from TrusJoist 2014 and APA 2015).

Finally, the requirement that a horizontal concealed space located above a required vertical fire separation shall be divided at the fire separation by an equivalent fire separation within the horizontal concealed space also applies to roof assemblies. Fire test reports are available for loadbearing or non-loadbearing wall assemblies with wood frame elements installed flatwise rather than edgewise. These reports can be consulted to create fire-rated fire separations in attics using light-frame trusses covered in gypsum board (SBCA, 2015). When a vertical fire separation wall is parallel with metal-plate-connected light-frame trusses, it is possible to maintain continuity of the fire separation by placing a truss with vertical web members above it, such as a gable truss, and fastening gypsum board to each side. *Figure 4.22* illustrates this situation, and **Table 5.13** contains examples of compositions that achieve a one-hour FRR for frame elements installed flatwise.

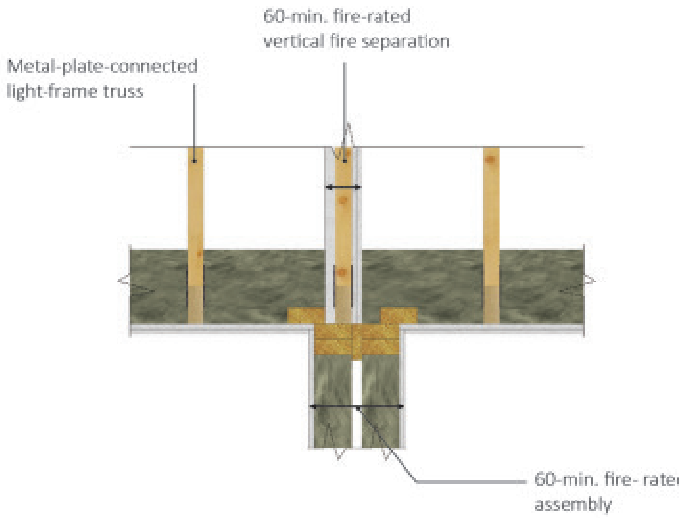


Figure 4.22: Continuity of a vertical fire separation inside an attic.

Table 5.13 One-hour fire-rated assemblies for loadbearing wood frame members installed flatwise.

Illustration	Description[1 3 4]	FRR (minutes	References[2]
	– 2 layers of 15.9 mm (5/8 in.) thick Type X gypsum board – 38 x 64 mm (2x3) or 38 x 89 (2x4) fl t @ 610 mm (24 in.) o.c. – Batt or sprayed insulation (optional) – 2 layers of 15.9 mm (5/8 in.) thick Type X gypsum board	60	UL-U338
	– 2 layers of 15.9 mm (5/8 in.) thick Type X gypsum board – 38 x 64 mm (2x3) or 38 x 89 (2x4) fl twise @ 610 mm (24 in.) o.c. – Batt or spray-applied insulation (optional) – Plywood or fib eboard (optional) – 38 x 64 mm (2x3) or 38 x 89 (2x4) fl twise @ 610 mm (24 in.) o.c. – 2 layers of 15.9 mm (5/8 in.) thick Type X gypsum board	60	UL-U339

Notes:
The descriptions in the above table are simplifications of specific fire-resistance-rated assemblies. Designers shall consult the various test reports from certification agencies to obtain comprehensive information on these assemblies.

1. References for the fire-resistance rating (FRR) values: Underwriters Laboratories (UL).
2. Dimensions listed for studs and gypsum board are minimum values.
2. Spacings listed for studs are maximum values.
4. Openings and penetrations in fire separations.

5.4.4.3 Openings and Penetrations in Fire Separations

Fire separations and other fire-resistance-rated assemblies, both vertical and horizontal, sometimes need openings or penetrations so that doors or windows may be installed, or to enable vents, plumbing or electrical services to pass through. These services may pass through the fire separations completely, or simply penetrate one membrane forming one face of the assembly. In order to maintain the integrity and seal of the fire separations or assemblies that require an FRR, it is important to pay special attention to these openings and penetrations.

Refer to Subsections 3.1.8. and 3.1.9. of the NBC for the various requirements for openings and penetrations in fire separations and fire-resistance-rated assemblies. The Code requires the use of closures or listed fire stops, as needed. A closure is defined in the Code as a device or assembly for closing an opening through a fire separation or an exterior wall, such as a door, a shutter, wired glass or glass block, and including all components such as hardware, closing devices, frames and anchors. A fire stop, on the other hand, means a system consisting of a material, component and means of support used to fill gaps between fire separations or between fire separations and other assemblies, or used around items that wholly or partially penetrate a fire separation (NBC, 2020).

When an FRR is required for a fire separation or other assembly, Article 3.1.9.2. of the NBC requires that ducts, pipes, electrical outlet boxes, or other similar service equipment penetrating this type of assembly be non-combustible, except as permitted by other NBC articles or unless the assembly was tested incorporating that service equipment.

The paragraphs below present some NBC requirements, explain the various protections used, and provide some examples of different types of service openings and penetrations. Much of the information found in this subsection is taken or adapted from the following references:

- *Les registres coupe-feu: Comment assurer une installation conforme (RBQ, 2008).*
- *Best Practice Guide on Fire Stops and Fire Blocks and their Impact on Sound Transmission (NRCC, 2007).*
- *Fire Stopping Service Penetrations in Buildings (CCBRD, 2003).*

Readers are strongly encouraged to consult these documents for more information about requirements and protective measures associated with openings and penetrations in fire separations or other fire-resistance-rated assemblies.

Doors

Doors are a common type of opening found in vertical fire separations. Walls that separate units from public corridors in multi-family buildings are a good example of fire separations with many doors. The related requirements can primarily be found in Subsection 3.1.8. of the NBC.

Doors located in a fire separation shall generally have a minimum fire-protection rating based on the required fire-resistance rating of the fire separation, as indicated in Sentence 3.1.8.4.(2) of the NBC. For a fire separation with a one-hour FRR, the minimum fire-protection rating should be 45 minutes. However, for a fire separation located between a public corridor and a suite, and which has a maximum required one-hour FRR, Article 3.1.8.10 of the NBC allows for a door assembly having a fire-protection rating of 20 minutes. The fire-protection rating of door assemblies shall be determined based on the results of tests conducted in conformance with CAN/ULC-S104, *Standard Method for Fire Tests of Door Assemblies* (ULC-S104, 2015).

Moreover, door assemblies shall be installed following the requirements of NFPA 80, *Standard for Fire Doors and Other Opening Protectives* (NFPA 80, 2013), as indicated in Sentence 3.1.8.5.(2) of the NBC. They shall also be equipped with self-closing devices in conformance with Article 3.1.8.13. of the Code.

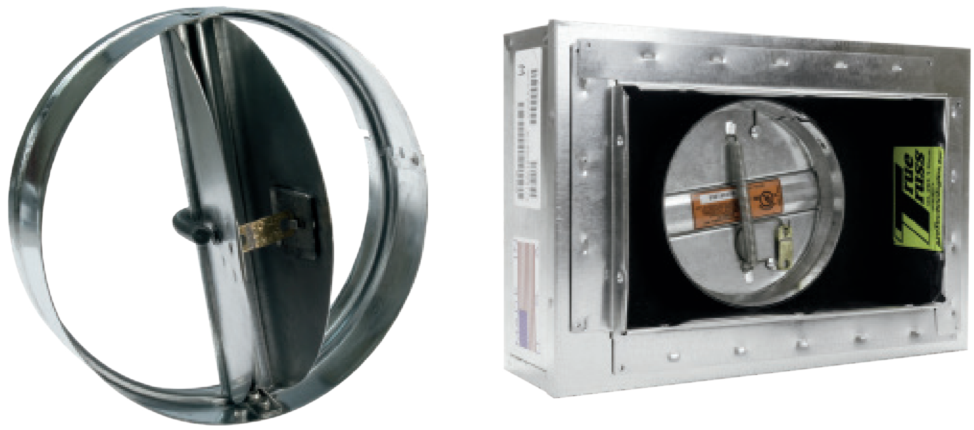
Penetrations for Ventilation

Buildings contain air supply duct systems serving heating, air-conditioning and air-exchanger systems, bathroom fans, kitchen hoods, and laundry-drying equipment exhaust ducts. These duct systems commonly pass through fire separations completely, or simply penetrate one membrane forming part of the fire-resistance-rated assembly.

The NBC mentions two main types of closures used for openings for air supply services: fire or smoke dampers *(Figure 4.23)* and fire-stop flaps *(Figure 4.24)*. The Code defines a smoke damper as a closure consisting of a damper that is installed in an air distribution system or a wall or floor assembly and that is normally held open but designed to close automatically in the event of a fire in order to maintain the integrity of the fire separation. On the other hand, a fire-stop flap is a device intended for use in horizontal assemblies required to have an FRR and incorporating protective ceiling membranes, which operates to close off a uct opening through the membrane in the event of a fire (NBC, 2020).

It is important to distinguish between these two types of closures. Fire and smoke dampers are installed in air supply ducts at the fire separation, in a wall or floor assembly, while fire-stop flaps are generally installed at the ceiling membrane at the opening of ventilation and recovery ducts. These two devices primarily work by closing automatically in the event of a fire in order to close off n air duct and maintain the integrity of a fire separation. The difference is that a fire or smoke damper prevents fire, smoke, or both from spreading from one compartment to another by passing through the fire separation by way of the vent, while a fire-stop flap maintains the fire-resistance of an assembly with a pierced ceiling membrane by protecting the above floor structure from the extreme heat of a fire that could lead to its collapse (RBQ, 2008).

Figure 4.24: Examples of fire-stop flaps.
(Source: Aire Technologies Inc.).



A) Open fire stop flap

B) Closed fire stop flap, in its installation housing listed for light wood-frame

Figure 4.23: Example of a fire damper.
(Source: Aire Technologies Inc.).

Requirements for fire and smoke dampers can be found in Subsection 3.1.8. of the NBC. The Code indicates that all ducts that penetrate an assembly required to be a fire separation shall be equipped with a fire damper evaluated in conformance with CAN/ULC-S112 (2010) *(Figure 4.25)*. A smoke damper or combination fire/smoke damper is required where a duct or air transfer opening penetrates certain fire separations, such as those in public corridors and where they serve assembly, care, treatment, detention, or residential occupancies (per NBC Sentence 3.1.8.7.(2)).

The fire-protection rating of the dampers shall be determined in conformance with Article 3.1.8.4., and their installation shall comply with the requirements in Article 3.1.8.10. However, Articles 3.1.8.8 and 3.1.8.9 of the NBC permits fire and smoke damper requirements to be waived in certain situations. When a vent penetrates a fire separation which does not require a fire damper in conformance with the exceptions listed in Article 3.1.8.8., the penetration shall be sealed by a fire stop that meets the requirements of Article 3.1.9.1. to ensure a minimum integrity for the fire separation *(Figure 4.26)*. On the other hand, when a fire damper is used in a duct at a fire separation, it is generally not required that the joint around the duct be sealed with a fire stop, unless the damper was specifically intended for use with a fire stop. Using a fire stop in combination with a fire damper could impair operation of the damper if it was not designed for such use. Therefore, it is important to follow the installation directions provided by product manufacturers.

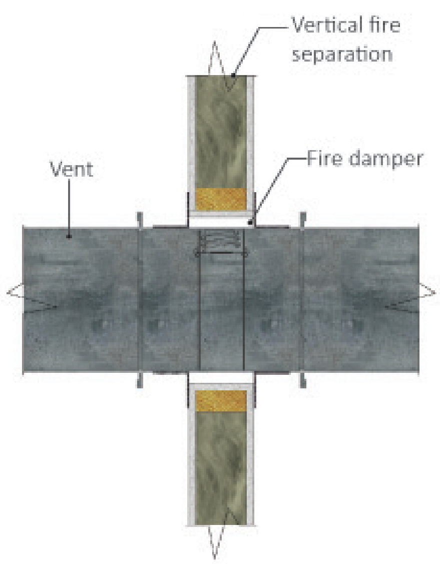


Figure 4.25: Detail of a vertical fire separation equipped with a fire damper (adapted from NRCC 2007).

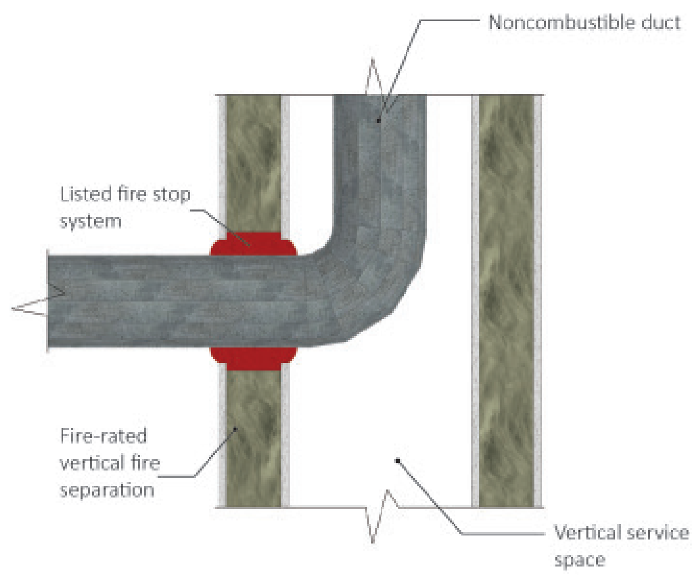


Figure 4.26: Sealed joint around a duct penetration without fire damper (adapted from NRCC 2007).

When there is an opening in the ceiling membrane of a fire-rated assembly for air ventilation or recovery ducts, this opening shall be equipped with a fire-stop flap to maintain the integrity of the assembly. As indicated in Article 3.1.9.6, of the NBC, the openings in a ceiling membrane forming part of an assembly assigned an FRR on the basis of Appendix D of the NBC shall comply with the requirements indicated in this Appendix. The requirements for floor or roof assemblies in combustible construction can be found in Appendix D-2.3.10. In particular, this Appendix indicates that an opening that exceeds 130 cm^2 in area shall be protected by a fire-stop flap. If, on the other hand, the FRR of a floor or roof assembly is assigned on the basis of proprietary fire-resistance test reports, the protective device for the membrane opening – i.e. the fire-stop flaps – shall be included in the assembly test report. Fire-stop flaps do not have an hour-based fire-resistance or fire-protection rating alone; rather, they are certified as components that form part of an assembly listed for a certain FRR.

There are not currently any listed fire dampers that can be installed in places other than a duct that completely passes through a fire separation. When a duct penetrates the ceiling membrane of a horizontal fire separation, runs within the assembly, and then leaves the assembly at another location, different protections shall be used to maintain the integrity of the fire separation with no fire damper. In its document covering fire dampers (RBQ, 2008), the Régie du bâtiment du Québec provides a detail for constructing a gypsum board enclosure fastened to the structural members surrounding the vent *(Figure 4.25)*. The number of layers and thickness of the gypsum board shall be the same as for the ceiling membrane. The gypsum board enclosure shall be constructed along the full distance of the duct, or to the point where the duct is equipped with a fire damper at a fire separation *(Figure 4.26)*. Other examples of details for this scenario can also be found in Section 10.3 of the *Best Practice Guide on Fire Stops and Fire Blocks and their Impact on Sound Transmission* (NRCC, 2007).

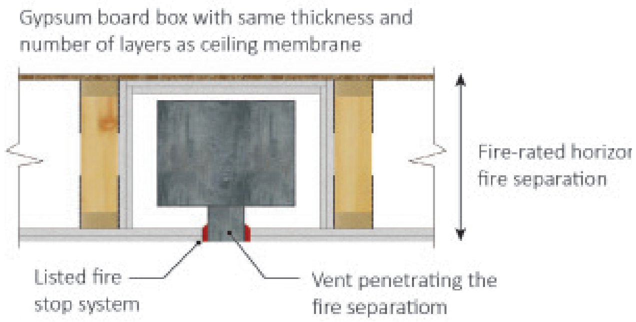


Figure 4.27: Gypsum board box on structural members surrounding a vent.

(Photo: Cecobois)

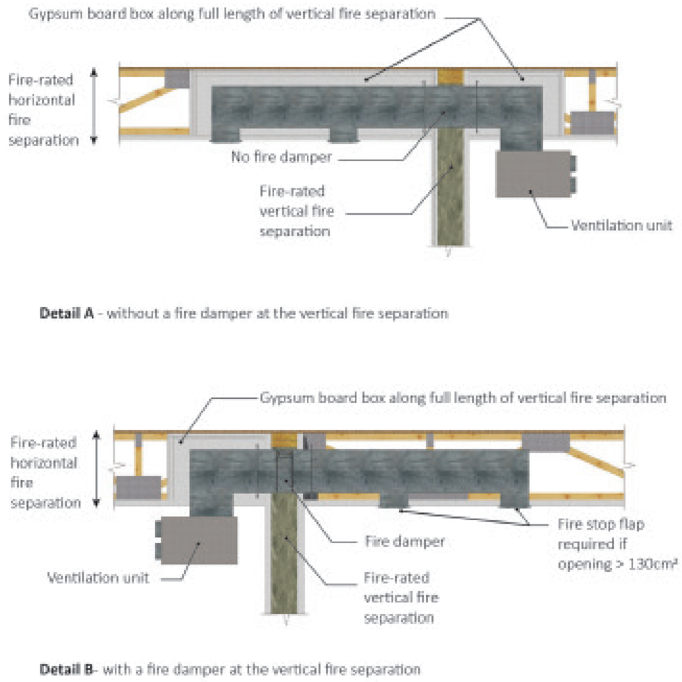


Figure 4.28: Path of a fire damper at a vertical fire separation (adapted from R 200).

Air supply ducts that pass through exterior wall assemblies generally do not require fire dampers because these walls are not considered fire separations. However, in this case, the opening should be added to the area of unprotected openings applicable to the design of exposing building faces in conformance with Subsection 3.2.3 of the NBC. The joint surrounding this penetration shall still be sealed by a fire stop in conformance with the requirements of Sentence 3.1.9.1.(1) in order to maintain the integrity if the wall is required to be a fire-resistance-rated assembly.

Penetrations for Plumbing

Multi-storey buildings generally have a large network of piping for potable water supply, sewage disposal, sprinkler systems, roof drainage and plumbing system ventilation. This piping runs throughout the building and often must penetrate an entire fire separation or just one membrane forming part of a fire-resistance-rated assembly. Any necessary penetrations must be accompanied by protections to maintain the integrity of these assemblies. The different requirements for these penetrations can be found in Subsection 3.1.9. of the NBC. In addition, requirements on the combustible or non-combustible nature of the piping that penetrates fire-resistance-rated assemblies are presented in Articles 3.1.9.2. and 3.1.9.5. of the NBC.

In particular, Article 3.1.9.1 of the Code indicates that penetrations of a fire separation or a membrane forming part of an assembly required to have an FRR shall be sealed by a fire stop that has been tested in conformance with CAN/ULC-S115 (2011). This fire stop shall have received an F rating not less than the fire-protection rating required for closures in the fire separation in conformance with Table 3.1.8.4. The rating required for fire stops in Article 3.1.9.1. is higher for penetrations through firewalls, or for assemblies for which the FRR is provided only by the ceiling membrane. In these cases, the fire stops also require a FT rating, which adds a temperature component on the unexposed side in the required testing procedure.

There are a wide variety of fire stops, such as flexible sealants, mouldable putties, foams, tapes, collars, sleeves and many others. Choosing the right fire stop depends on several factors, including the assembly's type of construction and if the pipe that runs through it is combustible or noncombustible. It is therefore important to consult fire-stop manufacturer data sheets to select the right product for a given situation.

As mentioned in Sentence 3.1.9.1.(4) of the NBC, fire stops are generally not used with sprinklers that pass through a fire-resistance-rated assembly membrane because, as with fire dampers, they could impair the operation of the sprinklers. The opening in the membrane is usually covered with a metal escutcheon plate in conformance with NFPA 13. However, sprinkler system piping shall be equipped with a fire stop at the locations where it penetrates fire separations or fire-resistance-rated assemblies.

When vertical piping passes through a fire-rated floor assembly, a fire stop shall be installed both at the ceiling and floor level *(Figure 4.29)*. Piping that penetrates a floor assembly may be located inside a fire-rated wall assembly such as a party wall, or a simple non-rated partition *(Figure 4.30)*. In this case, the choice of fire stop is important, because some products are only certified for use inside fire-rated wall assemblies. *Figure 4.31* shows two examples of fire-stop installation details for plumbing components that penetrate a fire-rated floor assembly.

Joints around piping that penetrates fire-rated wall assemblies shall also be equipped with a fire stop. When a pipe passes through an entire wall assembly, the fire stop shall be present on both sides, as shown in *Figure 4.32*. *Figure 4.33*, on the other hand, shows an example of piping that enters a wall assembly by way of the floor assembly below and leaves it through the wall's gypsum board membrane. In this case, the fire stop at the gypsum board membrane is only required if the wall assembly needs to be fire-rated, while the fire stop at the bottom wall plate is always necessary, even if the wall is not fire-rated, because it maintains the integrity of the horizontal fire separation or the fire-rated floor assembly.

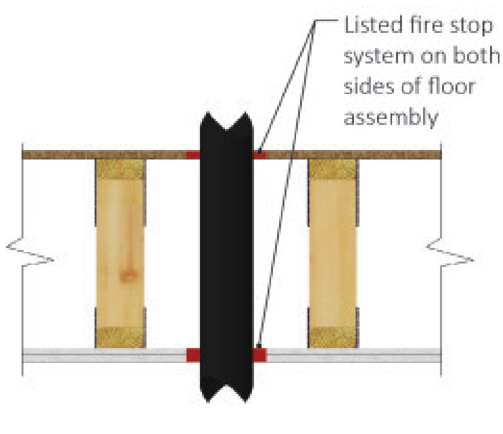


Figure 4.29: Example of a required fire stop for a pipe passing through a fire-rated floor assembly.

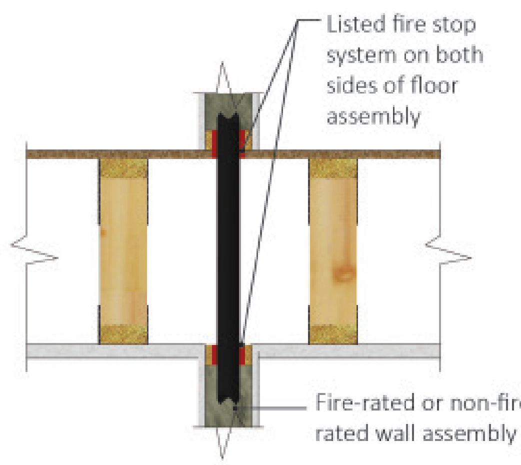


Figure 4.30: Example of a fire stop required for a pipe located inside a wall assembly and passing through a fire-rated floor assembly.

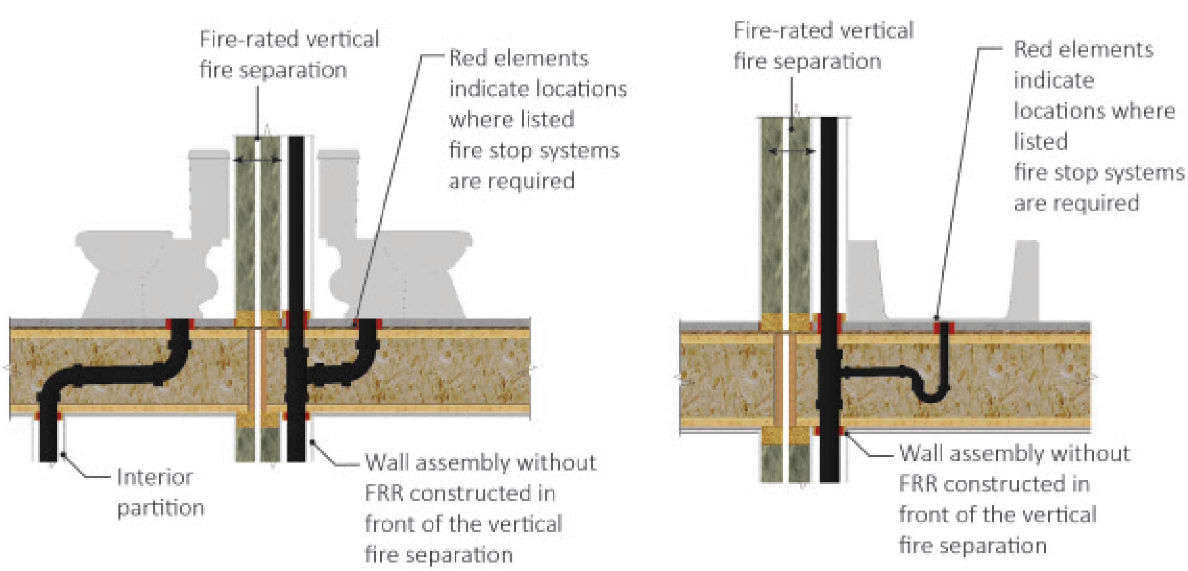


Figure 4.31: Examples of fire-stop details for plumbing components that penetrate a fire-rated floor assembly (adapted from NRCC 2007).

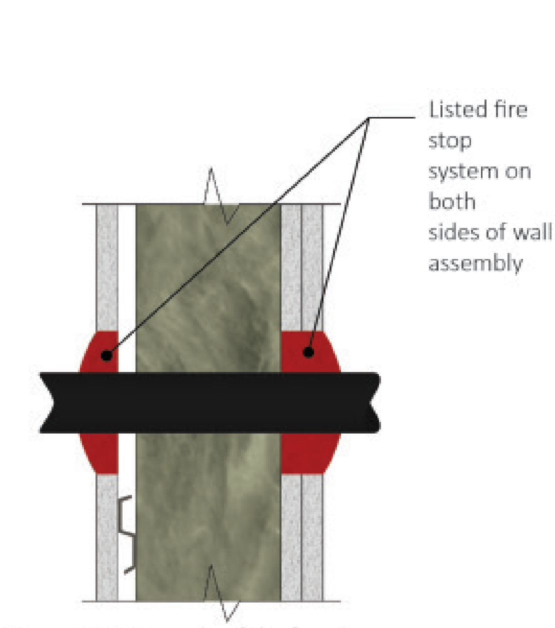


Figure 4.32: Example of the fire stop required for a pipe passing through a fire-rated wall assembly (adapted from NRCC 2007).

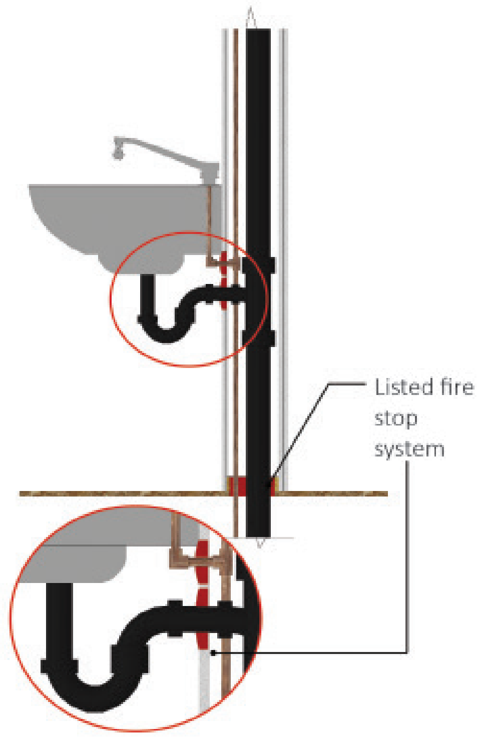


Figure 4.33 Fire stop required for piping that penetrates a fire-rated wall assembly (adapted from NRCC 2007).

Fire stops are also required when piping crosses through a fire-rated roof assembly. For example, *Figure 4.34* shows a fire stop used where a plumbing vent penetrates through a roof with a specific FRR.

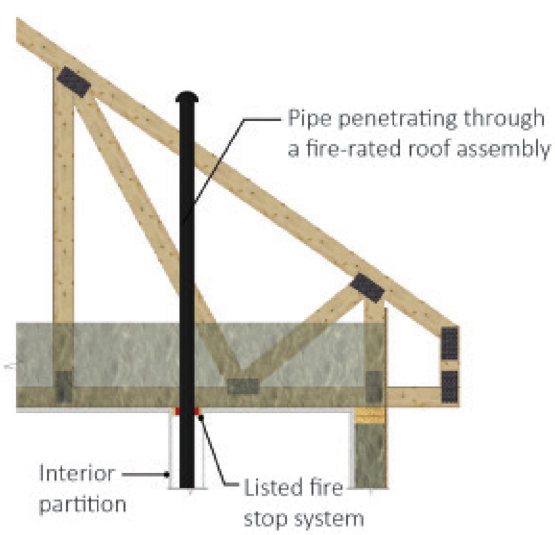


Figure 4.34 Example of a required fire stop for a pipe penetrating through a fire-rated roof assembly (adapted from NRCC 2007).

Penetrations for Electrical Services

Wires, cables, metal raceways, cable trays and other components of a building's electrical system that penetrate a fire separation or a fire-resistance-rated assembly are subject to the requirements of Subsection 3.1.9. of the NBC. Similar to the plumbing penetrations presented above, joints around electrical system components that penetrate a fire separation or a membrane forming part of a fire-resistance-rated assembly shall be sealed by a fire stop to meet the requirements of Article 3.1.9.1. of the NBC. The fire stop shall be listed when tested in conformance with CAN/ULC-S115 (2011), and its F rating shall be not less than the fire-protection rating required for closures in Table 3.1.8.4. of the NBC. Requirements on the combustible or non-combustible nature of the electrical system components that penetrate fire-resistance-rated assemblies are presented in Articles 3.1.9.3 and 3.1.9.4 of the NBC.

Electrical system components commonly pass through fire separations or penetrate one membrane forming part of a fire-resistance-rated assembly. Wires or cables may penetrate through a fire-resistance-rated assembly individually or in groups by way of a pipe or raceway. When elements penetrate through an entire fire-resistance-rated light wood-frame assembly, the fire stop shall be installed on each side of the assembly *(Figure 4.35 and Figure 4.36)*. Several types of fire stops are available for these situations, such as flexible sealants and sleeves. There are a number of factors that go into selecting the right fire-stop product, such as the assembly's construction type and the number and type of cables or raceways that penetrate it. It is therefore important to consult fire-stop manufacturer data sheets to select the right product for a given situation.

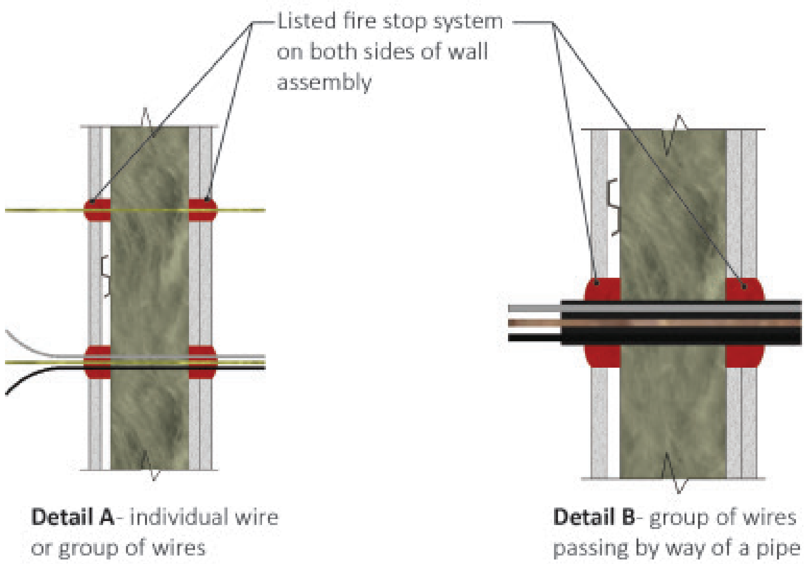


Figure 4.35: Examples of fire-stop details for wires or cables penetrating through a fire-rated wall assembly (adapted from NRCC 2007).

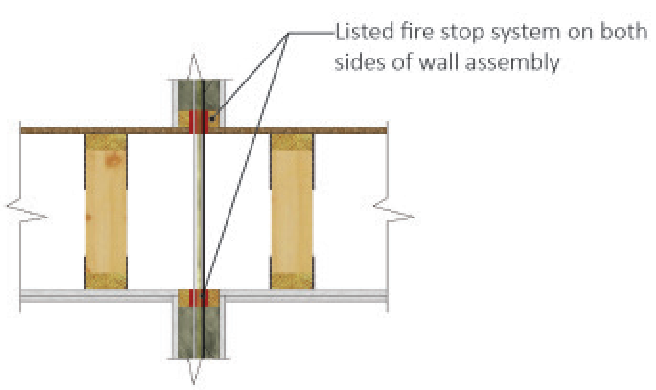


Figure 4.36: Example of a fire-stop detail for wires or cables located inside a wall assembly and penetrating through a fire-rated floor assembly.

The most common type of electrical system component found in the membrane of a fire-resistance-rated assembly or a horizontal or vertical fire separation are outlet boxes for lighting or receptacles. In general, outlet boxes penetrating a membrane in a fire separation are required to be sealed by a fire stop that has an FT rating not less than the FRR of the fire separation per Sentence 3.1.9.4.(1). of the NBC. Certain small, non-combustible outlet boxes located in vertical fire separations are exempt from this requirement, per Sentence 3.1.9.4.(2).

There are different types of fire stops on the market designed for these situations. Small electrical box pillow or pad inserts with adhesive can be installed against the back of electrical boxes, or mouldable putties can be used to create an envelope around the outside of the boxes *(Figure 4.37 and Figure 4.38)*.

Figure 4.37: Examples of fire stops for electrical boxes.

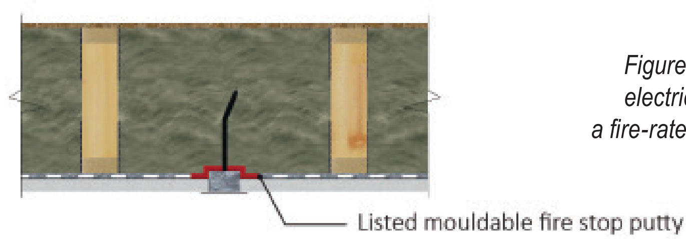


Figure 4.38: Example using fire-stop putty on an electrical box located in the ceiling membrane of a fire-rated floor assembly (adapted from NRCC 2007).

One alternative to mouldable putties for an electrical box located inside a ceiling membrane is to build a gypsum board enclosure in the concealed space above the electrical box, as shown in *Figure 4.39*.

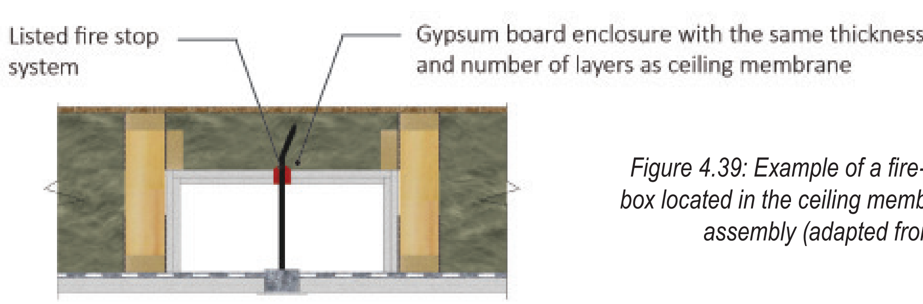


Figure 4.39: Example of a fire-stop detail for an outlet box located in the ceiling membrane of a fire-rated floor assembly (adapted from NRCC 2007).

Lastly, outlet boxes that penetrate opposite sides of a light-frame wall assembly serving as a fire separation shall be separated by a minimum of 600 mm or a fire block to maintain the integrity of the fire separation, in conformance with Sentence 3.1.9.4.(3) of the NBC. Offsetting the electrical boxes also maintains good acoustical separation for the wall assembly. *Figure 4.40* illustrates this practice for single and double walls.

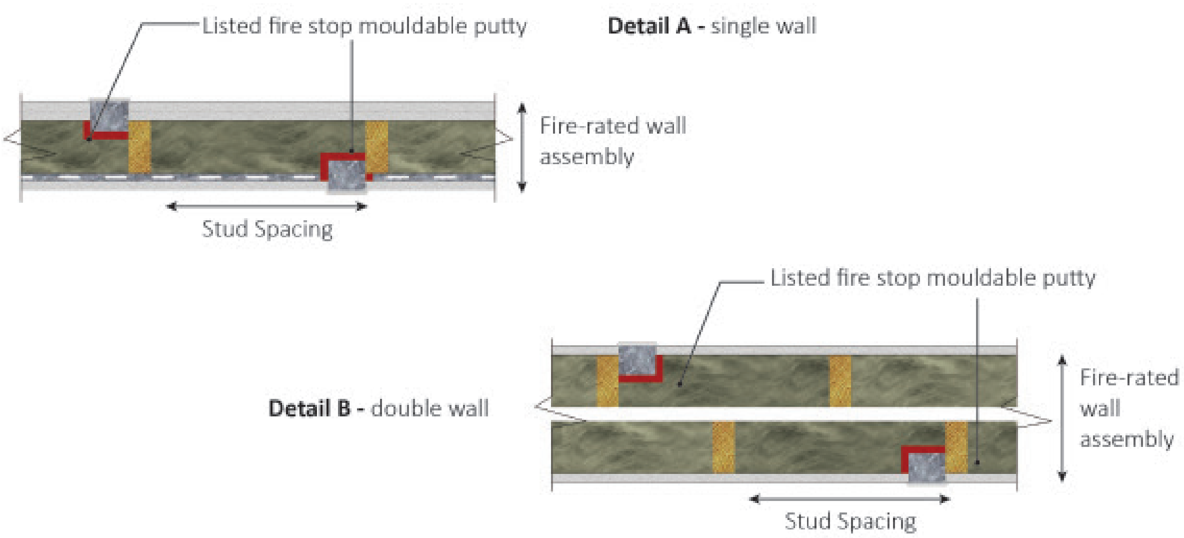


Figure 4.40: Offsetting necessary between two outlet boxes located on opposite faces of a light wood-frame vertical fire separation (adapted from NRCC 2007).

Multiple Penetrations

When several adjacent items are required to penetrate a fire-resistance-rated assembly, they shall be spaced in such a manner that each penetrating item is surrounded by sufficient fire-stop material and separated by sufficient base construction material, such as wood or gypsum board. There are fire-stop systems listed specifically for multiple penetrations. Some systems apply where several items penetrate through a single opening, while others work best where there are several adjacent penetrations. There are other fire-stop systems that can be used when two different types of items penetrate through a single opening, such as pipes and electrical wires. Users should refer to fire-stop manufacturer data sheets for directions on spacing and maximum diameters for multiple penetrations.

For multiple adjacent penetrations in light-frame wall assemblies, some fire-stop system details require a frame be built to form a large opening around the penetrating items to support the fire-stop system and items *(Figure 4.41)*.

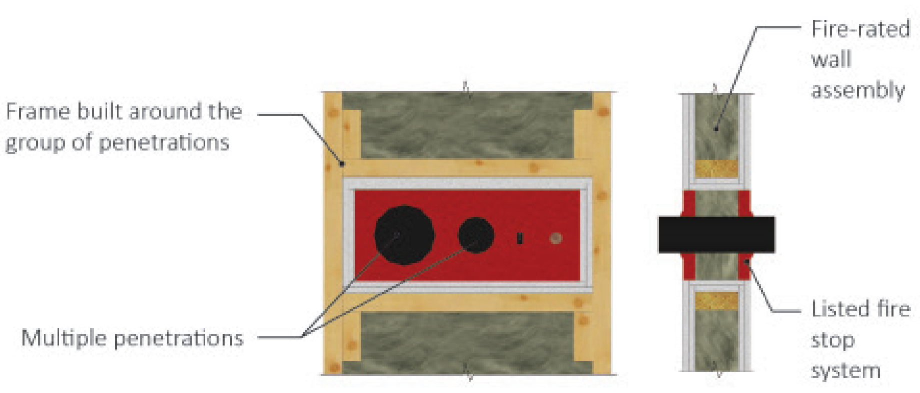


Figure 4.41: Example of a fire-stop detail for multiple penetrations through a fire-rated light-frame wall assembly (adapted from NRCC 2007).

Where several adjacent elements penetrate through the bottom wall plate or top wall plate of a light wood-frame wall assembly, and the technical documentation associated with the fire-stop system contains no directions on minimum spacing between items, good practice suggests that they should be spaced at least the same diameter apart as the larger adjacent item (NRCC, 2007). *Figure 4.42* shows this situation.

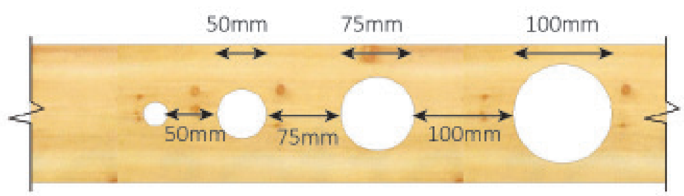


Figure 4.42: Minimum suggested spacing for multiple penetrations through a wood bottom wall plate or top wall plate when no directions are provided by the fire-stop manufacturer (adapted from NRCC 2007).

Where several adjacent elements penetrate through a light-frame wall, and no directions on minimum spacing between items are provided in the documentation for the fire-stop system, one good practice consists in placing sufficient base construction material – i.e., gypsum board – between the items to maintain the fire-resistance. When doing this, there should always be more base material around a penetrating item than the size of the opening for the penetration itself (NRCC, 2007). This situation is pictured in *Figure 4.43* for a light wood-frame wall assembly with studs spaced at 610 mm (24 in.) o.c. Fewer penetrations are possible in a wall assembly with stud spacing at 406 mm (16 in.) o.c.

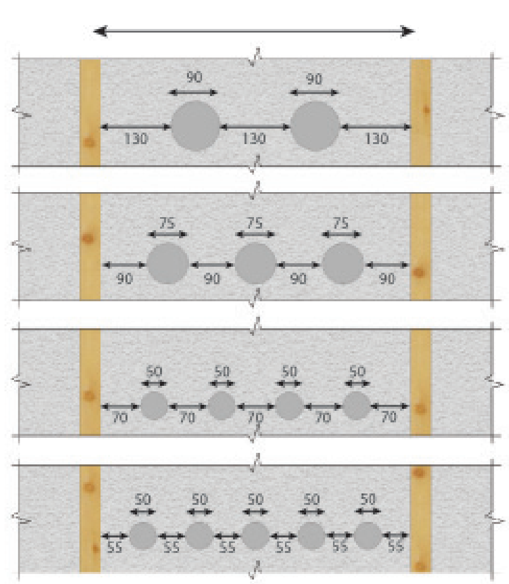


Figure 4.43: Minimum suggested spacing for multiple penetrations through a fire-rated light wood-frame wall assembly when no directions are provided by the fire-stop manufacturer, in mm (adapted from NRCC 2007).

Suggestions

The best way to maintain the integrity and seal of a fire separation or a fire-resistance-rated assembly is to avoid making openings or penetrations in them as much as possible. This eliminates the necessity for the penetration protections indicated in the NBC. For horizontal fire separations, one method involves installing the various ventilation or electrical system components inside a dropped ceiling constructed below the fire-resistance-rated assembly. However, this approach can create concealed spaces that require automatic sprinklers in conformance with NFPA 13, unless one of the exceptions of NFPA 13, Section 9.2.1 is met, as discussed in Subsection 4.2.1 of this chapter. For vertical fire separations, ventilation, plumbing or electrical system components can be installed inside furred-out walls constructed in front of vertical fire separations, or in non-fire-rated, non-loadbearing partitions located inside dwelling units. *Figure 4.44* illustrates these options for duct.

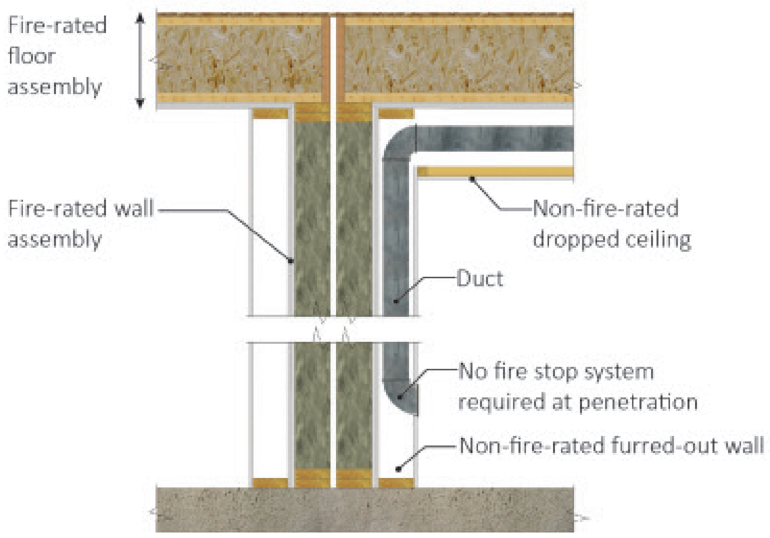


Figure 4.44: Example of a wall penetration where no fire stop is necessary (adapted from NRCC 2007).

Vertical service spaces also allow ventilation, plumbing or electrical elements to pass through several storeys of a building, without requiring additional fire-protection devices at each storey. Fire stops are required, however, when any of these elements penetrates in or out of the vertical service space membrane. Lastly, another solution involves installing bathroom fan or kitchen hood venting equipment such that it runs through a single dwelling unit in order to limit the number of times it penetrates fire separations.

5.4.5 Fire Blocks in Concealed Spaces

Another important aspect of building fire safety relates to containment in concealed spaces using fire blocks. A fire block is defined by the NBC as a material, component or system that restricts the spread of fire within a concealed space or from a concealed space to an adjacent space. In other words, fire blocks are elements that divide concealed spaces into smaller volumes or separate adjacent concealed spaces from each other. The goal of this containment is to restrict fire spread within concealed spaces, and to prevent one fire within a concealed space from spreading to an adjacent space. Containment within concealed spaces is important because these spaces are hidden and difficult for fire fighters to access. Fires inside these spaces can spread quickly and can be hard to control.

Article 3.1.11.7. of the NBC indicates which materials are permitted as fire blocks. For buildings of combustible construction, the following elements may be used as fire blocks in conformance with the NBC:

- Gypsum board not less than 12.7 mm (1/2 in.) thick;
- Solid lumber or a structural composite lumber product conforming to ASTM D 5456, Evaluation of Structural Composite Lumber Products (2010), not less than 38 mm (1-1/2 in.) thick;
- Plywood or oriented strandboard (OSB) not less than 12.5 mm (1/2 in.) thick with joints supported;
- Two thicknesses of lumber or a structural composite lumber product conforming to ASTM D 5456, each not less than 19 mm thick with joints staggered;
- Any other materials that, when subjected to the standard fire exposure in CAN/ULC-S101, remain in place and prevent the passage of flames for not less than 15 minutes.

5.4.5.1 Separation Between Vertical and Horizontal Concealed Spaces

The NBC first presents, in Article 3.1.11.1., some general requirements for separating concealed spaces from each other. In particular, the NBC specifies that concealed spaces in interior wall, ceiling and crawl spaces shall be separated from concealed spaces in exterior walls and attic or roof spaces by fire blocks. Article 3.1.11.4. provides more specific requirements about the fire blocks required between vertical and horizontal spaces. The Article indicates that fire blocks shall be installed at all interconnections between concealed vertical and horizontal spaces in interior coved ceilings, drop ceilings and soffits, as well as at the end of each run and at each floor level between stair stringers in which the exposed construction materials within the space have a flame-spread rating more than 25, which is generally the case for light wood-frame combustible construction. *Figure 4.45, Figure 4.46* and *Figure 4.47* show examples of fire block installations for these different situations.

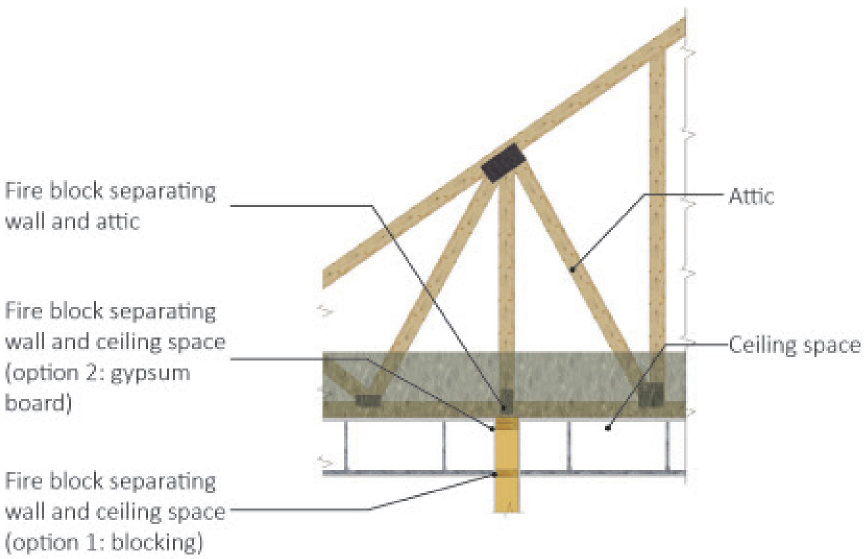


Figure 4.45: Examples of fire blocks separating a vertical space from an attic or ceiling horizontal concealed space (adapted from NRCC 2007).

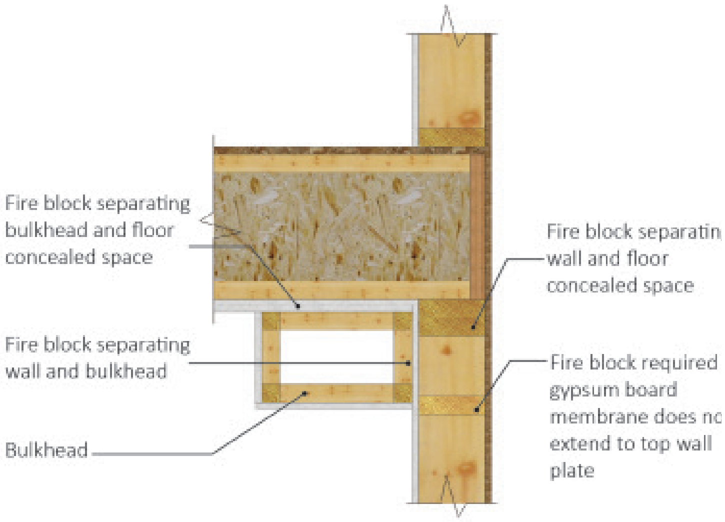


Figure 4.46: Fire block separating a vertical space from a horizontal bulkhead space (adapted from NRCC 2007).

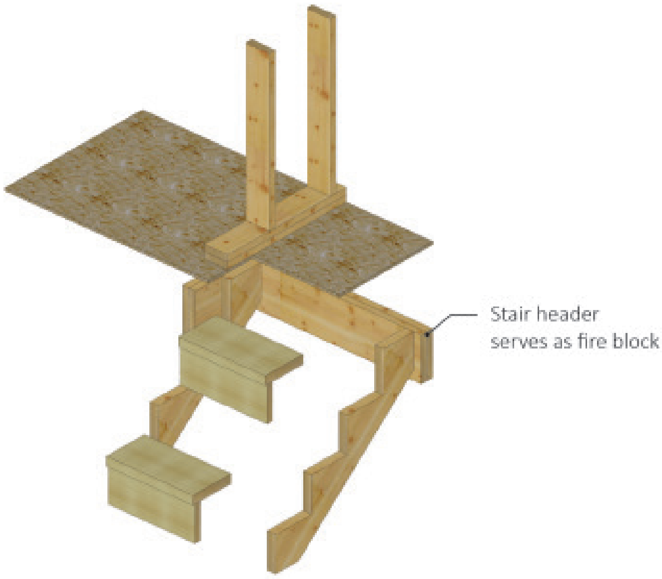


Figure 4.47: Fire block required at the end of each run of stairs (adapted from NRCC 2007)..

5.4.5.2 Fire Blocks in Wall Assemblies

Article 3.1.11.2. of the NBC contains the requirements for fire blocks in wall assemblies. Concealed spaces within wall assemblies shall be equipped with fire blocks at every floor level and at every ceiling level where the ceiling forms part of an assembly required to have an FRR. This aims to confine a fire within one wall on a single storey and prevent it from spreading from the wall cavity to inside a fire-resistance-rated floor or roof assembly. Fire blocks are also required in wall assemblies such that the maximum horizontal dimension is not more than 20 m and the maximum vertical dimension is not more than 3 m.

In platform light wood-frame construction, bottom wall plates and top wall plates generally serve as fire blocks at the floor and ceiling level *(Figure 4.48)*. However, certain details for supporting joists on wall assemblies may require the installation of additional girts or blocking as fire blocks at the ceiling level of a fire-rated floor assembly. This is particularly the case for top chord bearing trusses or when top-mount hangers are used *(Figure 4.49)*. These additional girts or blocking are required where there is no insulation within a wall assembly and the wall's gypsum board does not extend to the top plate. Moreover, when a light wood-frame wall is taller than 3 m, one or several rows of girts or blocking need to be installed to comply with the maximum vertical distance of 3 m required by the NBC.

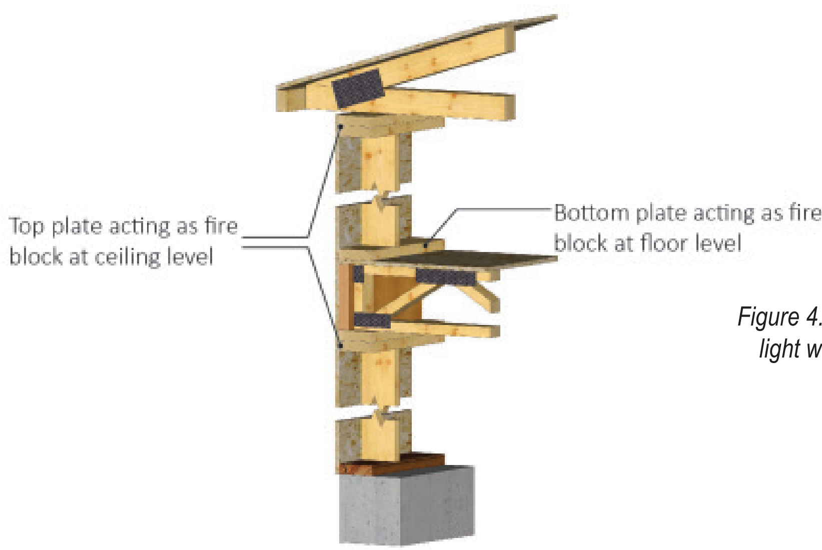


Figure 4.48: Fire blocks in platform light wood-frame construction.

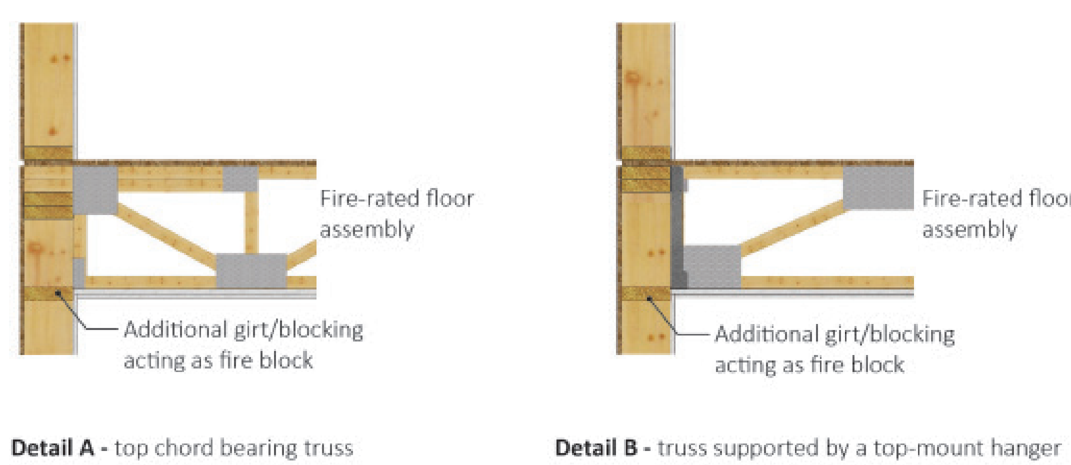


Figure 4.49: Examples of fire blocks required at the ceiling level of a fire-resistance-rated floor assembly.

Sentence 3.1.11.2.(2) provides several exceptions to the fire block requirement for walls. In particular, no fire blocks are required when the wall space is filled with insulation, or when the insulated wall assembly contains not more than one concealed air space, and the horizontal thickness of that air space is not more than 25 mm. *Figure 4.50* shows an example of a double-row light wood-frame wall in which fire blocks are not required at the floor and ceiling level because the air space between the two walls is at most 25 mm. However, these fire blocks would be required if one of the wall assemblies above or below the floor assembly did not contain insulation, or if the space between the walls was greater than 25 mm *(Figure 4.51)*. When a fire block is required because there is no insulation, but the air space between the double wall assemblies does not exceed 25 mm, the NBC permits the use of semi-rigid fibre insulation board produced from rock or glass to block the vertical space in conformance with specific conditions presented in Sentence 3.1.11.7.(7). *Figure 4.52* shows this option.

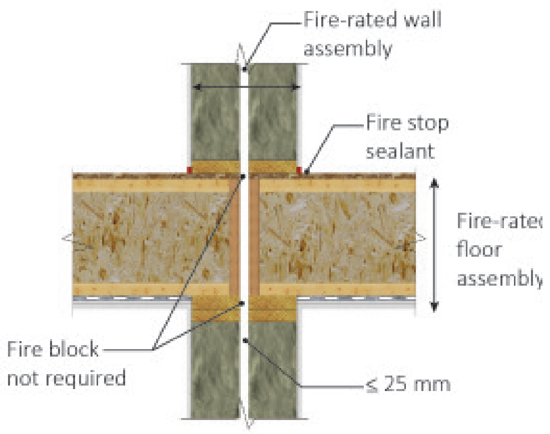


Figure 4.50: Example where a fire block is not required for a double-row light wood-frame wall assembly (adapted from NRCC 2007).

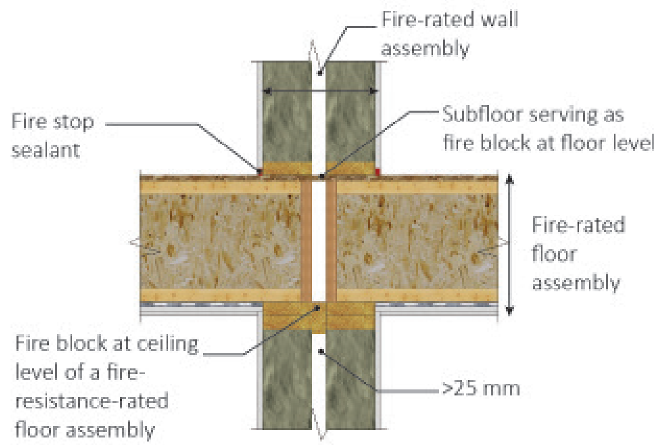


Figure 4.51: Example where a fire block is required for a double-row light wood-frame wall assembly with a space exceeding 25 mm (adapted from NRCC 2007).

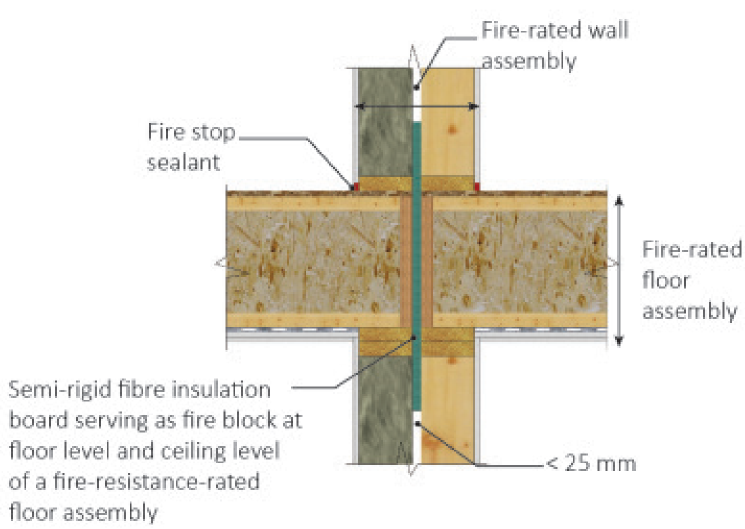


Figure 4.52: Example where a fire block is required for a double-row light wood-frame wall assembly without insulation on one side (adapted from NRCC 2007).

5.4.5.3 Fire Blocks in Horizontal Concealed Spaces

Requirements for the confinement of horizontal concealed spaces can be found in Article 3.1.11.5. of the NBC. Concealed spaces within floor assemblies or roof assemblies of combustible construction, and in which sprinklers are not installed, shall be separated by fire blocks into compartments in conformance with the dimensions indicated in Sentence 3.1.11.5.(1) based on the flame-spread rating of the exposed construction materials within the space. This can be done by fastening structural wood panels or gypsum board to the side of the floor joists or roof trusses following a specific interval that complies with the dimensions required *(Figure 4.53)*. Subsection 4.2.1 of this chapter covers the use of sprinklers in concealed spaces and situations in which NFPA 13 permits sprinklers to be omitted.

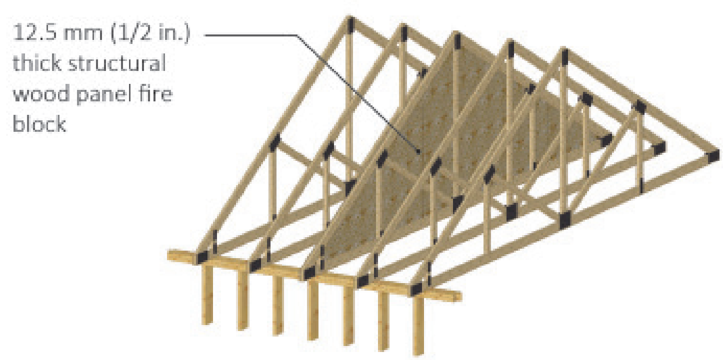


Figure 4.53: Example of installing a fire block within the horizontal concealed space of a roof assembly.

Specific requirements apply, however, for 5- and 6-storey wood buildings. Sentence 3.1.11.5.(3) of the NBC requires that horizontal concealed spaces of floor assemblies and roof assemblies in 5- and 6-storey wood buildings be separated by fire blocks into compartments in the same way as in unsprinklered combustible concealed spaces based on the flame-spread rating of the exposed construction materials within the space even when sprinklers are installed in the concealed spaces.

The NBC also requires fire blocks be added to exterior horizontal projections such as cornices, balconies, marquees, and other projections in which exposed construction materials within the space have a flame-spread rating more than 25. Fire blocks shall be installed at locations where these concealed spaces extend across the ends of required vertical fire separations, such as party walls between dwelling units, and so that the maximum dimension in these spaces is not more than 20 m. The NBC requires fire blocks for concealed spaces within horizontal projections whether or not the spaces are sprinklered.

5.4.5.4 Openings and Penetrations in Fire Blocks

Where fire blocks in vertical or horizontal concealed spaces need to be penetrated by service equipment such as plumbing or electrical services, Article 3.1.11.7. of the NBC requires that the openings or penetrations be protected to maintain the integrity of the fire blocks at these locations. As with penetrations through fire separations or fire-resistance-rated assemblies, the NBC stipulates that penetrations in fire blocks shall be sealed with a fire stop. For example, penetrations for electrical wires or plumbing pipes through top or bottom plates in light wood-frame walls should be sealed with a fire stop *(Figure 4.54)*. In addition to fire-stop systems listed in conformance with CAN/ULC-S115 (2011), the NBC permits the use of generic fire stops such as mineral wool or gypsum plaster to seal penetrations in fire blocks. Subsection 4.4.3 of this chapter contains more information on listed fire-stop systems.

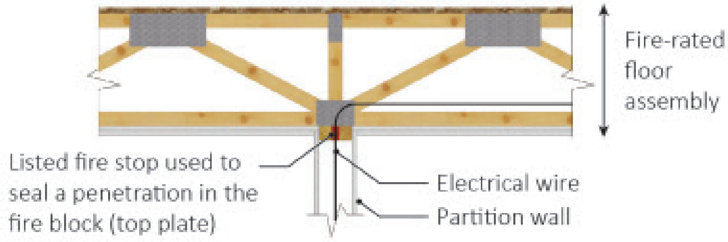


Figure 4.54: Example protecting a penetration in a fire block using a fire stop.

5.4.6 Elevator and Stair Shafts

This section of the chapter covers both elevator and stair shafts because these two building components present some similarities. They are both vertical shafts that generally run through all of a building's storeys from the lowest point to the roof. They are distinct in some ways, however, because the NBC considers elevator shafts to be vertical service spaces, while stairs are identified as exits. Prescriptive fire safety requirements for vertical service spaces used as elevator shafts are presented in **Section 3.5.** and Subsection 3.6.3. of the NBC, while requirements for stair shafts appear in **Section 3.4.** (NBC, 2010).

Types of Construction

Elevator or stair shafts are generally permitted to be of the same type of construction as that authorized for the whole building in Subsection 3.2.2 of the NBC. These shafts can therefore be of combustible construction in buildings where combustible construction is authorized. It is noted that certain provincial building codes, such as the Ontario Building Code, require exit stair shafts to be of non-combustible construction in mid-rise buildings permitted to be of combustible construction.

There are different systems for building elevator or stair shafts in combustible construction for multi-storey wood buildings. In particular, these include conventional light frame walls, nail-laminated solid-sawn lumber walls or solid-wood panels composed of structural composite lumber (SCL) or cross-laminated timber (CLT). *Figure 4.55* and *Figure 4.56* show examples of these systems.

Elevator or stair shafts in mid-rise buildings can also be built using masonry or reinforced concrete, per common practice. However, there are some special considerations when combining a main wood structure with a concrete or masonry shaft. The design must not only serve to properly connect these two types of construction; it must also take into account that using different types of structural materials could lead to differential vertical and/or lateral movement and compromise the integrity of the structure, as well as the smoke-tight construction of the fire separations. Additional information about vertical movement can be found in **Section 3.6** of this guide.

Figure 4.55: Example of a nail-laminated timber elevator hoistway.

(Photo: GHL Consultants Ltd.)

Figure 4.56: Example of an elevator hoistway composed of cross-laminated timber (CLT) solid panels.

(Photo: GHL Consultants Ltd.)

Fire Separations

A vertical service space used as an elevator hoistway shall be separated from all other portions of each adjacent storey by a fire separation having a fire-resistance rating (FRR) conforming to Table 3.5.3.1. of the NBC (2020). As a result, elevator shafts in mid-rise wood buildings shall provide no less than a one-hour FRR because floor assemblies in this type of building also require this same FRR. However, Sentence (2) of Article 3.5.3.1. permits that this requirement may be waived for elevators in an interconnected floor space provided the elevator machinery is located in a room separated from the remainder of the building by a fire separation, having an FRR not less than that required for the hoistway. Note that a higher FRR may be required for either elevator shafts of stair shafts if the building contains multiple major occupancies.

Stair shafts shall also be separated from the remainder of the building by a fire separation, as stipulated in Article 3.4.4.1. of the NBC. As with elevator hoistways, the FRR required for stair shaft re separations is based on the FRR required for the floor assemblies. Stairwells in mid-rise wood buildings shall therefore be separated from the remainder of the building by one-hour rated fire separations.

Moreover, elevator hoistways and stair shafts shall be continuous through the floor assemblies of each storey, and they shall also extend into the concealed space of the roof assembly. When a horizontal service space or concealed space is located above a vertical fire separation formed by the walls of a vertical shaft, Sentence 3.1.8.3.(1) of the NBC (2020) requires that this service space be divided at the fire separation by an equivalent fire separation within the service space. Additionally, Sentence (2) of Article 3.1.8.3. requires that these vertical fire separations shall be smoke-tight where they abut on or intersect a floor or roof assembly. These joints could be made smoke-tight by sealing them with a fire-stop sealant, for instance. *Figure 4.57* illustrates this requirement, and *Figure 4.58* shows some example details for the intersection between a vertical wood shaft nd the floor assemblies or roof assembly of a light wood-frame structure.

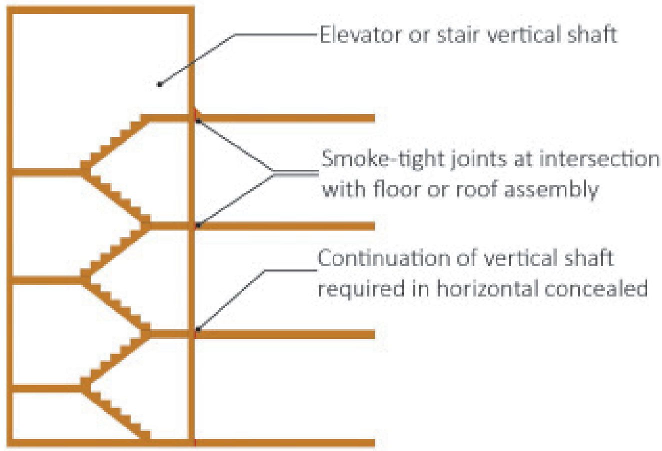


Figure 4.57: Requirements for continuity and smoke-tight construction in an elevator or stair shaft where it intersects with floor and roof assemblies (adapted from CWC 1997).

Sentence 3.6.3.1.(2) of the NBC also stipulates that a vertical service space, such as an elevator hoistway, that does not extend through the roof of a building, shall be enclosed at the top with construction having an FRR not less than that required for the vertical service space walls. Lastly, Sentence (5) of the same Article indicates that only openings that are necessary for the use of the vertical service space shall be permitted through the vertical service space enclosure. In exit stairwells, the only openings permitted in walls constructed as fire separations are those listed in Sentence (1) of Article 3.4.4.4. of the NBC. In both cases, the integrity of the fire separations at openings or penetrations shall be maintained by following the requirements in Subsections 3.1.8. and 3.1.9. of the NBC. Subsection 4.4.3 of this chapter covers this topic in more detail.

In shafts with light wood-frame wall construction, the FRR primarily comes from the gypsum board membrane covering the structure. A one-hour FRR can be achieved using one of the methods presented in Subsection 4.3.1 of this chapter. For shafts constructed in nail-laminated timber (NLT) *(Figure 4.55)*, the FRR can be determined using Appendix D-2.4. of the NBC (2020). This Appendix indicates that the wall shall be at least 140 mm thick to provide one hour of fire-resistance. Lastly, when CLT panels are used to construct an elevator or stair shaft, the FRR can be determined using the Method B of Appendix D-2.11. of the NBC, as indicated in Subsection 4.3.2 of this chapter.

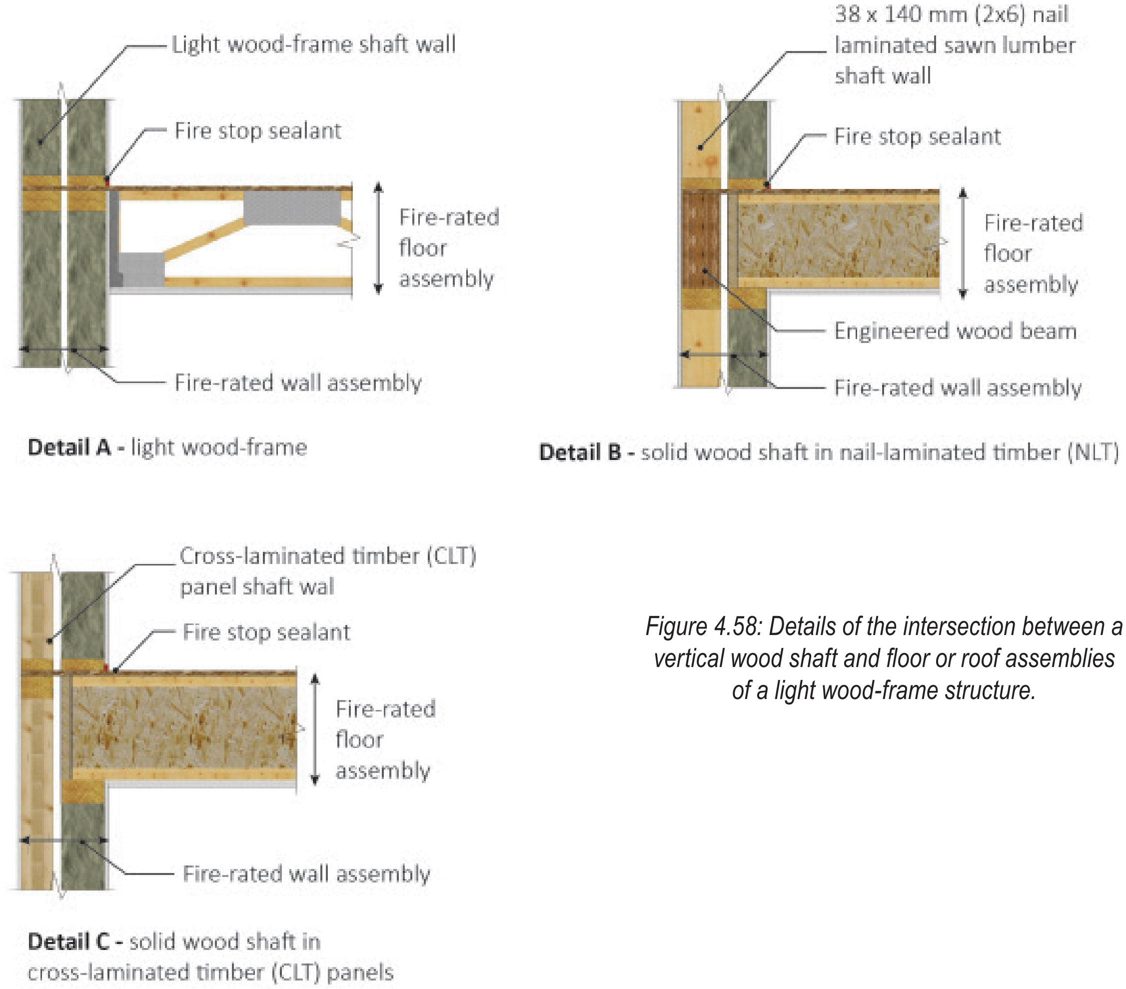


Figure 4.58: Details of the intersection between a vertical wood shaft and floor or roof assemblies of a light wood-frame structure.

Flame-Spread

Interior walls of elevator or stair shafts shall be covered in materials that meet the flame-spread rating requirements presented by the NBC. Regarding elevator hoistways, Article 3.1.13.2. of the NBC requires that the flame-spread rating for the finishes in vertical service spaces be less than or equal to 25. This rating shall be determined according to tests conducted in conformance with CAN/ULC-S102, *Surface Burning Characteristics of Building Materials and Assemblies* (ULC-S102, 2010). Gypsum board or plywood that is either coated with a listed fire-retardant coating or pressure-impregnated with fire-retardant chemicals in accordance with CSA O80 (2008) are examples of products that meet this requirement. For stair shafts, a flame-spread rating not exceeding 25 is also required for wall and ceiling finishes, in conformance with the requirements in Article 3.1.13.2 for exits. Up to 10% of the area of walls and ceilings are permitted to have a flame-spread rating not exceeding 150.

Sprinkler Protection

NFPA 13 requires that elevator shafts of combustible construction be protected by automatic sprinklers at two locations: at the top and bottom of the hoistway *(Figure 4.59).* At the bottom, sprinklers shall be located not more than 0.61 m (2 ft.) above the floor of the pit, and ideally installed on the elevator door side. Sprinklers are not required at the bottom of shafts of non-combustible construction that do not contain combustible hydraulic fluids or certain types of combustible suspension systems.

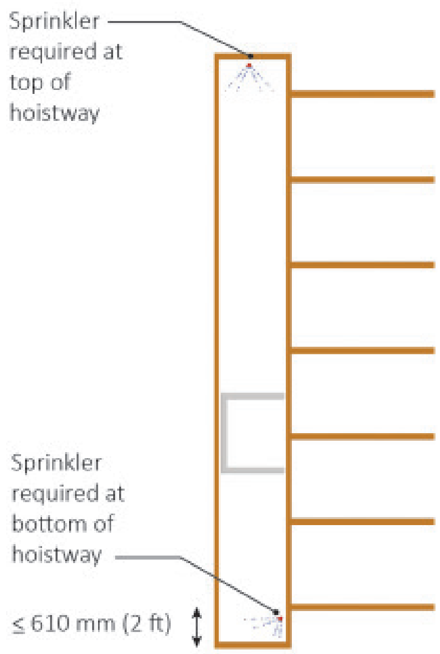


Figure 4.59: Sprinkler placement in elevator hoistway of combustible construction.

The sprinklers required at the top of the hoistway may also be omitted if the hoistway is of non-combustible construction, and if the car enclosure materials meet the requirements of ASME A17.1/CSA B44, Safety Code for Elevators and Escalators (2010).

For stairs, NFPA 13 requires automatic sprinklers at the top of all shafts. For shafts of combustible construction, the standard also requires that sprinklers be installed under the landings at each floor level, as well as beneath the lowest intermediate landing. Sprinklers located beneath landings shall be oriented such that they protect the landings and intermediate landings *(Figure 4.60)*. For stair shafts of non-combustible construction, sprinklers are required only under the first accessible landing above the bottom of the shaft, in addition to those required at the top of the shaft *(Figure 4.61)*. Only in the case where the shaft f non-combustible construction serves both sides of a fire wall are sprinklers required to be installed at each floor landing.

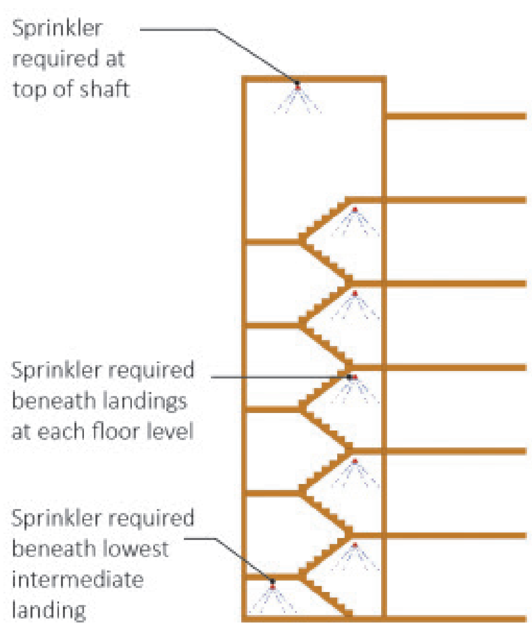


Figure 4.60: Sprinkler placement in stair shaft of combustible construction.

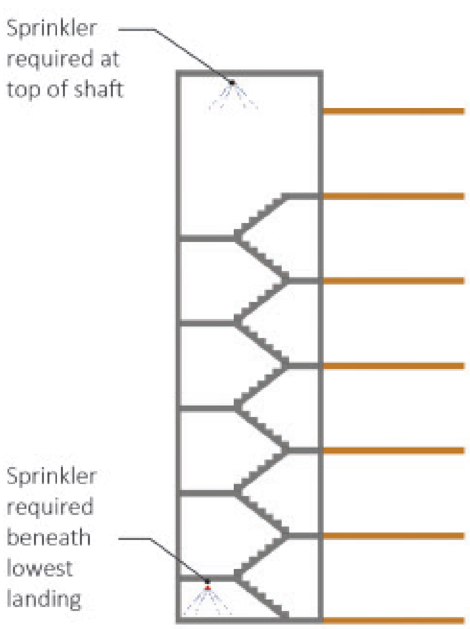


Figure 4.61: Sprinkler placement in stair shaft of non-combustible construction.

5.4.7 Exterior Cladding and Interior Finishes

The NBC requires that not less than 90% of the exterior cladding on each exterior wall of 5- and 6-storey wood buildings shall be non-combustible cladding or 90% of each exterior wall assembly design must meet the criteria when tested in conformance with CAN/ULC-S134, *Fire Test of Exterior Wall Assemblies* (2013).

Interior finishes, on the other hand, on wall and ceiling assemblies shall meet the flame-spread requirements in Subsection 3.1.13. of the NBC, which means a maximum flame-spread rating of 150 in most cases. Most interior finish products meet this criterion. More restrictive requirements apply to certain locations in buildings. In particular, this is the case for exits and lobbies where the maximum flame-spread rating for interior finishes on walls and ceilings is 25. In this case, interior finish products can be treated with a fire-retardant coating to lower their flame-spread rating to meet this requirement.

Lastly, combustible flooring, such as wood flooring, is authorized without restriction in mid-rise buildings of combustible and non-combustible construction. Therefore, it can be used in 5 or 6-storey wood buildings.

5.5 Mechanical Systems

5.5.1 Vertical Movement

The National Building Code requires mechanical systems and equipment to be designed and installed to accommodate the maximum relative structural movement provided for in the construction of the building.

Section 5.3.6 addresses the vertical movement in a 5- or 6-storey light wood-frame building. Vertical movement can be caused by shrinkage due to variations in moisture content between installation and service equilibrium, elastic deformation of structural elements from gravity loads, creep of structural elements from gravity loads and settlement caused by gaps and clearance between structural elements during installation.

Vertical movement normally occurs in the first year of service, as materials reach the equilibrium moisture content and relative humidity of the geographical location of the project. As vertical movement caused by shrinkage may total 50 mm (2 in.) cumulative over 6- storeys, using S-Dry dimensional lumber studs, and floor joists that have a lower moisture content, is a simple strategy to limit the effects. By using lower moisture content materials in the assemblies, it is reasonable to predict a lower total vertical movement of between 19 mm (3/4 in.) and 38 mm (1-1/2 in.), over the total building storeys. **Section 5.3.6.5** provides some strategies for reducing total vertical movement.

The structural engineer should provide information about the expected vertical movement and accommodations to vertical and horizontal service runs that need to be made. Installation details for all mechanical systems like pipework, plumbing stacks, electrical conduit, ventilation ducts and chases, must accommodate this predicted movement and notation that no modifications to the structural system will be allowed. Fastening, connections and tie-down systems that can accommodate this movement should be specified *(Figure 5.01)*.

Figure 5.01: Pipe sleeves accommodating shrinkage.

It is also essential to plan for differential movement with other structural elements, such as concrete or masonry walls. Precautions need to be taken to ensure that mechanical elements, raceway ducts and electrical conduit that cross these elements are not damaged by differential movement. Drainage slopes need to be designed with accumulated vertical movement in mind.

5.5.2 Fire Safety

The National Building Code requires 5- or 6-storey wood buildings, regardless of use and occupancy type, to be equipped with an automatic sprinkler system, in conformance with NFPA 13, *Standard for the Installation of Sprinkler Systems* (NFPA 13, 2019).
Section 4 presented detailed information on fire safety requirements for this type of wood construction.

If the code provisions for 5- or 6- storey wood buildings are being used for Group C, residential occupancy buildings, that are 1-, 2-, 3- or 4- storeys in height, permitting larger building areas, NBC allows buildings to be sprinklered in conformance with NFPA 13R, *Standard for the Installation of Sprinkler Systems in Low-Rise Residential Occupancies* (NFPA 13R, 2019).

NFPA 13 is generally intended for mechanical engineers responsible for designing sprinkler systems. It includes requirements for selecting the type of automatic sprinkler system, piping, fittings, valves, sprinkler locations, hanging methods, and necessary water supply. Any professional who is involved in designing wood buildings of up to 6 storeys should be aware of NFPA 13 and that it is tied to structural and architectural elements. NFPA 13 requires the protection of concealed spaces, horizontal exterior projections, vertical shafts, electrical equipment rooms, bathrooms, closets, and compartments, and requires pipe bracing be fastened to structural members. These additional requirements are different from NFPA 13R.

Section 2.2.5 discusses coordination of the mechanical, electrical, plumbing and fire systems (MEPF). Engaging in an open integrated design process can highlight potential problems that may arise later in the construction and fit-out stage with system integration, coordination and interference issues with mechanical systems.

5.6 Architectural Considerations

5.6.1 Location of Loadbearing Walls and Openings

Loadbearing wall locations within a building define the unit or suite layouts. Good communication is essential between the design team, because achieving the desired internal flow of the building, and layouts of the space needed for a functionality-based building type, needs to be in balance.

With respect to gravity loads, the placement of loadbearing walls affects the orientation, span and height of joists, beams, and roof trusses, as mentioned in **Section 5.3.3**. Aligning loadbearing walls and columns from storey to storey throughout the building, braces the building structurally. It helps prevent additional bending moment in the floor structure, and transfers shear forces between shearwalls from one storey to another. It is beneficial in the aligning of loadbearing walls with the column grids that may support the ground floor concrete transfer slab, if this scenario applies. Alignment reduces the forces that are transferred onto the concrete transfer slab and may lead not only to structural efficiency but may result in a more cost-effective solution. In underground parking garages for example, column layouts and grids are spaced 6 m (two parking spaces) or 8.7 m (three parking spaces) apart. For 8.7 m alignment, this is achieved by using a deeper floor joist system (I-joist or open web floor truss) above. Six-metre spacing of loadbearing walls is often utilized, enabling optimal floor joist depths, with reasonable loads acting on ground floor walls *(Figure 3.02)*.

As mentioned in **Section 5.3.4**, lateral (wind and earthquake) load resistance requires continuous walls without openings to act as shear walls in the two main directions of the building. Corridor walls and walls between units and suites, are often used for this. Wall alignment from storey to storey enables continuity in the shearwalls. Exterior walls can also be used when designing the structure, but opening sizes may be reduced, and windows must be aligned from one storey to another.

Coordination between the design team will result in the placement of walls and openings that allows for an effective and economical structural system, balanced with the architectural layout design details, and required aesthetics.

5.6.2 Vertical Movement

5- and 6-storey wood buildings are subject to vertical movement, primarily due to the effects of shrinkage of structural wood members due to moisture changes, the closing of gaps in wood framing, deflection and compression perpendicular to grain (**Section 5.3.6**). Managing material moisture content (MC) is a strategy to limit the effects of shrinkage. Understanding structural systems and their composition, gives the expected moisture content information to the structural engineer, and allows for vertical movement to be managed. Coordination is needed around vertical movement because it may cause building envelope issues.

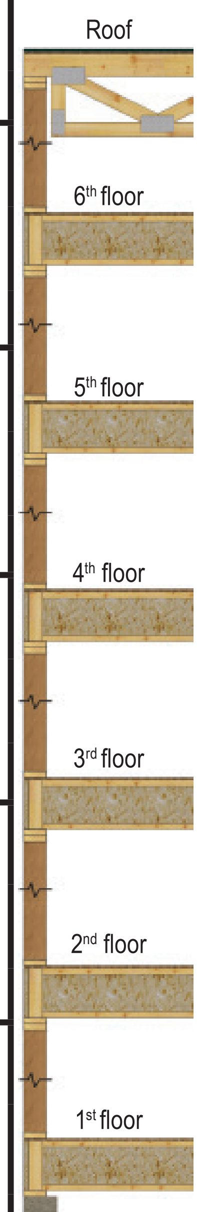
Shrinkage is cumulative from one storey to another, vertical movement can vary from floor to floor. As presented in Table 5.14, in a 6^{th}-storey building with an I-joist floor system bearing on walls, and sawn wood top and bottom wall plates, the total shrinkage is expected to be 27.5 mm (1-1/8 in.). Note the vertical movement caused by shrinkage of the 6th storey floor compared to the 1^{st} storey (or to a structure that does not experience shrinkage) is about 21 mm (7/8 in.), while floor shrinkage on the 2^{nd} storey is only 5 mm (1/4 in.).

Attention is required when detailing wood assemblies with materials such as firewalls, concrete or steel shafts for elevators or stairs are part of the project design. These are typically continuous and run through all storeys of the building. These shaft ystems are constructed using stiffer materials, and wood assemblies normally require to be isolated from them structurally. This will allow any movement caused from vertical movement to happen without causing distress or floor slope issues.

Wood structures that use brick/masonry veneer, concrete elevator shafts or steel frame construction members, the cumulative effect of vertical movement has to be accounted for when construction details and specifications are developed.

Table 5.14 Shrinkage in a 6-storey building with I-joists bearing on walls (initial MC of 19% and final MC of 8%).

	Materials used	Shrinkage (mm)		Vertical movement of fl or compared to initial position (caused by shrinkage) (mm)
Roof	Top chord of roof truss	2.5	6.5	= -21.0 – 6.5 = -27.5
	Bottom plate and double top plate in sawn wood	2.5		
	Studs	1.5		
6th storey	I-joists with squash blocks and rim joist	0.2	4.0	= -17.0 – 4.0 = -21.0
	Bottom plate and double top plate in sawn wood	2.5		
	Studs	1.3		
5th storey	I-joists with squash blocks and rim joist	0.2	4.0	= -13.0 – 4.0 = -17.0
	Bottom plate and double top plate in sawn wood	2.5		
	Studs	1.3		
4th storey	I-joists with squash blocks and rim joist	0.2	4.0	= -9.0 – 4.0 = -13.0
	Bottom plate and double top plate in sawn wood	2.5		
	Studs	1.3		
3rd storey	I-joists with squash blocks and rim joist	0.2	4.0	= -5.0 – 4.0 = -9.0
	Bottom plate and double top plate in sawn wood	2.5		
	Studs	1.3		
2nd storey	I-joists with squash blocks and rim joist	0.2	4.0	=- 1.0 – 4.0 = -5.0
	Bottom plate and double top plate in sawn wood	2.5		
	Studs	1.3		
1st storey	I-joists with squash blocks and rim joist	0.2	1.0	= -1.0
	Top plate in sawn wood	0.8		
			27.5	



Design details are also necessary to ensure that the effects or any vertical movement will not affect the performance of the building envelope. Flashing detailing should use slotted holes and a large enough drainage slope to accommodate any expected movement. Details appropriate for the specific type of exterior cladding must also be planned and understood.

With masonry veneer, any vertical movement in the wood structure, and potential swelling in the masonry should be anticipated. In CSA S304-14, masonry veneer can be supported vertically by a wood structure of 6 storeys or less if it is designed in conformance with Part 4 of the NBC. Masonry veneer walls are required to bear on a non-combustible support material such as steel angles. Expected vertical movement is required to be considered when choosing the location and width of isolation joints and selecting fasteners and flashing.

Masonry veneer walls with a total height greater than 11 m must be supported at each storey level (CSA S304-14). When veneer does not exceed 11 m in height, and is supported only by the foundation, accumulation of vertical movement on each storey must be considered.

For example, window installation details must be designed to accommodate vertical movement between the wood structure supporting the window and the masonry veneer. Designing sufficient flashing materials and strategies, between the window frame and the supporting masonry, maintains watertightness after shrinkage changes occur in the structure, without the frame bearing on top of the masonry veneer *(Figure 6.01)*. The minimum height for this flashing is determined by the total expected vertical movement. It is important to make sure that the seal at the outside of the window will not be compromised if it moves down in relation to the veneer. Managing movement at the top of openings is particularly important, especially for large openings.

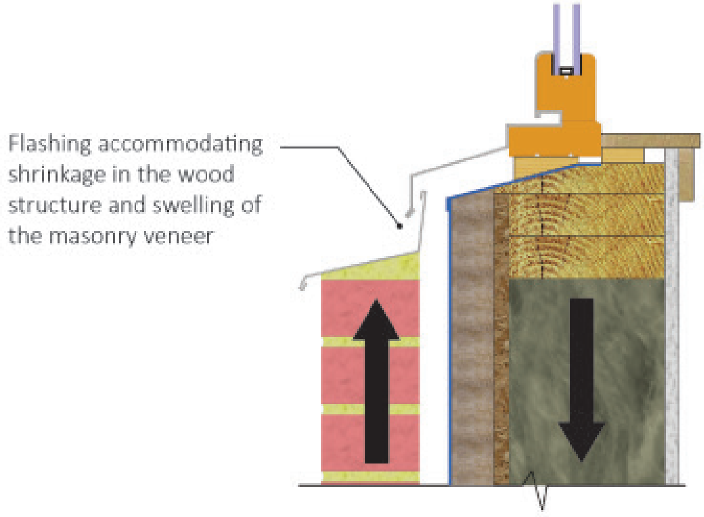


Figure 6.01: Joint at the window frame and the masonry wall (CMHC, 2006).

When brick veneer is installed on the lower storeys of a building, the flashing covering the veneer may be deformed by shrinkage of the wood structure, resulting in water ingress in the wall. Flashing that accommodates structural movement is necessary to prevent this *(Figure 6.02)*.

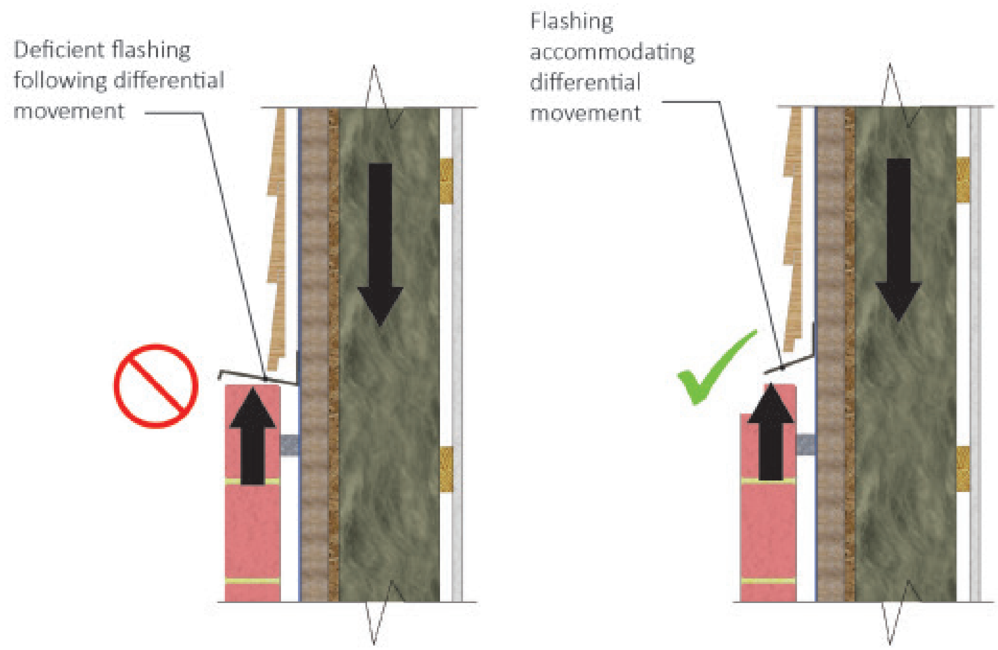


Figure 6.02: Flashing accommodating differential movement between the structure and masonry veneer.

When cladding is used, horizontal orientation is recommended to allow for the installation of flexible joints. When cladding is fastened directly to the wall, it moves gradually with the shrinkage of each storey. As with panel cladding, horizontal joints must be planned in the siding to maintain clearance at each floor to accommodate the shrinkage at every storey *(Figure 6.03)*. In addition, it is not necessary to leave a significant gap around windows and openings because the siding is directly fastened to the structure. Details following best practices for light wood-frame construction can therefore be applied directly (FPI 2013).

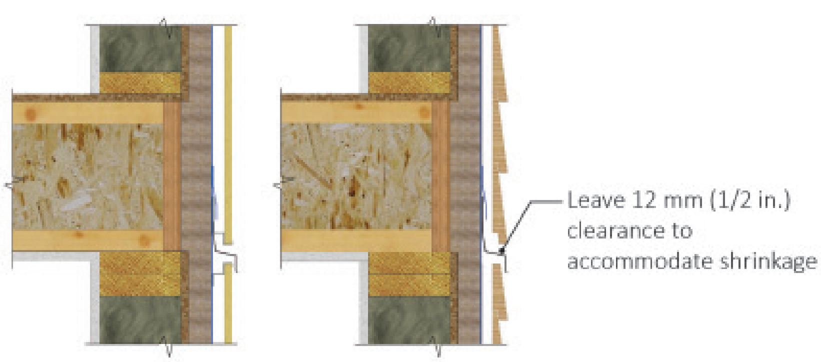


Figure 6.03: Watertight details to ensure proper envelope function (FPI 2013).

In British Columbia, a thin brick veneer adhered to a structural panel is commonly used to limit cladding weight and differential movement between the veneer and the structure *(Figure 6.04)*.

Figure 6.04: Thin brick veneer.

5.6.3 Building Envelope

The building envelope is an essential design and technical consideration. Energy efficiency and moisture control requirements are not different for 5- or 6- storey buildings. Exposure to the weather loading effects of wind and rain are increased on taller buildings, so the quality of the envelope plays a greater role. There are specific aspects that need to be examined in more detail.

The overall thickness, material, thermal performance and aesthetics are all considerations that must be thought out early on in the design process. Considering lightweight wood-framing and mass timber – incorporating a prefabricated envelope system can be an effective way of managing moisture during construction. Prefabricated envelopes can be incorporated in buildings because of the speed at which a building can be enclosed during construction. As well, it helps to mitigate complexities due to oversaturation of water on the wood structure. Having a clear strategy for the building envelope will allow system complexities to be considered early on, such as connectors and building science complexities that may warrant mock-ups and enhanced verification and testing to be planned for during construction.

Increased height of 5- and 6-storey buildings affects the amount of rainwater that runs down the exterior walls. It is important to design adequate waterproofing and to carefully plan a suitable rainscreen design for taller wood buildings. Detailing should ensure good performance and air-barrier continuity following any vertical movement of the structure. Windows should be selected based on the performance needed to withstand the greater weather loads the building will experience.

An understanding of the structural system is required when designing and modelling the energy code and performance expectations. Wall stud spacing may differ in walls on the lower storeys from those on the higher storeys. Additional studs in external walls should be considered when determining the effective thermal resistance of the envelope. Adding insulating sheathing and/or continuous external insulation with sufficient vapour permeability ensures proper thermal resistance. Continuous insulation layers must accommodate any expected vertical movement.

Particular care is required to ensure good hygrothermal performance of the envelope, including the full vapour barrier. Double furring on the inside can accommodate electrical elements without penetrating the vapour barrier.

As mentioned in **Section 6.2,** exterior cladding details are required to accommodate shrinkage. Exterior cladding selection must also consider the fire safety requirements described in **Section 4**.

5.6.4 Acoustic Performance

In multi-unit residential buildings, the National Building Code of Canada (NBC) regulates the acoustical design of interior wall and floor assemblies that separate dwelling units (apartments, houses, hotel rooms) from other units or spaces within a building. The sound transmission class (STC) rating requirements for interior wall and floor assemblies are intended to limit the transmission of airborne noise between spaces. The NBC does not mandate any requirements for the control of impact sound transmission through floor assemblies. Footsteps and other impacts can result in disturbances and complaints in multi-family residences. Builders concerned about quality and reducing occupant complaints should ensure that floor assemblies are designed to minimize impact sound transmission.

Beyond conforming to the minimum requirements of the NBC in residential occupancies, designers can voluntarily (or at the request of the client/owner) establish acoustic ratings for inclusion in designs of non-residential projects and specify materials, systems and construction practices to increase the sound level. In addition to limiting transmission of airborne noise through internal structural walls and floors, flanking transmission of sound through perimeter joints and sound transmission through non-structural partition walls should also be considered during the acoustical design.

For airborne sound control, dwelling units are required to be acoustically separated from each other and from any space in a building in which noise may be generated. Wall and floor assemblies must provide an STC rating not less than 50. Construction that separates a dwelling unit from an elevator shaft r refuse chute requires an STC rating not less than 55, (NBC, 2015) To achieve STC ratings that are tested in a laboratory, wall and floor assemblies must be constructed with quality and precision, and acoustic sealants must be applied and installed with care. Sound transmission between adjacent rooms can be higher if attention is not paid to flanking transmission at junctions. Flanking transmission can be caused by leaks in the assemblies, and issues at the wall-to-wall, floor-to-floor, wall-to-floor or through ceiling-to-wall joints and connections *(Figure 6.05).*

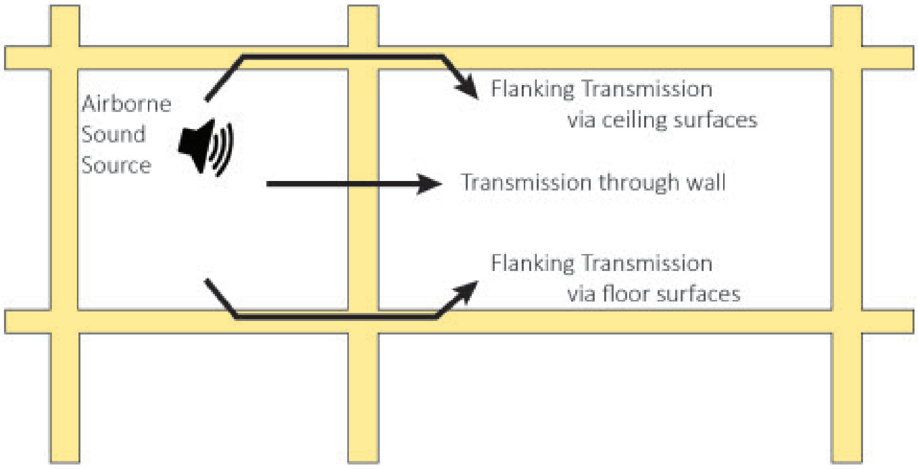


Figure 6.05: Direct and flanking sound transmission (NRCC, 2016).

In wood buildings, the important paths for structure-borne transmission generally involves the wall-to-floor junctions *(Figure 6.06). The uide for Sound Insulation in Wood Frame Construction* from the NRCC provides solutions for limiting flanking transmission of sound (NRCC, 2006a).

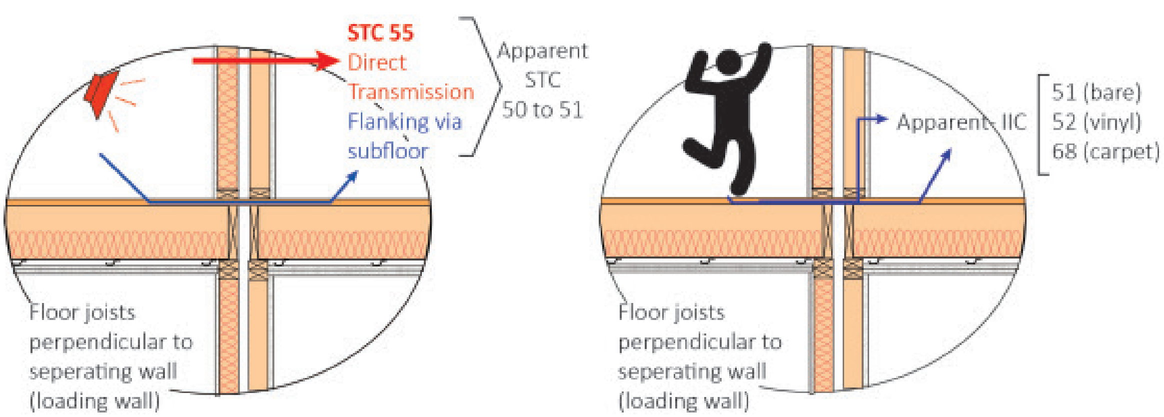


Figure 6.06: Wall-to-floor flanking transmission.

Structural or fire safety requirements for 5- or 6- storey light wood-frame buildings may make the implementation of some solutions for better acoustic performance more complex.

For instance, maintaining diaphragm continuity means that floor sheathing may have to be continuous between dwelling units. This continuity could lead to creating a flanking path through which sound can travel. One solution is to separate the floor surface and floating topping from the sheathing by using an acoustic/sound separation product. This will isolate the structural members from the floating topping and finished flooring. This way the wall insulation fills the wall cavity all the way to the wall base, providing the required soundproofing *(Figure 6.07)*.

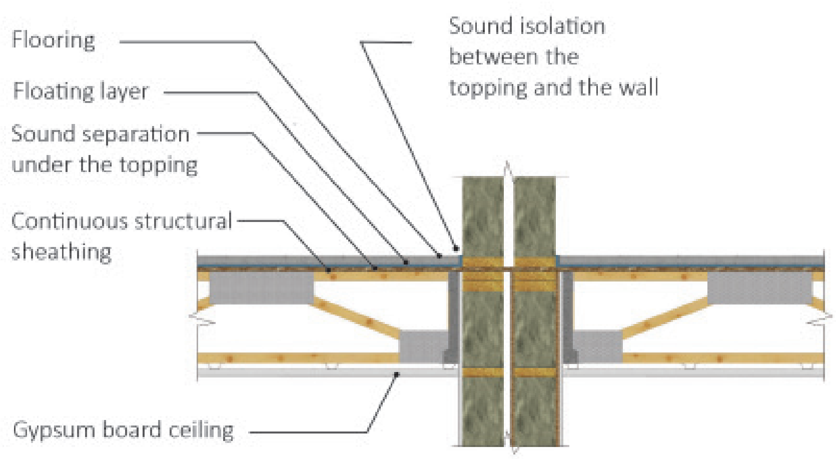


Figure 6.07: Double party wall with sound isolation under the floor surface.

The structural solution presented in the example above shows the floor trusses perpendicular to the party walls between dwelling units. A double party wall has been designed, with each half supporting a floor assembly on either side. An air space between the two floor assemblies and walls improves sound performance.

When an interior wall is serving as a shearwall, structural design may require the wall to have structural sheathing installed on one or both sides of the wall assembly. In this case, it is important not to install resilient channels between the structural panel and gypsum board to avoid creating a thin cavity that could amplify sound. For a single wall, when only one structural panel is required, the resilient channels may be used on the opposite side of the wall *(Figure 6.08)*.

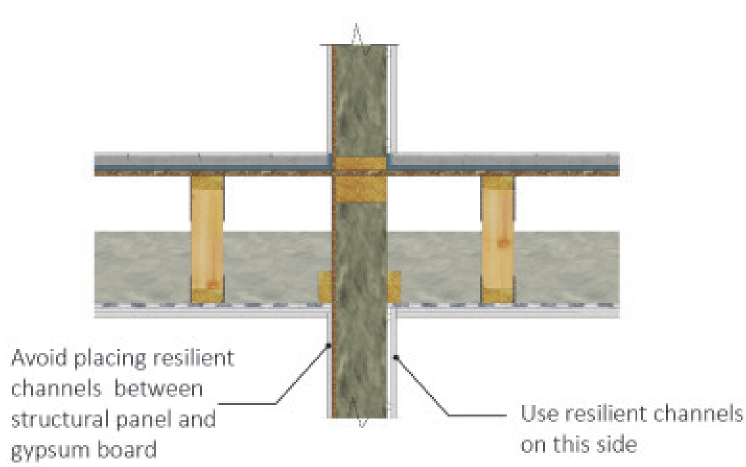


Figure 6.08: Single wall with structural panel on one side and resilient channels on the other.

As gravity loads are generated through the building and are transferred down onto lower storey loadbearing wall assemblies, stud spacing becomes closer and built-up columns may be required. This is most evident at the ends of shearwalls *(Figure 6.09)*. Double wall assemblies may be a good solution between dwelling units to limit the negative effects of additional studs and build-ups in terms of acoustical performance.

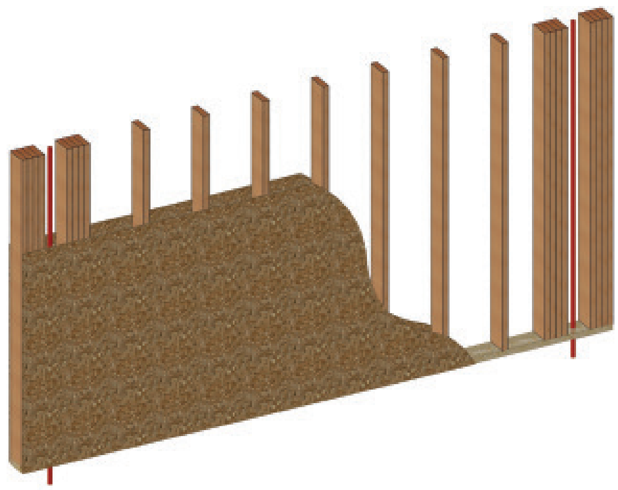


Figure 6.09: Shearwall with built-up columns (1st storey).

5.6.5 Balcony Design Specifics

As with all buildings, exterior balconies are required to be designed and built ensuring structural strength while maintaining the integrity of the building envelope, both in terms of water, airtightness and thermal breaks. Possible differential movement between the building and balcony structures must be properly considered. Although there are different possible structural options for the exterior balconies *(Figure 6.10)*, some solutions work better for 5 or 6-storey light wood-frame buildings.

Figure 6.10: Different options for external balconies.

Balconies were discussed in **Section 2.5.6.** As demands and expectations around health, mental and physical well-being place changing needs on the way we live, our approach to building design changes. Architects and designers need to carefully consider the technical and design challenges associated with balcony design.

Cantilevered balconies are not generally recommended. Several case studies conducted in Quebec and elsewhere have shown ingress or condensation issues at the junction between the balconies and external walls, particularly when the balcony structure contains cantilevered joists or steel profiles inset into the floor joist system. This type of connection can cause considerable discontinuity in the air barrier and lead to moisture penetration. Steel profiles that penetrate the building envelope can create significant thermal bridges.

Hung balconies and inset balconies are appealing solutions for small balconies *(Figure 6.11)*. These balconies will follow the vertical movement caused by the building's structural shrinkage. The balcony structure and hanging system needs to be anchored securely to the structure, and the applied forces are required to be considered in the structural design. The integrity of watertightness and insulation are also maintained in spite of the penetrations in the envelope for the balcony hanging system.

Photo credit: Cotter Architects.

Figure 6.11: Examples of inset balconies (Quattro project) and Figure 2.73.

Stacked balconies allow for larger balcony surfaces. Using this method, the balcony structure is supported on one side by the building structure and by columns on the other. Differential movement between the building structure and the columns could lead to a negative slope *(Figure 6.12)*. The building designers should understand the vertical movement expectations and design the balconies accordingly (**Section 3.6**). Column deformation will vary depending on the material used, so consider different possible solutions. One solution is to increase the initial slope to make sure that it does not become inverted with the expected differential movement that will take place inside the structure. More complex solutions could require the use of height-adjusting mechanisms in order to maintain a positive drainage slope. As with hung balconies, the balconies must be anchored securely to the structure, both to transfer structural forces and maintain envelope integrity. If exterior columns materials are wood, they must be protected in some form to maintain their strength.

Self-supporting balconies, where the balcony structure is independent from that of the building, maintains the building's envelope design. Differential vertical movement between the two structures must also be clearly understood, ensuring that movement can be accommodated at the junction between the balcony and the exterior building face.

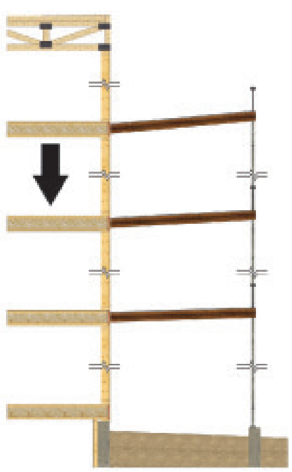


Figure 6.12: Potential negative slope in stacked balconies.

References

National Research Council of Canada: Guide to Calculating Airborne Sound Transmission in Buildings 2nd edition – April 2016.

National Research Council of Canada: Guide to Sound Insulation in Wood Frame Construction – March 2006.

5.7 Off-site Prefabrication

The planning and delivery of larger wood building projects, requires project teams to evaluate the project in terms of scheduling, delivery of a quality project, maintaining quality control measures, waste management strategies and construction costs. The preconstruction design and concept stage, provides necessary time to evaluate system integration of factory-built components and structural wood assemblies. The constructability of the project using this method of supply and build, should be considered as a way for optimization of construction efficiencies to be fully realized.

Off-site prefabrication of structural systems and assembly components has been steadily evolving into a modern and thriving industry. This includes the continuing development of supply channels, manufacturing operations, and site installation services. Prefabrication typically includes the manufacturing and utilization of the following:

- Structural components that can include prefabricated roof and floor trusses, I-joist systems, dimensional lumber, and structural composite lumber (SCL) assemblies, glulam beams and columns and mass timber systems.
- Panelized assemblies of open or closed type wall assemblies, floor and roof sections.
- Volumetric modular

In *Figure 7.1*, there are many different types of prefabricated construction methods, varying with increased complexity and increased scale and finishes of assemblies.

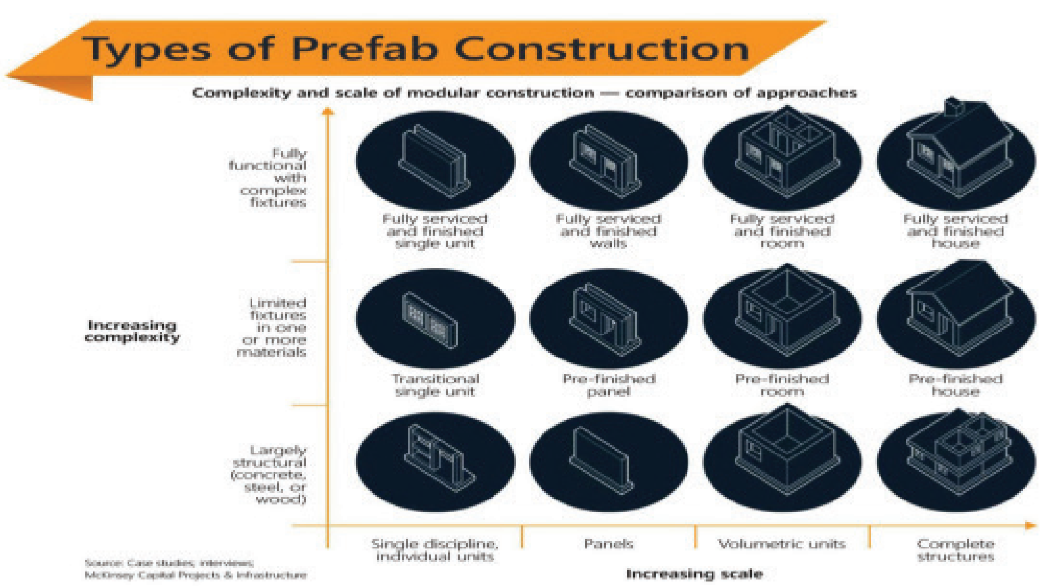


Figure 7.1: Methods and scale of prefabricated systems available.

Off-site prefabrication has advantages when utilized in the building and supply of structural components for light wood-frame and mass timber construction projects. This section presents an overview of the materials, processes and methods of prefabrication available.

5.7.1 Prefabricated Structural Components

Pre-engineered roof and floor trusses were the first levels of prefabrication that were utilized in wood building. The metal connector plate transformed the industry in the 1950's by allowing efficient manufacturing of wood floor and roof trusses for the construction industry. They are widely used in used in single- and multi-family residential, commercial, and agricultural wood construction. Today, wood trusses are designed using special 3D modelling software that optimizes the design for efficient manufacturing at the truss plant. The software produces cut files so that the truss chords and webs can be precision-cut on digital saws in the manufacturing facility.

Automation plays an important role in modern truss plants, as manufacturing equipment has evolved to streamline the manufacturing process. Software can communicate with the manufacturing equipment and laser projection technology enables precise placement of the truss chords, truss webs and metal connector plates for during fabrication processes *(Figure 7.2)*.

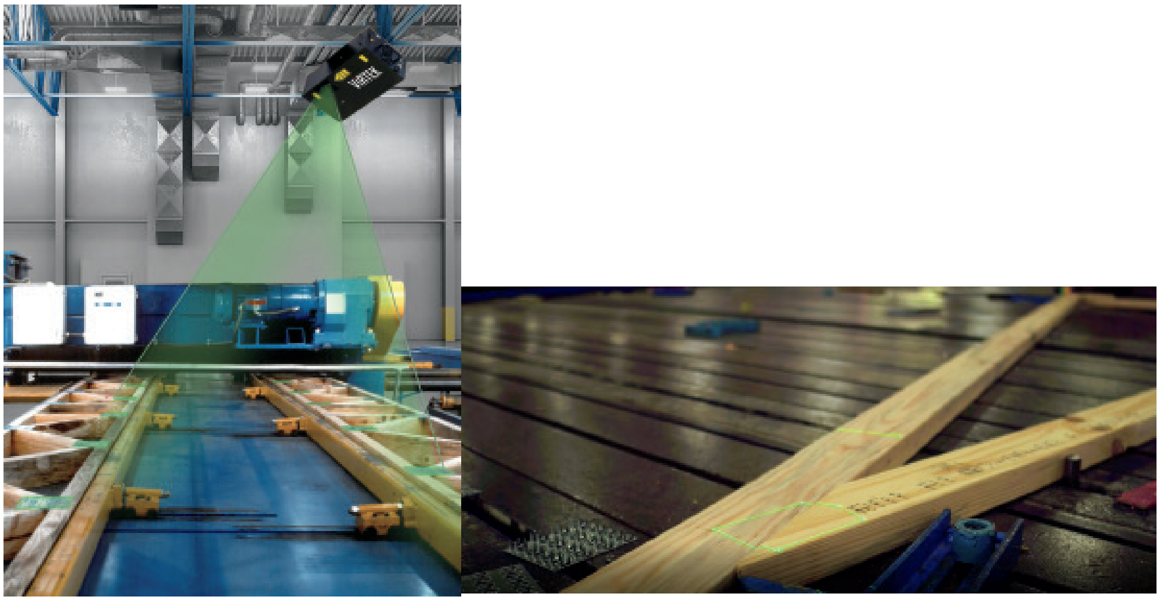


Photo courtesy of Virtek Vison International ULC.

Figure 7.2: Truss manufacturing plant with laser projection.

Trusses are designed in accordance with the design procedures from TPIC, *Truss Design Procedures and Specifications for Light Metal Plate Connected Wood Trusses*, as per NBCC Article 9.23.14.11 and in accordance with CSA 086-14.

Prefabricated wood I-joists, open web joists, structural composite lumber (SCL) and glulam are other types of prefabrication components that are used commonly in light-frame wood construction *(Figure 7.3)*. These components are manufactured in a controlled factory environment and have proprietary code evaluation reports evaluated by Canadian Construction Evaluation Centre (CCMC). Manufacturers offer standard sizes and have published literature and software available to design their products for applications in wood buildings.

Figure 7.3: I-Joist, SCL and glulam.

Clause 7 of CSA 086-14 applies to glued-laminated timber manufactured in accordance with CAN/CSA-0122. Clause 15 of CSA 086-14 specifies the design requirements for propriety structural wood products in specific applications. Clause 16 of CSA 086-14 applies to the derivation of design values for the proprietary structural products. These clauses provide assurances that the proprietary design values comply with applicable standards and are consistent with the intent of Part of the NBC 2015 with respect to strength, serviceability, and reliability.

Prefabricated structural components can be delivered directly to the construction site or used in another prefabrication step for prefabricated panel systems for floors, walls, and roofs, or in modular construction.

5.7.2 Prefabricated Panel Systems

Panelization is a construction method where the structural components of a building, such as wall, floor and roof panel assemblies are manufactured in an off-site facility. Assembled panels are shipped to the construction site and are rapidly assembled. The construction industry has embraced this method of supply due in large part to a shortage of skilled labour, the increased productivity that factory environment produces, no weather delays, fabrication that runs parallel with site clearing, excavation and foundation work, a reduction in site waste, cost and supply predictability and the growing demand for more efficient ways in delivering affordable housing. Panelized construction has been shown to result in tighter quality control and tolerances.

Prefabricated structural components listed in **Section 7.1** above can be assembled into panel systems at a manufacturing facility. The use of mass timber components and CLT panels are more frequently seen as more supply channels are realized. Mass timber elements can be incorporated into pre-assembled systems. Both methods can be used in facilitating panelized construction uses on site *(Figure 7.4)*.

Image courtesy of HummingbirdHill Timber Solutions (left).
Image courtesy of APA – The Engineered Wood Association (right).

Figure 7.4: Light frame wall panel/CLT floor panel.

Examples of factory-built systems in use: Wall panels and floor systems. Installation is rapid.
Images courtesy of Steven Street.

Image courtesy of Steven Street.

Panelization construction applies an engineering methodology called, Design for Manufacturing and Assembly (DFMA). DFMA focuses on reducing time-to-market and total production costs by prioritizing both the ease of manufacture for the product's parts and the simplified assembly on-site. This building approach involves a structural kit of parts being designed in partnership with a project's engineer and architect and is then prefabricated off-site. This process should be implemented during the early design development stages of a project. This means looking holistically at a project early on and designing the project with the appropriate manufacturing and assembly processes understood, in order to meet the functional goals that are laid out by the projects design team. (**Section 2.2.7**)

Specific design information is required prior to aid the DFMA process and meet manufacturing timelines and schedules. This allows the panelization supply company to begin the process of creating the 3D models. The 3D models are created using a specialized software, with Building Information Modeling (BIM), specific to their operation. This software is used to produce 3D framing models from which the required files for manufacturing are extracted. The software allows the panelization company to customize operations such as production, labelling, shop drawings, and the sequencing order of installation based on manufacturing type parameters and customer specifications. During the DFMA process, consultation with the project's structural engineer, architect and other stakeholders is key to maintaining manufacturing and production schedules required for the project. Project and design information is required in advance to begin designing the assemblies. Shop drawings are produced and typically reviewed and signed off y the design team in advance and prior to commencement of manufacturing.

Automation plays a significant role in panelization facilities in Canada. Equipment manufacturers make various types of manufacturing equipment such as manufacturing robotics and CNC machinery, custom-built for specific tasks. Equipment is state-of-the-art and includes saws, hydraulic presses, automated nailing stations and bridges, mechanical jigging, and material handling equipment. Prefabrication facilities incorporate robotic lines and high degrees of full and semi-automation (*Figure 7.5)*.

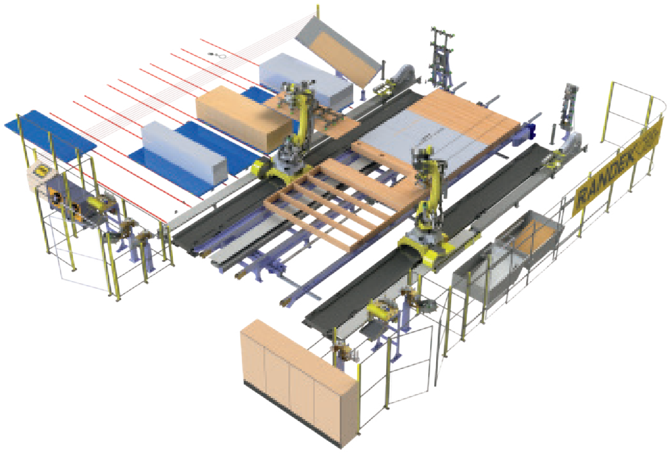


Figure 7.5: Light frame robotics wall line.
Image courtesy of Randek.

Robotic integration allows for manufacturing flexibility in a process and can be configured to perform specific tasks. The degree of automation in manufacturing plants determines the level of factory finish that is available to customers. Some panelized manufacturers factory install air barriers and windows on the pre-built wall panels, wall assemblies are pre-wired, insulation installed, and gypsum board attached. Floor panel assemblies are assembled with the floor joist and the required floor sheathing panels connected with adhesive and nails and supplied with all load transfer blocking and hangers contained within the panel assembly.

When floor panels are manufactured in a panelization plant, the floor sheathing is positioned continuously along the length of panel, therefore the sheathing is not staggered (*Figure 7.6* Continuous Sheathing Joint).

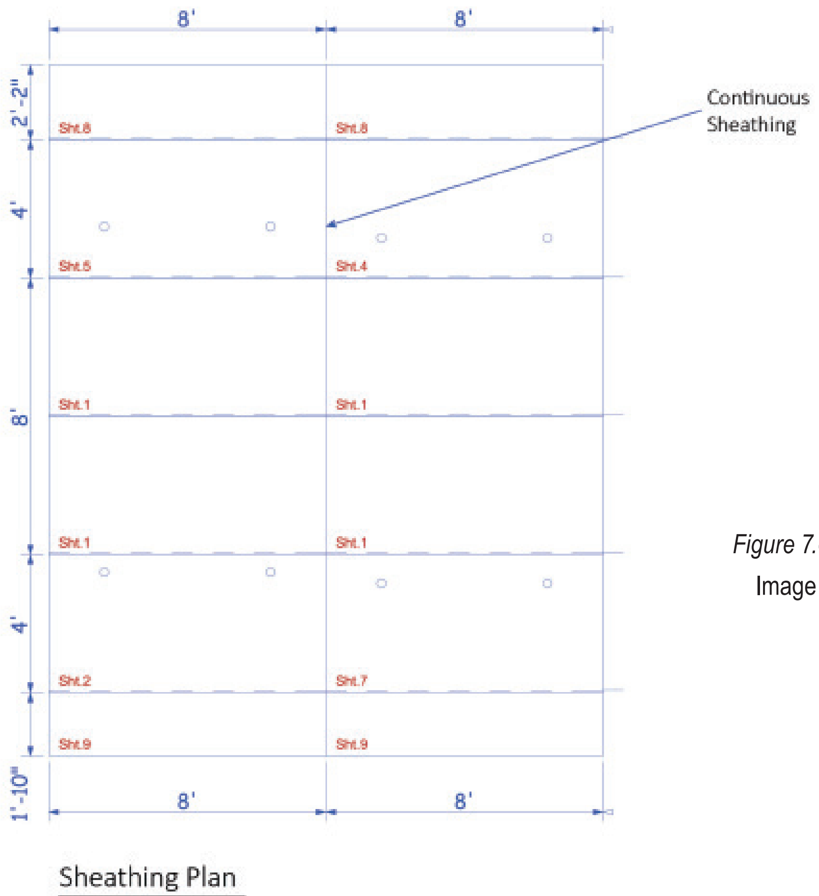
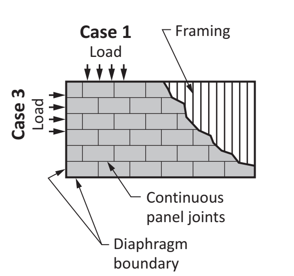
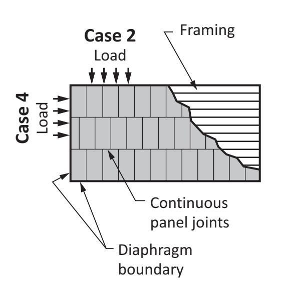
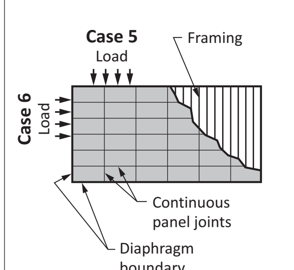
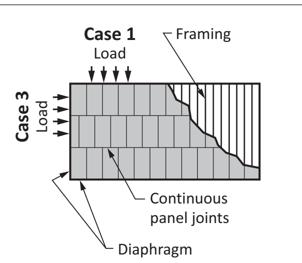
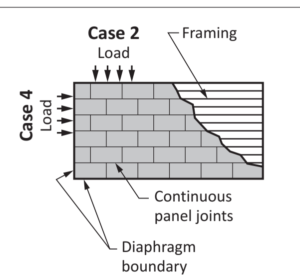
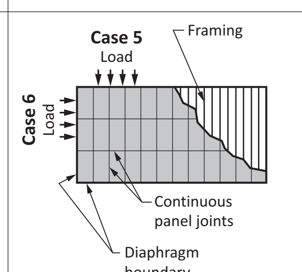


Figure 7.6: Continuous sheathing joint.
Image courtesy of Weyerhaeuser.

This application method is different than the stick-built construction on site, but recent updates to CSA 086-19 *Engineering Design in Wood* has provided more clarity on this type of sheathing arrangement. Diaphragm capacities can be calculated using these configurations as shown in CSA 086-19, *Figure 11.5*, Configurations of unblocked diaphragms (*Figure 7.7*).

	Cases 1 and 3: Continuous panel joints perpendicular to framing	**Cases 2 and 4: Continuous panel joints parallel to framing**	**Cases 5 and 6: Continuous panel joints perpendicular and parallel to framing**
Long panel direction perpendicular to supports			
Long panel direction parallel to supports			

Courtesy of APA – The Engineered Wood Association

Figure 7.7: Configurations of unblocked diaphragms.

Manufacturing plants that produce CLT panels, utilize automation in their operations. This produces a high quality and very precise product. A typical manufacturing process involves many steps: lumber selection, lumber grouping, adhesive application, panel lay-up and pressing, curing, product cutting, surface machining, marking, and packaging (*Figure 7.8*).

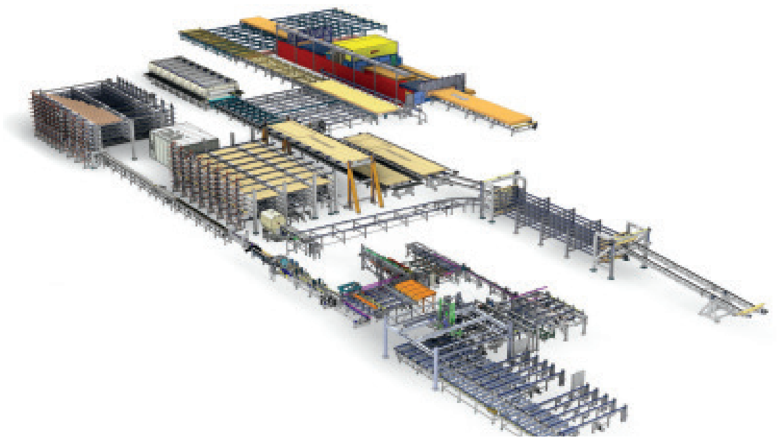


Figure 7.8: CLT manufacturing line.
Image courtesy of LEDINEK.

CLT manufacturers produce different panel dimensions, which can be cut to the required sizes. Shop drawings for panels and connector detailing are generated from 3D (BIM) models, and digital files are sent to CNC machines for fabrication which includes precision cutting and shaping. CNC machines provide a high degree of precision cutting for openings for windows, doors, mechanical, electrical, and plumbing (MEP) services, and connections.

In-plant quality control procedures are required to ensure the product is manufactured and certified to the required standards. CLT manufactures have ongoing certification and adherence to the ANSI/APA PRG 320-2019, "Standard for Performance-Rated Cross-Laminated Timber".

5.7.3 Modular Construction

Modular construction refers to the manufacturing and assembly of modules off-site such as fully finished bathroom pod, or a sub-assembly for mechanical, electrical, and plumbing (MEP) systems. The modules are shipped to site and assembled to form part of the building. Modular construction of sub-assemblies that can complement the panelization construction process and become part of the assembly process during construction to reduce time.

Volumetric modular construction refers to the manufacturing and assembly of modules that will complete spaces such as apartment bathrooms and corridors (or portion thereof) in a single module. The module can be either finished in the manufacturing plant or at site. Volumetric modules usually arrive on-site and only require placement and structural connection to the adjoining modules. Building service connections need to be made on-site after the modules have been placed and connected to the foundation (*Figure 7.9*).

Figure 7.9: Volumetric modular construction.
Image courtesy of Bonneville Industries.

Volumetric modular construction is better suited to certain building types. Volumetric modules are typically rectangular in shape, with maximum spans limited to the length and width of a module. This is by logistics and local transport regulations. High levels of quality control and tolerance are implemented during fabrication and site assembly.

North American model codes and standards organizations have recognized the need for codes and standards to be developed to respond to the specific challenges of modular construction. Following a review and gap analysis, CSA has developed standard, CSA Z250 – "Advancing modular construction standards in Canada." Release of CSA Z250 is scheduled for September 2021. CSA Z250 aims to help overcome challenges and to advance modular construction in North America. The standard will increase and expand adoption by provinces of CSA A277-16 Standard, "Procedure for certification of prefabricated buildings, modules and panels." This standard is already being used in Canada for prefabricated panel systems.

5.7.4 Benefits of Prefabricated Construction

The business case benefits of wood construction systems shown in **Section 3.1.2** laid out many of the points raised in this section and illustrated the importance of utilizing efficiency. Prefabricated systems allows for rapid building. By the reduction of on-site installation and build schedule, the benefits of time savings in erection time and the impact on the build schedule, allows developers and builders to see substantial cost savings associated with carrying costs for a project. Cutting unnecessary site waste and dumping fees, impacts construction costs and the project's overall budget. Any reduction in financing costs associated with bringing the project to market sooner should be considered. Taking more upfront time in the DFMA process provides a predictable installation schedule. Site development and foundation work can be done simultaneously while panel construction at the manufacturing plant occurs. Understanding the schedule savings with off-site construction is critical for producing an accurate cost model.

With panelized construction, fabrication and assembly of prefabricated panels takes place in a controlled environment for manufacturing. The processes of 3D/BIM modeling and manufacturing are more tightly integrated with the project's design team, therefore, capturing efficiencies.

A quality-controlled program implemented at the manufacturing plant will provide quality assurance for the panel products manufactured. Reducing issues on site avoids costly change orders, lengthy delays, repairs, and re-work. Manufacturing plants that are CSA-A277-16 certified provides additional quality control assurances for panels.

Reducing material waste is another significant benefit for the panelized construction method. Processes are optimized at the manufacturing plant and lean production principles are implemented, resulting in better inventory control on the material used for the prefabricated panels. Off-cuts that would generally be waste on the jobsite can be re-used into the production processes at the manufacturing plant. Waste management on the jobsite is reduced with a panelized system as shown in *Figure 7.10* – Waste Management.

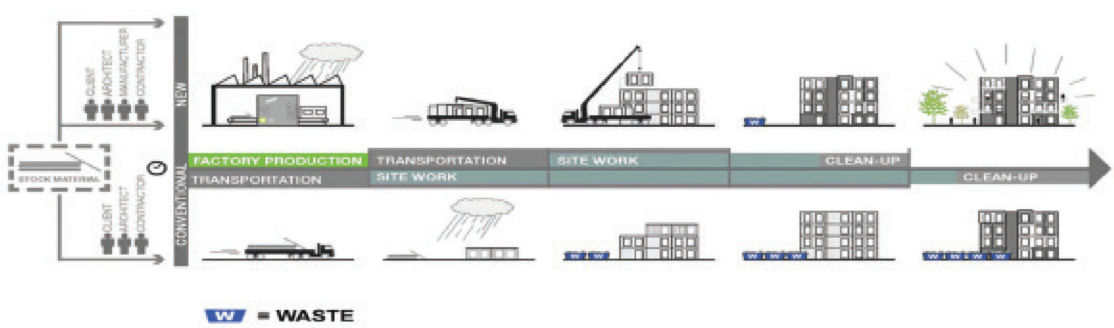


Figure 7.10: Waste management.

Image courtesy of Quadrangle Architects.

Panelization construction is a more sustainable way to build by reducing energy, waste and emissions reduction. Manufacturing plants are better able to control energy use and emissions, lowering carbon emissions when compared to conventional construction sites. A university study examined this topic in terms of life cycle emissions. The study demonstrated that the use of the panelized construction method reduced overall emissions by over 40% compared to the site-built method. This would have significant benefits as a way of further achieving green building and sustainability goals beyond using wood materials. (Construction Research Congress 2014: *Carbon Footprint of Panelized Construction: An Empirical and Comparative Study*). Hong Xian LI, Mehrdad NASERI ESFAHANI, Mustafa GUL, Haitao YU, Don MAH, Mohamed AL-HUSSEIN).

A panelized construction approach has less disruption to the surrounding community, as the on-site installation time portion is shortened. Lessening site noise and air pollution is advantageous, as the building and assembly stage of the build is taking place at the manufacturing plant. Proponents of panelization construction strongly believe that this approach delivers greater environmental and sustainability benefits.

5.8 Construction Site Best Practices

This guide primarily focuses on 5- and 6- storey wood buildings, but it is worth covering some important reminders about wood construction site safety, risk management and materials.

5.8.1 Safety During Construction

5.8.1.1 Fire Prevention

"An estimated 100,000-plus building projects in Canada each year involve wood-based construction, and these numbers may increase with building code changes that permit taller wood buildings. Research shows that wood buildings are as safe as steel or concrete buildings once fire-safety systems are in place, but, like all buildings, are more vulnerable to fires when they lack those systems."
(Garis et al. 2015)

The risks and hazards associated with the construction phase of a project, are different from that of a completed building. The construction phase is a time when many of the fire prevention and protection elements that are designed to be part of the operational building are not completed or in place. Careful management and pre-planning is a strategy to manage potential risk **(fire safety and security documents, Section 9 References)**.

The primary causes of fire at construction sites are incendiary or suspicious events, hot work, and temporary heating equipment. These three causes are responsible for about 70% of all fires *(Figure 8.1)*. Other causes include smoking, cooking equipment, lightning, electrical sources and other external elements such as forest fires.

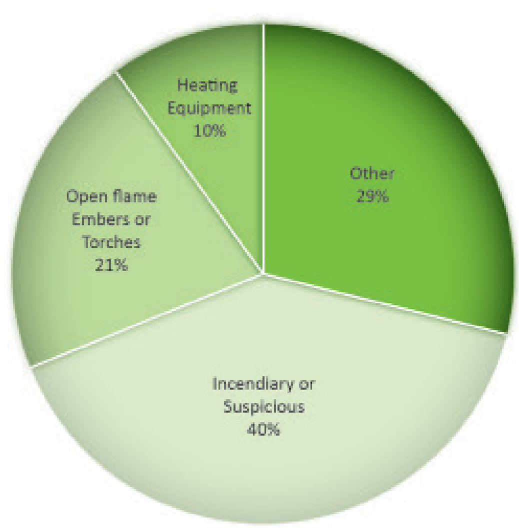


Figure 8.1: Main causes of construction site fires.

Three components are required for a fire to start: oxygen, an ignition source – that is, an external source of sufficient energy (heat), and sufficient fuel that is readily ignitable. These three elements make up the "fire triangle" *(Figure 8.2)*. Take away any one side of this triangle, and fire cannot start, or similarly, fire can be extinguished once it occurs.

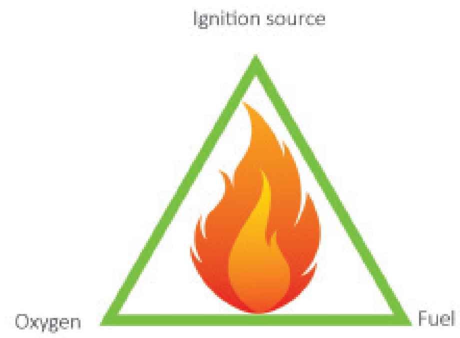


Figure 8.2: Fire triangle (CWC, 2015).

Construction sites tend to have an abundance of all three components. Since it is impossible to control the availability of oxygen on a construction site, construction site fire safety usually focuses on the reduction and control of possible sources of fuel and ignition.

5.8.1.2 Construction Processes and Procedures

Approaching projects with safeguards in place to minimize fire risk and to optimize fire prevention is good practice. These guidelines supplement federal and provincial requirements and are aimed at builders and contractors in providing safeguards:

- Coordinate the installation of fire protection equipment, such as standpipes, hose stations, sprinkler system and alarms, in stages to provide active fire control and suppression in synch with the development of the structure.
- Prioritize the installation of fire barriers, separation walls and fire doors on each floor platform as soon as possible to progress in step with the structure development. Fire doors should be installed at the same time as their frames.
- Fire blocking should be installed immediately where necessary and smaller openings identified, marked and scheduled for fire stopping as soon as the area has been completed.
- Any non-combustible finishes to be installed should follow in stages as the project progresses.
- Consider alternate construction materials and methods to reduce fire risk, such as build up hot tar roof covering instead of torch on roof applications.
- Prefabricated components and assemblies and just-in-time delivery reduces the amount of stored materials on site and reduces construction time.
- When projects are spread over multiple buildings, sequencing of buildings should be coordinated to create physical separations creating fire breaks.

5.8.1.3 Fuel Sources

It is important to monitor any easily combustible source of fuel on site. Proper management of combustible materials reduces the risk of fire and potential spread in case of a fire.

It is important to place strict controls on storage of combustible and flammable liquids and gases, as well as any refuelling activities, and all corresponding safety regulations must be followed rigorously. It is a good idea to minimize, as much as possible, the amount of flammable and combustible liquids in or near a building at any given time:

- Clearly identify all such hazardous materials, types, quantities, acceptable uses, that are to be part of the construction project.
- Develop and designate safe storage areas, including appropriate segregation and storage.
- Develop guidelines for safe practices when handling hazardous materials.
- Designated areas should be established for storage of combustible materials away from the building under construction.

Housekeeping and Waste Management Policy:

- Provide designated areas and facilities for storage and removal of waste materials.
- Prepare guideline on waste handling instructions. No burning on site.
- Maintain necessary clearances between storage of combustible materials and any ignition sources.
- Conduct daily clean-up of work sites to remove waste materials and unnecessary combustibles.

5.8.1.4 Sources of Ignition

Controlling ignition sources on-site is an obvious way at limiting risk of fire. Hot work (open flame, embers or torches) is the cause of 21% of fires in buildings under construction, a cause that can be directly controlled. Hot work operations include cutting, welding, brazing, soldering, grinding, thermal spraying, thawing of pipe, and installation of torch-applied roof systems. Special safety precautions must be applied when this type of work is performed on-site to reduce fire risk. Hot work protocols can be implemented as part of a Fire Safety Plan (FSP). Some recommendations in controlling ignition sources:

- Establish and enforce “No Smoking” rules.
- Training of on-site personnel and contractors on hot work procedures.
- Utilizing a hot work permit system as part of the on-site fire prevention tool.
- Establish and enforce roofing protocols.
- No open flame type heaters inside buildings. Establish guidelines for use of temporary heating systems.
- Establish guidelines for proper installation and use of electrical services and equipment, both temporary and permanent.

5.8.1.5 Site Surveillance and Security

The leading cause of fires in buildings under construction is criminal or suspicious in origin (CWC, 2015). It is important to fully secure the construction site using different protections, such as fencing or barricades around the full site perimeter, controlled access to the site, lighting, movement detection and surveillance cameras when the site is closed, and security guards.

Security is required on a construction site for many purposes, including arson prevention, theft, and unauthorized entry. Security measures may include:

- Erecting secure fencing or hoarding at least 1.8 metres in height around the perimeter, with access gates that can be closed and locked.
- Setting up security access points at site entrances, including entries to the construction zone in occupied buildings.
- Maintaining strict sign-in/sign-out procedures for anyone gaining access to the site, including visitors, contractors and the permanent workforce (sign in sheets are also useful for tracking occupants if evacuation is required).
- Employing 24-hour guards on larger or more hazardous sites, with orders that include recorded rounds, supplemented by intruder alarms.
- Storing expensive equipment and vehicles in a secure area when not in use.
- Installing security lighting, closed-circuit cameras and intruder alarms.
- Instituting a rigorous locking-up procedure that includes making sure all gates, doors and equipment are secure, and checking hot work areas for signs of fire.

CWC (2015). *Construction Site Fire Safety: A Guide for Construction of Large Buildings.* Canadian Wood Council and Simon Fraser University: Centre for Criminal Justice Research

5.8.1.6 Fire Safety Plan

The best strategy for minimizing risk is to establish a Fire Safety Plan (FSP) and strictly observe it. FSPs address construction site hazards – many are unique to a particular site, many are consistent and often found where construction is performed. FSPs are prepared by the site owner and/or builder. A Fire Safety Co-ordinator (FSC) is designated as the contact person, and they have the responsibility of implementing the FSP. The FSP contains several elements including:

- Emergency procedures to be followed in the event of a fire.
- Maintaining unobstructed road and site access for emergency services.
- Location, accessibility and number of fire extinguishers, as well as arranging required worker training to operate.
- Roles and responsibilities of key personnel on-site including sounding the alarm, notifying the fire department.
- Training of site personnel on the procedures to be followed when the alarm sounds, and firefighting procedures should they be required and can be safely performed.
- Measures for controlling fire hazards in and around the building.
- Documents and diagrams showing the type, location and operation of the building's fire emergency systems.

– A list of all emergency response numbers and the names, addresses and telephone numbers of the project's emergency contacts.
– Implementing and enforcement of hot work protocols.

(fire safety and security documents, Section 9 References)

5.8.1.7 Command Post

A command post on site should be established by the appointed Fire Safety Co-ordinator (FSC). The command post should include a copy of the fire safety plan, building and site drawings, emergency information, one or several means of communication, keys, and other equipment for use by both emergency responders and site fire-safety officers. The location of the command post should be based on emergency access and overall safety during a potential fire event.

5.8.2 Prevention

No matter how many safety measures are put in place in a construction site, prevention is the top priority, and it applies to everyone: owners, designers, general contractors, and contractors. Everyone working on the site should receive training on the risks and dangers of the construction project, along with measures for completing the work safely.

Construction methodology that utilizes prefabricated structural systems or modular construction considerably reduces construction time on-site, reducing risk exposure and should be considered as part of risk prevention.

Plan your work. A safe work plan should be developed as a way of everyone involved being aware of what is to come during the construction process, identifying the following information:

***Safe Work Plan* (SWP)**

– Identifies the expected installation sequencing. Drawings should clearly identify the number of installation pieces.
– Written processes should be developed that describe requirements and methodology to install assembly pieces.
– SWP should include material lifting and craning plans. Engineered rigging diagrams and capacity as required as well as certificates for qualified personnel and for rigging processes. Strategies for craning procedures should be outlined.
– If site welding (hot works) is required during the build process, the SWP should contain certifications of welders providing service onsite.
– Clear markings of all safety equipment and safe zones on-site will be clearly identified.
– Training and regular update meetings should be scheduled and held, reviewing policy for new trade training, highlighting safety and sequencing of the construction site. This process will help ensure everyone develops an understanding of site procedures, and work towards creating a culture of safety.

5.8.3 Weather Protection and Moisture Management

During the construction phase, it is important to protect the framing and structural elements from the harmful effects of weather. Understanding best practices is a key step in managing this. Strategies that keep components dry and warm during construction generally minimizes performance issues that could potentially be an issue.

Project planning should include moisture management planning strategies. Preparations will anticipate what may occur as weather changes through the seasons in each region. Addressing moisture exposure during construction, implementing strategies that remove ponding water from rain and snow from horizontal floor and roof decks, and ways to force dry should be planned. Managing material and product deliveries from suppliers, coordinating the project schedule to best utilize just-in-time delivery of components, not only expedites the build time, but leads to watertightness and weatherproofing of the structure. Adequate storage facilities may have to be considered, so planning for this is an important step in protecting components from moisture and weathering.

Understanding storage requirements for the structural systems is a part of the moisture planning and protection strategy. Check with product suppliers on recommended best practices.

During cold weather, care must be taken with the sudden application of heat. Rapid temperature changes adversely affect the moisture content of wood products and can lead to cracking and checking, which may lead to permanent damage. By gradually increasing heat over a period of time, this allows wood products to gradually change the moisture content to normal levels. Development of an on-site moisture management plan that addresses moisture monitoring, using on-site heaters and dehumidifiers, is recommended. Moisture testing prior to encapsulation is required.

5.8.3.1 Mass Timber

Mass timber products are susceptible to the effects of moisture. Particular attention should be given during transportation to the site location from the manufacturing facility, and during the installation phase.

Mass timber components will perform differently when exposed to moisture, by developing an understanding of the materials, systems and assemblies that will be used is a key step of the moisture management planning. Consultation with manufactures on how this can be managed and some strategies to employ.

Mass timber panels require slow drying if exposed to direct moisture. Protection and prevention is key. If more complete assemblies are supplied, factory applied acoustic underlayment's and/or membranes may provide additional site protection. Moisture levels should be closely monitored. Before the building is enclosed, the moisture content should not exceed 19%.

5.8.4 Temporary Lateral Bracing

It is important to plan temporary lateral restraints for loadbearing wall studs that have not yet been covered in wood structural panels or gypsum board during the duration of construction. During the build phase there may be considerable vertical dead loads applied on the lower storeys in a 5- or 6- storey wood frame building.

Wood structural panels (OSB or plywood) can also be planned for all loadbearing walls to avoid using temporary lateral restraints. This option also enables designers to include loadbearing walls in the lateral load resisting system.

5.8.5 Quality Control During Construction

Light wood-frame or mass timber buildings of 5- or 6- storeys that are site built require field reviews be performed by the structural engineer, as each storey is built and completed. This takes place before gypsum board is applied to the completed structure, allowing for access. The contractor should ensure quality fabrication processes, manage material moisture, and weather-protect the wood assemblies as much as possible before installation. Professional supervision and on-site quality control procedures are critical in maintaining building tightness and quality. There are generally more on-site framed assemblies to verify compared with off-site prefabricated components as quality control procedures are part of most fabrication processes. Manufacturers will need to provide documentation signed by a professional attesting that:

1. Factory production is subject to quality control procedures and supervision.
2. Factory built components for a particular project, are in conformance with the drawings and specifications of the structural engineer and architect.

Typically, the quality control procedures cover the following:

- Moisture content, dimensions, and grade for the wood elements;
- Thickness, grade and type of structural panels;
- Type and specification for nails (length, diameter and spacing);
- The installation of fasteners such as screws, anchor bolts, restraint hold-downs or other fasteners installed in the factory;
- The location of studs, posts, lintels, and other elements within tolerance limits;
- Proper installation of non-structural components such as insulation, vapour barriers, air barriers (if applicable).

As lateral load resistance of shearwalls depends not only on the wood components of the wall assembly, but also on nail specification and spacing requirements, structural engineers should be knowledgeable about the types of nails used in the industry. There are many choices available. Nails driven using pneumatic nailing guns can have smaller diameters than common nails of the same length. Strength and building performance depends on the quality of the fabrication of the assemblies, so importance should be placed on understanding and following the nail and spacing requirements on the structural drawings.

Following site installation of prefabricated assemblies, metal connections need to be installed and connected. Shearwall hold-downs and shrinkage compensators need to be located and installation procedures carefully followed. Field review maybe required as the build progresses from storey to storey. Generally, the structural engineer will identify their field review processes and requirements for the building as it progresses.

(Section 5.7 Off site Prefabrication)

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(Footnotes)

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