Mass Timber Building Science Primer

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Acknowledgments

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Disclaimer

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Foreword

The development of this primer commenced shortly after the 2018 launch of the Mass Timber Institute (MTI) centered at the University of Toronto. Funding for this publication was generously provided by the Ontario Ministry of Natural Resources and Forestry. Although numerous jurisdictions have established design guides for tall mass timber buildings, architects and engineers often do not have access to the specialized building science knowledge required to deliver well performing mass timber buildings. MTI worked collaboratively with industry, design professionals, academia, researchers and code experts to develop the scope and content of this mass timber building science primer. Although provincially funded, the broader Canadian context underlying this publication was viewed as the most appropriate means of advancing Ontario's nascent mass timber building industry. This publication also extends beyond Canada and is based on universally applicable principles of building science and how these principles may be used anywhere in all aspects of mass timber building technology. Specifically, these guidelines were developed to guide stakeholders in selecting and implementing appropriate building science practices and protocols to ensure the acceptable life cycle performance of mass timber buildings. It is essential that each representative stakeholder, developer/owner, architect/engineer, supplier, constructor, wood erector, building official, insurer, and facility manager, understand these principles and how to apply them during the design, procurement, construction and in-service phases before embarking on a mass timber building project.

When mass timber building technology has enjoyed the same degree of penetration as steel and concrete, this primer will be long outdated and its constituent concepts will have been baked into the training and education of design professionals and all those who fabricate, construct, maintain and manage mass timber buildings.

One of the most important reasons this publication was developed was to identify gaps in building science knowledge related to mass timber buildings and hopefully to address these gaps with appropriate research, development and demonstration programs. The mass timber building industry in Canada is still a collection of seedlings that continue to grow and as such they deserve the stewardship of the best available building science knowledge to sustain them until such time as they become a forest that can fend for itself.

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About This Publication

This primer has been designed as a "knowledge map" to help guide readers through a vast body of knowledge and information related to mass timber building technology. It is neither comprehensive nor complete as there is simply too much to compile and convey within a single guideline publication. Like a map, it attempts to reveal an entire territory through a document having a manageable scale.

Building with wood in any form involves a large number of heuristics that depend on a network of skilled and knowledgeable people working cooperatively within a culture of crafting wooden buildings.

Making maple syrup. *This guideline has required boiling down hundreds of publications and dozens of expert interviews to extract the vital information needed to help navigate the building science underpinning mass timber construction technology. [Photo courtesy Ontario Maple Syrup Producers Association.]*

The content has been kept as concise as possible so that the document serves as a digestible framework that can be explored in greater depth according to the needs and interests of the reader. Each of the sections can be reviewed quickly and the referenced materials may then be conveniently accessed to gain more detailed information. One of the guiding principles for these guidelines is that the reader should not only be able to grasp a reasonable overview of the critical building science issues related to mass timber buildings, but that it is just as important to reveal what the reader does not know. Building with wood in any form involves a large number of heuristics that depend on a network of skilled and knowledgeable people working cooperatively within a culture of crafting wooden buildings. Innovations in mass timber have not changed this underlying aspect of wood building technologies that have been inherited over the millennia.

Scope

This publication is confined for the most part to building science considerations related to mass timber building technology. However, it also contains more general resources about related subject matter.

Intended Audience

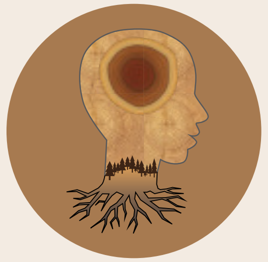
The intended audience for this publication is the key stakeholders associated with mass timber buildings, specifically:

- Owners/developers;
- Mass timber manufacturers/suppliers;
- Design professionals (architects and engineers);
- Constructors;
- Building officials;
- Facilities managers; and
- Insurers.

It is also a helpful learning resource for academic studies about mass timber building technology.

Mass Timber Resources

In accordance with the principles of Fair Use, a large number of resources may be downloaded by clicking on the icons throughout this digital publication related to various subject areas.



Mass Timber Resources
Click on this icon to obtain downloadable resources about a specific subject area. A compressed .zip file will download to your computer that may contain guides, reports, articles, papers, images, etc.

Mass timber resources are intended to provide in-depth information on a variety of subject areas. *Users of this primer are encouraged to download digital resources as desired for future reference.*

Primer at a Glance

This primer focuses on the building science aspects of designing and constructing mass timber buildings in Canada. The main objectives of this document are to: (1) inform stakeholders about the key building science issues that require consideration before undertaking a mass timber building project; and (2) ensure that mass timber buildings are safe, comfortable, durable and resilient. The publication's targeted audience is owners, developers, architects, engineers, wood suppliers, wood erectors, constructors, code officials, facility managers and insurers. However, it is also intended to be helpful to educators and students involved in architecture, engineering and construction management. This publication is neither comprehensive nor exhaustive. Rather, the intent of this document is to act as a directory alerting stakeholders to the key issues before they embark on a mass timber building, and providing numerous links to resources, researchers, suppliers, tools and websites to assist with the design and construction of a mass timber building.

This primer contains six sections followed by several resources arranged in appendices. The digital format also contains links to a library of downloadable resources that supplement the information contained in the following six sections of the primer.

1 - Introduction - Provides an overview on why the development of this primer was necessary, and the enormous challenges facing the mass timber industry in Canada.

2 - Mass Timber and the Need for Building Science - Outlines the many factors that necessitate the development of this building science primer. They include the inherent properties of wood and mass timber products, building performance requirements, the complexity of modern building enclosures and systems integration, the absence of widespread academic and professional instruction in mass timber design, engineering and construction, the lack of mass timber knowledge among design, engineering, and construction and code professionals, and the nascent nature of the industry. This section also introduces the building as a system concept and identifies contemporary building performance requirements and expectations.

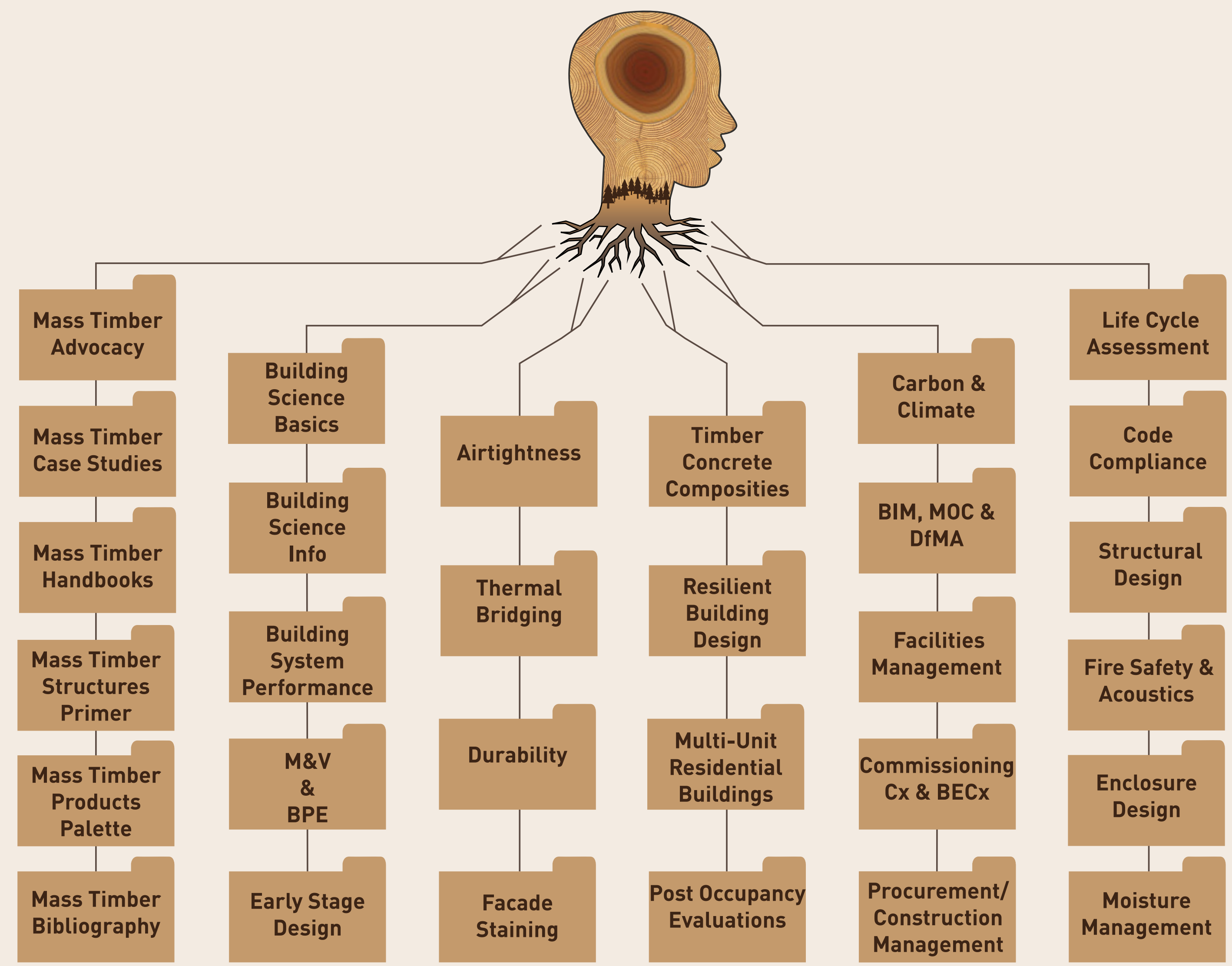
3 - Mass Timber Construction Technology - Presents primary mass timber building typologies and key considerations for selecting an appropriate typology. This section also outlines the eight primary mass timber engineered wood products and the types of connectors that are available to put them all together.

4 - Mass Timber Industry Stakeholders - Identifies the various stakeholders involved in mass timber building technology and describes their roles and responsibilities. It also includes an inventory of organizations at the international, bi-national, federal and provincial levels that support the mass timber industry.

5 - Critical Considerations for Mass Timber Buildings - Describes key design parameters that should be considered, such as: synergies, planning, an integrated design process and collaborative team structure, appropriate building typology, structural systems, fire safety, acoustics, moisture management, enclosure design, procurement and construction logistics, and operations and maintenance.

6 - Looking Ahead - Summarizes the gaps and needs for more in-depth knowledge about mass timber building technology, in particular for the building science field. There is also discussion about a national strategy for increasing the supply of highly qualified personnel, design professionals, constructors and their trades to help meet future demands for mass timber buildings.

This primer is aimed at the average design practitioner and construction professional. It assumes that readers have little to no familiarity with mass timber building technology. This publication would not be possible without the collective wisdom of the practice and thought leaders in our mass timber industry.



Mass Timber Building Science Knowledge Tree. *A number of helpful resources are available by clicking on any of the subject folders – the resources will be downloaded to your computer for convenient reference. All of these resources are available online and free of charge, but the effort of assembling this knowledge map required countless hours that can be better devoted to teaching and learning more about mass timber.*

1 Introduction

Compared to the vast number of conventional buildings designed and constructed around the world, mass timber buildings represent a minuscule fraction, and recently here in Canada only a handful have been constructed and subsequently occupied. It is too early to determine if they perform significantly better than conventional buildings with which architects have much greater experience. The recently released *Claims Experience Workbook*[1], a joint publication funded by the Ontario Association of Architects and ProDemnity Insurance Company, indicates that a large proportion of claims for water damage are associated with a lack of building science knowledge on the part of the architect and/or not selecting an appropriately qualified building science consultant. A significant issue associated with the control of heat, air and moisture flows in mass timber buildings is that unlike structural materials, such as reinforced concrete and steel, wood is susceptible to serious degradation from moisture. The implications of failing to control moisture in mass timber buildings go beyond defective and/or under-performing enclosures to include compromised structural systems. Clearly, mass timber buildings will pose challenges.

Yet across Canada over the past two centuries, large and tall timber buildings have been successfully constructed and many of these are still occupied, often re-purposed from industrial and warehouse facilities into offices and loft apartments. These stand in sharp contrast with some of the recent tall wood building projects across North America because they relied on heavy timber milled from old growth forest resources and were designed using rules of thumb that developed from a traditional palette of methods and materials. Contemporary mass timber buildings involve sophisticated structural engineering and building science, as well as accommodations by the entire supply, delivery, erection and commissioning chain. If we only aspired to reproduce the 19th century "brick and beam" buildings, then there would be no need for these building science guidelines to inform proven and successful evidence-based design precedents. But the shift to a low carbon economy demands that our buildings should, to the greatest extent technically possible, be constructed of wood and provide all of the high performance expected from other types of construction technologies.

In order for mass timber commercial, institutional and multi-unit residential buildings to become as commonplace as light wood-frame houses, a major transformation of the building industry is needed all the way from forestry through to facilities management. Procurement, design, construction management and commissioning will all need to undergo significant changes to accommodate fully integrated building systems that arrive "just in time" and are rapidly erected by skilled technicians working within a moisture management plan. What has now only been accomplished by highly advanced design teams delivering a limited range of demonstration projects will have to be translated to the average architectural practitioner to become as routine and reliable as so many of our common building typologies. It is with this disruptive and evolutionary process in mind that this primer has been developed, fully realizing it will be superseded as our mass timber industry matures.

This publication is not intended to be original or unique; instead it comprises a broad array of materials synthesized from numerous publications and web sites that represent authoritative sources of building science knowledge and information needed to deliver well performing mass timber buildings. Unlike steel and concrete building technologies that have benefited from over a century of applied research and countless applications, mass timber is a relative newcomer to the building industry. Technical guides and handbooks, textbooks and courses of study for engineers, architects and technologists have only started to emerge. This publication attempts to respond to this situation by helping building owners/developers, design practitioners, constructors and building officials navigate what are largely the unfamiliar and uncharted waters of mass timber buildings.

Everything old is new again? *Mass timber construction technology will rely heavily on building science if it aspires to achieve the same durability and service life of historic brick and beam buildings, while doing more with less. [Photo courtesy Modern Structural Engineering, PLCC.]*

At this point, it is important to acknowledge that numerous individuals and organizations have done much of the heavy lifting associated with mass timber building technology, both in Europe and across North America. The traditions of building with wood have deep roots around the world and mass timber is a shining example of how engineered wood products are responding to the emerging context of a low carbon economy and sustainable development. We will always owe much of human existence to forests.

But at the moment our state of mass timber building knowledge is not like a forest, rather a loose collection of individual trees. To deal with the diversity and complexity of information, this guidelines publication has adopted a "knowledge mapping" approach. Rather than researching and developing new knowledge, the building science aspects of mass timber building technology have been mapped and connected so that users of this publication can efficiently access the information they require to inform their respective roles and associated responsibilities. In the process, knowledge maps also reveal uncharted territories where gaps in the collective knowledge base need to be addressed in the future. The intent is to develop and maintain a living digital document until such time as the knowledge and information it encompasses become integrated within professional practice and education. It is hoped the learning curve associated with a transition towards mass timber buildings is manageable in terms of time, effort and risk. The recontextualization of 19th century heavy timber construction into 21st century high-performance, low carbon buildings will demand more than any single publication can ever hope to accomplish.

[1] *Claims Experience Workbook, Prepared by The Research in Architecture Studio for the OAA/Pro-Demnity Joint Working Group, October, 2017. http://prodemnity.com/wp-content/uploads/Claims-Experience-Workbook.pdf*

Generally, mass timber building design and engineering are not part of the core curriculum of architectural and engineering education in Canadian universities. Typically, elective courses in wood design and engineering at the undergraduate level are limited and dependent on the faculty members' background and interest. Consequently, Canadian architects and engineers have limited knowledge about wood and mass timber compared to other materials such as reinforced concrete and steel. Similarly, there are few college programs that address mass timber construction, although new programs are being developed and launched for technologists and the trades. Only a small cohort of students who specialize in structures, fire safety and acoustics in buildings annually graduate from post-secondary institutions across Canada. The integration of structure, fire safety and acoustics is critical to the success of mass timber buildings. If there was a spike in demand for mass timber buildings, there is insufficient capacity, not only among design and construction professionals, but also among product suppliers, to sustain timely delivery of mass timber projects.

This lack of knowledge and training about mass timber building technology is a bottleneck that includes authorities having jurisdiction. Since mass timber is a relatively small and nascent industry across Canada, very few comprehensive mass timber standards and guides have been developed, disseminated and absorbed by the design, engineering and construction industry to date. Yet mass timber requires the same sophistication as the aerospace and automotive industries have developed over the past half century – it is a daunting challenge.

The objective of this primer is to address the unique characteristics of mass timber by outlining the major issues, concerns and gaps with this material from a building science perspective, so that our nascent industry can confidently and effectively design and construct mass timber buildings that are safe, durable, resilient and sustainable. To do so, Canada must dramatically transform its construction culture to become a vertically integrated knowledge-based industry. Innovation and entrepreneurship are vital ingredients for success.

The Future of Mass Timber

- Mass timber will always be dependent on sustainable forestry practices to fulfill its environmental sustainability promise.
- Integrated design, digital fabrication and building information modelling (BIM) are key to the successful delivery of mass timber buildings.
- Best practices based on building science principles and evidence are essential to produce safe, durable, resilient, and sustainable mass timber buildings.
- The future of mass timber will require stakeholders to adopt a life cycle perspective on buildings and to treat them as cultural resources in the same way as we view forests as our natural resources, not as commodities.

The Eightfold Path to Successful Mass Timber Building Projects

1. Why Wood?

Building with wood has many benefit that make it a good choice for a building project:

- Low Carbon
- Renewable / Sustainable
- Jobs / Economy
- Durability / Serviceability
- Flexibility / Adaptability
- Beauty / Warmth

If building with wood is chosen, then suitable wood materials and methods must be selected.

2. What Wood?

Wood construction offers many options that can be applied in cost effective applications:

- Light wood-frame
- Engineered wood products and systems (e.g. structural insulated panels)
- Traditional heavy timber
- Mass timber
  - Post and beam
  - Post and plate
  - Mass timber panels
  - Mass timber braced frame

3. Design Team

A fully integrated design team is critical to project success. The disciplines listed below represent the core design team

- Architect
- Structural Engineer
- Fire Engineer
- Acoustics Engineer
- Building Science Engineer (enclosure)

It is advisable to include the mass timber supplier and constructor(s) as early as possible for practical input. Additional expertise as required may be introduced at the pre-design stage.

4. Pre-Design

Design team plus additional key players make up the project team:

- Construction Manager
- Mass Timber Supplier (design assist
- Commissioning Agent(s)
- Cost Consultant and Specifications Writer

The project team works to establish:

- Owner's project requirements (OPR)
- Basis of design / commissioning plan
- Approvals / code compliance path(s)
- Budget and schedule (preliminary)
- Site control and construction logistics
- Insurance / bonding

5. Design

The integrated design process is key to the success of mass timber projects and to ensure applicable approvals and code compliance are obtained at each stage:

- Schematic Design
- Design Development
- Contract Documents

Special attention must be devoted to resolving:

- Site, storage and construction logistics
- Moisture management plan
- Enclosure design
- Fire safety
- Acoustics
- MEP systems integration
- Commissioning

6. Construction

Successful mass timber projects are highly dependent on proper coordination and scheduling. Ensure proper protocols are implemented to deal with:

- Just-in-time mass timber delivery schedules
- Proper on-site storage and handling
- Moisture mitigation and management roles, responsibilities and measures
- Quality assurance and commissioning

For projects where inclement weather may lead to unavoidable wetting, establish:

- Drying protocols / remedial measures
- Allowance in schedule for proper drying before encapsulation / closing in.

7. Commissioning

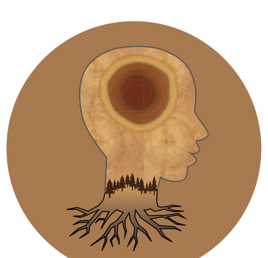
From the pre-design stage through all critical stages of the design and construction process, carry out:

- Design reviews of each enclosure details + HVAC systems and controls
- Quality assurance through the inspections and field testing (e.g. moisture content of mass timber)
- Air tightness testing of isolated assemblies followed by whole building
- Full commissioning of HVAC system, electrical and plumbing
- Confirmation reviews of all repair and remediation measures
- Review technical documentation, manuals and confirm as-builts (BIM)

8. Facilities Management

Along with transmittal of BIM model plus operations and maintenance manuals, facilities management personnel must be provided with:

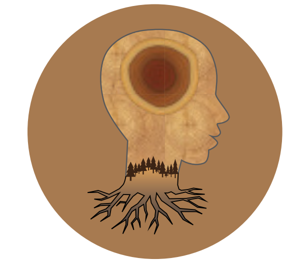
- A training period during handover of operations administered by the commissioning agent(s) - this must include proper operation of the building automation system
- Checklists of periodic visual inspections, routine maintenance procedures and record keeping within the BIM system
- Emergency measures and procedures (e.g. internal water damage, flooding, extended power outages, fire and smoke, etc.)



Mass Timber Advocacy
Click on this icon to download a number of publications that deal with mass timber advocacy issues ranging from sustainable forests to better building technology, and from opportunities to challenges.

Doing Right by Mass Timber – *Due to the nature and properties of wood, mass timber buildings require careful attention to numerous critical aspects over their entire life cycle. Starting with the promise of sustainable forestry and renewable resources all the way through the design, procurement, construction and commissioning processes, and finally the stewardship needed in facilities management practices and protocols, mass timber buildings demand that we do things right.*

2 Mass Timber and the Need for Building Science



Building Science Basics
Click on this icon to download a number of publications that provide insights into building science fundamentals and wood science.

Canadian building scientist, Neil Hutcheon, defined building science as *"a term now widely used, for want of a better one, to describe the growing body of knowledge about the relevant physical science and its application."* [2]

Today, building science is a very broad field that intersects with applied science, engineering, architecture, economics, and the biological, behavioural and health sciences. At its core, building science seeks to help deliver modern buildings that are safe, healthful, efficient, durable, resilient and sustainable. But it also looks at how to rehabilitate the existing buildings that are underperforming so that they can reduce their carbon footprints; thus, protecting our natural world while providing healthier indoor environments and extending the useful service life of buildings. Leading edge building science is also interested in the bigger picture that involves not just a single building, but entire communities and urban regions in terms of their metabolism. In the 21st century, building science concerns itself with a spectrum that ranges from nanotechnology to entire cities and regions, and is concerned with all aspects related to the full life cycle of buildings, including:

- policy (codes and standards);
- planning;
- design;
- construction;
- commissioning;
- facilities management;
- performance assessment (energy, water, comfort, durability, ecological footprint);
- forensics and rehabilitation;
- restoration and retrofit;
- preservation and conservation; and
- demolition (deconstruction) and recycling.

The need for building science is unquestionable in the context of our current building industry, but also our existing built environment. The societal aspiration for sustainable development hinges on the application of building science principles that apply for all ages and types of buildings, not just mass timber.

At its core, building science seeks to help deliver buildings that are safe, healthful, efficient, durable, resilient and sustainable.

Unfortunately, the need for building science is commonly recognized after the occurrence of building performance problems, or worse, after failures, rather than proactively at the planning and design stages of building projects. For this reason, contemporary building science has taken on greater importance in response to an increasing trend of innovative departures from traditional and proven building practices.

Innovation is not a trial and error process that relies on gradually refining successful past precedents. It is usually a significant departure from normative practices and relies on the scientific method to advance its agenda. Modern building science, as we know it today, was born of innovation - more correctly, because of the large number of failures encountered when building designers attempted to innovate without applying building science principles. There was no need for building science when only successful precedents were copied and handed down from one generation to the next.

Traditional building technologies that evolved by a process of trial-and-error resulted in rules of thumb that guided design and construction practices which were tested and refined over generations, in some cases centuries. Innovative building technologies incorporating novel methods and materials demand a more scientific and empirical approach to informing acceptable design and construction of buildings that satisfy today's code requirements and societal expectations. This publication is premised on the view that mass timber building technology requires innovation over the entire life cycle of buildings, from planning and design, through procurement, construction and commissioning, and then on to operations, monitoring and maintenance (facilities management).

Many factors necessitated the development of a building science primer for best practices associated with mass timber buildings:

- the diversity of products used to construct mass timber buildings;
- the lack of standardization among mass timber products;
- the inherent properties of wood and the influence of moisture;
- contemporary building performance requirements and expectations;
- the complexity of design for mass timber structures, building enclosures, fire safety and acoustics;
- the absence of widespread academic instruction and professional training in mass timber design, engineering and construction;
- the shortage of mass timber knowledge and experience among design, engineering, construction and code enforcement professionals; and
- the nascent nature of the mass timber building industry.

This primer is intended to increase the awareness of the critical importance of building science for mass timber building technology and to provide a framework for continuous learning and improvement.

[2] *Hutcheon, N. and Gus Handegord, Building Science for a Cold Climate. NRCC 39017, Ottawa, 1983.*

This section of the primer focuses on the most critical building science-related concepts and factors pertaining to mass timber buildings:

- the building as a system and the need for integrative design;
- the properties of wood and the influence of moisture;
- the combustibility of wood;
- the acoustical properties of wood.

The sections which follow highlight these factors. Their implications are more fully explored later in this primer.

Building as a System

Modern building science is premised on the building as a system concept - a relatively new development in building science that springs from modern systems theory and the application of building science principles to observed building performance and inhabitant behavior. It started in the 1960s with the introduction of a systems approach to building science practice. As innovation increasingly became the means to achieving new forms of architectural expression in the latter half of the 20th century, analysis and review of building failures indicated that traditional approaches to design were inadequate. This consequence was due to inappropriate adaptations of successful past precedents, or an unknowingly narrow analysis at the building component level for radical departures from technical norms. The building performance problems we continue to witness largely result because the behaviour of the whole building system is not considered – each element was designed independently without accounting for interactive effects.

The *building* as a system approach requires designers to explicitly and consciously consider the interactions between the primary elements comprising the system:

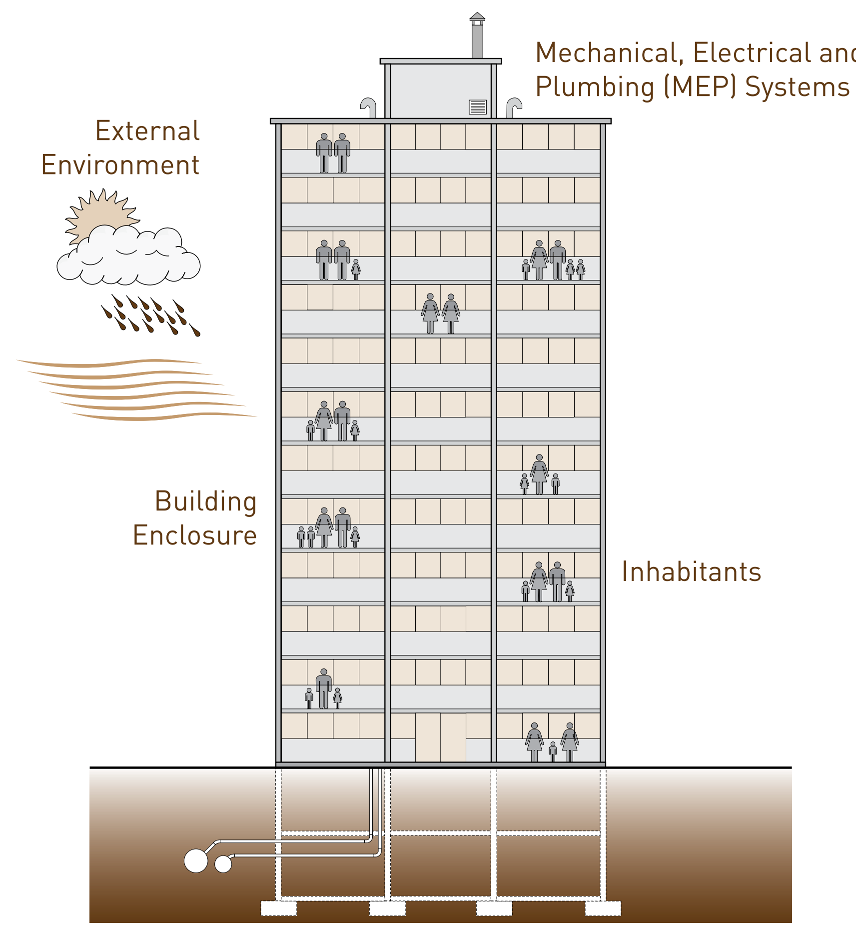
- the building enclosure (building envelope system for the control of heat, air, moisture and solar radiation) and its supporting structure;
- the inhabitants (humans and/or animals and/or plants, etc.);
- the building services (mechanical, electrical and mechanical (MEP) systems);
- the site, with its landscape and attached services infrastructure; and
- the external environment (weather and micro-climate).

Harmonization of these elements is the key to well performing buildings.

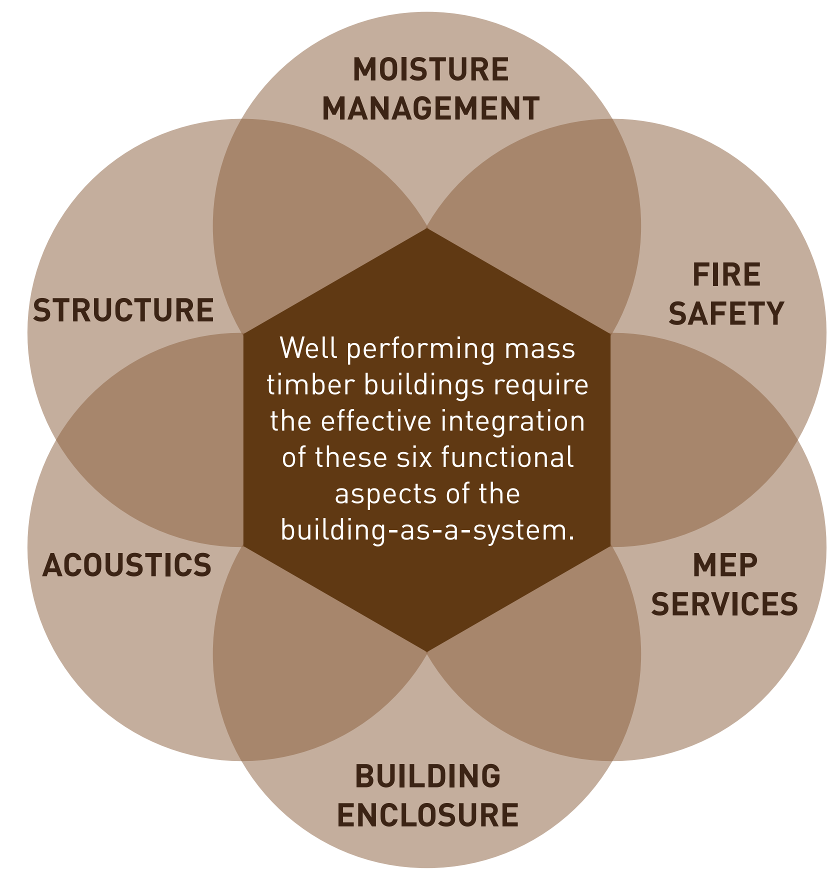
The building performance problems we continue to witness largely result because the behaviour of the whole building system was not considered – each element was designed independently without accounting for interactive effects.

Systems Integration

Within this primer, the focus of building science is premised on the *building as a system* approach that seeks to integrate moisture management, structure, fire safety, acoustics, mechanical / electrical / plumbing (MEP) services, and the building enclosure, also referred to as the building envelope. It also examines the various processes that deliver mass timber buildings: the procurement process; the integrated design process; the construction process; the building commissioning process; and the facilities management process. Building science goes beyond building physics and seeks to apply the scientific method and empirical techniques to improve every aspect of building design, construction, commissioning, operation and maintenance.



The building as a system model. *The interactions between the primary elements comprising the building as a system have led to a more effective means of achieving high-performance buildings. Instead of each design discipline carrying out responsibilities in isolation from one another, integrative design now involves all of the building project stakeholders and team members from the outset, guided by an explicit framework of performance objectives.*



Systems integration is the key to mass timber buildings. *Due to the organic nature of wood and its unique qualities and properties, these six functional aspects of the building-as-a-system must be appropriately integrated to achieve acceptable performance. Factors influencing economy, health, safety, comfort, efficiency, durability and resilience are highly interrelated in mass timber buildings and this requires coordination across the project team.*

Building Performance Requirements

The requirements for wall performance were outlined some half a century ago by Canadian building science pioneer Neil Hutcheon, and are still applicable to all enclosure systems and components.[3] Since Hutcheon's time, additional objectives have been adopted, such as energy efficiency, consideration of the environmental impacts associated with building methods and materials, and the need to provide secure and resilient buildings. The well-being of the inhabitants has also been elevated beyond basic levels of health and safety to embrace daylighting, natural ventilation and indoor environmental quality.

[3] *Hutcheon, N.B. CBD-48. Requirements for Exterior Walls. Canadian Building Digest #48, National Research Council of Canada, Ottawa, December 1963.*

Requirement	Parameters	
Structural Strength / Rigidity	• Dead and Live Loads • Wind Loads	• Seismic Loads • Thermal Effects
Control of Heat Flow	• Effective Thermal Resistance • Thermal Bridging / Air Leakage	• Window to Wall Ratio • Heat / Energy Recovery Efficiency
Control of Air Flow	• Stack and Wind Pressures • Airtightness	• HVAC Influences • Air Barrier / Internal Partitioning
Control of Moisture Flow	• Rain Penetration • Vapour Diffusion	• Air Leakage • Condensation Potential
Control of Solar Radiation	• Glazing Opacity / Emissivity • Solar Orientation	• Fenestration U-Value • Shading Devices
Control of Sound Transmission	• Airborne Sound	• Impact / Vibration
Control of Fire	• Fire Rating / Compartmentalization	• Combustibility / Flamespread
Durability	• Ultraviolet Degradation • Corrosion • Freeze / Thaw • Abrasion • Fatigue • Instability / Incompatibility	• Biological Attack (mold, insects, animals, plants) • Chemical Attack (soils, contaminants, pollutants) • Efflorescence • Subflorescents • Spalling
Resilience / Security	• Flooding Protection • Blast / Ballistic Protection	• Passive Survivability • Wind-Borne Projectile Protection
Economy	• Initial Cost • Maintenance Cost	• Operating Cost • Life Cycle Cost
Environmental Impacts	• Resource Depletion • Environmental Degradation • Reduction of Biodiversity	• Greenhouse Gases • Pollutants • Ecological Footprint
Building (Ease of Construction)	• Seasonality • Tolerances	• Coordination • Sequencing
Aesthetics	• Visual • Tactile • Daylighting	• Acoustic • Olfactory • Indoor Environmental Quality

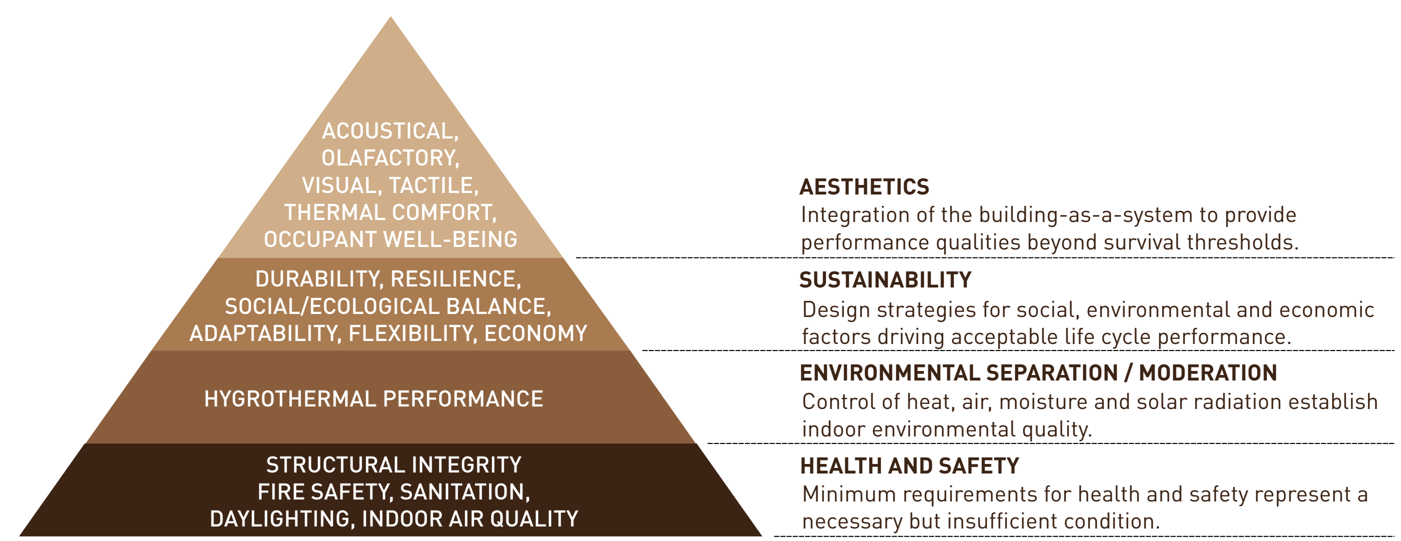
* Refer to CSA S478-2019 Durability in Buildings. This Standard provides criteria and requirements for the design of a durable building and its building elements and includes provisions for cost analysis and management and for a quality management program for the design, construction, operation, maintenance, repair, and renovation of a building and its building elements.

***Performance requirements for buildings have gone beyond simple shelter.** It is now recognized that buildings must be good for people and the planet and deliver sustainable life cycle performance.*

Contemporary high-performance buildings are expected to attain the triple bottom line of social, environmental and economic sustainability. In the face of climate change, this means healthful, efficient, durable and resilient buildings must also have a low embodied energy and carbon content, within an environmentally responsible ecological footprint. Passive measures are privileged over active systems, the enclosure is separated from the structure, critical components are accessible for maintenance and replacement, and enhanced levels of airtightness enable full control over ventilation through intentional openings such as operable windows and ventilation systems. The building as a system is deeply integrated through its form and fabric rather than its HVAC and control systems. It must also be designed to be flexible and adaptable over its life cycle. Modern buildings must now return to the traditional roots of architecture where the passive elements did almost all of the environmental moderation with only mild inputs from active systems fed by renewable energy sources. The era of industrialized buildings conditioned by high carbon, brute force heating and cooling systems is no longer sustainable environmentally and economically.

Due to the off-site digital fabrication of mass timber building components, it is necessary for designers to work collaboratively on multi-disciplinary teams and closely with the mass timber component manufacturer to develop a building system that is almost entirely manufactured offsite, and then delivered just in time to be rapidly assembled on site.

Unlike conventional buildings that are mostly constructed on site in a gradual fashion, mass timber buildings rely heavily on building information modelling (BIM) to completely resolve the structure, the enclosure, mechanical, electrical and plumbing services, fixtures and finishes. There are few if any field modifications that can be performed hence the integration of building science, design and construction must be completely orchestrated in advance. This is best accomplished through integrative design.



***Building Performance Hierarchy Based on Building Science Principles.** Health and safety considerations along with the provision of adequate shelter conditions form the essential basis for the building performance hierarchy. Sustainability aspirations must consider the entire building life cycle without compromising health, safety and shelter imperatives. As these three levels of performance are being addressed, care must be exercised to integrate aesthetics within the building as a system.*

Integrative Design

Integrative design is different than the integrated design process upon which it is based. Integrated design involves a design team assembled by the architect working collaboratively among the various disciplines to develop the building design progressively. Integrative design begins at the pre-design stage and involves the owner, the contractor/construction manager, the design team and additional specialty consultants. The owner's project requirements are set out against a framework that includes performance objectives such as sustainability, and resilience along with more conventional goals for social, environmental and economic performance. Integrative design seeks to find synergy and symbiosis such that key building elements and components serve to accomplish multiple objectives and become so deeply embedded they cannot be value engineered out of the project. In addition, integrative design includes commissioning, measurement and verification of performance – it goes far beyond certification labels that are often not confirmed by objective evidence.

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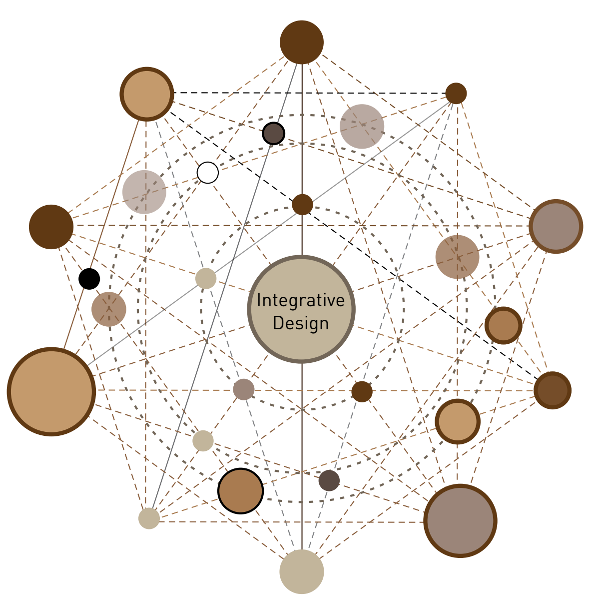
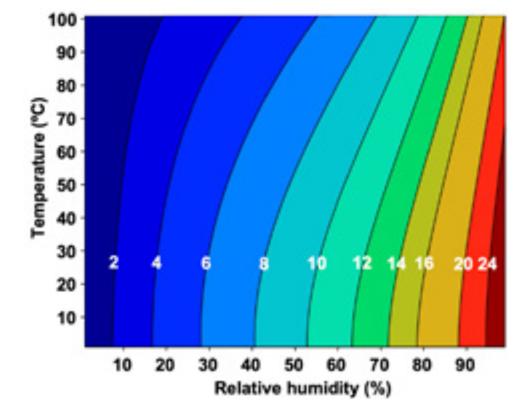


The integrative design process is premised on the building as a system concept. *Taking a life cycle perspective on building performance, integrative design relies on building science and building information modelling to address every aspect of the building as a system before the building is constructed. It is intended to produce a building that fulfills its social, environmental and economic aspirations by meeting or exceeding the corresponding performance objectives.*

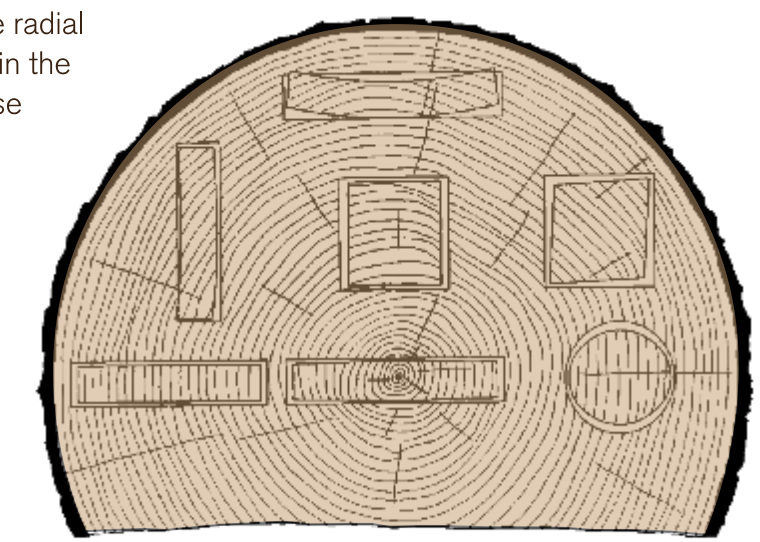
Properties of Wood and Influence of Moisture

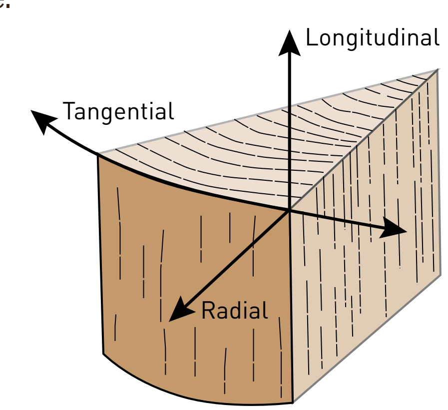
Wood is an adaptable building material with a large range of physical and mechanical properties across a large number of diverse wood species. It also has many unique properties that must be considered carefully when designing and constructing with wood. Wood is a hygroscopic material with anisotropic properties, and it is susceptible to moisture damage that may lead to staining, mold and decay. Yet evidence indicates that wood buildings can provide useful service for centuries when they are properly designed, constructed, operated and maintained. Hence it is critical to appreciate and take into account the unique properties of wood as a building material, in particular the engineered wood products that are used in mass timber buildings.

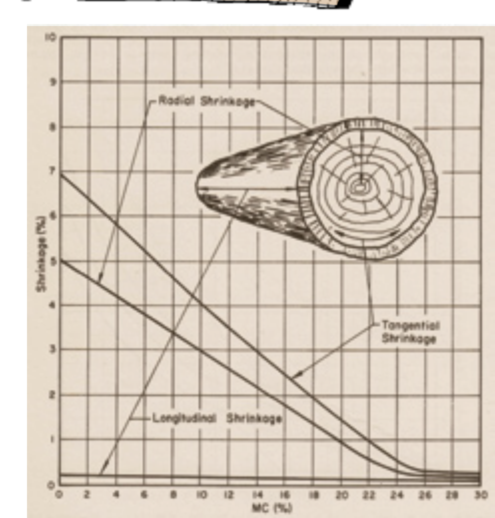
Wood is anisotropic and it exhibits different properties along three principal directions: longitudinal, radial and tangential. For example, dimensional stability differs significantly in each of the three axis directions. Dimensional changes between oven dry conditions and the fibre saturation point range from 0.1% to 0.2% in the longitudinal direction. Shrinkage in the radial direction can reach in the range of 5%, and in the range of 7% in the tangential direction. These different rates of shrinking and swelling can result in cupping, bowing, crooking, twisting and warping of the wood. The degree of dimensional change is dependent on many additional parameters, such as wood species, material and moisture content. When detailing the vertical structural elements in tall mass timber buildings, an unequal or excessive shrinkage may impact the alignment and elevation of critical building elements and may even compromise the integrity of the building enclosure.



Equilibrium moisture content of wood depends on temperature and relative humidity. *Equilibrium moisture content (EMC) is defined as that moisture content at which the wood is neither gaining nor losing moisture. EMC is more strongly determined by relative humidity than temperature, and the environments and elements to which it is exposed. This is why effective moisture management measures are critical. [Source: Forest Products Laboratory. 2010. Wood Handbook—Wood as an Engineering Material. General Technical Report FPL-GTR-190. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.]*







Wood is an anisotropic material. *Due to its growth structure wood exhibits different physical properties in three principal directions. The shrinkage of wood, like its structural strength, exhibit anisotropic properties. These properties inform the proper design, use and in-service behaviour of wood that make it very different from isotropic materials like steel. [Source: Keenan, Fred J. Limit States Design of Wood Structures. Morrison Hershfield, October 1986.]*

Moisture and Mass Timber Buildings

"Moisture is arguably the most important factor affecting the performance and service life of wood and wood products. Moisture affects the dimensional movement of wood and wood products; under certain conditions, moisture change can result in major dimensional change. The integrity and strength of adhered (bonded) wood products can be compromised by swelling-induced stresses that accompany wetting. Progressive deflection over time of wood members under load is influenced by moisture conditions, particularly by large repetitive fluctuations in moisture content. Mechanical connections between wood members can be compromised by exposure to elevated moisture conditions or by significant moisture cycling. It is widely recognized that the structural integrity of wood can be irreversibly degraded by biological attack. In some cases, biological infestation does not influence structural integrity but never-the-less influences serviceability. For many insect pests and all fungi, moisture conditions higher than the preferred in-service conditions are either required for infestation, or increase the likelihood of infestation." [4]

Wood is susceptible to moisture, and as a result, possibly to decay, producing structural damage and mold growth. Two conditions are necessary to support decay: (1) a moisture content between 40 and 80% and (2) a temperature between 21°C and 32°C. The critical relative humidity range for mold growth development is 80% to 85%, and the temperature range is 0°C to 50°C.

Various mass timber assemblies absorb and trap water and dry at different rates. Numerous factors can influence a material's resistance to water absorption, moisture movement and distribution. They include the wood species, dimensions, method of manufacturing, presence of internal spaces, exposure of end grains, adhesive and wax contents for composite materials, and, if applicable, surface treatment.

To prevent decay and mold growth from developing in a building enclosure, the most effective and practical method is to keep the wood dry through design details, specifically addressing heat, air and moisture movement through the building enclosure assembly, and on-site moisture management during construction. It is important to examine thermal bridges (e.g., foundation, window-wall, floor-wall, wall-roof) and transitions between materials to mitigate these risks.

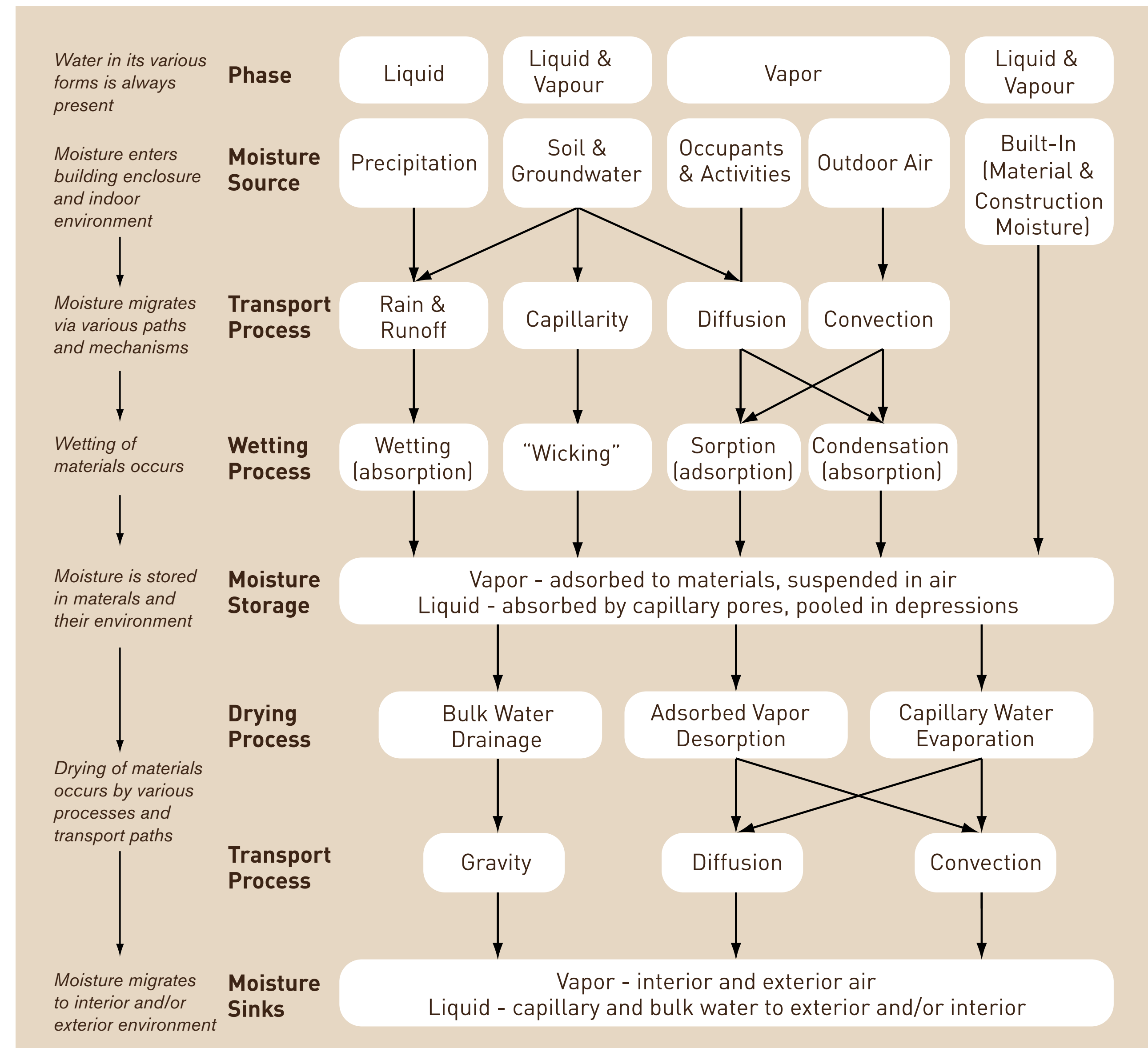
Modern building science originated from dealing with moisture problems in buildings. While the discipline has branched out extensively since then, a major contribution continues to be in the area of moisture management. Sophisticated hygrothermal analysis tools validated by laboratory and field measurements are now available to inform the design of effective building enclosures. Significant research efforts aided by testing and measuring materials and whole building systems make it possible for designers to manage moisture risks and make proper allowances for dimensional changes due to seasonal moisture content variations.

Wood is susceptible to decay by rot fungi if it is exposed to high moisture contents during long periods of time and it is therefore important to limit the duration of such periods. Critical points in outdoor wood structures are, for example, end grain surfaces in joints where water can get trapped after a rain. This has important implications for moisture management during construction where wood can remain very wet for days or weeks at a time unless appropriate moisture management measures are implemented.

Other considerations for managing moisture in buildings involve how incidents like accidental water leaks are addressed. The chart below represents how water behaves in buildings and each source, process and path must be carefully considered for all aspects of mass timber buildings.

From a practical perspective, it is important to devise strategies for managing moisture exposure, such as may occur during construction or afterwards during occupancy, for example when a water pipe bursts and causes severe wetting. Wood is a material that rapidly absorbs water but releases it much more slowly. It is critical to develop protocols for managing moisture exposure and to ensure that effective drying processes are not compromised by improper design or the selection and arrangement of materials in assemblies such as walls, floors and roofs. It is also very important that after a mass timber building is enclosed from weather, a period of drying is necessary to allow the wood to reach its moisture content equilibrium before the wood is encapsulated or a finish is applied.

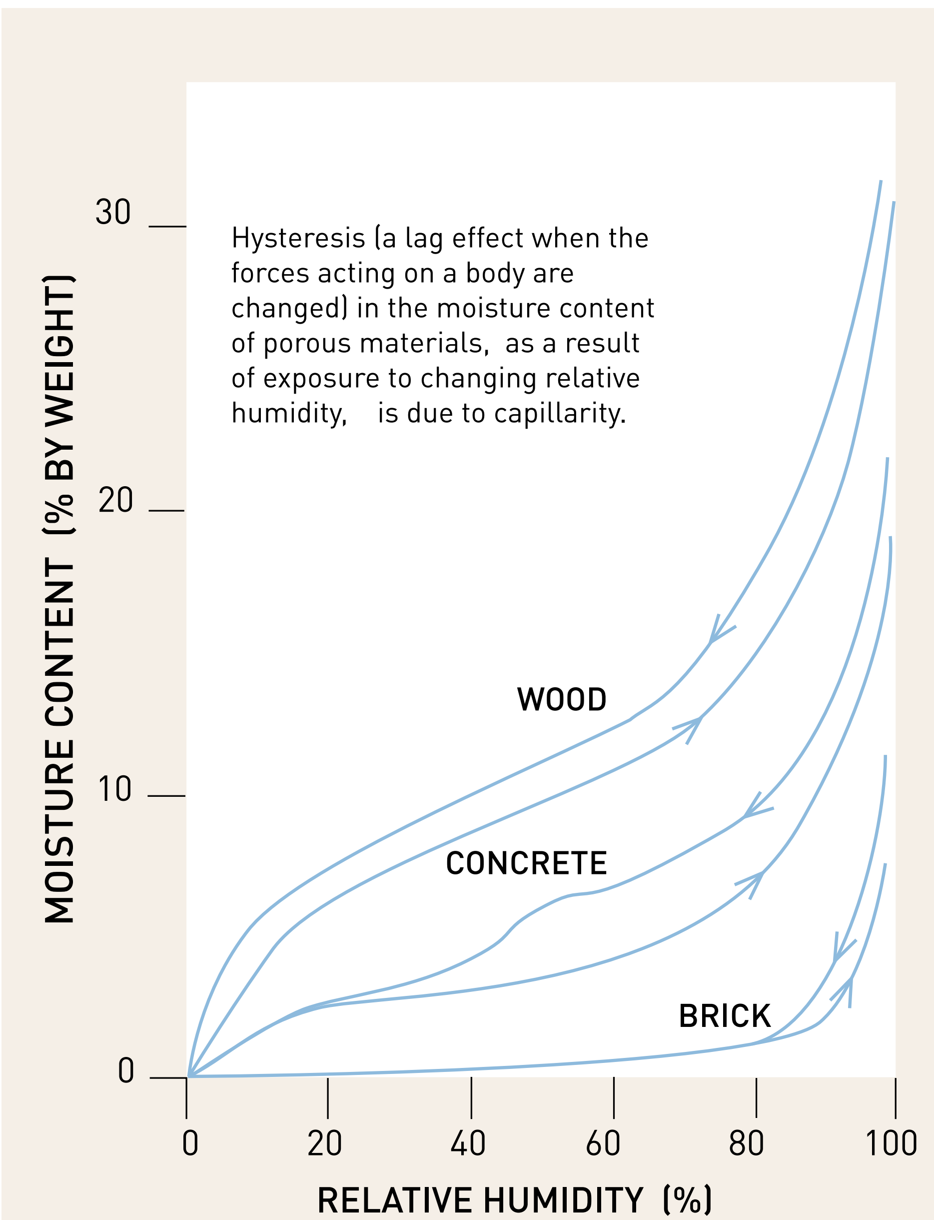
[4] Carll, Charles and Alex Wiedenhoeft. 2009. Moisture Related Properties of Wood and the Effects of Moisture on Wood and Wood Products. In Moisture control in buildings: The key factor in mold prevention, Chapter 4, pp. 54-79, H.R. Trechsel and M.T. Bomberg, eds. ASTM MNL 18-2. West Conshohocken, PA: ASTM International.



Moisture management is complex and challenging. *The chart above outlines moisture sources, processes, storage and sinks for buildings. The moisture management design challenge is to consider these explicitly and ensure all critical factors have been addressed during design, construction and ongoing operation and maintenance of the building. [Source: Straube, John. Moisture in Buildings. ASHRAE Journal, January 2002, pp. 15-19.].*

Wetting/Drying Potential

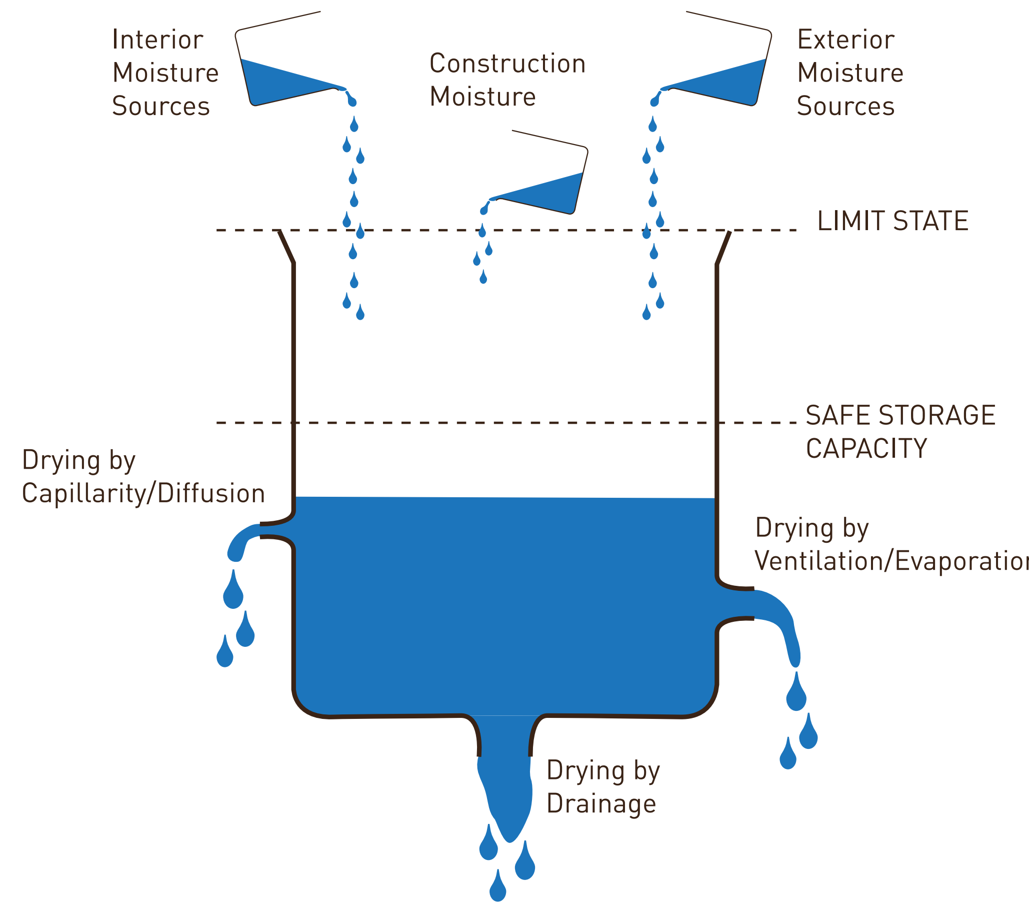
If it was easy to dry out wet wood, then nobody would store liquids in wood barrels. Most traditional building materials like brick, concrete and wood have a very high wetting potential and a low drying potential. But only wood is highly susceptible to damage and degradation from chronic exposure to moisture. It is always preferable to minimize or entirely eliminate the exposure of untreated wood to moisture for an extended duration. When the wetting of wood is unavoidable, then it is important to ensure that the drying potential exceeds the wetting potential in order to maintain a safe moisture balance.



Wood is a material that wets quickly but dries slowly. *The hysteresis observed in the wetting and drying curves for wood products indicate that wetting, both by bulk water and water vapour, is relatively rapid compared to drying. Water is retained in the capillaries of wood and these require extremely dry conditions to release the moisture accumulation. Unlike materials such as concrete and brick, wood durability is significantly affected by the frequency, duration and intensity of moisture exposure. [Source: Building Science for a Cold Climate. Neil Hutcheon and Gus Handegord, Institute for Research in Construction, 1983.]*

Moisture Balance

The concept of moisture balance is extremely important in wood buildings because of the susceptibility of wood to dimensional changes (shrinkage/swelling), decay and mold growth. Best practices ensure that the likelihood of exceeding the safe storage capacity of a wood material, component or assembly is highly unlikely, even under extreme conditions. In the event of unavoidable exposure to moisture and wetting, it is critical to provide effective means of drying to avoid damage and performance problems. Prevention is preferable to remediation.



The concept of moisture balance is more easily understood than achieved. By maintaining a balance between wetting and drying, moisture will not accumulate and exceed the safe storage capacity of the material. The extent and duration of wetting, storage and drying must always be considered when assessing the risk of moisture damage. It is also important to reconcile strategies for reducing the amount of wetting potential versus providing greater drying potential and storage.

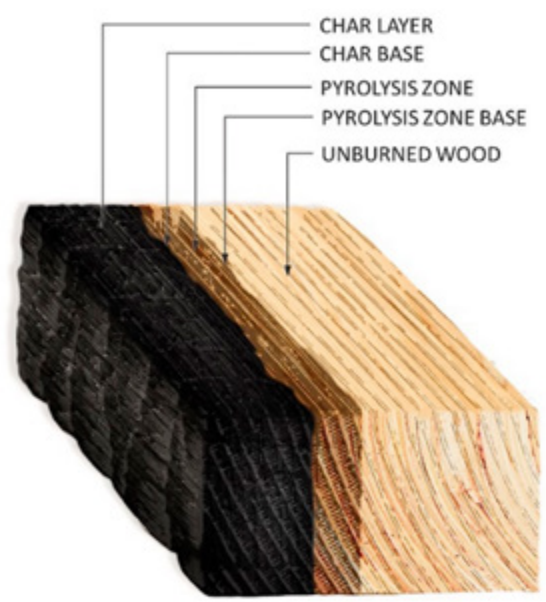
Moisture management in mass timber buildings is critical. *Calculating the moisture balance for materials comprising an enclosure assembly (wall, roof, etc.) is not a precise science because materials and workmanship are imperfect, and exposure to weather is difficult to predict. In the absence of a limit-states design approach to moisture management engineering, a prudent design practice is to provide multiple lines of defense, while ensuring it is easier for water to drain out of the assembly than to penetrate it.*

Wood and Fire Safety

Fire safety is a critical consideration in all buildings in order to protect the inhabitants, but also the building asset, its contents and adjacent properties. Because wood is a combustible material, fire safety is critical in the design and construction of a mass timber building. Although wood ignites at a comparatively low temperature to steel, it has the capacity to maintain its strength when exposed to high temperatures. Fire resistance is imparted by the thickness of the wood component and wood's propensity to char at a constant, predictable rate and preserve its structural integrity over prolonged periods of fire exposure. Two important factors for retaining the integrity of solid wood systems are the protection of the joints between components to avoid air and hot gasses from penetrating the assembly, and adequately tight joints between panels.

The thermal control layer of a building enclosure also can have an impact on fire performance. For example, non-combustible insulation materials like mineral wool must be installed carefully and in direct contact with wooden beams to ensure sufficient fire protection and performance. Empty spaces contribute to earlier fire exposure of wooden components in the event of a fire. Meticulous installation of insulation is critical in nominally empty attic areas, where frequently it is installed indifferently due to the non-occupied state of the roof space.

Controlling the spread of flame and smoke movement is also an important aspect of fire safety. Fire safety engineering is a branch of building science that is critical to the performance of mass timber buildings.



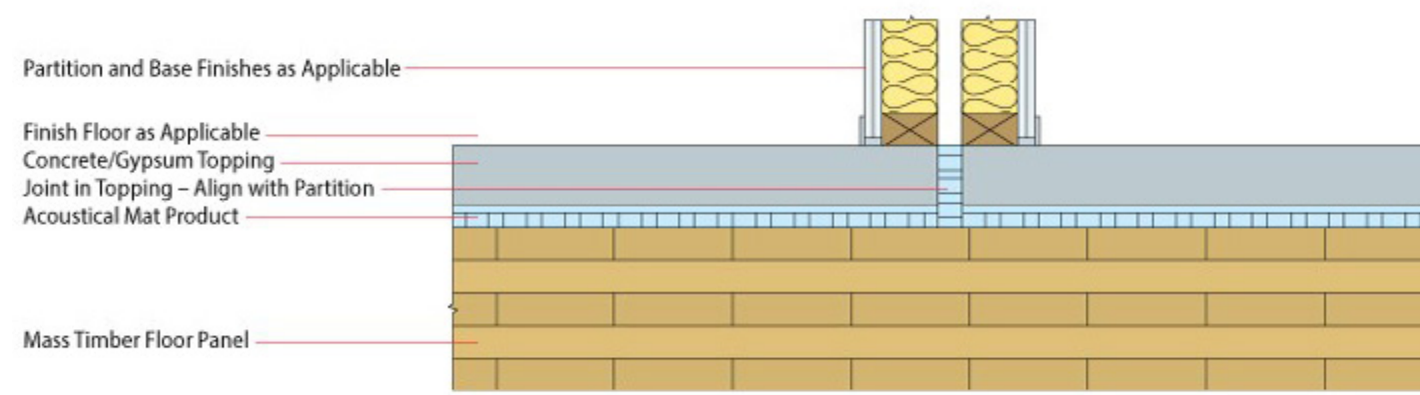
Mass timber is a combustible material that provides impressive fire safety. *During fires, exposed mass timber chars on the outside, which forms an insulating layer protecting interior wood from damage. Additionally, when the code requires mass timber to be protected with gypsum wall board, fire testing indicates it can deliver much higher than required fire ratings.*

Wood and Building Acoustics

The unique properties and characteristics of wood that make it so beautiful and desirable also underly the many constraints governing the design of mass timber buildings, especially sound and vibration control. The acoustical properties of wood and building assemblies, such as floors and walls that use wood for their structure, pose special challenges in the design and construction of mass timber buildings. Acoustical design must also take into account fire safety requirements and often these two aspects of performance are considered together. Building science has made tremendous progress in advancing the acoustical performance of mass timber buildings and designers have access to a growing body of testing data and predictive methods for satisfying sound control requirements in codes and standards.

Vibrations in mass timber buildings are also important to control because these are induced by occupants walking around in the building and can be a source of disturbance. Unlike impact sounds, vibrations induced by normal activities, such as persons walking, are typically below the threshold of hearing but can still be sensed through our bodies. Noise and vibration are common complaints from occupants, especially in multi-unit residential buildings.

Wood is a relatively light building material, so it does not perform well as sound insulation. Smooth, solid wood surfaces do not dampen sound, so wood alone is not a good absorption material. Wood conducts sound better in the longitudinal direction of the grain than perpendicular to it, explaining why wooden structures conduct sound and vibrations efficiently. For these reasons, acceptable levels of sound insulation in wood buildings are typically achieved by using multi-layered constructions.



Mass timber floors must incorporate additional materials to provide adequate sound control. *Mass timber floor assemblies are very efficient at transferring impact sounds and so acoustical control layers and/or floor toppings are needed to absorb impact sounds.*

Wood has a lighter mass per unit area ratio compared to concrete and masonry. Since materials with a higher mass per unit area generally perform better acoustically, mass timber buildings may present acoustical issues that may not be present typically in concrete or brick buildings. Solid wood floors and walls by themselves are not likely to meet acoustic performance requirements. Decoupling fasteners and the use of discontinuous mass timber components can improve acoustic performance, but this has implications for structural integrity. Quality craftsmanship, insulating and sealing are essential for good acoustic performance.

Synopsis

Looking around at many of the buildings that serve us, it is obvious that critical building science principles and best practices have not been implemented in their design, construction, operations and maintenance. This is evident from the numerous defects and performance problems they are experiencing, such as a lack of durability, high energy consumption and unacceptable indoor environmental quality. It is not surprising that a vast majority of post-occupancy evaluations of modern buildings reveal that their inhabitants are not satisfied with their performance. Recent research indicates that the ecological and carbon footprints of our conventional buildings are not sustainable. This awareness has promoted a rekindled interest in mass timber buildings.

"Architects, builders, and sustainability advocates are all abuzz over a new building material they say could substantially reduce greenhouse gas (GHG) emissions in the building sector, slash the waste, pollution, and costs associated with construction, and create a more physically, psychologically, and aesthetically healthy built environment. The material is known as, uh, wood." [5]

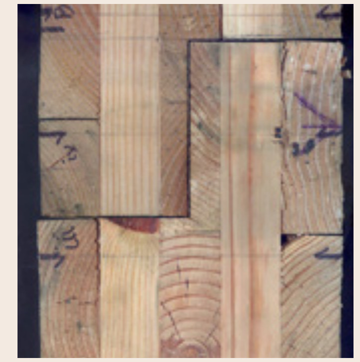
But the new generation of mass timber buildings is not like the traditional brick and beam timber buildings of over a century ago. Today's mass timber buildings aspire to be truly high-performance buildings with all the warmth and charm of their traditional counterparts, but without the unsustainable life cycle footprints.

[5] *The hottest new thing in sustainable building is, uh, wood.* David Roberts, January 15, 2020. https://www.vox.com/energy-and-environment/2020/1/15/21058051/climate-change-building-materials-mass-timber-cross-laminated-clt

The unique properties and characteristics of wood that make it so beautiful and desirable also underly the many constraints governing the design and construction of mass timber buildings.

It is crucially important for those who are interested in promoting mass timber buildings to realize that unlike buildings constructed with more conventional methods and materials, mass timber buildings are less forgiving because they are not wrapped in a massive masonry enclosure that acts as a hygric buffer to manage moisture. They are not made from timbers that came from old growth forests possessing superior wood DNA imparting exceptional strength and durability. They are being constructed at a time when societal expectations for the social, environmental and economic performance of buildings are rapidly escalating – simply copying the old typologies is unacceptable.

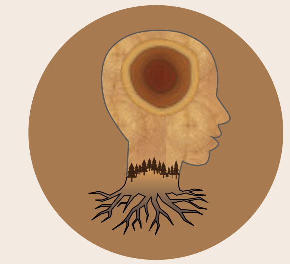
For these reasons, the application of building science to mass timber building technology is critical. In the same way that today's computers and smart phones depend on the discipline of computer science, the resilient and sustainable life cycle performance of today's mass timber buildings demand the application of building science, in all of its aspects, at each stage in the life cycle from pre-design, through design, construction and commissioning, to operations and maintenance. The sections of this primer that follow are intended to help integrate 21st century building science within mass timber building technology.



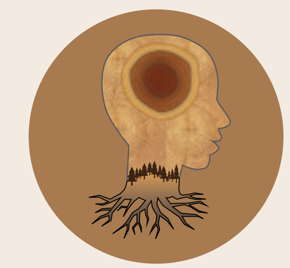
Mass timber performance problems are mostly moisture related. *The SMART CLT project, led by Oregon State University (OSU) Assistant Professor Mariapaola Riggio and funded by the TallWood Design Institute (TDI), recently demonstrated that exposure to rain, followed by simulated interior conditions, can result in higher levels of checking and other stress-relief discontinuities, particularly at the edges where connections would occur.*

Mass Timber and Building Science

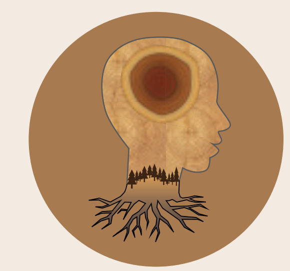
- Building science is key to well performing mass timber buildings that are safe, healthful, durable, efficient and resilient.
- Effective moisture management measures based on building science principles and best practices are essential to achieving sustainable life cycle performance.
- The building as a system concept provides an evidence-based framework for the application of building science principles.
- The integration of structure, building enclosure, moisture management, fire safety, acoustics and mechanical, electrical, plumbing (MEP) services drives the integrative design process.
- The integrative design process aims to satisfy a hierarchy of building performance objectives that extend across the entire life cycle of the building.
- Innovation in all aspects of mass timber building technology hinges on the application of building science knowledge combined with evidence-based design thinking.



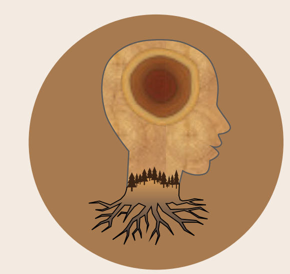
Building Science Info
Click on this icon to download a listing of building science sources of information and learning resources.



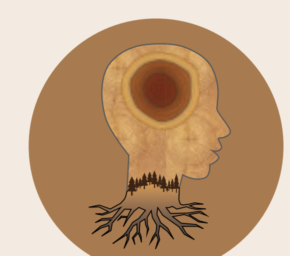
Building Science Performance
Click on this icon to download information about whole building system performance concepts, indicators and metrics.



Early Stage Design
Click on this icon to download resources related to early stage design processes for the integration of the building as a system.



M&V and BPE
Click on this icon to download resources related to measurement and verification and building performance evaluation.



Carbon and Climate
Click on this icon to download information about research and analysis related to embodied carbon, energy and climate change mitigation.

3 Mass Timber Building Technology

Building with wood is not a new idea. But making big and tall buildings out of engineered wood products is a relatively recent innovation. The use of wood composites dates back several millennia, but it was not until the 20th century that engineered wood products were introduced. Up to that time, building with wood was confined to either light wood-frame construction for housing and small buildings, or heavy timber construction that relied on old growth forests for massive timber columns, beams and planks. The alternatives to wood construction were load-bearing masonry structures, but often even these used wood for roofs and interior finishes. Traditional wood buildings often employed wood cladding materials such as boards, shakes and shingles, but masonry enclosures from brick and stone were also common. With the advent of the Industrial Revolution, steel and concrete displaced wood for most large building structures that continued to feature masonry enclosure systems, which were subsequently replaced by highly glazed façades in commercial office buildings.

The 1970s energy crisis marks the beginning of a growing interest in building performance. What started with a movement to improve the energy efficiency of buildings for largely economic reasons inadvertently led to "sick building syndrome" resulting from energy conservation measures that compromised indoor air quality, such as the elimination of operable windows, combined with enhanced envelope airtightness and reduced mechanical ventilation rates. The widespread use of building materials that off-gassed contaminants like volatile organic compounds (VOCs) was identified as an unhealthy practice, and mold in buildings caused by enclosures that could not adequately manage moisture resulted in widespread litigation. By the 1980s, the *building as a system* concept emerged among the building science community as a means of integrating building technologies to economically deliver buildings that are safe, healthful, comfortable and energy efficient. In parallel with this development was a growing awareness about the "greenhouse effect" and the numerous environmental impacts associated with buildings, such as resource depletion, environmental degradation, reduction in biodiversity and climate change. The social and psychological impacts of buildings on their inhabitants were also being researched as more and more people lived in cities.

Over the past half-century, a new consciousness has emerged, confirmed by scientific evidence, that we must change how we design, construct, operate and maintain our buildings. Whole building life cycle assessment (WBLCA) is revealing the unsustainable ecological footprint of conventional, industrial-era building methods and materials. This has given rise to a renewed interest in not just wood, but many types of biologically-based building materials to promote more sustainable buildings.

In the 21st century, mass timber building technology transcends wood as simply a material consideration by itself. Digital design and fabrication, building information modelling, procurement and construction have become integral to mass timber building technology transforming it into a disruptive force that is changing every aspect of today's building industry. The assembly line approach to design, where each discipline sequentially adds more information to architecture drawings, has been replaced by an integrative design paradigm. The owner, the architect, the engineering and specialty consultants, the mass timber supplier and the contractor/construction manager work together as a vertically integrated design team. This process results in as much of the building as practically possible being fabricated off site and then delivered just in time to be assembled on site by specially trained workers. The traditional role of trades is significantly streamlined and the finished product comes with a building information model to guide facilities management. Mass timber buildings have become more like aircraft, automobiles and computers – highly sophisticated, manufactured products accompanied by complete technical documentation. Manual craft has been replaced by digital craft that reliably fulfills its performance promise while providing the natural warmth of wood unlike any man-made material.

Over the past half-century, a new consciousness has emerged, confirmed by scientific evidence, that we must change how we design, construct, operate and maintain our buildings.

We continue to witness a growing interest in mass timber for a number of significant reasons.

Speed of Construction: Prefabricated structural components can be manufactured off site, decreasing overall construction time and labour costs.

Environmental Impact: Wood is a renewable carbon-sequestering resource. Mass timber from sustainably managed forests can help reduce our carbon footprint.

Safety and Performance: Mass timber can be engineered to provide superior fire safety and seismic resilience.

Reduced Structural Weight: Lighter than concrete or steel construction, mass timber allows foundations to be reduced in size, saving construction time, material cost, and CO_2 emissions due to less concrete.

Thermal Performance: Unlike steel and concrete, wood is a natural insulator and has less potential for thermal bridges reducing the effectiveness of insulation.

Biophilic Benefits: Exposure to wood contributes positively to human well-being. Exposed mass timber is aesthetically pleasing and saves on interior finishes since the structure is also the finish.

T3 Bayside by 3XN Architect, Denmark. *This proposed development near Toronto's waterfront seeks to create a campus of two office buildings using mass timber building technology. According to the architects, the breathable and absorbent properties of wood allows for the release of moisture to ensure a naturally regulated, healthy indoor environment. (Hines)*

Building with Wood

Wood is one of the oldest and most versatile building materials. It can fulfill the role of structure, cladding and interior finish, and it was a common building material in most of North America prior to the 1800s. In Canada, wood construction can be grouped into two main categories: (1) light frame construction; and (2) mass timber construction. Light frame construction, also known as stick-built, is used in some 90% of new homes in Canada. This type of wood construction uses dimensional lumber (e.g., 38 mm x 89 mm (2" x 4"), 38 x 140 mm (2" x 6"), etc.), to build structural framing systems for floors, walls and roofs, that are reinforced with wood sheathing panels. Mass timber construction, also referred to as heavy timber construction, can be subdivided into two categories: (1) large dimensional solid sawn timbers and logs, or (2) engineered wood products, comprising small dimensional lumber, veneers, strands or fibres attached together using adhesives, screws, nails or dowels to form a composite material. In common speech, heavy timber and mass timber are used interchangeably. However, in this document, mass timber refers to composite engineered wood products in the form of solid members or panels of wood, engineered for consistent physical properties such as strength.

Canadians have a tradition of building housing with wood. *Light wood-frame house construction continues to represent the predominant single-family housing typology across Canada. Recently, the demand for mid-rise and high-rise multi-unit housing has increased due to the scarcity and rising land costs in most urban regions of Canada. (CMHC)*

Wood buildings represent a long-standing Canadian tradition that precedes the European colonization of Canada, and wood buildings continue to dominate Canada's housing market. Canadians pioneered low energy wood-frame housing starting with the Saskatchewan Conservation House in the 1970s and went on to develop the R-2000 Program for energy efficient homes in the 1980s that featured high levels of insulation, airtightness and heat recovery ventilation systems. The Passivhaus movement stemmed from this pioneering work and continues to rely on wood as a structural building material. Wood-frame house construction is not just confined to single-family detached housing. A large variety of attached, semi-detached and row housing typologies have been constructed across Canada over the years and continue to make a significant contribution to annual housing starts across our country.

Mid-rise, multi-unit residential buildings (MURBs) are also commonly constructed from light-frame wood construction. Mid-rise light-frame wood construction is more than building taller with basic 2×4 or 2 x 6 framing and wood sheathing panels. Innovations in wood science and building technology have resulted in superior quality engineered wood products and off-site, prefabricated components are expanding the options and choices for constructing safe, durable mid-rise housing.

Up until less than a decade ago, light-frame mid-rise housing was confined to a maximum of four storeys in Canada. Some provincial jurisdictions forged ahead with an increase to the allowable number of storeys, but it was not until the 2015 edition that the National Building Code of Canada (NBC) permitted the construction of six-storey residential, business, and personal services buildings using traditional combustible construction materials. The NBC changes recognized the advancements in wood products and building systems, as well as in fire detection, suppression, and containment systems that had been successfully implemented.

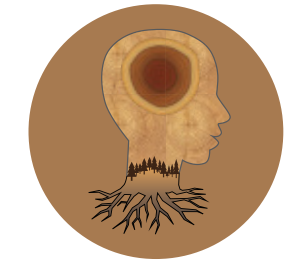
Canadian building codes now permit wood-frame construction up to 6 storeys in height. *This has allowed for the relatively economical development of mid-rise multi-unit housing in traditional wood building materials and methods. But now mass timber alternatives to wood-frame offer competitive alternatives with faster erection times. (MFE)*

More recently, mass timber building technology that was largely pioneered in Europe has made its debut in Canada and the United States. While mass timber has not been deployed widely in single family detached, semi-detached and row housing, it holds great potential for transforming mid-rise and high-rise multi-unit residential building developments. [6]

[6] *Refer to a report and case studies on Emerging Building Systems and Wood Innovation developed by BC Forest Innovation Investment. https://www.naturallywood.com/resources/emerging-building-systems-and-wood-innovation*

Mass Timber Materials Palette

Before providing an overview of mass timber building typologies, it is helpful to become familiarized with the eight engineered wood products that comprise the mass timber materials palette.



Mass Timber Product Palette
Click on this icon to download a folder containing detailed information about each of the eight mass timber building materials.

Cross-Laminated Timber (CLT)
CLT is an engineered product consisting of layers of dimension lumber (usually three, five, or seven) oriented at right angles to one another and then glued to form structural panels.

Glue-Laminated Timber (Glulam)
Glulam is composed of dimension lumber pieces bonded together with durable, moisture-resistant adhesives. The grain of all laminations runs parallel with the length of the member.

Dowel-Laminated Timber (DLT)
DLT is a mass-timber panel product created by stacking dimension lumber together on its edge, friction-fit together with hardwood dowels. DLT is the only all-wood mass-timber product with no metal fasteners, nails, or adhesives.

Laminated Veneer Lumber (LVL)
LVL is made of dried softwood veneers, glued together so that the grain of each veneer is parallel to the length.

Nail-Laminated Timber (NLT)
NLT is created by stacking dimension lumber together on its edge and fastening it together with nails or screws. It can be site built or fabricated in panels off site.

Mass Plywood Panel (MPP)
MPP, sometimes dubbed "super plywood," consists of several layers of wood veneer glued and pressed together in staggered alternating directions of grain.

Laminated Strand Lumber (LSL)
To make LSL, thin strands of wood are aligned parallel to the length of the member, glued under pressure, and then machined to consistent finished sizes.

Parallel Strand Lumber (PSL)
PSL is manufactured from veneers that are clipped into long strands, laid in a parallel formation, and then bonded together with an adhesive to form the finished structural member.

Mass timber building materials are innovative. *Unlike building materials such as brick, steel and concrete, engineered wood products represent enormous advances in materials technology enabling specialized applications while offering consistent physical properties that ensure predictable performance and material economy. (Perkins and Will)*

Mass Timber Construction Typologies

Canada's first National Building Code, published in 1941, allowed heavy timber structures up to seven storeys or 22.5 metres in height. This height was decreased to four storeys in 1953 following the introduction of a risk assessment approach to code development, associated with building volume, construction type and fire load. As a result of the extensive application and acceptance of fire simulation modelling, advancements in wood products and building systems, as well as in fire detection, suppression, and containment systems, the height restriction of wood buildings was revised in the 2015 National Building Code of Canada (NBCC) from four to six storeys. To obtain provincial building code authorization for tall mass timber construction that exceeded six storeys, owners and developers had to pursue "alternative solution" provisions in the building code, whereby expert evidence had to demonstrate that a proposed design meets all regulatory performance requirements.

The 2020 NBCC will include the use of mass timber construction for up to 12-storey structures not exceeding 42 metres in height. The 2020 NBCC refers to encapsulated mass timber construction (EMTC), a construction method using engineered wood products which have a fire and strength rating. The most common mass timbers are cross-laminated timber (CLT), nail-laminated timber (NLT) and glulam. Encapsulated means the mass timber is encapsulated by a gypsum wallboard or other non-combustible materials, such as concrete topping, to resist fire spread. Under the new ratings, EMTC buildings would use mass timber with a minimum thickness of 96 mm and a minimum 50-minute fire rating. These regulatory changes along with environmental, economic, and societal influences are behind a renewed interest in mass timber building technology.

This section of the primer is intended to provide an overview of contemporary mass timber building technology. There are essentially four basic types of mass timber buildings being currently constructed in Canada based on their structural systems:

- Post and beam;
- Post and platform (a.k.a. post and plate);
- Mass timber panels; and
- Braced mass timber frame.

There also exist a large number of hybrid types developed from variations and/or combinations of one or more of the basic mass timber types. Mass timber buildings often incorporate more traditional wood building materials, like lumber, timber, plywood and structural insulating panels (SIPs). It is also possible to combine mass timber technology with other types of materials and systems such as reinforced concrete and structural steel. The intent here is to briefly highlight the contemporary typologies and discuss their suitable applications, advantages and disadvantages.

Post and Beam

This type uses a framework of mass timber posts and beams to support wood floor and roof panels made from cross laminated timber (CLT), dowel laminated timber (DLT) or nail laminated timber (NLT). Large spans similar to steel and reinforced concrete structures are possible, but this requires relatively large columns, deep beams, thicker panels and an increase in the floor-to-floor heights. Optimal columns grids are in the range of 4 to 6 metres for most types of building uses and occupancies.

The post and beam typology is suitable for a diverse range of building uses from agricultural and light industrial to commercial, institutional and residential occupancies. A major advantage of mass timber post and beam is that the columns, beams and floor/roof decking materials can be sourced from a number of different suppliers, depending on availability. The construction process is not quite as time efficient as other mass timber building typologies because of the larger number of members and connections.

Post and beam mass timber evokes depth and warmth. *Modern buildings with flat painted ceilings are not as expressive and inviting as exposed wood columns, beams and decking. (Albina Yard, Portland, Oregon by LEVER Architecture.)*

Four storey mass timber post and beam mixed use building. *Located in Skellefteå, Sweden, this building features three storeys of parking on top of the ground level stores. The parking deck floors are covered with polyurethane to protect the cross-laminated timber decking from absorbing water. Generous overhangs and an open screen façade for ventilation ensure the drying potential exceeds the wetting potential on an annual basis to maintain a safe moisture balance. (Setra Group)*

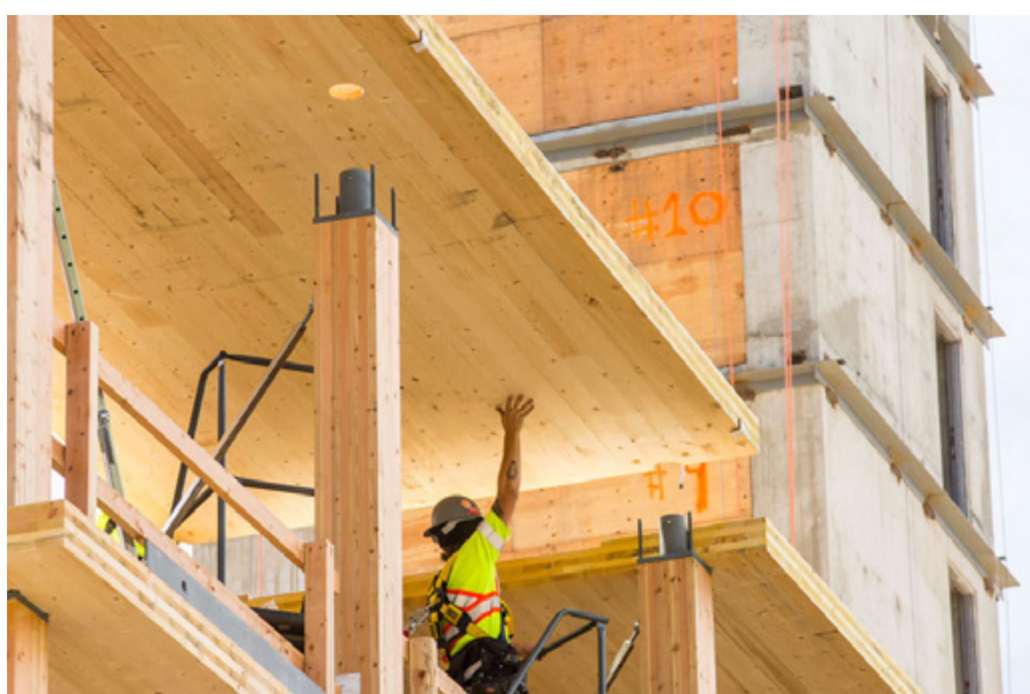
Mass timber post and beam with exposed wood differentiates this innovative project from a typical white-box condo. *The Carbon12 mixed-use condominium building in Portland, Oregon employs mass timber, glued laminated timber (glulam) and CLT (cross-laminated timber) in its structural system. (Kaiser + Path)*

The T3 project in Minneapolis, Minnesota is a seven-storey, commercial building. *Post and beam glulam frame with nail laminated timber (NLT) panels recreate the ambience of 19th century brick and beam buildings. (Michael Green Architecture)*

Post and Platform (a.k.a. Post and Plate)

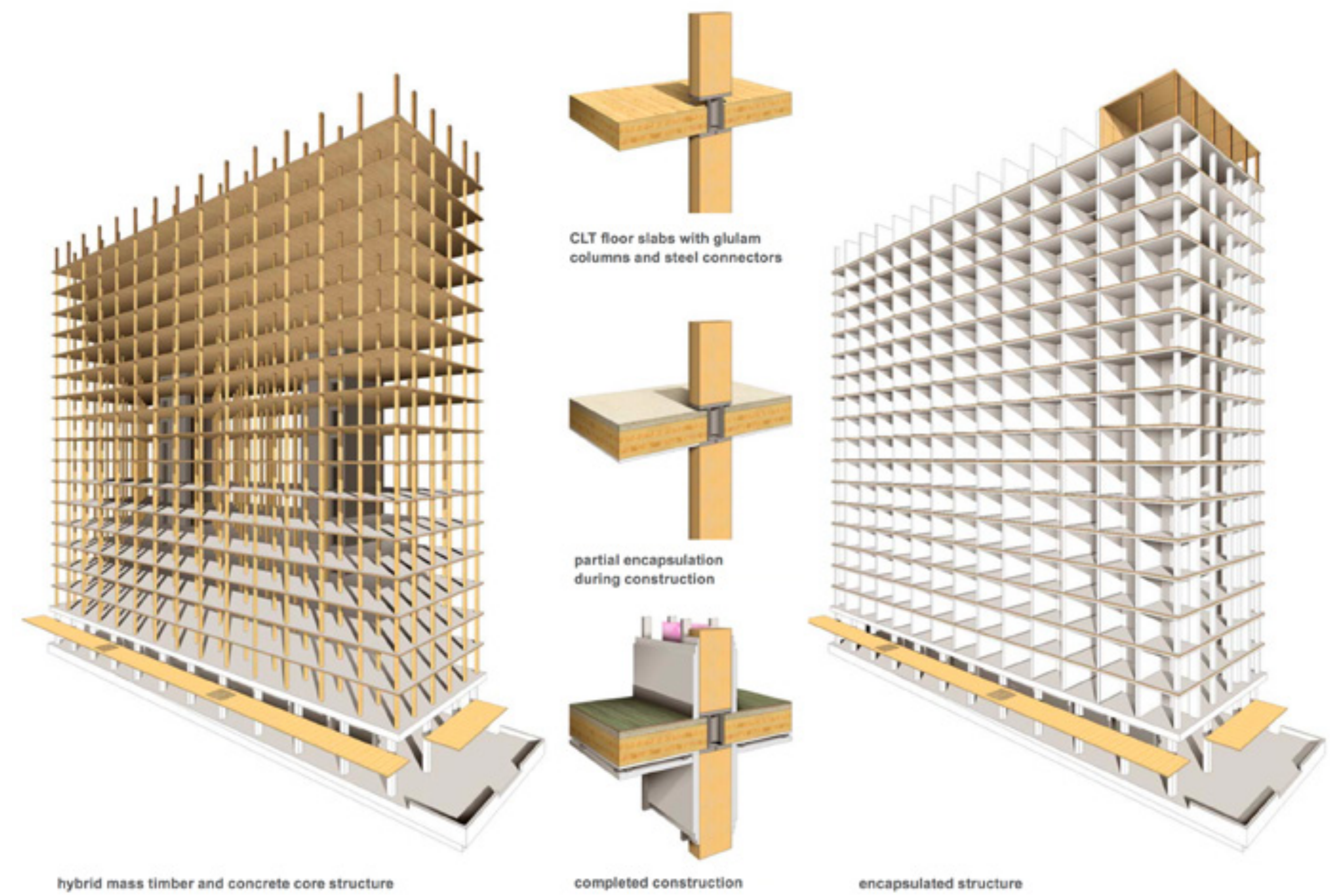
For buildings where a regular, repeating floor plate is suited to the building's purpose, the post and platform typology is a proven approach that is time and cost effective. As with all mass timber buildings, the integration of mechanical, electrical and plumbing services requires a completely resolved layout so that all penetrations in the CLT panels are made during fabrication prior to delivery on site. Post and plate systems do not provide sufficient lateral resistance on their own. Special attention must also be paid to prefabricated, modular enclosure systems so their installation can closely follow the structural erection to help manage construction moisture.

__Post and plate systems are efficient in terms of time and size of work force needed to erect the structure.__ The logistics for the delivery, on-site storage and handling of mass timber components are critical. (Naturally Wood)



__Building information modelling (BIM) is essential for mass timber buildings.__ Digital fabrication eliminates the need for on-site cutting and drilling of mass timber components. Workers focus on assembly of a precision structural system. (ArchDaily)

One of the major disadvantages, but also advantages, of post and plate systems is that they are proprietary. Unlike conventional building systems where a number of equivalent components from competing suppliers may be selected, proprietary systems have the disadvantage of not giving owners and constructors latitude to make substitutions in order to save on costs. But this is also a major advantage because the mass timber supplier can provide design assistance to the project team at the early stages of design without being concerned the investment in technical support may not pay off in sales. Time, labour, material and construction logistics can all benefit from the involvement of a proprietary system supplier at the early stages of design within an integrative design process. [7]



Student residences, such as Brock Commons, are well suited to take advantage of smaller column grid spacings that enable the elimination of beams to support the cross-laminated timber floor panels. T*his saves time and materials but also enhances daylighting without having to increase floor-to-floor heights to compensate for downward projecting beams. Concrete cores used in the Brock Commons project are one type of lateral force resistance system for post and plate buildings. Shear walls and lateral bracing are alternatives, but they obstruct the outer perimeter for access to light and air. (Acton Ostry)*

[7] *Information about the innovative design and construction of the Brock Commons project is available at: https://www.naturallywood.com/emerging-trends/tall-wood/brock-commons-tallwood-house*

Mass Timber Panels

The mass timber panel building typology takes advantage of cross-laminated timber as its primary structural building material. CLT panels serve as floor, wall and roof structural elements that are strategically combined with glulam beams and columns to achieve diverse architectural expressions.

Mass timber panel systems are well suited to multi-unit housing projects. *The Origine is a 12-storey, 92-unit timber tower situated on a ground level concrete podium. It features numerous innovations including a lateral load resistance system using cross-laminated timber panels. (Cecobois)*

Lateral load resistance is a challenge for mass timber buildings that increases with building height. Recent innovations in mass timber structural engineering have developed methods where shear walls and floor diaphragms are connected to gravity load bearing elements to provide efficient lateral load resistance systems. [8]

Fire safety in mass timber panel buildings primarily involves the encapsulation of the cross-laminated timber panels to achieve the same levels of fire-resistive construction required in building codes. Acoustic separation between occupancies can often be more challenging than fire safety since the CLT panels are prone to transmitting impact sounds. Experience indicates that an integrated approach to fire safety and acoustics should be adopted by the design team to arrive at cost-effective solutions with multi-functional attributes that address fire and sound phenomena.

Mass timber panels save construction time. *The wooden structure for the Origine project was erected in just four months. It was estimated that about a 25% savings in total project construction time resulted from selecting the mass timber panel structural system. (Cecobois)*

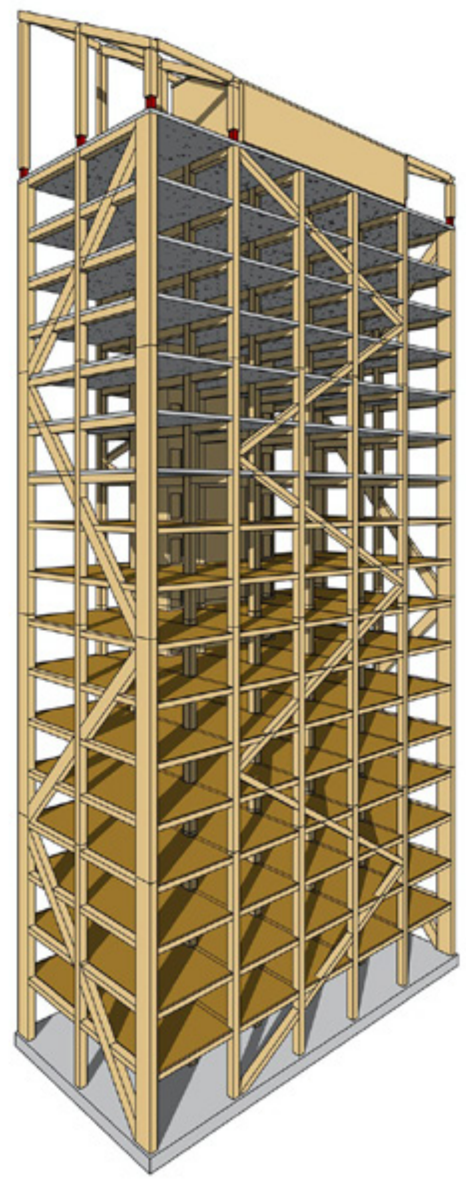
The major advantage of the mass timber panel building typology is the enhanced design freedom and architectural expression compared to post and beam, or post and plate systems that require a regular grid and repeating elements to achieve the same level of technical and economic feasibility. On the other hand, a significant disadvantage is that in order to satisfy requirements for fire safety and acoustics, most of the wood structural elements have to be encapsulated, and/or insulated/isolated. The relatively small areas of exposed wood that are permitted are often less than the expectations for the expression of wood's warmth and beauty that initially motivate the choice to build with wood.

Mass timber panels are proprietary systems and it is important to recognize the need to work closely with a manufacturer/supplier starting at the pre-design stage. Until such time as mass timber panel technology is as standardized as dimensional lumber and plywood products, choosing this approach involves a continuous commitment and relationship between the designer, the constructor and the manufacturer/supplier. This is often a beneficial relationship since the pooling of knowledge and experience can improve the quality of design and the time and cost of construction.

[8] Refer to the Origine case study for detailed information about structural engineering innovations for mass timber panels. https://www.nordic.ca/en/projects/structures/origine

Braced Frame

The braced frame mass timber building typology is a variation on post and beam that utilizes diagonal bracing to create a space frame that is able to adequately resist lateral forces. The bracing helps to avoid the need to employ shear walls and elevator/stair shafts to provide lateral load resistance.

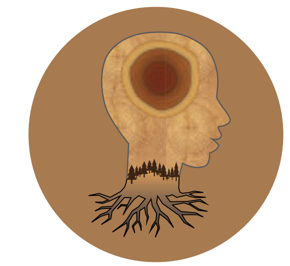


Braced frames avoid the need for shear walls and/or moment connections. *Mjøstårnet in Brumunddal, Norway is an 85.4 metre-high tower. At the time of its completion in March 2019, this was the tallest all-timber tower in the world. It does not rely on shear walls or reinforced concrete elevator/stair shafts to resist lateral forces. The Mjøstårnet building's timber structure consists of a braced frame made from glue laminated timber (glulam) columns, beams and diagonal braces. Floors are not structurally connected to the frame and elevator shafts are made entirely from cross laminated timber (CLT) panels. (Voll Arkitekter)*

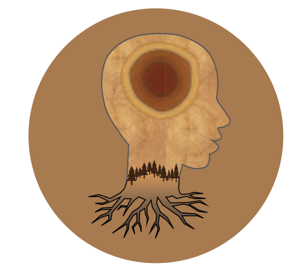
In tall mass timber buildings, a lateral force-resisting system (LFRS), also termed a lateral load-resisting system (LLRS), represents a structural design challenge. Braced timber frames are efficient lateral load resistance systems in buildings where large open spaces are required, and the more commonly used timber shear wall systems cannot be utilized. Braced timber frames allow for flexibility in the design and use the wood in its strongest direction - parallel to grain in tension or compression.

Braced frames are ideally suited to taller and more slender buildings and leave the interior floor plates open to more flexible space plan arrangements. But the diagonal bracing may obstruct views through windows and be perceived as intrusive by inhabitants. However, in high seismic zones braced frames may offer the most efficient and economical means of providing an adequate lateral force-resisting system for many types of buildings.

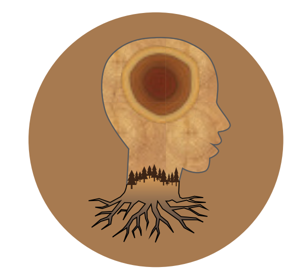
As noted earlier, mass timber buildings may incorporate one or more of these basic typologies and combine them with other types of building components to create highly versatile hybrid building systems. A number of technical resources pertaining to mass timber building technology are available for download under the respective icons listed on this page.



Mass Timber Structures
Click on this icon to download a folder containing a primer on mass timber structures appearing in Canadian Architect by structural engineer David Bowick.



Mass Timber Handbooks
Click on this icon to download a folder containing a variety of handbooks that provide information about wood, mass timber materials and whole building systems.



Mass Timber Case Studies
Click on this icon to download a folder containing case studies describing a wide variety of mass timber building projects.

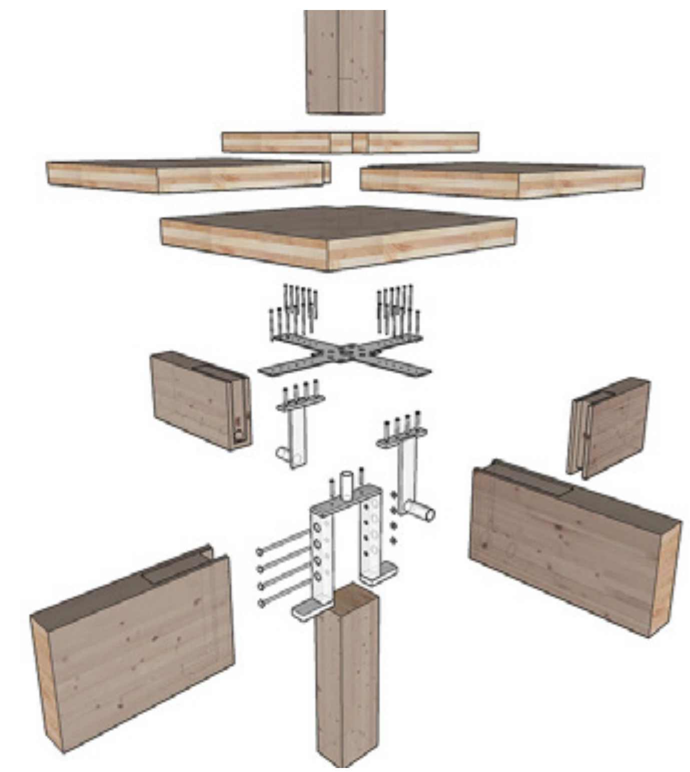
Mass Timber Connectors and Fasteners

In mass timber buildings, the joints of connecting members are the weakest links of a structure. Traditionally, there are two types of mechanical fasteners used for timber connections. The first type are dowel type fasteners and include nails, screws, staples, bolts and dowels. For these fasteners, load transfer causes bending of the dowel, and bearing and shear in the timber along the shank of the dowel. The second type of fasteners are split rings, shear plates and punched metal plates where the load is transferred to the bearing at the surface of the timber members. There are many proprietary connectors and fasteners available in the mass timber market that have been specially engineered. It is also possible to design a custom connection, but to do so properly it is important to understand the possible failure modes so that the appropriate level of safety is ensured for each of the modes.

Connections in mass timber construction play essential roles in providing strength, stiffness, stability and ductility to the structure – as a consequence they deserve careful attention by designers. Post-disaster investigations following extreme events such as major earthquakes and hurricanes have revealed that, among many reasons, structural failures often occur due to inadequately designed or improperly fabricated connections. The proper assembly of connections in the field is also a critical consideration since poor workmanship can undermine high quality design and fabrication. The interruption of continuity in the timber structure caused by the presence of connections may result in a decrease in the overall strength and stiffness of the structure unless this is accounted for through proper engineering design. Less sophisticated approaches to structural design often result in the increased cross-sections of the mass timber elements adding avoidable material costs to the project. In mass timber buildings, investing in the proper selection and/or design of structurally efficient connections has the potential to yield enormous returns and a more resilient structure.

Mass timber involves a large number and assortment of connectors and fasteners. *The efficient design and fabrication of connections often determines the level of success of timber buildings when competing with other types of structural applications such as steel or concrete. The image on the left depicts a line of proprietary connectors. (Rothoblaas) The image on the right depicts the use of glulam rivets with a steel truss plate in the fabrication of a glulam truss. (CWC)*

For mass timber buildings where a large number of identical connections are required, it is cost effective to engineer and fabricate special connectors that simultaneously address a number of considerations, such as satisfying fire safety requirements, contributing to lateral load resistance and enabling rapid erection. Special attention must be paid to careful coordination between the mass timber and custom connector suppliers and may involve mock-ups to ensure the digital fabrication of both the mass timber and the connectors is precise, compatible and easy to assemble.



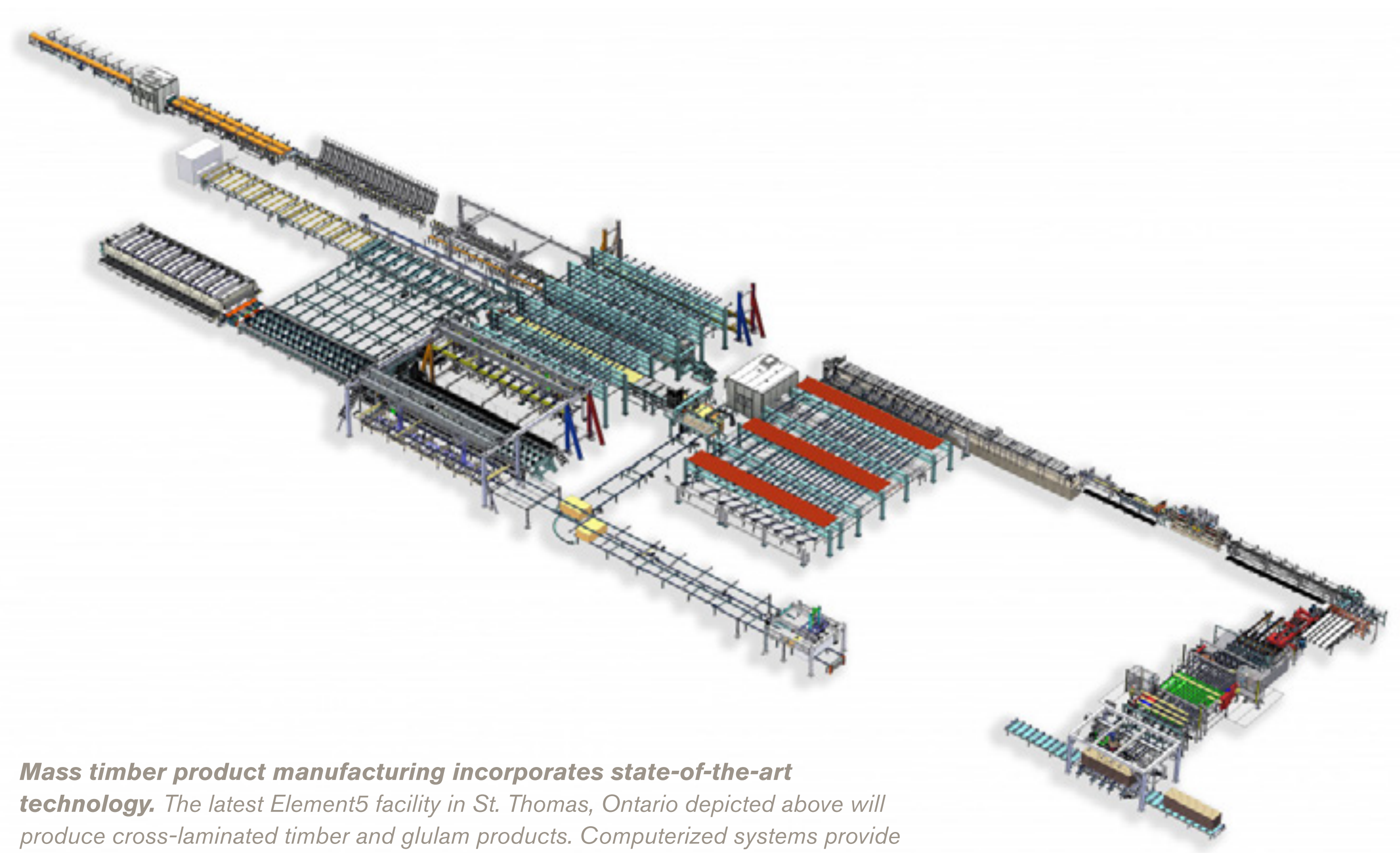
Example of a concealed custom beam-column connection assembly. *The design of these custom connections for the Albina Yard project, situated in North Portland, Oregon, required meaningful collaboration among the architects, structural engineer and digital fabricator to determine realistic tolerance expectations and understand CNC capabilities. The prevalence of concealed connections is only going to grow with the increased adoption of mass timber in fire rated construction where wood cover at the connections will serve to protect the concealed steel connectors. (LEVER Architecture)*

The correct installation of mass timber fasteners and connectors requires special training for constructors. Similar to the aircraft and automotive industries where sophisticated digital fabrication processes produce high technology components, the final assembly of mass timber structural elements and their connections must be carried out by skilled workers who are properly trained and qualified.

Design Software, Digital Fabrication and Building Information Modelling

Mass timber building technology involves more than just engineered wood products, connectors and fasteners. While the building structure is comprised of these elements, the whole building as a system is a product of sophisticated processes that are disrupting traditional approaches to building design and construction.

Unlike lumber and timber, today's engineered mass timber products are dimensionally consistent and can be cut and shaped precisely by computer numerically controlled (CNC) equipment. Computerized factories produce mass timber products with consistent physical properties while optimizing the use of forest resources.



Mass timber product manufacturing incorporates state-of-the-art technology. *The latest Element5 facility in St. Thomas, Ontario depicted above will produce cross-laminated timber and glulam products. Computerized systems provide production management, production flow control and visualization, statistics, real-time information and production analysis tools. (Ledinek)*

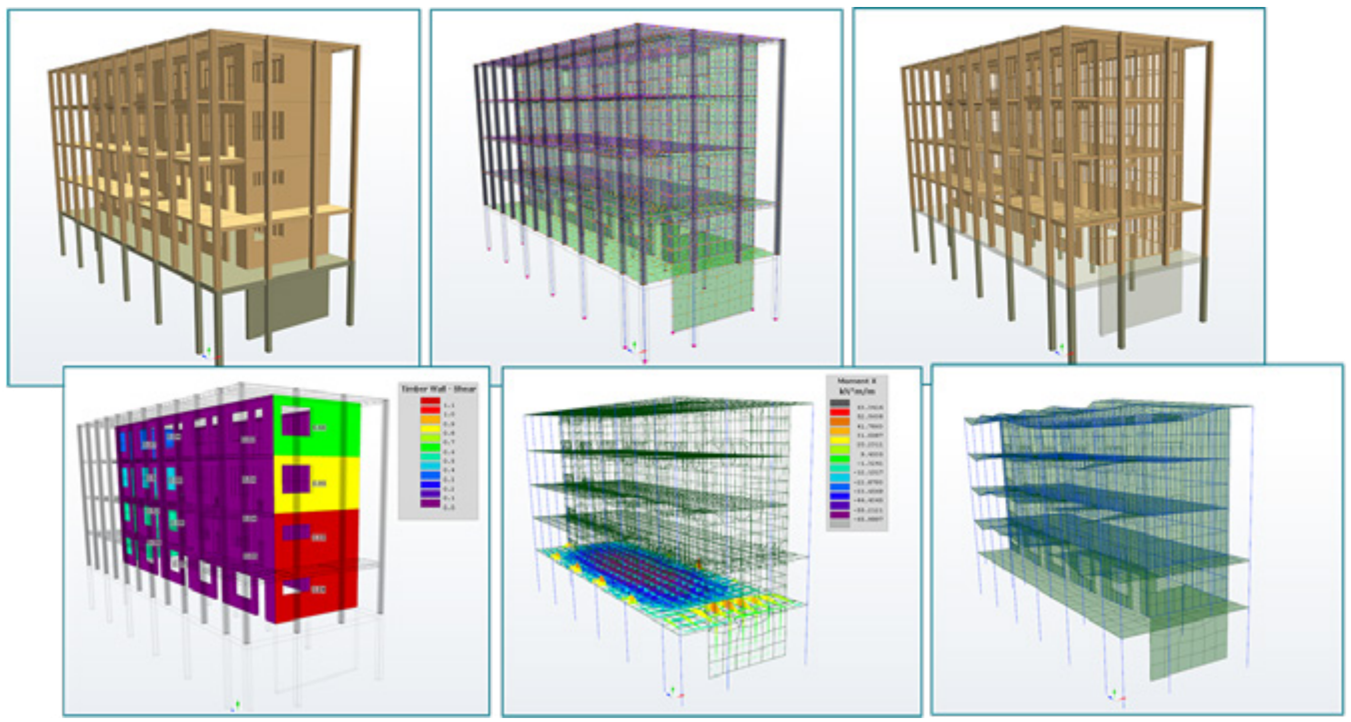
Mass timber building technology has fostered a growing interest in design for manufacturing and assembly (DfMA) and modular and off-site construction (MOC). There are many advantages for manufacturing building components and assemblies in controlled conditions that include precision, moisture management, and savings in cost and time. Manufacturing off site then assembling on site also minimizes the number of workers and reduces interference between the various trades such that higher levels of productivity may be achieved. Inspection at the factory prior to delivery to the site enhances quality and consistency of the mass timber structure and eliminates delays resulting from the rejection of substandard workmanship and products.

Off-site manufacturing of building components and assemblies is a major advantage of mass timber. *Computerized and vertically integrated manufacturing that incorporates CNC cutting and routing capabilities is able to efficiently produce mass timber products, such as the CLT panels depicted above, in a safe and controlled environment. (Nordic Structures)*

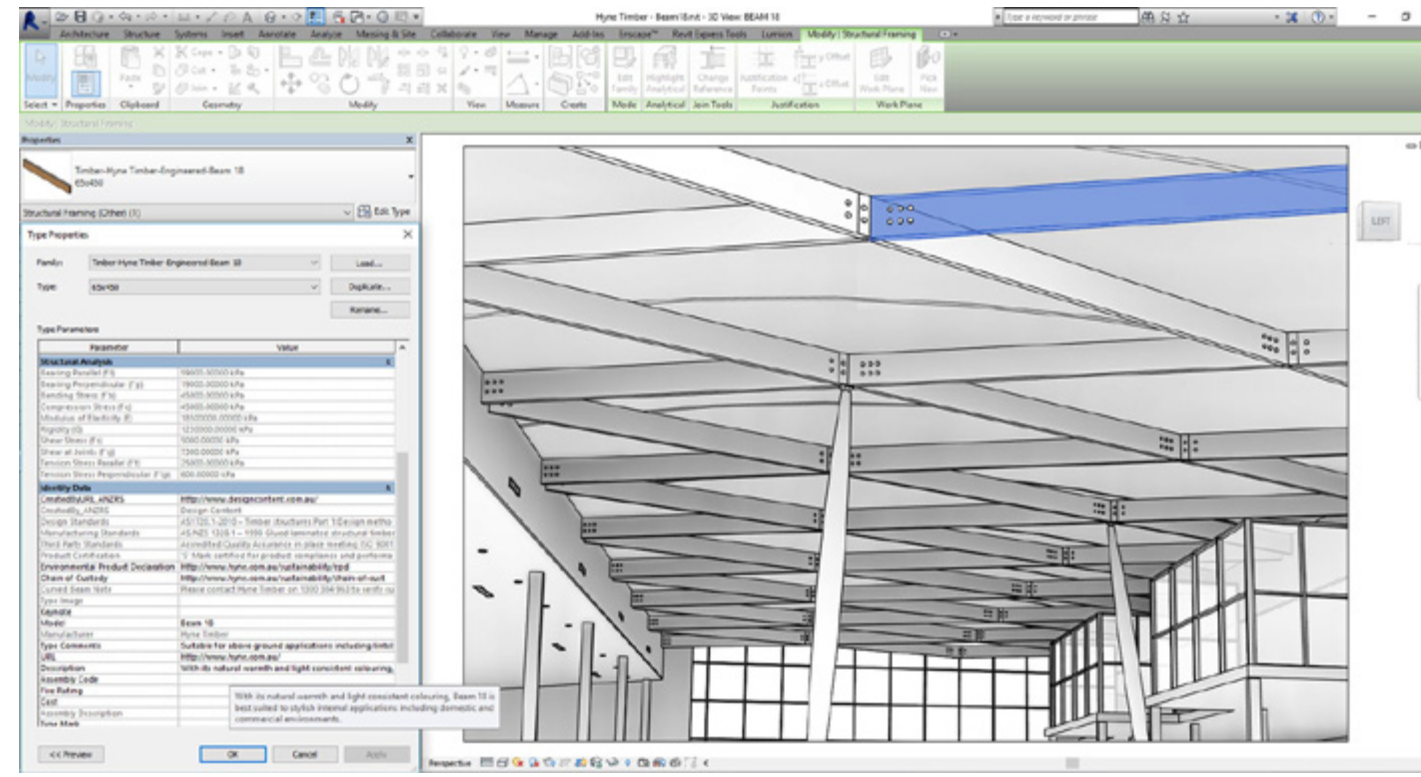
Modular and off-site construction can deliver sub-systems, such as bathrooms or entire apartment suites, that can be hoisted and easily connected within the structure.[9] The prefabrication of unitized enclosure systems has also been advanced through the adoption of mass timber building technology. Installation of enclosure assemblies that quickly follow the erection of the structural system and modular components compresses the on-site work schedule and provides better moisture management during construction.

[9] *Building Information Modeling (BIM) and Design for Manufacturing and Assembly (DfMA) for Mass Timber Construction. November 2018. https://www.naturallywood.com/sites/default/files/documents/resources/bim_and_dfma_for_mass_timber_construction.pdf*

The numerous synergies that can be realized through contemporary mass timber building technology start with sophisticated structural analysis and design software. By being able to accurately simulate the structural behaviour of mass timber structures, a more efficient use of mass timber is possible while maintaining safety and serviceability.



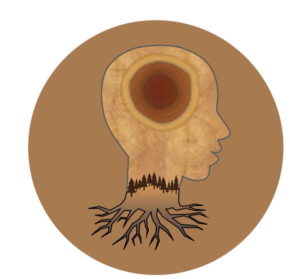
Sophisticated structural analysis and design software powers the mass timber revolution. *Without finite element software that has a specialized capability for simulating the physical behaviour of mass timber materials and connectors, the full potential of mass timber structures cannot be realized. (S-TIMBER)*



Building information modelling (BIM) is key to mass timber building systems integration. *Similar to advances in the aircraft and automobile manufacturing industries, BIM enables the integration of the structure, the enclosure, all of the mechanical, electrical and plumbing services, and the interior fit out at a high degree of resolution. The 3-D design carries within it all of the dimensions, properties, attributes and specifications for each of the components. This feeds into off-site digital fabrication and eventually provides the owner with a complete model/manual of the facility. (Autodesk)*

Managing design, manufacturing and construction has always posed significant challenges for traditional building technologies, but the implementation of building information modelling is integral to mass timber buildings. It is acknowledged that off-site manufacturing demands fully resolved designs since there is practically no possibility of field modifications. This level of resolution and integration has required mass timber building projects to adopt building information modelling tools to drive everything from fabrication, handling/delivery logistics, and construction scheduling through to facilities management.

Mass timber has the potential to transform how we design, procure and construct buildings, including the traditional roles and skills of many of our trades. The mass timber revolution is still in its nascent stage of development and holds great future promise as innovations advance a harmonized suite of technologies to achieve a fully integrated building as a system having a sustainable life cycle.



BIM, MOC and DfMA
Click on this icon to download information about mass timber and building information modelling (BIM), modular and off-site construction (MOC) and design for manufacturing and assembly (DfMA).

Synopsis

Mass timber buildings are the future of a building industry that contributes to a low carbon economy and sustainable development. Renewable resources that are sustainably managed and enterprises that distribute economic opportunity throughout the entire value chain are the most equitable means of managing not only the embodied carbon in our buildings, but also their ecological footprint. While there is some limited ecological carrying capacity available for non-renewable materials within the global building industry, the prudent and responsible strategy is to continue research and development of renewable, biologically-based materials that can be sustainably harvested with no appreciable resource depletion, environmental degradation or reductions in biodiversity.

Mass timber buildings offer a means to not only manage the environmental impact of buildings, but also to transform the social and economic dimensions of our building development industry.

Mass timber buildings are the future of a building industry that promotes a low carbon economy and sustainable development.

- Building with wood has expanded our sustainability horizon through innovations in mass timber building technology.
- Mass timber engineered wood products provide superior performance compared to lumber and timber providing performance, value and a more efficient utilization of our forest resources.
- Contemporary mass timber building typologies promote diverse architectural expression demonstrated through numerous successful precedents for sustainable and resilient buildings around the world.
- Connectors and fasteners for mass timber enable the sophisticated design of structural systems that optimize the advantageous properties of engineered wood.
- Building information modelling (BIM), digital fabrication and advances in the construction sciences represent technological innovations that promote modular and off-site construction (MOC) and design for manufacturing and assembly (DfMA) to economically deliver superior quality buildings.
- Ongoing innovations in mass timber research and development promise to extract even greater value from our forest resources promoting sustainability across the entire mass timber value chain.

As innovations in mass timber building technology continue to advance, it is important to recognize the fundamental transformations involve moving from a labour-based to a knowledge-based construction industry where the entire life cycle of buildings is responsibly managed as a cultural resource rather than a commodity. The direct connection between our renewable natural resources and our limits to growth will encourage the adoption of sustainable development principles that address climate change and reverse so many of the negative social, environmental and economic impacts stemming from our current approaches. Mass timber is a positive and proactive 21st century game changer for a variety of stakeholders as highlighted in the following section.

Mass Timber Building Technology

Modern mass timber building technology involves an integrated suite of processes, methods and materials that make it unlike conventional buildings.

- Digital design of the entire building as a system using robust building information modelling (BIM) software that is used to resolve the integration of structure, enclosure, services and finishes before construction begins.
- Construction planning and logistics coupled to an effective moisture management plan to deliver a serviceable building on time and on budget.
- Application of advanced structural engineering, fire safety and acoustical control measures for optimal performance.
- Automated manufacturing and digital fabrication of mass timber components enabling precise and time efficient assembly on site.
- Unitized high-performance building envelope systems that rapidly enclose the structure and enable interior fit out and finishing to proceed with minimal delays.
- Complete documentation and a 3-dimensional model of the building asset for effective facilities management over the life cycle of the building.

Mass Timber Bibliography
Click on this icon to download biliographic information about various aspects of mass timber building technology.

4 Mass Timber Industry Stakeholders

From the forest to the mill, and from the mill to the mass timber manufacturer, onward to the construction site where the building is assembled and afterwards inhabited, operated and maintained, a large number of stakeholders are involved. Many of these, such as policy makers, forest conservationists and financial institutions, are invisible to the average person observing the erection of the mass the timber building. But each and every stakeholder plays a vital role in making mass timber buildings possible. As with any new technology such as mass timber, it takes time and effort to establish explicit roles, relationships and protocols between the various stakeholders that enable a time and cost-effective way of delivering buildings without compromising affordability, public health and safety, or the environment. There is also inherent in every society a normal skepticism or resistance to innovation, especially in a world where so many things change so rapidly. It may be expected that a healthy gestation period is needed to iron out all the kinks and wrinkles before unique building prototypes can be refined and then rolled out on a broader basis. Every historical building typology we observe today was once a daring experiment of architecture and engineering. If we wish to expedite this transition from inventive novelty to reliable convention, it will require all of the stakeholders to work together.

Mass Timber and the Triple Bottom Line

Most mass timber building projects that have gained public attention involve large and/or tall structures that are intended to demonstrate the potential of mass timber building technology. These projects are architecturally impressive and executed by highly skilled teams of design, engineering and construction industry experts. But the aspiration to reduce the carbon footprints of buildings through the use of renewable building materials such as wood will not be realized unless there is widespread adoption of mass timber for “bread and butter buildings” for typical everyday uses. Only then will the triple bottom line of environmental, economic and social benefits ascribed to mass timber actually achieve levels of influence that make a measurable difference.

Environmental

One of the most significant global environmental issues today is climate change. It will be challenging to transform Canada’s economy and society, primarily based on non-renewable energy, to one that is carbon neutral. Buildings will play a pivotal role in this transformation since they are among the largest contributors to greenhouse gas (GHG) emissions. These emissions result from the heating, cooling, lighting, and power demands of the occupants in the building. As we make our buildings more energy efficient, the embodied carbon emissions from the building materials used to construct buildings has grown in importance. Energy efficient buildings made from wood address both the operating and embodied energy/carbon contributions of buildings.

Wood is a renewable building material. Trees receive energy from the sun and absorb carbon dioxide from the atmosphere to photosynthesize. As trees grow, they store carbon. By harvesting sustainably managed trees, the carbon in the trees is sequestered preventing the release of carbon dioxide into the atmosphere. The cycle of carbon storage will continue when new trees are planted to replace harvested trees. Since conventional building materials, such as concrete and steel, have higher embodied carbon emissions compared to wood, increasing the use of the wood in the construction of buildings has the potential to reduce the embodied carbon emissions from the construction of buildings.

Because wood is a lighter material than concrete and steel, soils with reduced bearing capacity can support taller buildings constructed from wood compared to concrete and steel structures. This advantage allows increased densification on marginal soils. Studies demonstrate that compact, pedestrian-oriented, mixed-use urban designs can greatly reduce the transportation emissions per household compared to traditional suburban neighbourhoods Controlling the expansion of urban sprawl through rural lands decreases emissions, and protects valuable agricultural lands, ecosystems and natural resources for the future.[10]

[10] *Ontario Climate Change Action Plan 2016-2020 outlines numerous benefits associated with densification, energy efficiency and building material choices. http://www.applications.ene.gov.on.ca/ccap/products/CCAP_ENGLISH.pdf*

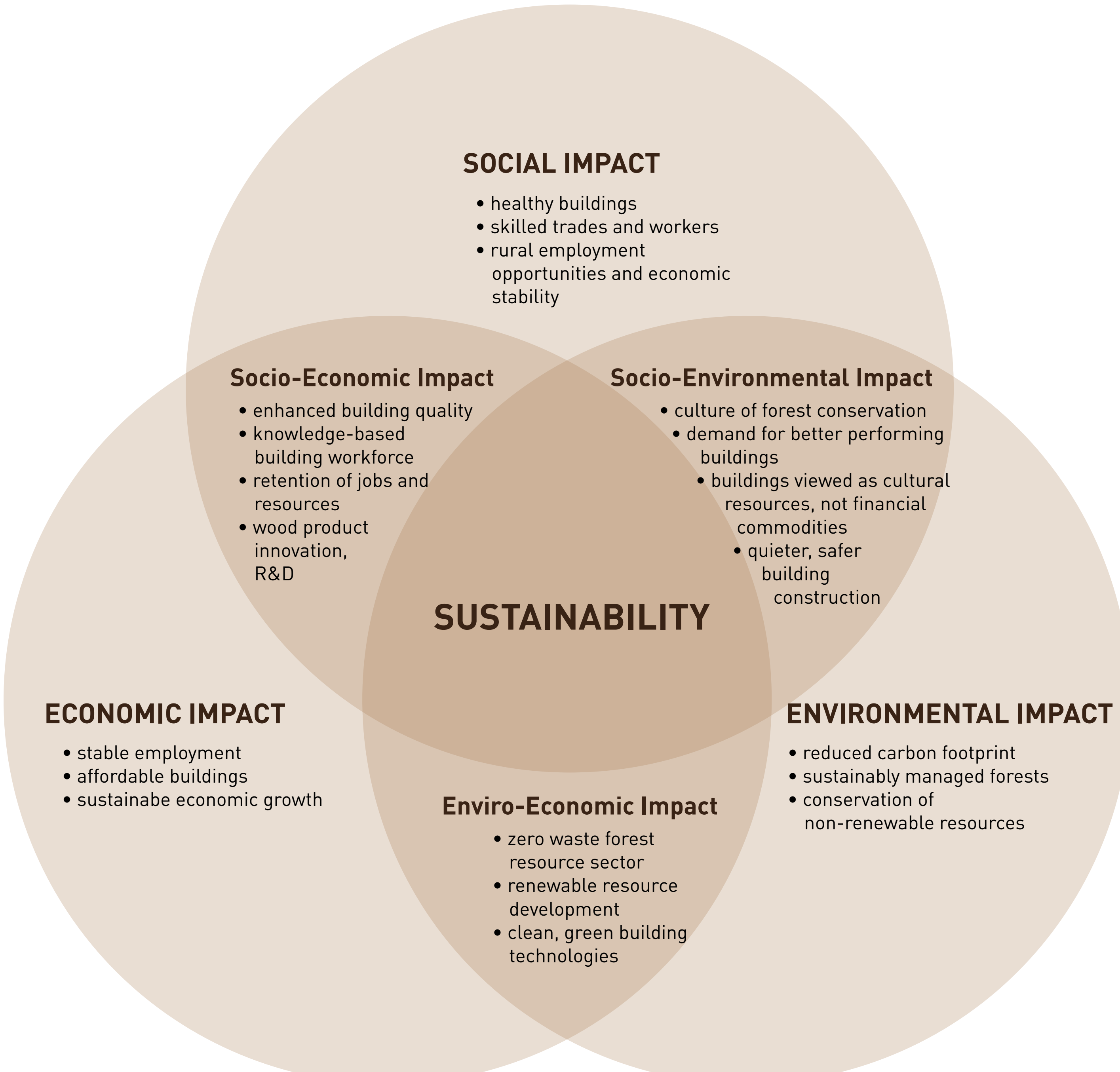
Wood has greater thermal resistance than steel and concrete. This material property is advantageous when designing and constructing a high-performance building enclosure because the impact of thermal bridging is reduced. Building enclosures with superior thermal performance reduce the heating and cooling demands in buildings and ensuing carbon emissions.

Economic

Mass timber not only provides many environmental benefits; it offers exciting new economic opportunities. Engineered wood products represent an economic opportunity to transform low value timber from small diameter trees into a high value-added industrial product. This transformation increases the value extracted from the forestry products industry. Mass timber is an industrial product, manufactured in facilities using computer numerical control (CNC) machines and a highly skilled workforce. Engineered wood products and the mass timber industry offer the potential to be a market leader and innovator exporting mass timber products, knowledge and skills globally. Taller mass timber buildings located on soils with decreased bearing capacity allows development to occur on marginal lands and in seismic sensitive zones enhancing land valuation.

Social

Many societal issues may be resolved if there is strong support for the growth of mass timber. Many rural communities across Canada depend on the forestry sector. Increasing demand for forestry products strengthens these communities and can help mitigate the risk of depopulation, unemployment and poverty. Furthermore, it has the potential to strengthen connections between rural and urban communities across regions of Canada. The construction of mass timber buildings generates less noise than conventional buildings minimizing potential noise disturbances to neighbours. As the mass timber industry evolves over time, it is expected that the cost and speed of construction for mass timber buildings will decrease compared to traditional construction methods. The anticipated reduced cost and speed may lower financial barriers to constructing affordable housing. Wood buildings offer biophilic benefits to their inhabitants and a unique warmth and beauty.



Mass timber building technology positively impacts a diverse and large number of stakeholders. *Mass timber's triple bottom line is more economically inclusive, socially equitable and environmentally responsible than conventional buildings.*

Key Stakeholders

Various stakeholders are involved in the design and construction of a mass timber building. Each plays a key role in the project, and their responsibilities are outlined below.

The web of mass timber stakeholders is vital to building technology transfer and innovation. *The network of Canada's nascent mass timber building industry is only as strong as its weakest link. For mass timber to thrive through the alliances that have naturally developed over more than a century for conventional building technologies, a conscious and consistent stewardship will have to be fostered and actively promoted.*

Forest Industry

The forest industry in Canada is an important contributor to our national economy creating employment and generating wealth from our natural resources. Forest stewardship through sustainable practices that observe and respond to ecological evidence is the key to maintaining healthy forests for future generations. The mass timber building movement is made possible by investments into the research and development of mass timber products by forest industries in Canada and around the world.

Owner/Developer & Occupants

These two stakeholders drive the entire building development process and share many common interests. Building owners/developers need occupants for their buildings and occupants are typically unable to undertake building projects on their own. They also require facilities management professionals to operate and maintain the buildings they inhabit. For owners/developers, mass timber building technology holds the potential to better manage project costs to reduce financial risks, and reduced construction times can help lower borrowing costs. This serves occupants by making mass timber buildings more affordable while providing a welcoming wood building environment. Evidence indicates that timber buildings retain their value and are highly desirable, thus preserving the security of investment for owners and occupants. Both owners/developers and occupants alike can share in the accomplishment of promoting building developments with a low carbon footprint.

Registered Architect of Record (AOR)

An appropriately qualified professional architect registered in the jurisdiction where the project is being built. The AOR is contracted to be the overall designer of the building and provides architectural specifications and drawings with details for the supplier and erector to plan, price, supply and erect the structure, and also reviews the shop drawings in conjunction with retained consultants to verify conformance with the original design intent. For architects, mass timber buildings offer higher control over quality and a more equitable distribution of liability with the constructor and supplier since these stakeholders form the core of mass timber building project teams.

Registered Professional Structural Engineer of Record (EOR)

An appropriately qualified professional structural engineer registered in the jurisdiction where the project is being built. The EOR is contracted to be the overall structural engineer for the building. He/she provides structural specifications and drawings with details for the supplier and erector to plan, price, manufacture and erect the structure, and reviews the shop drawings to verify conformance with the original design intent. It is important to note that the deliverables from a structural engineer is different in a mass timber building compared to a conventional building, where the role of the structural engineer is to consider the forces on the building and design it to withstand these forces and maintain structural integrity. However, in a mass timber building, the structural engineer may have an enhanced role by supporting or educating the architect on durability issues of mass timber components.

Supporting Registered Professional Structural Engineer (SRP)

This professional is retained or employed by the wood supplier and/or erector to develop the assemblies and connections according to structural requirements defined by the EOR. He/she provides detailed specifications and manages production of detailed drawings to manufacture and erect the structure. The SRP is responsible for certifying that the manufacturing of the assemblies and connectors conforms to his/her designs when hired by the supplier. The SRP is responsible for the erection of the assemblies for the structure and is accountable for its execution, (i.e., that it conforms with his/her erection sequencing and procedures when hired by the erector).

Constructor

The constructor supervises the execution of the construction project, including the coordination of all tasks, contractors and subcontractors on the project. The constructor's responsibilities include managing the construction process and ensuring that the budget, design, quality, regulatory and site safety requirements are met. The constructor is typically responsible for ensuring the moisture management plan is carried out properly and in a timely manner to protect the mass timber structure and moisture susceptible materials and components.

Erector

Erectors may be independent sub-contractors who are a part of the constructor team. They employ a skilled construction team that assembles the pre-manufactured mass timber structure, components and assemblies on sit. Erectors work closely with the constructor and manufacturer/supplier to observe all applicable specifications and procedures, including moisture management protocols.

Specifier

Often referred to as a specifications writer, this individual or organization develops specifications for all aspects of a building project including specifications for the mass timber manufacturer/supplier. Specifications are essential to quality assurance and building commissioning, and without specifications it would be impossible to estimate costs and obtain approvals from code officials. In some cases, specifications may also be developed by the architects, engineers and manufacturer/supplier, but these are eventually amalgamated into a set of construction documents that comprise plans, drawings, details, specifications and specialty consultant reports.

Quality Control and/or Commissioning Agent

Quality assurance and commissioning agents are pivotal stakeholders in the delivery of well performing buildings. These agents are ideally retained at the early stages of design by any one of the key project team stakeholders, but typically report to the architect/owner. Their role is that of an objective third party to provide audited quality control of materials and methods, conduct site inspections, and to commission the building enclosure and mechanical/electrical systems. This stakeholder is responsible for confirming whether or not the materials, components, assemblies, equipment, fixtures and systems conform to the specifications, the project's performance targets and owner's project requirements.

Building Official/Authority Having Jurisdiction

Reviews and evaluates the building for conformance to building and fire codes. He/she performs inspections for fire safety, life safety and structural integrity of a building at various stages during the construction process. In projects where the traditional prescriptive requirements are not followed, and an alternative solution is pursued, building officials review the proposed project to determine if it conforms to the intent of the building code's objectives and functional statements.

Mass Timber Manufacturer/Supplier
The manufacturer/supplier develops the shop drawings to provide information required by the computer numerically controlled (CNC) equipment operators to manufacture the mass timber components and assemblies. In some cases, the manufacturer and the supplier are different enterprises, with the manufacturer fabricating the mass timber components according to reviewed and approved shop drawings, and the supplier coordinating logistics between the manufacturer, design team and constructor. Manufacturers/suppliers are critical to providing products of specified quality in the proper sequence according to the schedule for erection and assembly. Unlike traditional building technologies, the mass timber manufacturer/supplier chain involves a high degree of building information management (BIM), design for manufacturing and assembly (DfMA) and modular and off-site construction (MOC).

Government
All levels of government are important stakeholders in the mass timber building industry. Through the implementation of policies and programs that guide natural resources management, foster research and innovation, or promote the acceptance of mass timber building technology in codes and standards, governments at all levels can accelerate a transition towards a low carbon buildings sector in Canada.

Legislation, Codes and Standards
The building regulatory framework is intended to achieve safer, healthier, durable and more sustainable and resilient buildings. Unlike research and innovation, the regulatory framework serves as a ratchet that prevents backward slipping by the building industry. This framework is a vital stakeholder because it provides the legal basis for minimum standards of health and safety in buildings, worker health and safety, and protection of the environment.

Facility Manager/Building Operator
Part of the building construction and development industry, facility managers and building operators manage, operate and maintain the building after construction has been completed. His/her responsibilities include operating and maintaining the building to ensure it performs optimally and delivers the functionality required by its occupants.

Insurers and Financial Sector Insurance Agent/Broker
The insurance industry is a significant stakeholder in the mass timber buildings sector. Not only do insurers provide coverage against risks incurred during construction of the building, but also coverage for the building asset and its contents. It is critical that mass timber buildings during their construction and throughout their occupied service life do not constitute a higher insurance risk than their conventional steel and concrete counterparts; otherwise high premiums, or possibly withholding coverage, may discourage the transition towards mass timber buildings. The financial sector is an important stakeholder as well since investing in buildings is a long-term strategy for wealth management that is critical to financing mass timber building projects. A sustainable life cycle for mass timber buildings must be demonstrated to continue attracting investment.

Building Services and Equipment Technology Providers
Important players in the construction and development industry stakeholder group are the manufacturers, suppliers/distributors and installers of mechanical, electrical, plumbing and telecommunications services in buildings. Elevators, HVAC systems, lighting, Wi-Fi, fire alarms and sprinklers are among the many essential services in modern buildings that respond to the functional needs of occupants.

Education and Research Institutions
Universities, colleges, research laboratories and institutions are indispensable stakeholders since they drive innovation and deliver the training and education of highly qualified personnel. Wood material scientists, engineers, architects, construction managers, technologists, technicians and tradespeople along with manufacturers/suppliers of mass timber are among the various players who depend on education and research institutions. Qualifications, innovations and entrepreneurship rely on education and research institutions for fresh ideas, novel approaches and lifelong learning.

Environment and Ecology
The environment and ecology are last, but not least, in this overview of the key stakeholders. In fact, without the proper stewardship of the environment and ecology underpinning our forests, there would be no mass timber building industry.

A listing of stakeholder organizations specific to mass timber is tabled in the following section. It does not include the various professional and industry organizations associated with the design, construction, operation and maintenance of buildings. It is intended to provide sources of helpful information and to reinforce the multi-faceted nature of the mass timber building industry.

Stakeholder Organizations

The following organizations represent mass timber stakeholders across various sectors.

International	
The Timber Research and Development Association (TRADA) https://www.trada.co.uk/	TRADA is an international membership organization whose goal is to inspire and inform best practice design, specification and use of wood in the built environment and related fields. This organization provides independent, authoritative design and technical guidance through its website, online software, printed publications, e-books, and telephone helpline.
Binational	
APA - The Engineered Wood Association https://www.apawood.org/	APA – The Engineered Wood Association is a non-profit trade association that works with its US and Canadian members to produce structural wood products of exceptional reliability, strength and versatility. This website offers access to numerous publications, videos, CAD details, and photographs.
Binational Softwood Lumber Council http://www.softwoodlumber.org/	The Binational Softwood Lumber Council (BSLC) was established by the Canadian and U.S. federal governments. The Council's mandate is "to promote enhanced cooperation between the U.S. and Canadian softwood lumber industries and to strengthen and expand the market for softwood lumber products in both nations."
Canada - Federal	
Natural Resources Canada https://www.nrcan.gc.ca/home	Natural Resources Canada is a federal economic, science-based department with a mandate to promote the sustainable development and responsible use of Canada's forestry resources. It operates scientific laboratories in the pursuit of scientific and economic research related to forestry.
Canadian Forest Service (CFS) https://www.nrcan.gc.ca/forests/about/17545	The Canadian Forest Service is the national and international voice for Canada's forest industry. It is part of Natural Resources Canada and has an office in Ottawa and 6 research centres across the country. It collaborates closely with Canada's provinces and territories to ensure our forests are sustainable and healthy
Canadian Wood Fibre Centre (CWFC) https://www.nrcan.gc.ca/forests/research-centres/cwfc/13457	The Canadian Wood Fibre Centre is part of the Canadian Forest Service. One of the CWFC's mandate is to work closely with FPInnovations and other stakeholders in the development and uptake of end-user relevant wood fibre research.
Forest Innovation Program (FIP) https://www.nrcan.gc.ca/forests/federal-programs/13137	The Forest Innovation Program (FIP) supports research, development and technology transfer activities across Canada's forest industry. Together, these activities are intended to assist the sector pursue its ongoing transformation through the development and adoption of innovative science-based solutions.
Canada - National Organizations	
The Canada Wood Council http://cwc.ca/	The Canadian Wood Council represents the Canadian wood products industry through a national federation of associations. The mission of the Council is to expand market access and increase demand for Canadian wood products through excellence in education, codes, regulations and standards.
FPInnovations https://web.fpinnovations.ca	FPInnovations is a not-for-profit international leader that specializes in the creation of innovative scientific solutions in support of the Canadian forest sector's global competitiveness and responds to the priority needs of its industry members and government partners.
Wood Works! http://wood-works.ca	Wood Works! is a construction sector education program operated by the Canada Wood Council with programs in several Canadian provinces.

Canada - Provincial Organizations	
Ministry of Natural Resources and Forestry https://www.ontario.ca/page/forestry	Ontario's Crown forests span almost two-thirds of the province. The Ministry of Natural Resources and Forestry manages the health of these forests so they can continue to provide ecological, social and economic benefits.
Forest Innovation Investment (FII) https://www.bcfii.ca	Forestry Innovation Investment (FII) is the B.C. government's market development crown agency for forest products. It works to strengthen and diversify international markets
Naturally:wood https://www.naturallywood.com/	Naturally:wood, developed by Forestry Innovation Investment, is a comprehensive information resource promoting British Columbia as an international supplier of quality, environmentally-responsible forest products from sustainably-managed forests.
Education Programs	
https://www.canadian-forests.com/universities-colleges.html	Directory of Canadian Universities and Colleges Offering Post-Secondary Education in Forestry and Forest Products Technology
Institutes	
Mass Timber Institute (MTI) https://www.masstimberinstitute.ca	The Mass Timber Institute (MTI) aims to help position Canada as a global leader in sustainable mass timber research, education, development, and export by leveraging relationships between educators, researchers, industry, and Indigenous groups across Canada and internationally.
Tallwood Design Institute (TDI) http://tallwoodinstitute.org	Tallwood Design Institute (TDI) is an industry-academic collaboration that unites practitioners with faculty from top U.S. engineering, sustainable architectural design and wood science programs to advance research and education on mass timber and other state-of-the-art wood building solutions.
U.S. and Europe	
Think Wood https://www.thinkwood.com	The primary support of Think Wood is the Softwood Lumber Board, an industry-funded initiative responsible for increasing demand for softwood lumber products in outdoor, residential and non-residential construction.
Forest Products Laboratory (FPL) https://www.fpl.fs.fed.us	The Forest Products Laboratory (FPL) is the national research laboratory of the U.S. Forest Service.
Swedish Wood https://www.swedishwood.com	Swedish Wood spreads knowledge, provides inspiration and encourages development relating to wood, wood products and wood construction.
Finnish Timber Council https://www.woodproducts.fi	The Finnish Timber Council called Puuinfo seeks to promote the use of wood in construction and interior design to create demand for wood products.
German Timber Trade Federation https://www.gdholz.net/en/home-gb.html	The German Timber Trade Federation (GD Holz) is the timber trade's neutral trade association and represents the specialist timber trade and its distribution channels.
European Timber Trade Federation (ETTF) https://www.ettf.info	The European Timber Trade Federation (ETTF) promotes the interests of the timber trade across Europe, representing key national federations for importers, merchants and distributors.

Synopsis

Before the advent of the mass timber building revolution, there was no lack of authoritative building science knowledge to guide the proper design, construction, operation and maintenance of buildings. Despite this widely accessible know-how, the building performance gap between what is predicted and promised, and what is actually evidenced, continues and is both avoidable and unacceptable. It is critical that mass timber buildings avoid all of the performance problems, defects and failures that plague so much of our building stock.

If sound building science was a sufficient condition underlying high-performance buildings, there would be no need for stakeholder involvement, but unless all stakeholders keep each of the others honest, it will be difficult to ensure that the aspirations for mass timber buildings will be realized in built works.

Mass Timber Stakeholders

Building science alone is insufficient to drive the mass timber building revolution. It is critical that the various stakeholders work together to advance the mass timber agenda and ensure the application of better building science.

- Mass timber buildings must incorporate building science best practices to fulfill their performance promise – codes and standards cannot be expected to provide leadership and promote innovation.
- Stakeholders need to become active advocates of mass timber while ensuring that each stakeholder observes their respective responsibilities. There is no central authority playing this integrative role and providing the necessary oversight.
- Monitoring and reporting building performance along with post-occupancy evaluations are key to understanding critical issues and performance problems. If you can't measure it, you can't manage it.
- Training and education of all professions and trades associated with mass timber is essential to ensure proper qualifications and suitable skills.
- Technology transfer between researchers, innovators, manufacturers, educators, design professionals, tradespeople and regulatory officials is the path to continual progress and performance improvement.
- Like our forests, the mass timber building industry is an ecosystem that needs to be respected, protected and sustained through vigilance, intelligent intervention and strategic investment.

Biodiversity is a major stakeholder without a voice. *It is the duty of all stakeholders who have a voice to ensure stewardship of our forests and ecosystems is not forgotten as we strive to roll out a mass timber revolution. (The Narwhal – Peter Mather)*

5 Critical Considerations for Mass Timber Buildings

Critical considerations for mass timber buildings must be addressed during the early stages of design. Failure to resolve these issues at the schematic design stage will result in having to undo design development efforts, leading to the loss of both time and money, while undermining project team confidence.

The success of the mass timber building revolution is highly dependent on making sure that all critical factors have been carefully considered – the earlier the better. If the promised benefits of mass timber buildings are to be fully delivered, they must achieve the highest levels of social, economic and environmental performance. This is not something that has proven easy to accomplish in today's building industry where performance gaps – the difference between performance that is predicted and the actual observed performance – are very common, and sometimes unacceptable. By paying attention to the critical considerations listed below and adopting an evidence-based approach to building design and performance, successful mass timber building projects may be more consistently realized.

- Life Cycle Thinking
- Building Code Compliance
- Structural Design
- Fire Safety and Acoustics
- Enclosure Design
- Moisture Management
- Procurement and Construction Management
- Commissioning
- Facilities Management

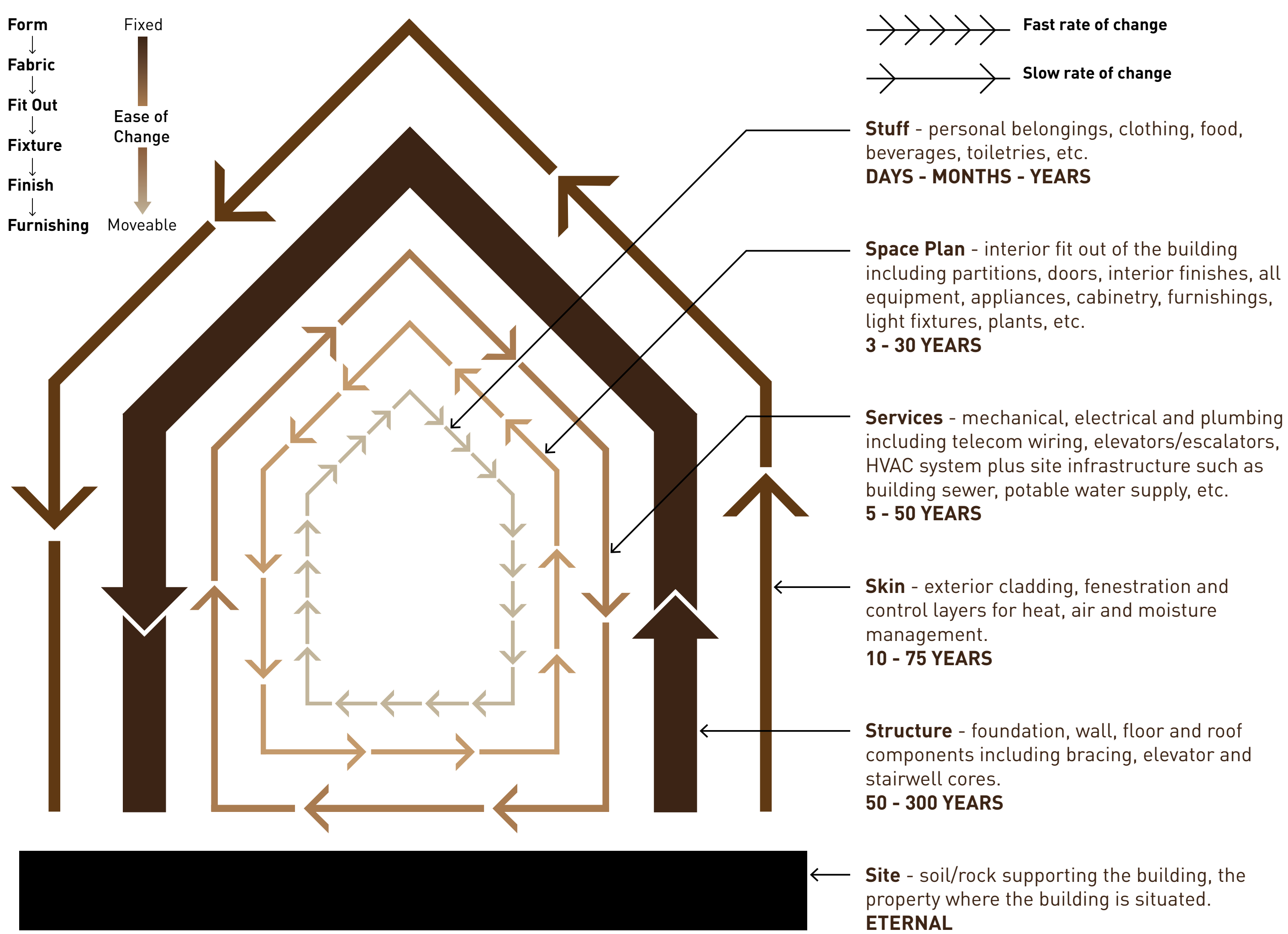
In many ways, mass timber buildings have provided an opportunity to address the many problems and issues that face today's construction industry. The steady escalation in building costs without corresponding improvements in building quality continue to plague today's building industry. Innovation in other sectors has delivered enormous improvements in efficiency and quality while costs have actually been driven down. Mass timber provides an opportunity to explicitly reconsider and reassess every aspect of design, procurement, construction, commissioning and facilities management rather than blindly accepting a business-as-usual approach to conventional building typologies and practices. It may be hoped the mass timber revolution will also be a building industry revolution in the 21st century.

***Mass timber demands integration at the earliest stages of design.** Successful mass timber building projects integrate critical considerations in design, fabrication, construction, commissioning, operation and maintenance. The future of mass timber building technology hinges on taking advantages of the strengths of engineered wood products while responsibly managing their limitations. Mass timber may prove to be ideally suited to low and mid-rise building typologies rather than attempting to compete against every type of alternative building system, but it has definite weight advantages when building over existing buildings. Beyond technical and environmental considerations, the human scale and biophilic experience are important factors that should not be ignored. (UofT Academic Wood Tower - MJMA + Patkau Architects)*

Life Cycle Thinking

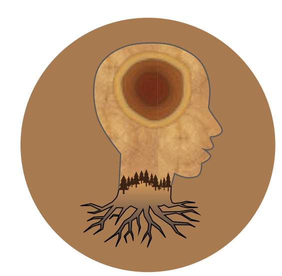
The appropriate choice of a mass timber building typology must consider its life cycle performance. The 19th century brick and beam heavy timber buildings that are still in use today have been able to flexibly adapt to a number of changing uses by virtue of their regular grids, discrete punched windows, ample floor to ceiling heights, robust structures and overall loose fit. Robust durability and adaptability are the primary factors influencing the longevity of buildings and these stem from decisions made at the early stages of design.

The appropriate choice of mass timber building typology must consider its life cycle performance.

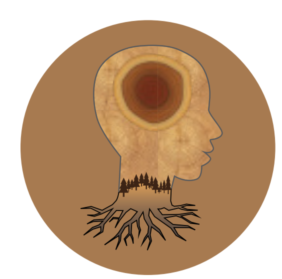


It is critical to select an appropriate mass timber building typology. *In Stuart Brand's How Buildings Learn, the relative time scales for various components comprising the building as a system imply appropriate life cycle design strategies. The dynamics between physical durability and functional obsolescence also underline the need to accommodate adaptability/flexibility in order to minimize the life cycle ecological footprint of the building.*

An important first step is to select a suitable mass timber typology for the proposed building project. Not all buildings should be mass timber and as importantly, the design, selection and integration of systems and materials for any project should be made with the building's life cycle in mind. Adaptive reuse is an important consideration for certain types of buildings such as offices and schools that may be repurposed to serve other occupancies. The selection of materials for the interior fit out of the building along with the accommodation of churn rates are being recognized as an effective means of reducing the recurring embodied energy and carbon in buildings. Universal design principles speak to social equity and should be observed. Once it has been decided that a mass timber building represents a viable choice for a given project, and an appropriate typology has been selected, then the critical considerations described in the sections that follow may be explored.



Resilient Building Design
Click on this icon to download resources to designing resilient buildings to better withstand extreme weather events associated with climate change.



Life Cycle Assessment
Click on this icon to download resources related to the life cycle assessment of mass timber buildings.

Building Life Cycle Considerations

- Avoid functional obsolescence by choosing an appropriate mass timber building typology.
- Adaptability and flexibility are enhanced through a regular floor plan, and punched windows that allow partitioning of perimeter zones.
- A loose fit with raised access floors and/or generous floor-to-ceiling heights provides clear access to mechanical, electrical and plumbing services for ease of maintenance, repair and upgrading.
- Recurring embodied energy and carbon should be carefully considered when selecting finishes and fixtures that may be changed out many times over the building life cycle – anticipate and plan for churn rates.
- Durability should be harmonized for all critical assemblies, such as the building envelope, to avoid weak links in the chain.
- Resilience measures, both passive and active, should afford habitable shelter in the face of extreme weather events, extended power failures and equipment break downs.

Code Compliance

It is important to appreciate that mass timber buildings will likely require a different code compliance path than more conventional building technologies. In order to understand how this applies to mass timber buildings, it is helpful to have an overview of building codes in Canada.

The National Building Code of Canada (NBC) is the model building code in Canada that forms the basis of most building design in the country. The NBC is a highly regarded model building code because it is a consensus-based process for producing a model set of requirements which provide for the health and safety of the public in buildings. Its origins are deeply entrenched within Canadian history and culture and a need to house the growing population of Canada safely and economically. Historical events have shaped many of the health and safety requirements of the NBC.

Model codes such as the NBC and NECB have no force in law until they are adopted by a government authority having jurisdiction. In Canada, that responsibility resides within the provinces, territories and in some cases, municipalities. Most regions choose to adopt the NBC, or adapt their own version derived from the NBC to suit regional needs. The table below indicates building code adoption across Canada.

Jurisdiction	Building Code in Effect	Notes
Yukon	National Building Code of Canada 2015	Adopted with no significant amendments.
Northwest Territories	National Building Code of Canada 2015	Adopted with no significant amendments.
Nunavut	National Building Code of Canada 2015	Adopted with no significant amendments.
Newfoundland and Labrador	National Building Code of Canada 2015	Adopted with minor amendments.
Prince Edward Island	National Building Code of Canada 2010	Adopted with no significant amendments.
Nova Scotia	National Building Code of Canada 2015	Adopted with no significant amendments.
New Brunswick	National Building Code of Canada 2010	Adopted with no significant amendments.
Quebec	Code de construction du Quebec 2012	Based on 2010 NBC with variations that are primarily additions.
Ontario	Ontario Building Code 2012	Based on 2010 NBC with significant variations in content and scope.
Manitoba	National Building Code of Canada 2010	Adopted with no significant amendments.
Saskatchewan	National Building Code of Canada 2015	Adopted with minor amendments.
Alberta	Alberta Building Code 2019	Based on 2015 NBC with variations that are primarily additions.
British Columbia	BC Building Code 2018	Based on 2015 NBC with variations that are primarily additions.

For more information visit:
https://nrc.canada.ca/en/certifications-evaluations-standards/codes-canada/model-code-adoption-across-canada

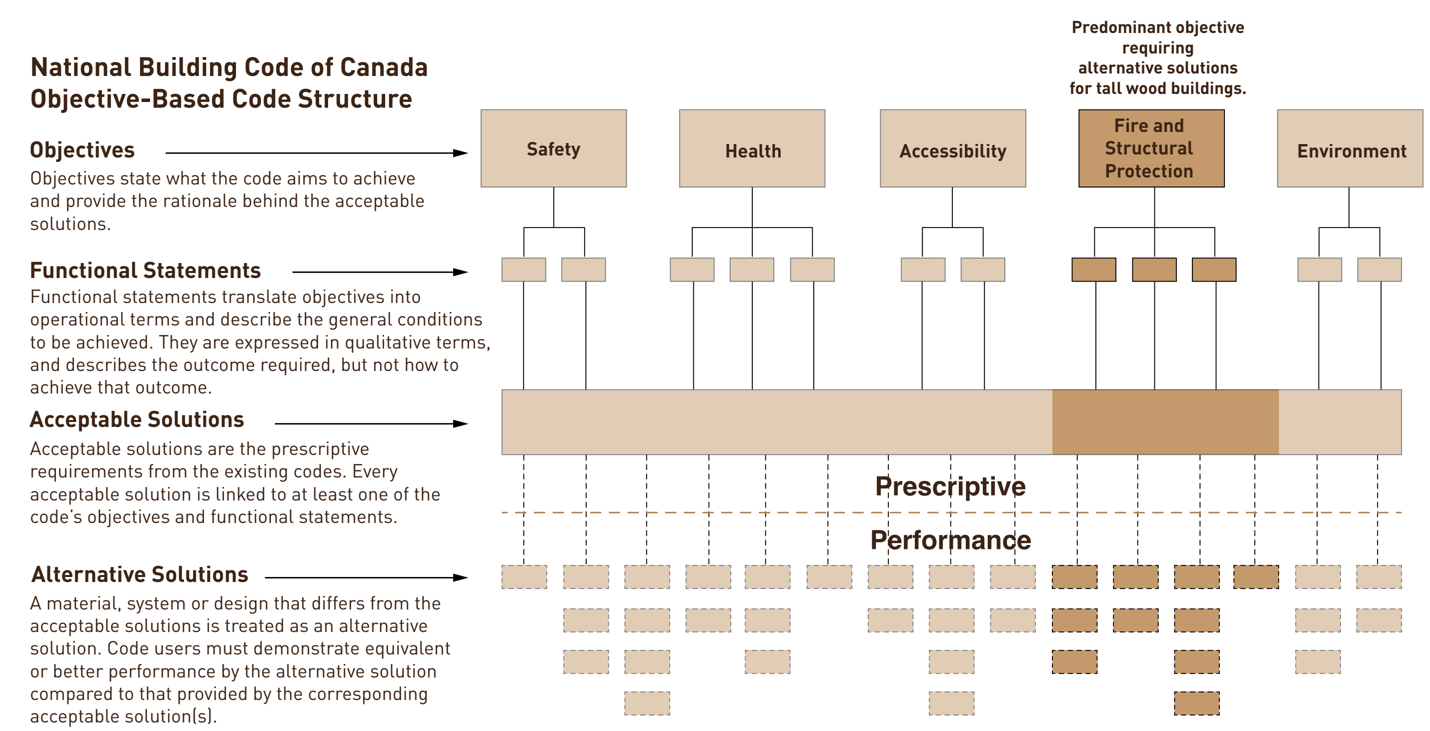
Building codes differ across Canada. *It is important to consult the latest building code in effect in order to correctly identify acceptable and alternative solutions that are needed to achieve code compliance for a proposed wood building.*

The NBC and National Fire Code (NFC) each contain provisions that deal with the safety of persons in buildings in the event of a fire and the protection of buildings from the effects of a fire. These two National Model Codes are developed as complementary and coordinated documents to minimize the possibility of their containing conflicting provisions. It is expected that buildings comply with both the NBC and NFC. The NBC generally applies at the time of construction and reconstruction while the NFC applies to the operation and maintenance of the fire-related features of buildings in use.

In 2005, the National Model Codes adopted an objective-based code structure. An objective-based code includes objectives or goals that the code is meant to achieve. In an objective-based code, every technical requirement achieves one or more of that code's stated objectives (e.g., Safety, Health, Accessibility, Fire and Structural Protection of Buildings, Environment).

Within objective-based code, compliance is achieved through two paths: (1) acceptable solutions prescribed in the codes; or (2) demonstrating that a proposed alternative solution provides at least an equivalent performance. Converting Canada's building codes to an objective-based format has made them more accommodating to innovation by clarifying their scope as well as the intent behind their requirements. Each code provision is now supplemented by clearly stated objectives and functional statements that help guide code users in crafting alternative solutions.

The 2020 NBC will feature acceptable solutions for encapsulated mass timber construction in buildings up to 12 storeys to provide a specific prescriptive path for tall mass timber buildings that will avoid the need for alternative solutions. Refer to AIBC and EGBC Joint Professional Practice Guidelines - Encapsulated Mass Timber Construction Up to 12 Storeys, 2021 for further information.



The alternative solutions code compliance path is essential to tall wood building projects. *While the 2020 National Building Code now features acceptable solutions (prescriptive requirements) for wood buildings up to 12 storeys, it is likely these may not address many expressive or innovative aspects of proposed designs. Engaging qualified consultants to develop acceptable solutions is probably unavoidable except for the most rudimentary building typologies.*

At present, acceptable solutions (prescriptive requirements) apply to wood buildings up to 6-storeys in most parts of Canada. Wood buildings greater than 6-storeys, often referred to as tall wood buildings, currently require an alternative solutions compliance path, primarily in relation to code objectives for fire safety and structural integrity. (NOTE: The term *tall wood buildings* generally refers to any wood building greater than 6-storeys in building height, where the top floor is higher than 18 m above grade, and structural systems other than light-frame construction are used.)

The 2020 edition of the National Building Code will feature acceptable solutions for tall wood buildings up to 12-storeys. In the meantime, British Columbia and Quebec have special provisions for alternative solutions applied to tall wood buildings. Alternative solutions will almost always be necessary for tall wood buildings until such time as acceptable solutions in provincial and territorial codes catch up to mass timber building technology.

British Columbia has issued site-specific regulations for tall wood buildings that exempt a project from some parts of the British Columbia Building Code, such as limits on building size for combustible construction, ensuring occupant health and safety protections equal to or better than current code provisions for non-combustible construction of the same size.

Régie du bâtiment du Québec (RBQ), has developed a publication titled, *Mass timber buildings of up to 12-storeys - Directives and Explanatory Guide*. The guidelines contained in that publication offer a specific alternative solution under the Quebec Building Act.

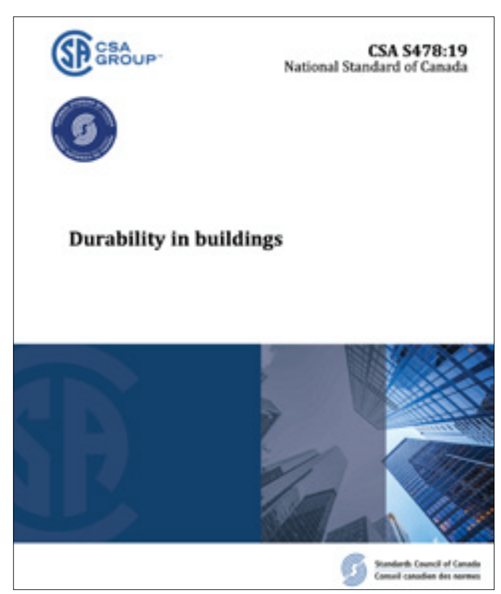
The process in Ontario is distinct from British Columbia and Quebec, and similar to what is required in the other provinces. It is expected that until the national and provincial building codes adopt tall wood buildings as one of the Acceptable Solutions in Division B, Alternative Solution submissions will be required to allow permitting of tall wood buildings.

Alternative solutions will almost always be necessary for tall wood buildings until such time as acceptable solutions in provincial and territorial codes catch up to mass timber building technology.

FPInnovations has developed *Technical Guide for the Design and Construction of Tall Wood Buildings in Canada 2021* to assist architects, engineers, code consultants, developers, building owners and authorities having jurisdiction (AHJ) in understanding the unique issues to be addressed when developing and constructing tall wood buildings that are beyond the height limits found in the National Building Code of Canada.

CSA S478:19 Durability in Buildings standard has not been adopted in building codes, but it is a highly recommended best practice to include to include it in contract documents to ensure a reliable building service life resulting/extending from proper design, operations, maintenance through to documentation for facility management.

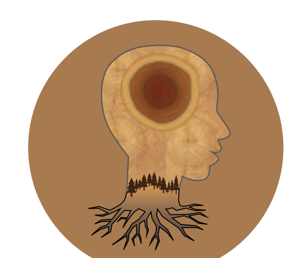
It is important to determine the code compliance path that will apply to a proposed wood building project so that research into comparable precedents may be sought and to identify qualified experts that may be required to develop and demonstrate alternative solutions to the satisfaction of the authority having jurisdiction.



For a comprehensive approach to designing, operating and maintaining for durability, refer to: CSA S478: 19 Durability in Buildings.

Code Compliance

- Light wood-frame buildings up to 6-storeys can be designed according to prescriptive requirements (acceptable solutions) under present building codes.
- Specific alternative solutions for tall wood buildings are available in British Columbia and Quebec.
- The 2020 edition of the NBC will feature acceptable solutions for tall wood buildings up to 12-storeys based on encapsulated mass timber construction (EMTC).
- Alternative solutions will almost always be necessary for tall wood buildings until such time as acceptable solutions in provincial and territorial codes catch up to mass timber building technology.
- Architects should retain expert structural engineering, fire safety and acoustical consultants at the outset of a mass timber building project to navigate code compliance through alternative solutions.



Building Code Compliance
Click on this icon to download information related to building code compliance for mass timber buildings.

Structural Design

The importance of structural design for safe and efficient mass timber buildings cannot be overstated. In Canada, dedicated and ongoing efforts by the Canadian Wood Council and FPInnovations, not to mention a network of wood structural engineering researchers across numerous academic institutions, have continued to make significant advances in mass timber engineering. Developments in mass timber materials, especially innovations in connectors, make it possible to deliver a full range of building typologies that are reliable and cost effective.

This section of the primer cannot possibly address structural design in a comprehensive manner due to the depth and breadth of the subject area; however, it attempts to highlight the critical considerations for mass timber buildings. According to wood structural design experts, the critical considerations for the engineering design of wood structures involve:

- Gravity framing;
- Lateral systems;
- Connections;
- Details for shrinking and swelling; and
- Floor vibration.

It is also important to ensure that structural mass timber elements have adequate strength in terms of axial, bending, shear and bearing capacity. From a serviceability perspective, it is also very important to check deflections (creep) and vibrations.

Part 4 of the 2020 National Building Code sets out the structural requirements for buildings and it references national standard of Canada CSA 086:19 Engineered Design in Wood. The Canadian Wood Council's Wood Design Manual is another authoritative resource for the design of wood buildings.

An additional consideration for the design of mass timber building structures is the size of structural members, components or elements, such as beams, columns and floor panels. These are typically determined by the size of structural grid in post and beam type structures, the spacing of bays in braced frame and panel type structures. From a cost perspective, structural designs may need to optimize the volume of mass timber in relation to desired clear spans, since the cost of mass timber is largely determined on a volumetric basis. In order to be cost competitive with alternative structural system materials, the volume of mass timber associated with clear spans is a critical factor. As the scale and market penetration of mass timber buildings increase, the volume of mass timber in a building may no longer be a primary consideration, but forest resource conservation will never go out of style.

R&D in mass timber materials, systems and connectors requires the constant updating of structural engineering knowledge and design tools to take the fullest advantage of ongoing innovations.

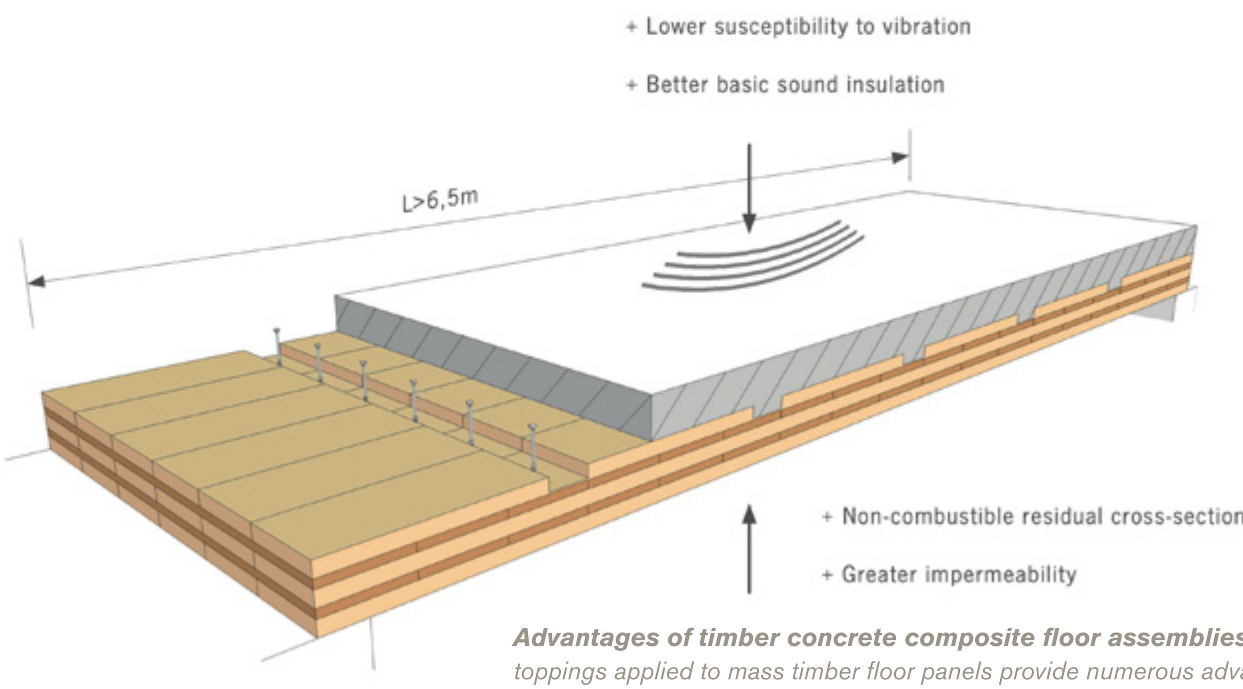
For a comprehensive approach to designing, operating and maintaining for durability, refer to: CSA O86:19 Engineering Design in Wood.

The 2017 Wood Design Manual, published by the Canadian Wood Council, provides practitioners with essential information for the design of structural wood components following an NBC Part 4 engineered design approach.

CSA 086:19 Engineered Design in Wood and 2017 Wood Design Manual. *These two publications reflect requirements in Part 4 of the National Building Code for the current state of the art in the structural engineering of wood buildings.*

Canadian CLT Handbook, 2019 Edition. *For additional in-depth technical information about structural design refer to: Chapter 3 – Structural Design of Cross-Laminated Timber Elements; Chapter 4 – Lateral Design of Cross-Laminated Timber Buildings; Chapter 5 – Connections in Cross-Laminated Timber Buildings; Chapter 6 – Duration of Load and Creep Factors for Cross-Laminated Timber Panels; and Chapter 7 – Vibration Performance of Cross-Laminated Floors, in Volume 2 of the CLT Handbook.*

One of the most widely researched developments in mass timber construction technology is timber concrete composite (TCC) floor assemblies. This approach is widely acknowledged as an optimal means to achieving structural integrity, fire safety and sound control.



Advantages of timber concrete composite floor assemblies. *Concrete toppings applied to mass timber floor panels provide numerous advantages in terms of longer spans, lower vibrations, better sound insulation and enhanced fire safety. (KLH Massivholz GmbH).*

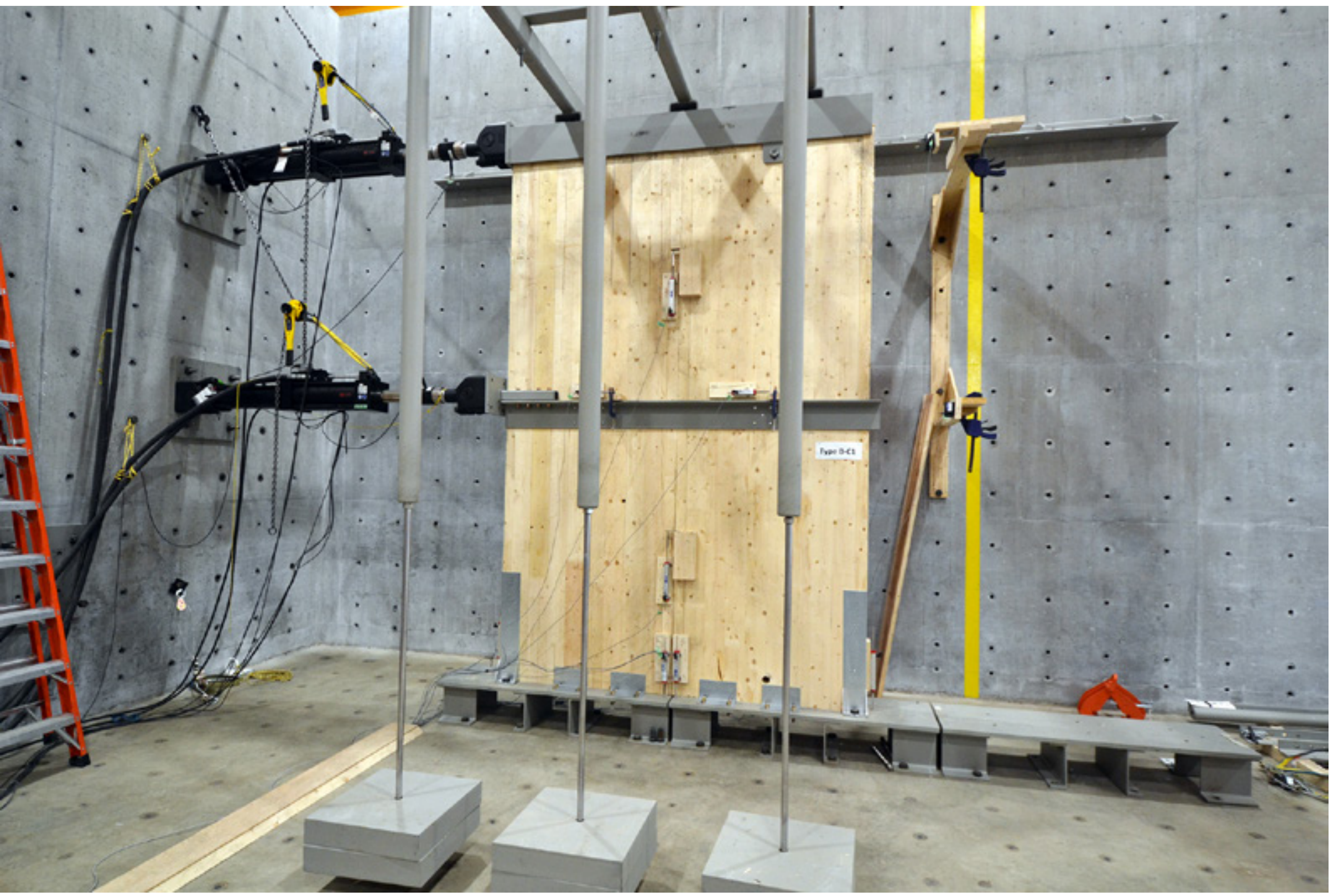
Testing timber concrete composite assemblies. *The use of TCC assemblies addresses a number of structural, acoustical and fire safety issues in mass timber buildings. A great deal of research into the performance various TCC technologies is running parallel to the development of reliable design methods. (Oregon State University)*

In tall mass timber buildings, a lateral force-resisting system (LFRS), also termed a lateral load-resisting system (LLRS), continues to represent a structural design challenge. Advances in the engineering design of wood structures are a global phenomenon as the mass timber revolution unfolds. In North America, the forest products industries and various councils and advocacy groups have played a pivotal role in establishing the limit states design for various components, assemblies and structural systems.

Post and beam mass timber building types that do not wish to incorporate either reinforced concrete or mass timber panel shear wall, must rely on moment connections to achieve the required lateral resistance. Highly efficient connectors and bracing configurations are among the approaches being tested at full scale.

Full-scale seismic testing of mass timber. *Testing of full-scale mock-ups on a shake table to assess lateral resistance is an ongoing global research effort as mass timber technical innovations develop new concepts, materials and connectors. Special testing of this kind may be required to confirm compliance for alternative solutions under building codes. (University of California, San Diego)*

For mass timber buildings where a low carbon footprint is targeted, it is often necessary to forego reinforced concrete shear walls and to deploy mass timber panels as shear walls. Current challenges are associated with effective connector designs that enable the realization of a robust diaphragm to resist lateral forces.

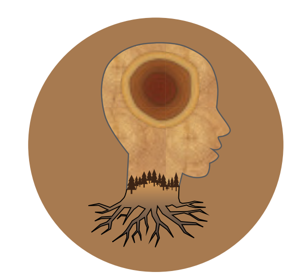


CLT shear wall testing. *At the University of Northern British Columbia (UNBC), the testing of connections to CLT panels acting as shear walls has advanced their application in multi-storey buildings. (Fast and Epp)*

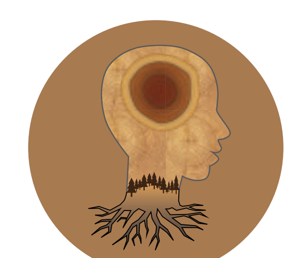
In Canada, the federal government through Natural Resources Canada and its Green Construction in Wood (GCWood) program continues to collaborate with the Canadian Wood Council, FPInnovations, the National Research Council of Canada and a network of academic researchers to advance the engineered design of wood structures. A number of Canadian provinces have also launched complementary initiatives to bolster the adoption of mass timber in buildings.

Structural Design Considerations

- Design codes and standards are unable to keep up with rapid advances in technical innovation in the area of mass timber structural design.
- Typical low and mid-rise mass timber projects can be routinely designed according to the currently available design codes and standards.
- Tall timber buildings will require specialized structural design expertise, particularly when innovative approaches to lateral load resistance systems are adopted.
- Structural connections between mass timber components must be designed with due consideration for their influence on sound transmission.
- The structural health monitoring (SHM) of wood structures is being recommended as a prudent practice for tall mass timber buildings.



Timber Concrete Composites
Click on this icon to download various resources related to timber concrete composite (TCC) floor assemblies.



Structural Design
Click on this icon to download helpful resources related to the structural design of mass timber buildings.

Fire Safety and Acoustics

Fire safety and acoustics are important for all types of buildings, but in the case of mass timber buildings it is both time and cost effective to approach and develop fire and acoustical measures together, beginning at the early stages of design. By taking this approach, it is possible to simultaneously address fire and sound control through the selection of appropriate assemblies and identification of critical details.

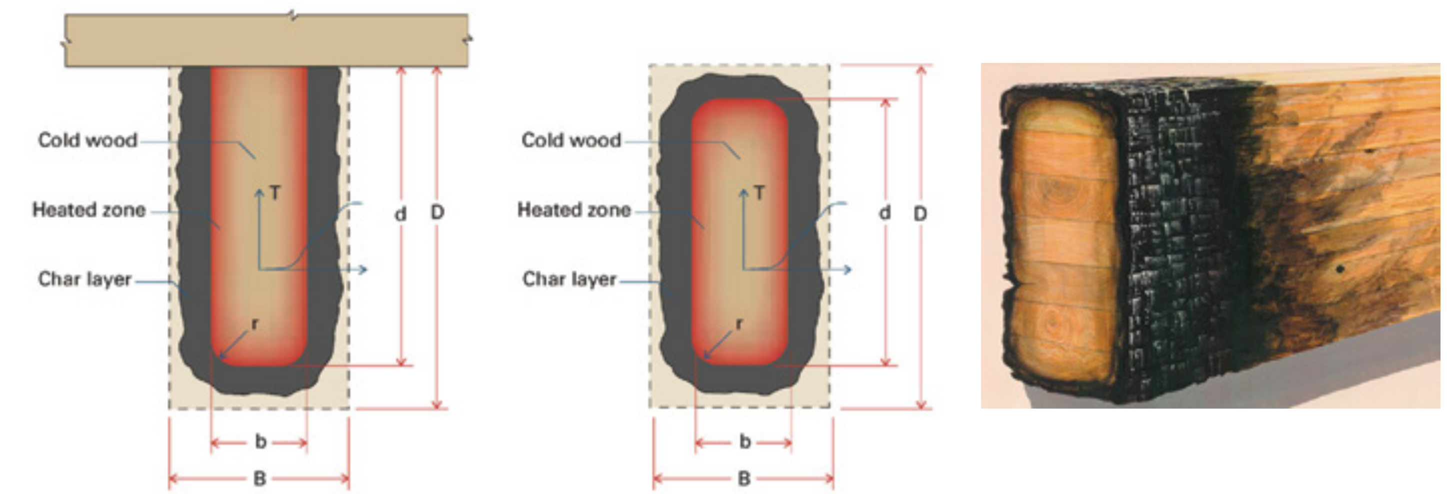
The 2020 editions of the National Building Code and National Fire Code were developed by the National Research Council and the Canadian Commission on Building and Fire Codes. They contain requirements for encapsulated mass timber construction up to 12 storeys in building height. EMTC refers to buildings where the mass timber components of the building are surrounded or encapsulated with fire-resistive material. This approach provides for equivalent or better fire protection compared to many other construction types, and the 2020 code provisions also include additional requirements for fire protection during construction and ongoing maintenance.

Acceptable solutions for fire safety avoid the development of alternative solutions under the guidance of expert fire safety consultants, saving both consulting fees and the additional time needed to review and approve alternative solutions. However, there are cases where there is a desire to expose the mass timber wood elements for aesthetic reasons and in these situations, expert assistance is necessary.

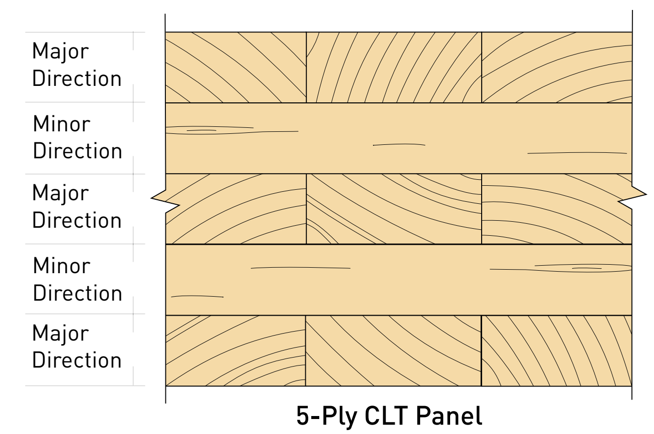
For mass timber buildings it is both time and cost effective to approach and develop fire and acoustical measures together, beginning at the early stages of design.

The concept behind demonstrating the fire safety of a proposed mass timber building assembly relates to how much of a mass timber structural element's integrity is compromised by exposure to fire. Laboratory testing data are used to establish the depth of char that develops when mass timber elements are exposed to various durations and intensities of fire.

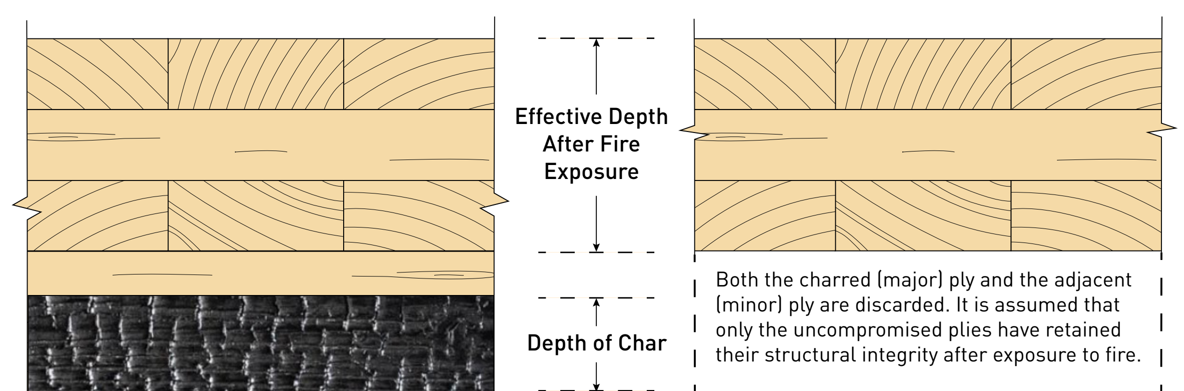
Typically, mass timber elements are oversized to account for loss of structural integrity due to depth of char in buildings where it is intended to expose the wood structure. This adds cost for the mass timber materials comprising the exposed structure, but since this design approach represents an alternative solution under the building code, additional fees and time for approvals are also associated with this approach.



Reduction in member size after exposure to fire. *This wood beam has a reduction in its effective structural cross section from B x D to b x d, due to the amount of burned wood (char). To comply with fire safety requirements, the beam must have sufficient integrity to safely carry the in-service loads after exposure to a specified duration and intensity of fire. (American Wood Council)*



Effective depth of a CLT panel. *After accounting for the depth of char and the effects of heat exposure on the affected lamination, in this hypothetical example the panel's effective depth is reduced from 5 to 3 plies. (CLT Handbook)*



Mass timber buildings are far more challenging acoustically than from a fire safety perspective. The nature of wood is at the root of this challenge since it does not have sufficiently high density to absorb impact and airborne sounds, but is sufficiently dense to transmit certain frequencies of airborne sound along with impact sounds very efficiently. Connections between mass timber components and assemblies also tend to transmit sound efficiently and require special attention to achieve satisfactory performance. The control of sound transmission in buildings must effectively address airborne and impact noises.

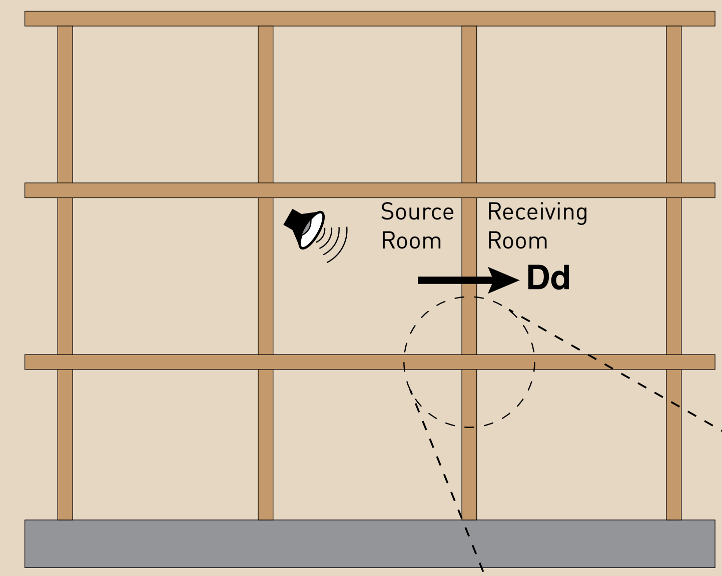
Airborne sounds come mainly from sources such as human speech, musical instruments, radio, television, and in some cases appliances such as vacuum cleaners and food processors. Airborne noise is a sound wave carried by vibration through the air which then penetrates assemblies such as floors, ceilings and walls. Airborne sounds transmit directly through these assemblies, but also through any small openings around doors, air vents, pipes and electrical outlets. Sound can also carry from one assembly, such as a floor, to a wall where they are connected, and all of these indirect sound transmission paths are referred to as flanking. For the control of direct airborne sound transmission, the more mass, the greater it will absorb energy and reduce airborne noise. For the control of flanking noise transmission, the sealing of all openings and the isolation of vibrations between adjacent partition assemblies, such as floor and walls, or floors and ceilings, are effective measures.

Impact sounds are noises that are created by an impact or vibration, such as moving furniture, a person walking, falling objects striking the floor or the rumble of appliances or equipment such as exercise equipment. Impact noise is transmitted by vibration through the structure of the building via assemblies such as floors and walls.

A new approach to controlling sound transmission between adjoining units in residential buildings was adopted in the 2015 edition of the National Building Code of Canada (NBCC). The design objective was changed from a minimum Sound Transmission Class (STC) for the wall or floor/ceiling assembly separating adjacent units, to a minimum **Apparent Sound Transmission Class (ASTC),** which includes transmission of both direct and flanking sound. This design approach uses data from ASTM E90 Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements of direct transmission through wall or floor/ceiling assemblies, together with flanking transmission data conforming to ISO 10848 as inputs to calculation procedures based on ISO 15712-1.

There are several different criteria used in the rating of sound insulation against impact noise. **IIC** stands for **Impact Insulation Class**, the degree of soundproofing of the impact noise of a floor/ceiling assembly in a laboratory. The higher the IIC, the better the acoustic insulation. This measurement index, obtained by standardized acoustic tests, is done in a laboratory where the testing and site conditions are controlled. **FIIC** stands for **Field Impact Insulation Class**. This is a unit of measurement that determines the degree of soundproofing of the impact noise of a floor/ceiling assembly on site rather than in a laboratory. The higher the FIIC, the better the acoustic insulation. A FIIC test is carried out on site, in real buildings. It can be argued that this rating is more representative of reality than an IIC laboratory test. **AIIC** stands for **Apparent Impact Insulation Class**, which is the insulation index of the apparent impact noise of a floor/ceiling assembly on site. Since ASTM E1007-14 and ASTM E336-14 came to affect, details have been provided on how to measure and present the results of acoustic tests carried out on site. All new tests carried out on site will now be preceded by the letter "A" rather than "F". Other than designating the unit of measurement for acoustic efficiency, these changes represent more accurately the reality of an onsite test, with its characteristics and weaknesses.

The application of these updated sound control criteria will help take into account actual impact sound transmission that more accurately reflects the methods of construction.



The 2015 edition of the National Building Code adopted a new airborne sound transmission rating called the Apparent Sound Transmission Class (ASTC). This new rating takes into account both the direct sound transmission and the "flanking" sound transmission, which together provide a more realistic measure of the actual sound level perceived by occupants, as it includes noise transmitted through all possible paths.

Important Note: Flanking sound control where demising walls intersect exterior mass timber walls is critical.

ISO 15712-1 labelling convention for direct and flanking sound transmission paths. Each transmission path connects one surface in the source room (denoted by a capital letter) with a surface in the receiving room (denoted by a lower case letter).

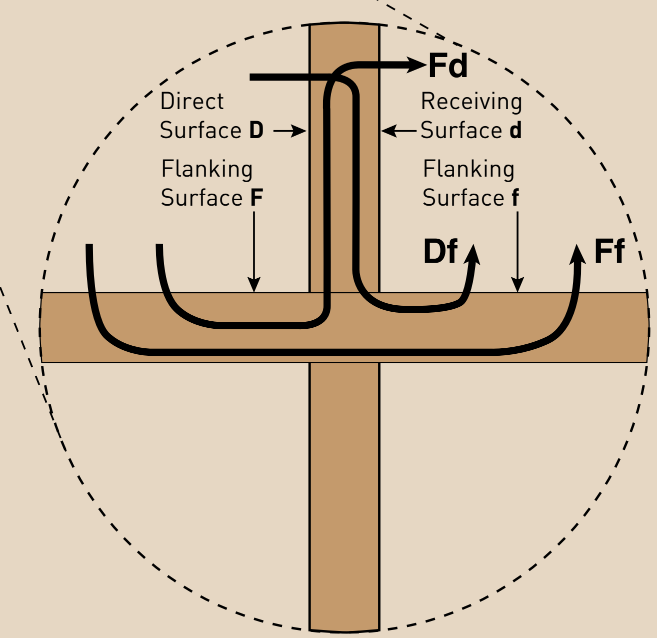
Dd - direct transmission through the separating assembly.
For each edge of the separating assembly there are three flanking paths.

Ff - from flanking surface F to flanking surface f.

Df - from direct surface D to flanking surface f.

Fd - from flanking surface F to direct surface d.

Typically, every separating assembly has four edges (top, bottom, and two sides) where airborne flanking sound transmissions occur.



Systems approach to sound control. *The adoption of the apparent sound transmission class rating in building codes requires designers to consider both the direct and flanking airborne transmission of sound. Methods of structural connection and sound isolation materials between assemblies are now important considerations in the design of mass timber buildings.*

Understanding the practical interpretation of impact insulation class and sound transmission class ratings is important when designing for sound control. The listing below provides a guide to various rating levels.

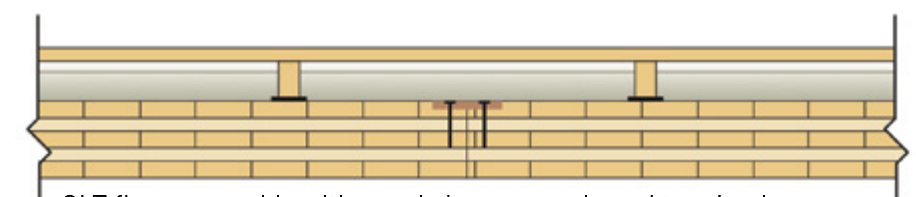
- IIC-STC 70 Virtually soundproof
- IIC-STC 60 Superior sound proofing
- IIC-STC 50 International Building Code
- IIC-STC 40 Sound proofing below most codes

In multifamily buildings with more than one floor, the National Building Code now requires an apparent sound transmission class rating of 47, which accounts for flanking paths, instead of STC 50. The NBCC does not require a minimum impact noise rating but recommends a FIIC 55. It is important to appreciate the NBC provides minimum requirements designed to address health and safety issues, but not occupant comfort or satisfaction. In cases where a higher level of acoustic comfort is desired, a design target should be ASTC 55 (for satisfactory performance) or ASTC 60 (for ideal performance), and other unwanted sources of noise such as impact or environmental noise must also be addressed. Even though code requirements for sound control may not apply to a particular building type, building owner/occupant expectations should always be taken into account. If a mass timber building is to be occupied by medical offices, then sound privacy may be an important consideration. Similarly, purchasers of a luxury mass timber condo may expect superior sound control well above minimum code requirements.

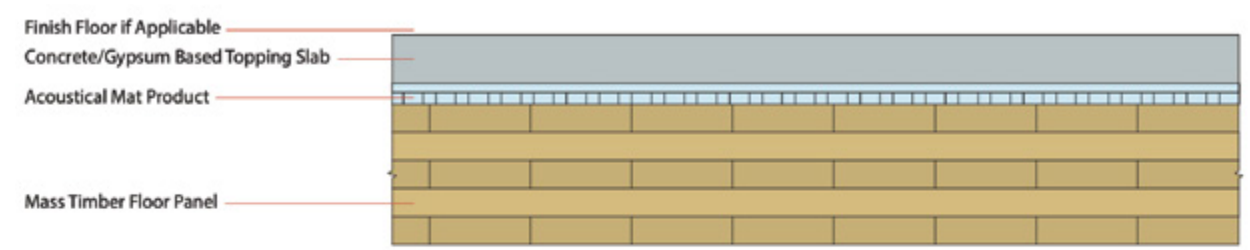
The National Research Council's soundPATHS web application is a prediction tool for the calculation of direct and flanking sound transmission between adjacent rooms. The software uses the calculation procedure that was developed for and outlined in the 2015 National Building Code. The soundPATHS application[11] and related publications are derivatives of a series of industry-sponsored research projects conducted at the National Research Council of Canada. The focus and construction details for each phase were decided by various technical representatives from each of the industry partners supporting the software development and its calibration and validation through testing. Canada's wood product industry sponsored a large series of tests related to wood and mass timber assemblies. Use of the software requires expert knowledge in sound transmission control but this predictive tool can avoid the need for additional laboratory and field testing.

[11] *The soundPATHS application is available at: https://soundpaths.nrc-cnrc.gc.ca/#/*

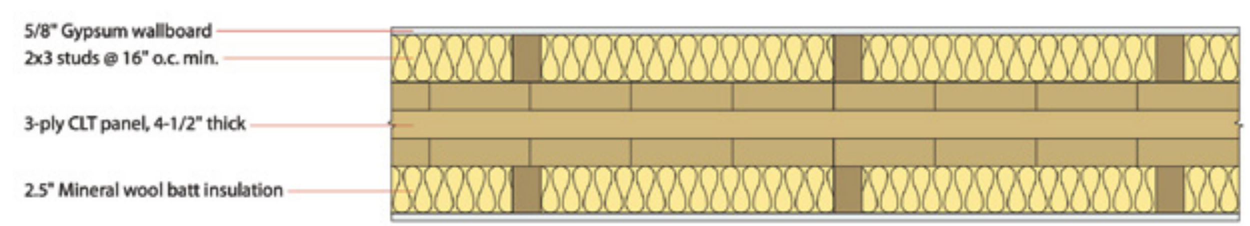
The science and engineering for controlling sound transmission in buildings have shifted from a focus on individual assemblies to the performance of the complete system. Standardized procedures for calculating the overall transmission, combined with standardized measurements to characterize assemblies, such as floors and walls, including their connections, provide a more reliable prediction of sound transmission between adjacent indoor spaces.



CLT floor assembly with wood sleepers and sand topping layer. (Note the isolation gasket between the sleepers and the CLT panel. Membrane required to prevent sand leaking through gaps in CLT.)



CLT floor assembly utilizing a proprietary acoustical mat product and a concrete/gypsum based topping.

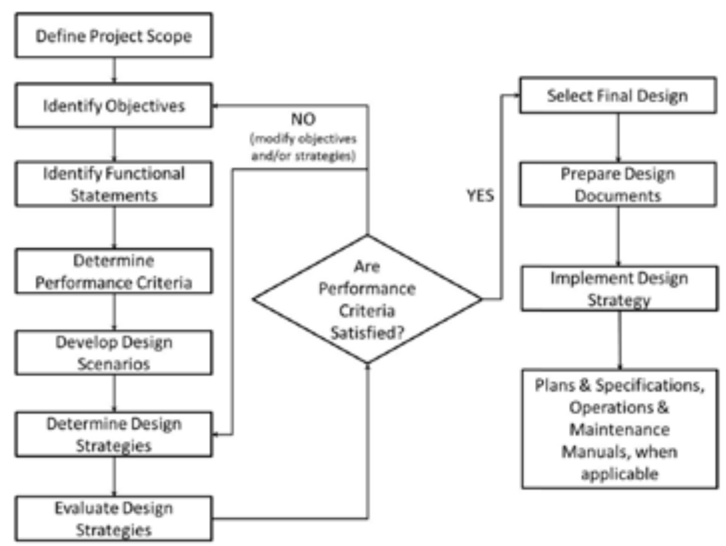


CLT wall assembly with insulated lumber-framed chase walls on both sides. 2" x 3" (38 mm x 64 mm) studs are the minimim depth to accommodate the integration of services.

***Sound rated assemblies.** Laboratory and field testing of a wide variety of mass timber floor and wall assemblies provide designers with a range of alternatives to achieving sound control in mass timber buildings. Connections between these assemblies must now be considered to achieve required levels of acoustical control. (Adapted from Acoustics and Mass Timber: Room-to-Room Noise Control. Woodworks, 2018.)*

Raised floor systems help address acoustical issues. *In addition to helping integrate mechanical, electrical and plumbing systems unobtrusively, raised floor systems, such as this one installed at 80 Atlantic, designed by Quadrangle Architects, also minimize the transmission of airborne and impact sound transmission across floor assemblies. Note that a concrete topping over the NLT floor panels is required to fireproof concealed cavities. (Bob Gundu, Canadian Architect)*

As noted previously, for many types of mass timber buildings, alternative solutions will be required to demonstrate code compliance because the acceptable solutions do permit the aesthetic expression of the mass timber components and assemblies. Developing and obtaining approval for alternative solutions is a time-consuming process that typically involves professional peer review of proposed alternative solutions for a particular building project. Fire safety and acoustics account for a high proportion of alternative solutions required for mass timber building projects. The flow chart below outlines the essential elements of a performance-based design process.

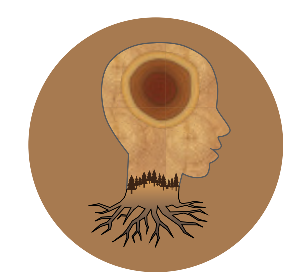


Performance-based design process. *This flow chart represents a general approach applicable to a variety of building performance attributes related to structure, fire and acoustics. [Source: Development of Performance Criteria for Wood-Based Building Systems, FPInnovations, March 2016 (reformatted May 2020).]*

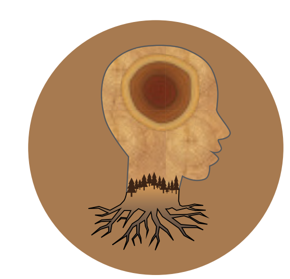
Fire Safety and Acoustics

- It is both time and cost effective to approach and develop fire and acoustical measures together, beginning at the early stages of design.
- Mass timber buildings can be well designed to achieve the same levels of fire safety and sound control as more conventional building methods.
- A large number of resources are available to assist designers with selecting appropriate strategies and measures for fire safety and acoustics.
- Exposing mass timber components and assemblies will normally require alternative solutions to demonstrate code compliance, for both fire safety and acoustics. Consulting with qualified experts at the early stages of design is highly recommended.
- Acceptable solutions for encapsulated mass timber construction up to 12 storeys in height are available for mass timber buildings under the 2020 National Building Code.

Fire Safety and Acoustics – CLT Handbook. *For more in-depth technical information about fire safety and acoustics, refer to: Chapter 8 – Fire Performance of Cross-Laminated Timber Assemblies; and Chapter 9 – Acoustic Performance of Cross-Laminated Timber Assemblies, in Volume 2 of the Canadian CLT Handbook, 2019 Edition.*



Fire Safety and Acoustics
Click on this icon to download helpful resources related to the design of mass timber buildings for fire safety and acoustics.



MURBs
Click on this icon to download resources related to the design and construction of multi-unit residential buildings (MURBs) to enhanced quality of life.

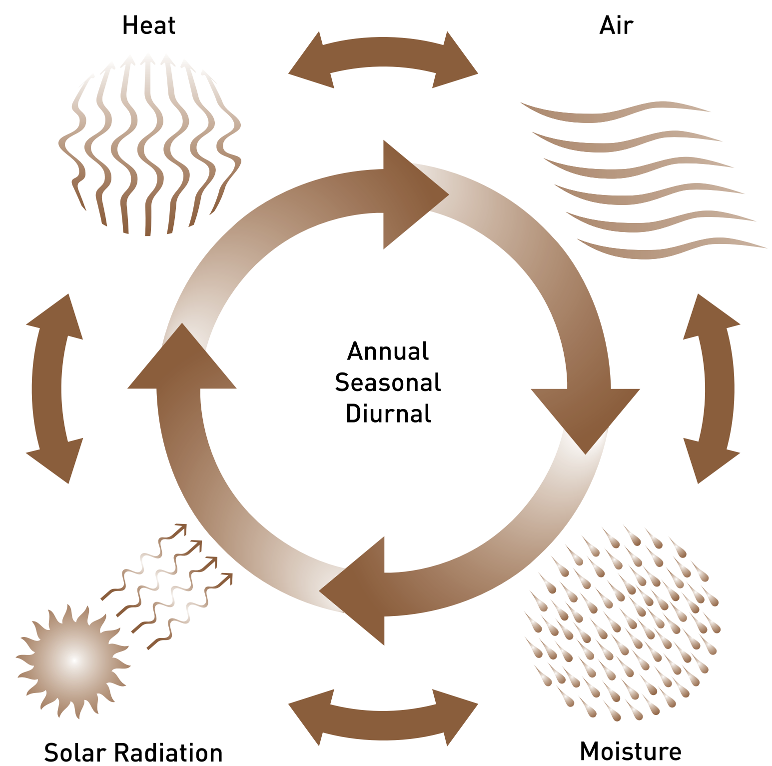
Enclosure Design

Building enclosure design is critical to the performance of mass timber buildings. During construction, enclosures must be installed rapidly to close in the mass timber assemblies in order to manage moisture and protect against chronic wetting, unsightly staining and potential degradation. After the building is completed, enclosures need to deliver thermal efficiency, comfort and aesthetics. Enclosures are also a significant factor impacting the life cycle performance of buildings in terms of energy costs and carbon footprint. Most importantly, along with the structure, enclosures represent the most critical passive systems in buildings, providing resilience and passive habitability during prolonged power outages that coincide with extended extreme weather events.

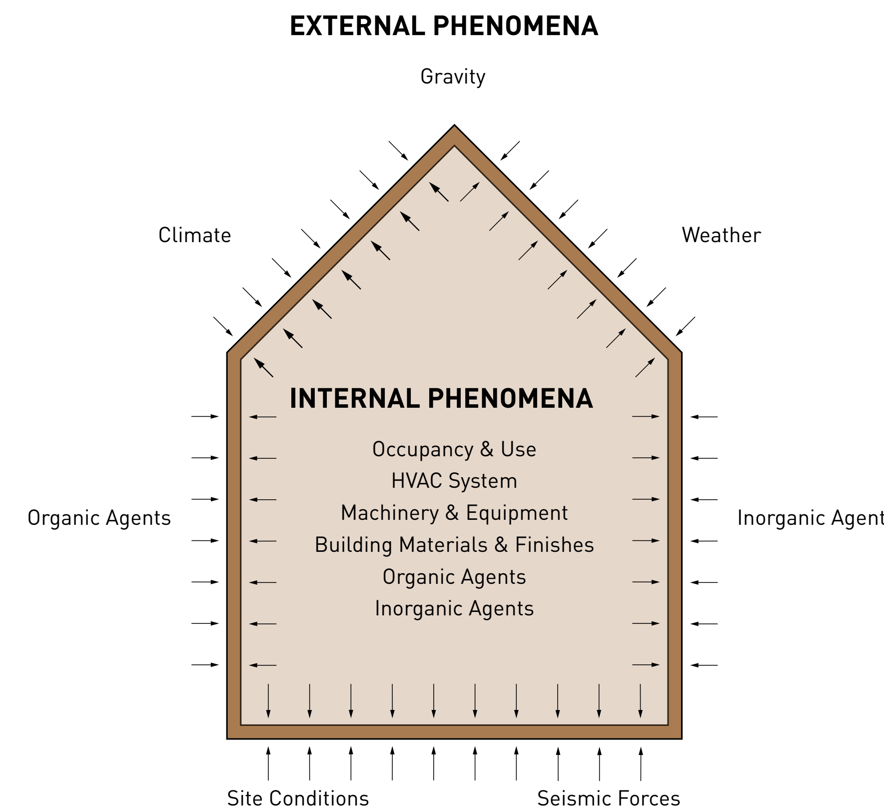
Building enclosures separate the outdoors from the indoors and must be designed and constructed to adequately control heat transfer, air leakage, moisture sources and solar radiation. Over the service life of a building, which typically extends beyond 100 years for most residential, commercial and institutional buildings, the building enclosure must manage a number of external and internal phenomena.

Climate change is causing an increase in the frequency and intensity of certain extreme weather events, in particular winds, precipitation and warming. As a result, the weather effects and climate trends must be carefully considered when designing enclosures since most of the data informing contemporary design practice represent normal that are likely to significantly change over the service life of the building.

For mass timber buildings, durability is only skin deep. Failure of the enclosure to fulfill critical control functions will potentially translate into failure of the entire building system to provide acceptable life cycle performance.



Enclosures manage heat, air, moisture and solar interactions. *They serve as the primary passive moderator of the indoor environment providing continuous service under conditions which change daily, seasonally and annually. The enclosure must be robust and durable, remaining serviceable over the life of the building.*



Enclosures manage external and internal phenomena. *Based on the occupancy and building use, internal sources drive heat, air and moisture outward while external phenomena impose stresses inward. Seismic forces, thermal and wind stresses may compromise the integrity of the enclosure. Soil contaminants (gases) and insects may also enter the building through gaps in the enclosure. It is prudent to anticipate the likely future external phenomena, such as climate change, and internal phenomena, such as adaptive re-use (repurposing).*

Modern building science has made considerable advances in enclosure design, fabrication and field assembly and well-defined frameworks for the application of building science have been in existence for several decades. These frameworks, or design protocols, involve an explicit assessment of the adequacy of a proposed building enclosure to satisfy critical requirements. For proven assemblies that have been validated through acceptable past performance, there is considerably less risk associated with their adoption, but their performance may not satisfy today's requirements and expectations.

Requirement	Parameters	
Structural Strength/Rigidity	Loadbearing/Non-loadbearing Wind Loading	Seismic Loading Thermal Effects
Control of Heat Flow	Effective Thermal Resistance	Thermal Bridging
Control of Air Flow	Stack and Wind Pressures Normalized Leakage Area	HVAC Influences Internal Partitioning
Control of Moisture Flow	Rain Penetration Vapour Diffusion	Air Leakage Condensation Potential
Control of Solar Radiation	Opacity/Emissivity Solar Orientation	Fenestration Shading Devices
Control of Sound Transmission	Airborne Sound	Vibration
Control of Fire	Fire Rating	Combustibility
Durability	Ultraviolet Degradation Corrosion Carbonation Freeze/Thaw Abrasion Fatigue Instability/Incompatibility	Biological Attack (mould, insects, animals, plants) Chemical Attack (soils, contaminants, pollutants) Efflorescence Subflorescence Spalling
Economy	Initial Cost Maintenance Cost	Operating Cost Life Cycle Cost
Environmental Impacts	Resource Depletion Environmental Degradation Reduction of Biodiversity	Greenhouse Gases Pollutants
Buildability (Ease of Construction)	Seasonality Tolerances	Coordination Sequencing
Aesthetics	Visual Tactile	Acoustic Olfactory

Adapted from: *Requirements for Exterior Walls* by Neil Hutcheon. Canadian Building Digest #48, Division of Building Research, National Research Council Canada, December 1963.

Enclosures fulfill a large number of critical requirements. *The multifunctional requirements for building enclosures are challenging to satisfy when economic, environmental, tectonic and cultural constraints are imposed. Numerous and diverse performance parameters must be considered and then integrated to provide appropriate enclosure solutions.*

Innovative systems and assemblies will often require the testing of full-scale mock-ups to ensure the details and transitions satisfy the required control functions. The development of innovative approaches to building enclosure design can now take advantage of building science frameworks for effective control strategies. These frameworks assist designers in selecting an appropriate basic control strategy which can then be adapted to the particular context for a building project.

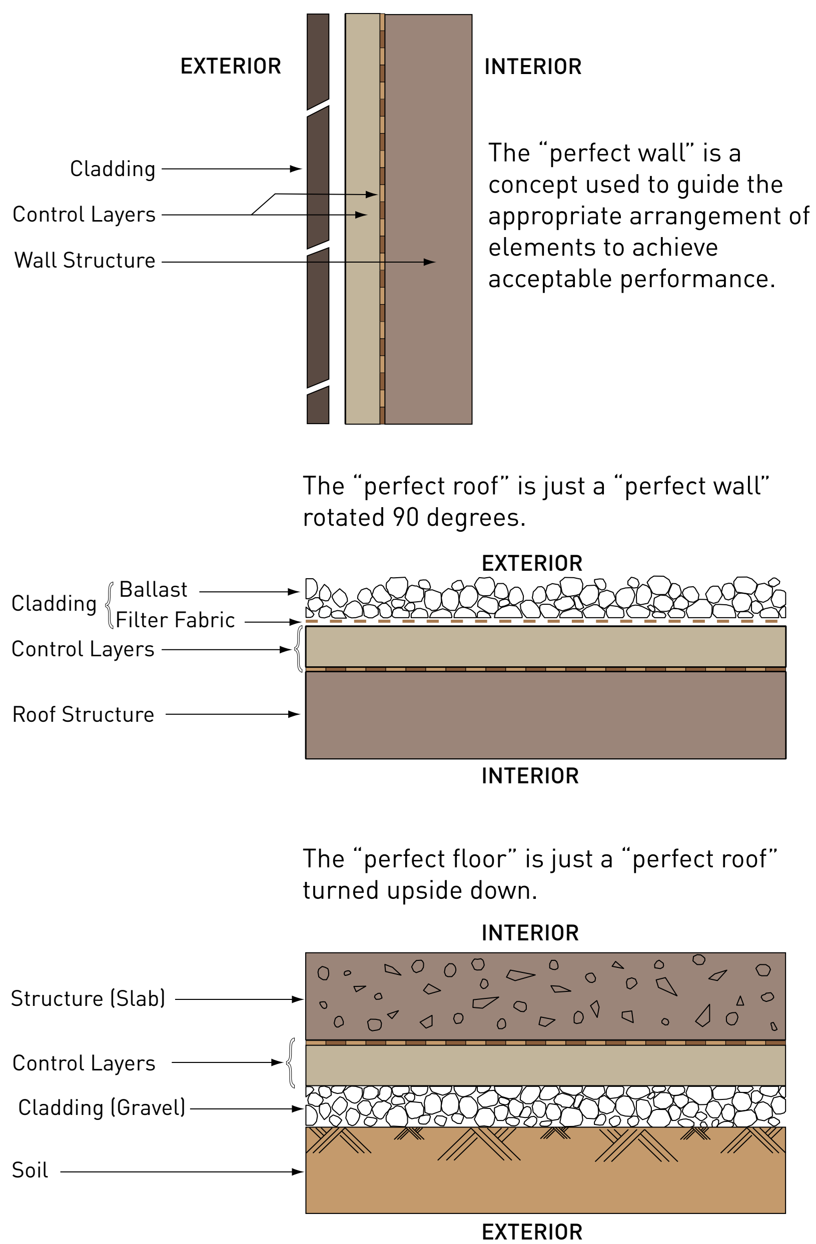
Control Function	Physical Mechanism	Control Strategy
Moisture Migration	Bulk Water	Shedding Conveyance Drainage Storage & Drying Drain-Screen Rain-Screen Dynamic Buffer Zone 'Perfect Barrier'
	Capillary Water	Capillary Barrier Capillary Break
	Vapour Diffusion	Vapour Barrier Thermal Insulation (Condensation)
	Air Leakage	Air Barrier System Thermal Insulation (Condensation)
Heat Transfer	Conduction Radiation Convection	Thermal Insulation Radiation Barrier Air Barrier System
Air Leakage	Stack, Wind and Mechanical Effects	Air Barrier System
Solar Radiation	Heat	Orientation Fenestration Shading Devices Thermal Resilience Glazing Reflectance and Emissivity
	Visible Light	Orientation Fenestration Shading Devices Glazing Optical Properties

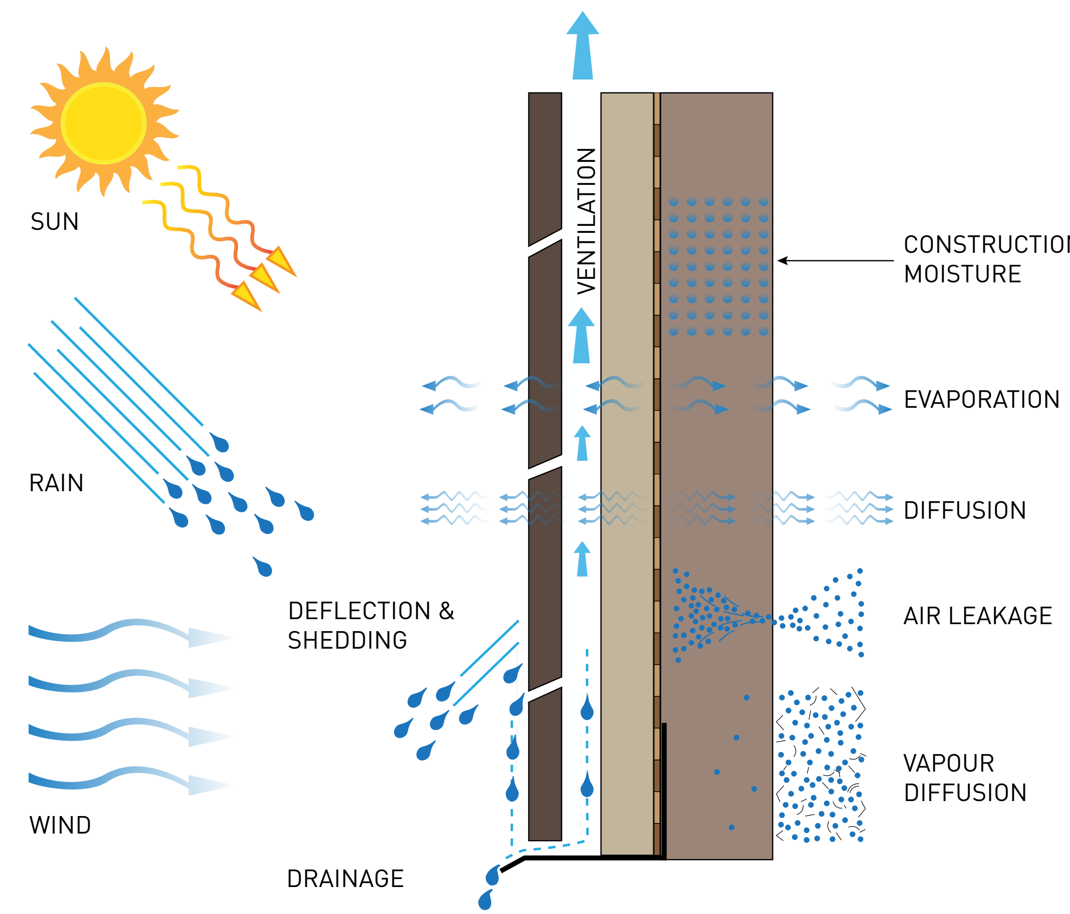
Adapted from work by Bomberg, M.T. and Brown, W.C., 1993. *Building Envelope and Environmental Control: Part 1 - Heat, Air and Moisture Interactions*. Construction Canada, 35 (1).

Building science has established an effective framework of control strategies for enclosures. *Much of the complexity of enclosure design can be reduced by recognizing that tried and true control strategies for physical mechanisms exist and may be suitably applied.*

At the most fundamental level, modern building science has established that building enclosures must observe the principles of “the perfect wall” to achieve acceptable performance. Extensive evidence of performance problems indicates that other types of enclosure configurations do not exhibit acceptable long-term performance.

Modern building science has established that building enclosures must observe the principles of the “perfect wall” to achieve acceptable performance.





Deflection - Use overhangs, flashings and cladding profiles to deflect precipitation and shed water away from the building.

Drainage - Provide an adequate airspace to drain the water that may penetrate the cladding to the outside

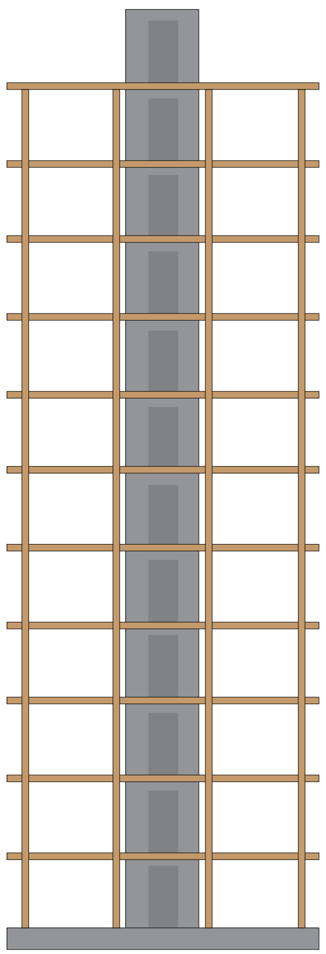
Drying - Properly vent the drainage cavity select and arrange control layer materials to minimize wetting and promote drying by diffusion and evaporation.

Durability - Use durable materials that can tolerate periodic wetting without risk of deterioration and decay.

Cladding, control layers, structure – the constant order of enclosure elements going from outside to inside. *Regardless of climate zone, the arrangement of elements comprising well performing enclosures must observe the order depicted above based on building physics. The cladding manages bulk water intrusion while the control layers manage heat, air and moisture movement, and help maintain the structure at a relatively constant temperature and moisture content. Control layer properties are selected to provide the required level of thermal resistance, airtightness and moisture control.*

The 4 Ds of durable wood construction: deflection; drainage; drying; and durability. *Mass timber absorbs moisture quickly but is very slow in releasing it. The frequency, intensity and time of wetting are critical for mass timber buildings. It is important to ensure that enclosures for mass timber buildings can deflect and drain away most of the rainfall immediately, while affording drying of any moisture accumulations by multiple mechanisms. Enclosure assemblies that can dry both to the outside and the inside reduce the risk of moisture problems, especially for highly insulated assemblies in cold climates.*

Sufficient experience has been gained from the design and construction of mass timber buildings to help inform prudent choices for enclosure systems. Issues related to moisture management factor into critical considerations driving the selection criteria, but in the case of tall buildings, lateral movement and wood shrinkage also have to be accommodated to maintain the continuity of moisture and air barriers and prevent excessive stresses on cladding, fenestration and assembly transitions.

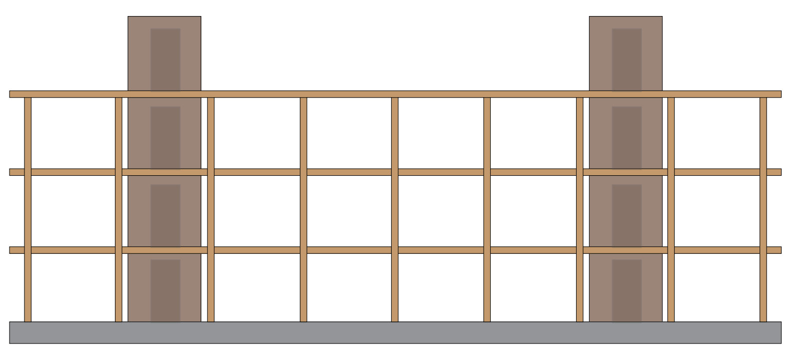


Tall Wood Structures

- More repetitive, more exposed, difficult access, need for more speed - ideal for pre-fabricated facades.
- Less focus on roof and more on walls for weather protection.

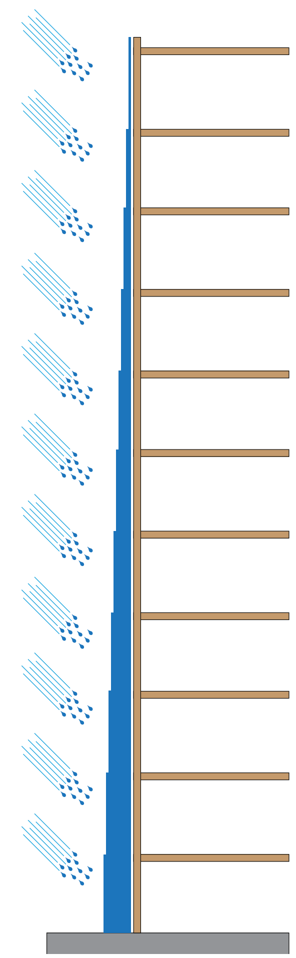
Low to Mid-Rise Structures

- Easier access to walls from ground
- Greater focus on roof for weather protection than walls
- Prefabrication of facades also possible but less economies of scale



The selection of suitable enclosure systems for mass timber buildings is critical. *For tall wood buildings, the enclosure should be capable of being installed shortly after the structure for each floor level is completed. In low to mid-rise wood buildings, alternative moisture management techniques other than rapidly erectable walls may be deployed. (Refer to the next section on Moisture Management.)*

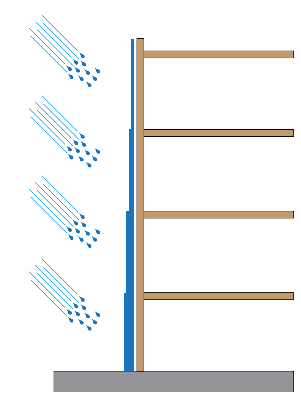
Rain control measures for the purposes of in-service moisture management are critical to the long-term performance of enclosure systems. A related consideration is the potential or staining and degradation associated with shedding, runoff and dripping patterns over the façade surfaces. This is especially important for mass timber buildings that incorporate wood cladding materials, regardless of their scale.



Taller Buildings Need Better Rain Control

- Increased building height collects increased rain deposition that accumulates and runs down to lower levels of the facade.
- Water shedding features such as flashing, drip edges and continuity of surface water flow become more critical as the building gets taller.
- A more robust water penetration resistance strategy is needed for tall buildings - good practice: pressure equalized rainscreens, drained and rear ventilated facades.
- Unfinished facades will experience increased exposure to moisture during construction in tall buildings, resulting in a greater severity of wetting over a longer period of time.

Facade design for mass timber buildings must carefully consider both the rain penetration control of the finished facade system, as well as the management of its exposure to construction moisture throughout the site erection process.

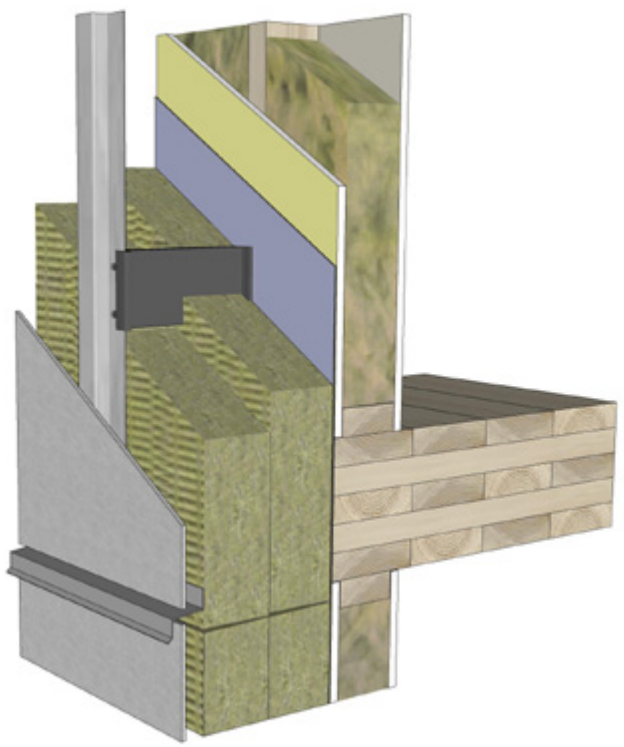


Enclosures for tall wood buildings must be properly engineered. *Shrinkage, settlement, side sway, high wind pressures and moisture accumulations are among the critical factors that must be carefully considered. The water shedding and runoff patterns must not lead to staining and deterioration of the façade.*

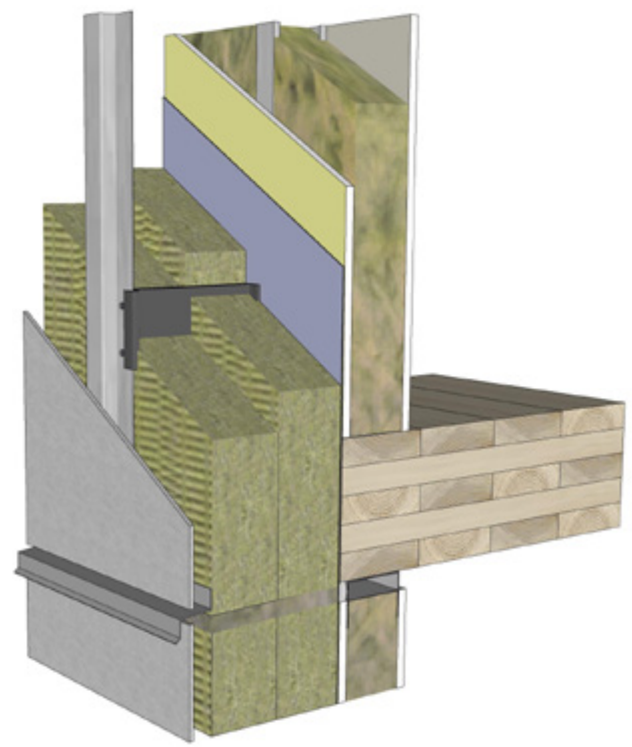
Once the practicality (buildability) and rain control effectiveness criteria have been established, it is possible to select an appropriate enclosure system. These range from the entirely site built to completely prefabricated enclosure systems, with options for some hybrid approaches incorporating both types.

For prefabricated enclosure assemblies one-storey high and wider is better than multi-storey high and narrower.

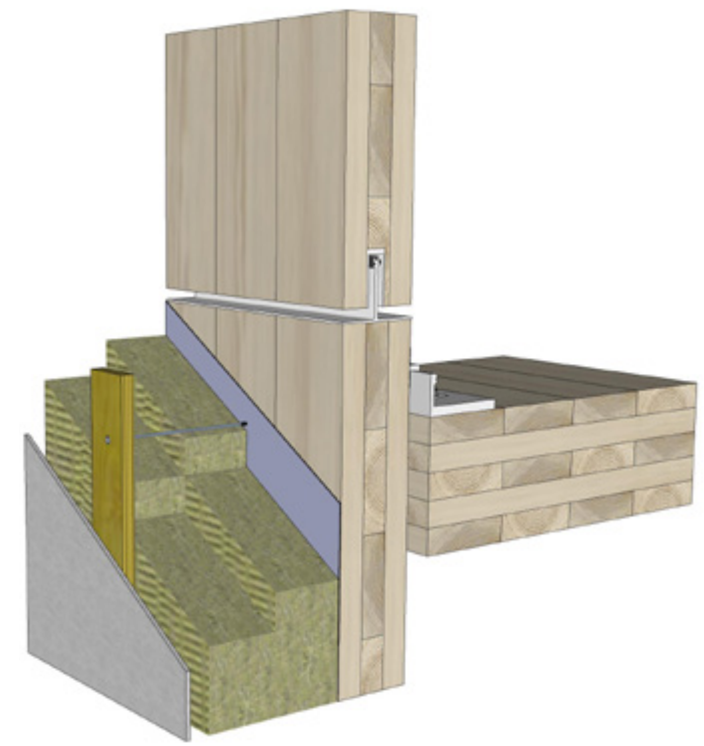
Non-Loadbearing Enclosures



Light wood infill framing is simple and reliable. *Typically assembled on site as non-loadbearing exterior walls, this approach may also be used for loadbearing walls in buildings up to 6 storeys in height. Inclement weather is an important factor since it affects on-site assembly and the accumulation of construction moisture. (RDH Building Science Inc.)*



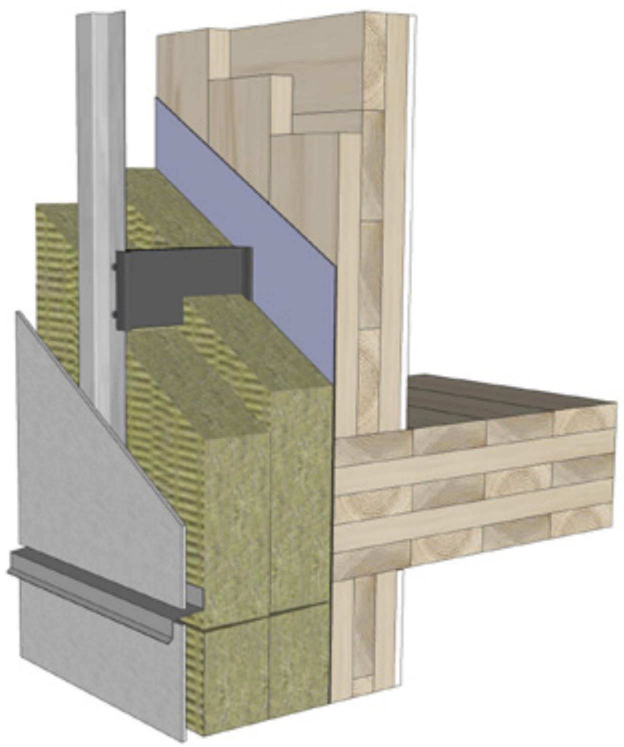
Light steel infill framing is an economical alternative. *Thermal bridging is higher in steel studs than wood studs, but the integration of services is less labour intensive. This approach makes it easier to achieve higher required fire ratings. It is also possible to use this approach for load bearing walls in buildings up to 6 storeys in height. (RDH Building Science Inc.)*



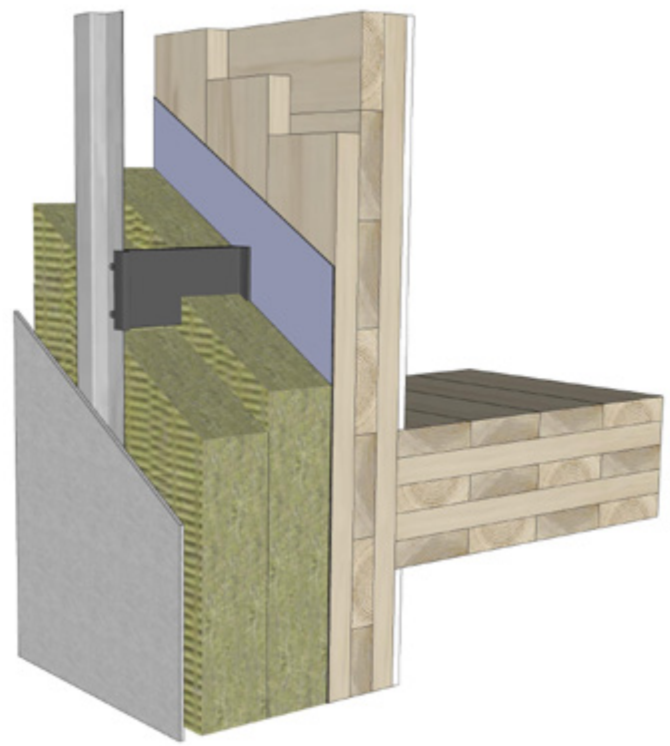
"Curtainwood" CLT panels provide rapid enclosure for exterior non-loadbearing walls. *CLT panels are hung from the edges of floor panels using connections with sufficient tolerances to accommodate movement. Conventional exterior control layers and cladding may be applied after erection along with the integration of services and finishes on the interior. (RDH Building Science Inc.)*

Conventional stick-built or unitized glass and metal curtainwalls offer highly glazed façade options. *No different than how they are installed on concrete and steel building structures, glazed curtainwalls provide relatively rapid enclosure to aid in moisture management. Interior finishing requirements are minimal but high window-to-wall ratios should be avoided to conserve energy and enhance thermal comfort. (RDH Building Science Inc.)*

Loadbearing Enclosures



Mass timber infill panels provide rapid enclosure. *Similar to platform framing, the loadbearing CLT exterior wall panels are erected to support the mass timber floor panels. In addition to streamlining the supply chain by delivering mass timber panels with precut openings for windows and doors, this approach quickly encloses the structure to provide effective moisture management. The application of conventional control layers and cladding can follow, along with the optimal installation of interior furring to integrate services in exterior walls. This approach is only suitable to low-rise buildings and not recommend for taller mass timber buildings due to the accumulated wood movement in this loading configuration due to shrinkage of the CLT in the load path. (RDH Building Science Inc.)*

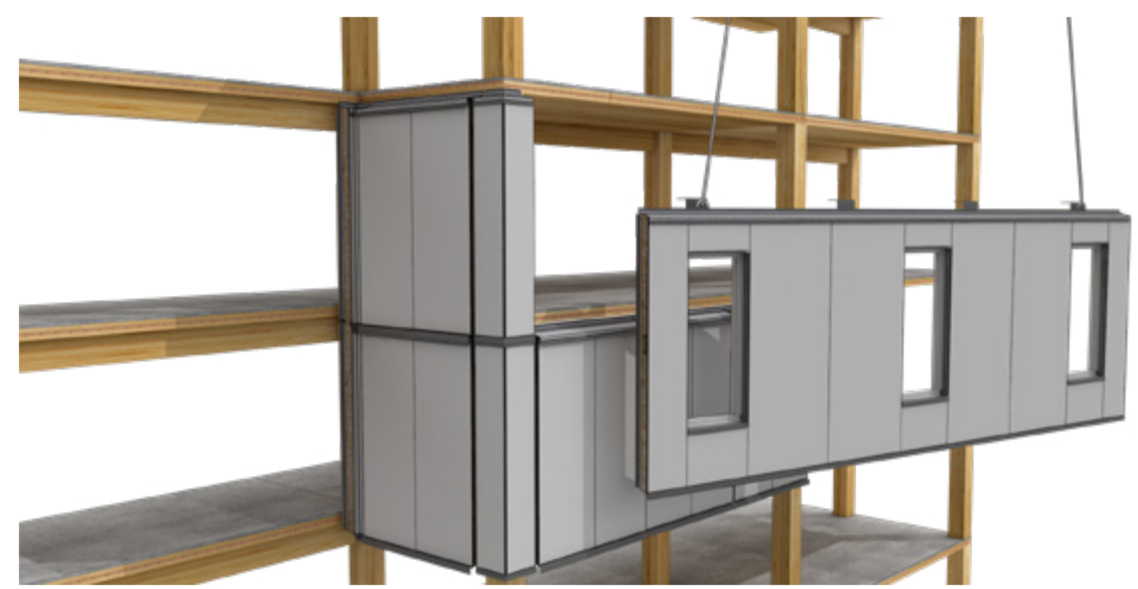


Mass timber exterior wall panels can span multiple storeys. *Using an approach analogous to balloon framing, multi-storey, loadbearing exterior wall panels are erected and support the mass timber floor panels using steel angles or ledger beams fastened to the exterior wall panels (not shown). Loadbearing mass timber panels offer rapid erection and longer spans to enclose several floors at once. Exterior control layers and cladding can follow erection of the structure. The integration of services within exterior wall assemblies will require wood or metal furring and a suitable interior finish. (RDH Building Science Inc.)*

Prefabricated Enclosure Systems

Prefabricated façade panels have been successfully deployed on a large number of projects around the world and they are often an advantageous alternative to site-built enclosures. There are different panel formats with various types of connectors that can be deployed. The height and scale of the project, as well as the type of hoisting equipment available, will largely influence the most appropriate approach.

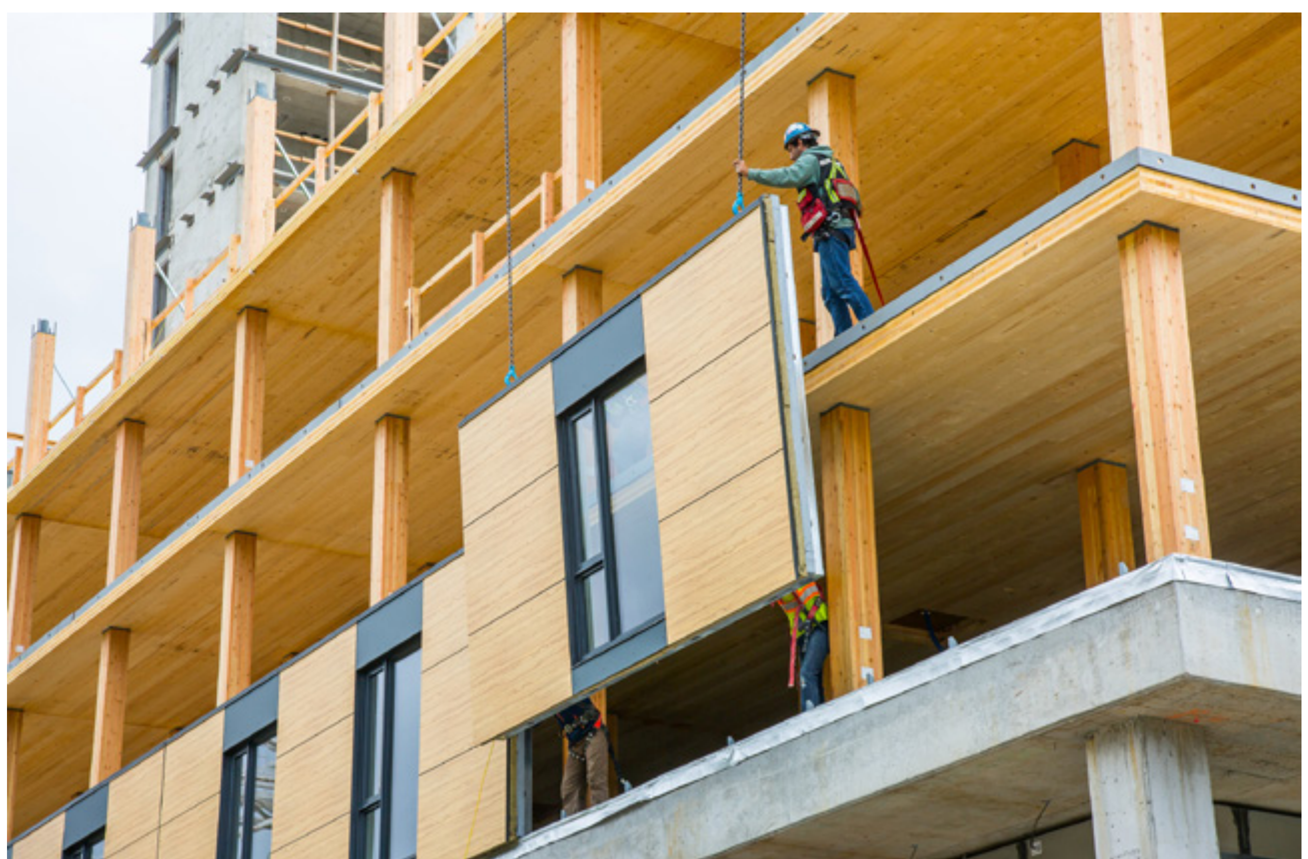
Small format prefabricated panels are easily stored and installed on site. *This approach is suitable where only small cranes and hoisting equipment are available on the site. The reduced size and weight of small panels makes them easier to handle and hoist, but the number of joints and transitions between panels demands better workmanship and quality assurance. Window sizes are also confined to a similar scale. Alternatively, a window wall system can be combined with the opaque panels. (RDH Building Science Inc.)*



Large format prefabricated panels can rapidly enclose the building. *The logistics for delivery, hoisting and installation are critical since site storage is seldom feasible. Tower cranes of similar hoisting equipment must be able to pick up large panels directly from trucks and hoist them into position on all sides of the building. (RDH Building Science Inc.)*

Non-loadbearing steel stud infill framing. *Lower floors in reinforced concrete and upper floors in mass timber. A contemporary commercial office façade is rendered over both using conventional components and windows. (80 Atlantic – Julian Mirabelli)*

Conventional enclosure over multi-storey, loadbearing mass timber panels in balloon frame configuration. *Water resistive air barrier membrane, mineral wool insulation between girts and cladding are applied after the panels are erected to complete the structure. (L'Origine – Nordic Structures)*



Large format panels with integrated windows and cladding. *Detailing resembles curtainwall and/ or precast wall systems technology spanning outboard of the floors. (Brock Commons – NaturallyWood, K.K. Law)*

Very large format panels with integrated windows and cladding. *An unconventional approach relying on tapes and gaskets is used to provide an interior finish and exterior wood cladding. (Mjøstårnet, The Tower of Lake Mjøsa - Moelven Limtre)*

Ideally, the mass timber supplier will assist in the design and manufacture of the enclosure system. This minimizes the additional effort associated with coordination between the various team players involved in delivering the building project. There are some mass timber suppliers that will provide a complete turnkey solution for both the structure and the enclosure. Regardless of the supply chain and logistics, it is important to ensure that the enclosure incorporates sufficiently high levels of thermal insulation to enable the building to comply with code requirements for building energy efficiency. High-performance windows are critical especially if higher window-to-wall ratios are desired.

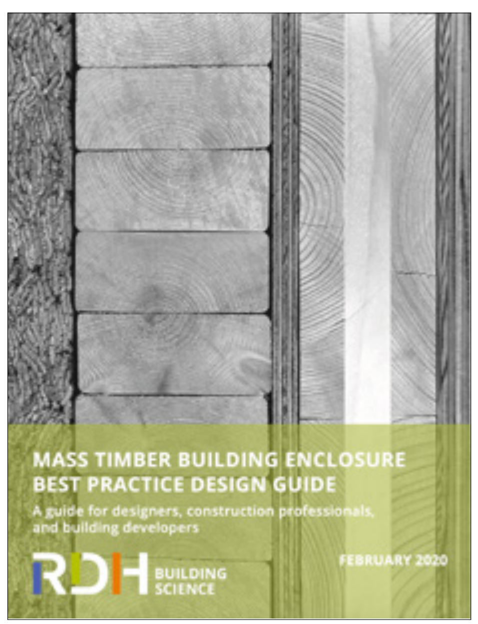
Where testing of innovative enclosure systems is required, sufficient lead time must be anticipated to construct the mock-up and then to access the testing laboratory. Subsequent field testing may also be required to ensure that assembly on site is of a consistent and acceptable quality. Commissioning of the building enclosure as part of the whole building commissioning process must also be carefully planned and coordinated so that deficiencies can be detected and remediated.

A large number of authoritative resources for the design and construction of enclosures are now available. It is highly recommended to engage a building science and or enclosure engineering consultant to review the design, construction and commissioning of the building enclosure to ensure satisfactory performance over its service life.

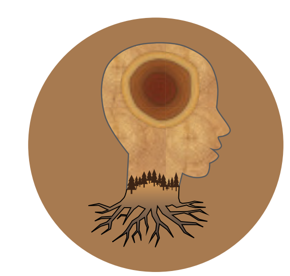
Enclosures for Mass Timber Buildings

- It is both time and cost effective to approach and develop fire and acoustical measures together, beginning at the early stages of design.
- Mass timber buildings can be well designed to achieve the same levels of fire safety and sound control as more conventional building methods.
- A large number of resources are available to assist designers with selecting appropriate strategies and measures for fire safety and acoustics.
- Exposing mass timber components and assemblies will normally require alternative solutions to demonstrate code compliance, both fire safety and acoustics. Consulting with qualified experts at the early stages of design is highly recommended.
- Acceptable solutions for encapsulated mass timber construction up to 12-storeys in height are available for mass timber buildings under the 2020 National Building Code.

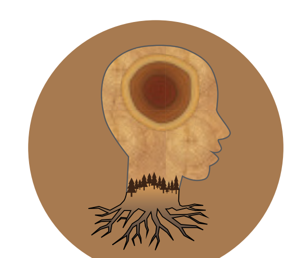
For more in-depth technical information about fire safety and acoustics, refer to: Chapter 10 – Building Enclosure Design of Cross-Laminated Timber Construction, in Volume 2 of the Canadian CLT Handbook, 2019 Edition.



For more information about building enclosure design and construction refer to: Mass Timber Building Enclosure Best Practice Design Guide, February 2020 Edition.



Enclosure Design
Click on this icon to download information about best practices and critical considerations for enclosure design.



Façade Staining
Click on this icon to download information about how to avoid staining that results from the shedding of water from the surfaces of façades.

Moisture Management

Among the most critical considerations for mass timber building projects is the need for an effective moisture management plan. This requirement reflects that mass timber building products can readily absorb large quantities of water but exhibit extremely slow drying rates. In an era of climate change, extreme weather events, and knowing the health risks associated with mold in buildings, it is widely recognized that every building project requires an effective moisture management plan.

Protective membranes protect CLT floor panels and glulam columns from moisture accumulations. *The cost of protective measures must be weighed against the savings due to the reduction in delays caused by bad weather and the elimination of mitigation measures for potential water damage resulting from ineffective moisture management. (Catalyst – Katerra)*

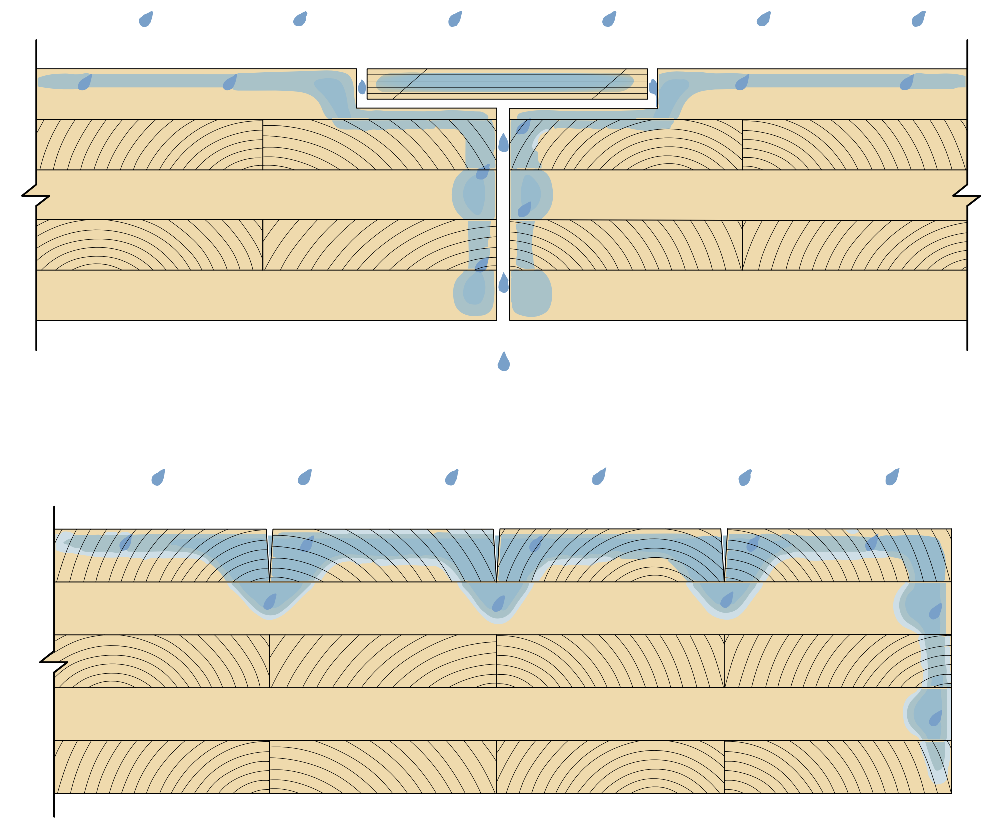
In an era of climate change, extreme weather events, and knowing the health risks associated with mold in buildings, it is widely recognized that every building project requires an effective moisture management plan.

Moisture management does not just apply to the construction phase of a project. After the building is commissioned and occupied, the care and protection of wood, both exterior and interior, should be addressed as part of a comprehensive moisture management plan. This is especially important where wood is exposed on the exterior of a building, but also if wood finishes are featured on the interior. The durability and aesthetics of wood must be viewed over the entire building life cycle.

Construction safety and productivity are enhanced by proper moisture management practices. *The installation of this prefabricated, panelized enclosure system proceeds on a year-round basis under dry site conditions. (Swedish Wood)*

Exceeding the moisture balance of mass timber must be avoided. *Moisture absorption for mass timber elements is a delayed process, however, it must be recognized that long-term or frequently recurring exposure to moisture is likely to be more problematic than the overall quantity of water to which the mass timber is exposed. This is because wood absorbs water rapidly and after it is saturated it releases this moisture very slowly as it dries out. In practical terms, trapped and concealed moisture must be avoided by providing multiple layers of defence against moisture intrusion. If the risk of moisture penetration cannot be avoided, then the assembly must be designed so that it is much easier for the water to get out than to get in. The severe deterioration depicted in the lower image occurred in a cantilevered CLT balcony panel suffering concealed moisture migration.*

An often overlooked aspect of moisture management planning involves the occupancy phase of a building. Sources of moisture during occupancy can include plumbing leaks, occupant activities such as bathing and food preparation, appliances such as clothes and dish washers that use water, and fire protection methods, such as sprinkler systems. Isolating washroom groups and applying impervious surfaces sloped towards floor drains represent an example of how to plan a building where zones are designated and serviced to confine the potential for water damage. Leak detection systems that alarm facilities staff to water leakage are among a number of prudent post-occupancy moisture protection measures for mass timber buildings.

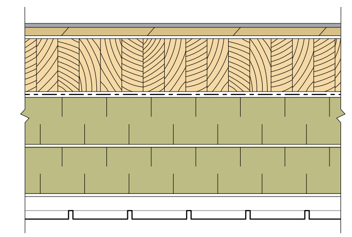
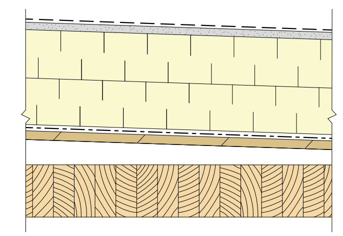
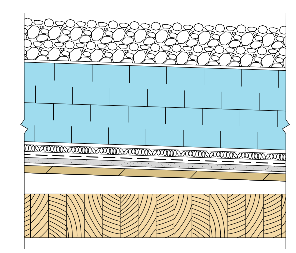
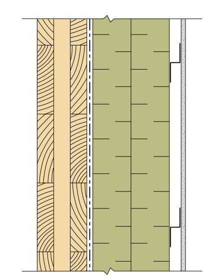


Wetting patterns vary among mass timber products. *In this figure, the typical wetting patterns for cross-laminated timber indicate the need for continuous moisture protection over the top surface and at all joints. Understanding how mass timber will absorb and retain moisture is key to deploying effective moisture management measures.*

Old fashioned approaches to moisture management have not gone out of style. Mopping up and/or squeegeeing away water that has accumulated on the surface of mass timber goes a long way to reducing the potential for moisture absorption. Planning ahead for inclement weather, particularly overnight, weekends or during any periods, such as holidays, when the construction site is not operating, is a highly recommended best practice. Anticipating rainfall events and assigning personnel to monitor the site and attend to uncontrolled wetting episodes is an effective means of minimizing exposure to moisture.

Moisture Management for Mass Timber Components			
NLT **Nail-Laminated Timber** **DLT** **Dowel-Laminated Timber**	• High susceptibility to wetting and swelling given grain orientation and pathways for water entry. • Made of 2x dimension lumber fastened together with nails (NLT) or wood dowels (DLT), each lamination joint is a potential moisture pathway. • Sheathing may be added to one face which could protect from wetting if joints sealed, but may also trap moisture.	• Primarily used in floor/roof assemblies. • Use high risk wetting protection on top face. • Manage water build-up and runoff on site.	• Not typically made from preservative-treated lumber. • Often intended to have "show side" so rapid wetting and drying may lead to unsightly gaps / cracks. • Moisture remediation and cleaning to original design intent is challenging. • Nails within NLT should be corrosion protected to minimize staining if wetted.
CLT **Cross-Laminated Timber**	• Moderate susceptibility to wetting and swelling. • Glue laminations may help limit moisture transfer. • Solid wood and glue layers can limit drying potential. • Exposed end grain on all edges can absorb significant amounts of moisture.	• Used in floor/roof assemblies and in wall assemblies. • Use moderate risk wetting protection (for exposed components). • Manage water build-up and runoff on site, protect top edges of exposed walls from wetting.	• Not typically made from preservative-treated lumber. • Dimensionally stable due to cross-laminations, however excessive repetitive wetting and drying poses risk to appearance and structural capacity (delamination of plies). • Glue of lamination edges can significantly reduce moisture transfer and potential gaps / cracks.
GLT **Glue-Laminated (Glulam) Timber**	• Low to moderate susceptibility to wetting and swelling. • Glue laminations help limit moisture transfer. • Typical manufactured with high-quality seal at face.	• Typically used as columns, beams and headers. • Use moderate risk wetting protection (for exposed components).	• Can be made from preservative-treated lumber. • Dimensional movement primarily in depth. • Often used in exposed applications, most glulam is fabricated with tight moisture control and wood selection and coated in the factory to reduce moisture sensitivity.
LSL **Laminated Strand Lumber**	• Moderate susceptibility to wetting. • Made from flaked strands laminated with significant amounts of glue, moisture transfer may be limited.	• Typically used as columns, beams and headers. • Use moderate risk wetting protection (for exposed components).	• LSL highly dimensionally stable, rapid wetting / drying may impact appearance. • Not typically used in exposed applications.
LVL **Laminated Veneer Lumber** **MPP** **Mass Plywood Panel**	• Moderate susceptibility to wetting. • Glue laminations may help limit moisture transfer. • Solid wood with glue layers can limit drying potential. • Exposed end grain on all edges can readily absorb moisture.	• Used in floor/roof assemblies and in wall assemblies. • Use moderate risk wetting protection (for exposed components). • Manage water build-up and runoff on site, protect top edges of exposed walls from wetting.	• Not typically made from preservative-treated lumber. • MPP dimensionally stable due to cross-laminations, rapid wetting / drying not typically a risk except to appearance.
PSL **Parallel Strand Lumber**	• Moderate susceptibility to wetting. • Made from veneer strands with significant amounts of glue, moisture transfer may be limited.	• Typically used as columns, beams and headers. • Use moderate risk wetting protection (for exposed components).	• Can be made from preservative-treated lumber. • Highly dimensionally stable, rapid wetting / drying may impact appearance. • Typically used as an exposed structural element.

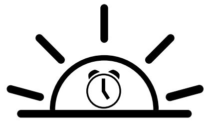
Recommended protection measures for mass timber products. *This chart is a helpful guide to deploying appropriate moisture protection measures according to the type of mass timber building material.*

Moisture Protection Approach			
Assembly	**Low Exposure**	**Moderate Exposure**	**High Exposure**
 Exposed Floor	• Factory-applied hydrophobic face sealer or moisture-resistant sheathing, and high-build paraffin edge sealer. • Panel joints taped/sealed upon installation	• High-build paraffin edge sealer. • Factory-installed permeable membrane with laps and joints sealed • If used, factory-installed impermeable acoustic mat with laps and joints sealed.	• High-build paraffin edge sealer. • Factory-installed, fully adhered impermeable membrane with laps and joints sealed. • If used, factory-installed impermeable acoustic mat with laps and joints sealed.
 Conventional Roof	• Factory-applied hydrophobic face sealer or moisture-resistant sheathing, and high-build paraffin edge sealer. • Panel joints taped/sealed upon installation. • Air gap created by tapered overframing allows two-way drying or use tapered insulation.	• High-build paraffin edge sealer. • Factory-installed, fully adhered impermeable sheathing/structure membrane with laps and joints sealed.	• High-build paraffin edge sealer. • Factory-installed, fully adhered/welded impermeable sheathings/structure membrane with laps and joints sealed/welded. • Consider venting/drying ability of completed assembly.
 Inverted Roof	• Factory-applied hydrophobic face sealer or moisture-resistant sheathing, and high-build paraffin edge sealer. • Panel joints taped/sealed upon installation.	• High-build paraffin edge sealer. • Factory-installed sheathing/structure membrane with laps and joints sealed. • Consider factory-installed permanent roofing membrane instead.	• High-build paraffin edge sealer. • Factory-installed, fully adhered/welded impermeable sheathing/structure membrane with laps and joints sealed/welded/ • Consider venting/drying ability of completed assembly.
 Wall	• Factory-applied hydrophobic face sealer or moisture-resistant sheathing, and high-build paraffin edge sealer. • Panel joints taped/sealed upon installation.	• High-build paraffin edge sealer. • Factory-installed, permeable sheathing/structure membrane with laps and joints sealed.	• High-build paraffin edge sealer. • Factory-installed, permeable sheathing/structure membrane with laps and joints sealed. • Consider pre-fabrication of wall assembly, ensure top edges of exposed walls are covered.

Moisture protection approaches for different types of enclosure assemblies. *Recommended approaches to moisture protection vary according to the type of assembly and the degree of exposure. Given the high variability in weather patterns, it is advisable not to optimistically underestimate the exposure conditions for any building project.*

Moisture remains the most significant cause of performance problems in buildings and the mass timber industry has developed a number of helpful publications to assist in the development and implementation of effective moisture management plans. Examples of centuries old wooden buildings around the world are evidence that where properly protected and maintained, wood can deliver a robust service life.

Effective Moisture Management Planning

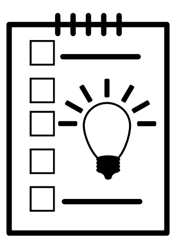


Step 1: Start Early

Planning for moisture management should start early in the schematic design phase with a focus on enclosure assemblies and intermediate floor assemblies. Work with the mass timber manufacturer/supplier to identify the risks associated with exposing mass timber to moisture and then develop necessary protection measures. These can be incorporated into the drawings and specifications during the design development phase.

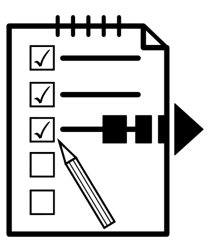
Step 2: Conduct a Risk Assessment

The architect, structural engineer, constructor and mass timber manufacturer/supplier should work as a team to assess the risk for moisture exposure, both during construction and post occupancy. Factors such as the type of mass timber being used, rainfall, snowmelt, project duration, and length of exposure for each storey must be considered. Potential plumbing failures, floor and roof drain locations, floor and roof slopes must be identified to manage and divert water flows. Specify all factory and/or site-installed protective coatings and membranes. The need for protective tarping and tenting should also be evaluated.



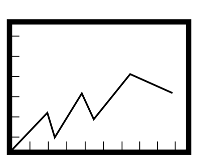
Step 3: Develop a Moisture Management Plan

For each phase of construction, a set of procedures and protocols must be developed that assign responsibility to a specific player on the construction team. Alternatively, consider establishing an active water management team on its own. Conduct an orientation of the players involved in moisture management to ensure 24/7 risk abatement preparedness before construction begins. Ensure that all protective membranes, tapes, tarping, tenting, squeegees, active drying equipment are on site and accessible for timely response. It is prudent to make allowances for unexpected moisture risks, such as extreme weather events or prolonged delays.



Step 4: Execute the Moisture Management Plan

The execution of the moisture management plan starts during the design development stage when appropriate control layers, protective coatings and membranes, along with suitable details are rendered and specified. This will establish the moisture protection measures applied by the mass timber manufacturer/supplier, including protection of the mass timber during transportation and on-site storage. During construction, the protective measures and moisture management procedures and protocols must be observed. The facilities management team must subsequently be provided with a post-occupancy moisture protection plan that identifies inspection and maintenance requirements along with how to deal with accidental moisture damage, such as burst pipes.



Step 5: Monitor, Adjust and Improve the Moisture Management Plan

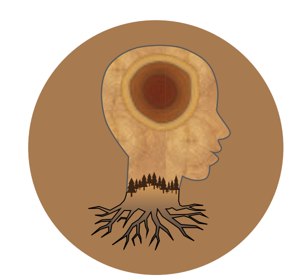
Be proactive throughout the construction of the building by deploying a quality assurance approach to monitor and evaluate the effectiveness of the moisture management plan. Schedule periodic meetings to review and debrief on the plan and to gain feedback about ways to improve protocols and procedures. Be prepared to make adjustments and to expand the plan to include additional measures for drying or removing bulk water. Identify vulnerable areas and highlight these in the hand-off to facilities management.

Make a plan and stick to it. *Any plan is better than no plan, and when it comes to moisture protection, prevention is the most cost-effective strategy. For buildings with large expanses of exposed mass timber on the interior, remediating water stains is an avoidable waste of time and money. The original patina of wood can often not be acceptably restored.*

Moisture Management for Mass Timber

- Moisture management begins at the project planning stage, is implemented during the construction stage and then is maintained over the entire service life of the building.
- Moisture management plans are absolutely essential and should clearly delineate responsibilities, protocols and procedures.
- Factory-applied moisture protection is often a more effective and economical alternative to field-applied measures. Regardless, field protection measures against inclement weather are unavoidable.
- Vigilant inspection and monitoring of moisture levels in mass timber elements before, during and after construction are better practices. This will help indicate how much drying time is needed before it is safe to close in the building.
- Moisture management inspections and routine maintenance procedures must be documented and conveyed to facilities management.

For more information about managing moisture risk for mass timber building projects refer to: Moisture Risk Management Strategies for Mass Timber Buildings, February 2020 Edition.



Moisture Management
Click on this icon to download resources related to the management of moisture during construction and for the protection of exposed wood over its service life.

Procurement and Construction Management

Mass timber buildings require a different procurement and construction management approach than most conventional building types. The design of large and tall mass timber buildings is not a widely held skill set in most parts of North America at this time. In Canada, the number of architecture/engineering firms that have successfully delivered mass timber building projects represents only a fraction of the entire body of licensed practitioners. This does not imply that firms with little or no mass timber building design experience are incapable of delivering a successful building project, but they will require guidance from a team of experts from fields such as: mass timber engineering; fire, acoustics and code consulting; building science and/or enclosure engineering; cost consulting; and project management.

From the owner/architect perspective, there are a number of key considerations pertaining to procurement and construction management.

- Qualified design professionals;
- Prequalification of constructors;
- Bonding / fire insurance;
- Design assist;
- Alternative solutions;
- Chain of custody;
- Crane and staging coordination (site logistics);
- Moisture management;
- Commissioning; and
- Warranties.

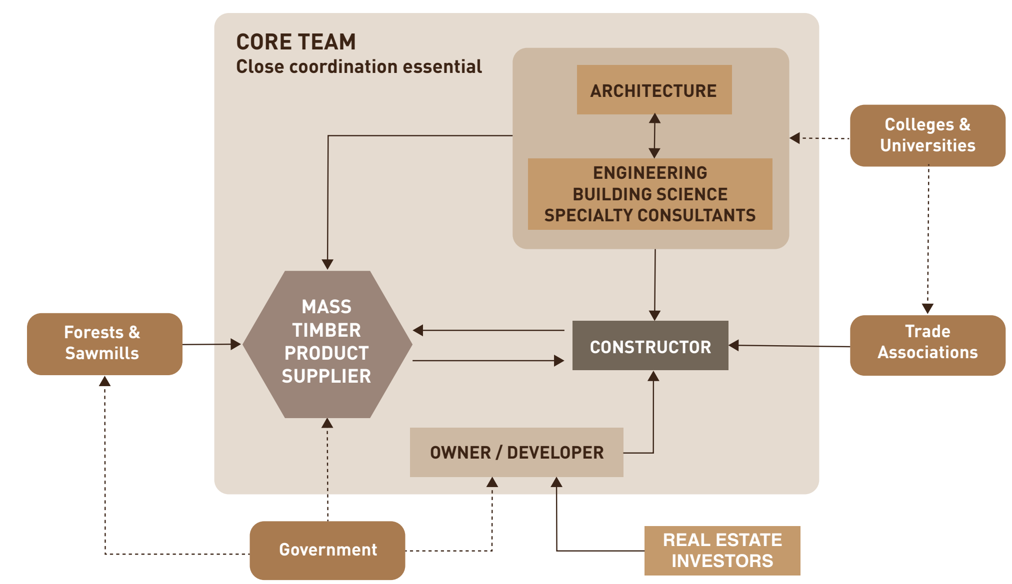
Qualified design professionals are individuals and organizations that are licensed to practice architecture and/or engineering and in some cases, such as in British Columbia, building enclosure engineering carries special requirements and responsibilities. Demonstrated experience in past projects similar in scale and scope as a proposed building is an important consideration. The design team should be familiar with and willing to engage in the integrated design process that, as a minimum, addresses: approvals and construction strategy; differential shrinkage between dissimilar materials; acoustic performance; behaviour under wind and seismic loads; fire performance; durability; and construction sequencing to reduce the exposure of wood to the elements.

Prequalification of constructors is essential to ensure that construction management is appropriate for a given project. It is prudent to start with a request for proposal (RFP) from a select number of firms that requires interested proponents to submit a technical proposal with special emphasis on past experience and risk mitigation for the proposed project.

Bonding / fire insurance are mandatory risk mitigation requirements for every mass timber building project. Fire insurance during construction is an important consideration and typically involves additional fire suppression measures such as multiple water supplies, fire pumps, interconnected risers, and higher density sprinkler coverage. Fire safety measures and protocols incur additional costs over conventional building types.

Design assist is highly recommended because traditional procurement models for mass timber building projects are unable to take advantage of the synergies between the design team, the mass timber supplier and the constructor working together at the early stages of design. Typically, preconstruction fees are paid to the mass timber supplier and constructor in exchange for assistance with the schematic design and design development for a given building project. It is important to ensure early involvement by a mass timber supplier that can provide design assistance services that can further reduce manufacturing costs through the optimization of the entire building system and not just individual elements. Even small contributions, in connection designs for example, can make a difference to the speed of erection and overall cost. In addition, the constructor and the mechanical, electrical and plumbing (MEP) trades should be invited in a design-assist role at the outset of the project. Fixtures such as sprinklers must be accommodated to minimize their intrusiveness when exposed wood is featured. Such careful coordination allows for a more complete virtual model, additional prefabrication opportunities and quicker installation.

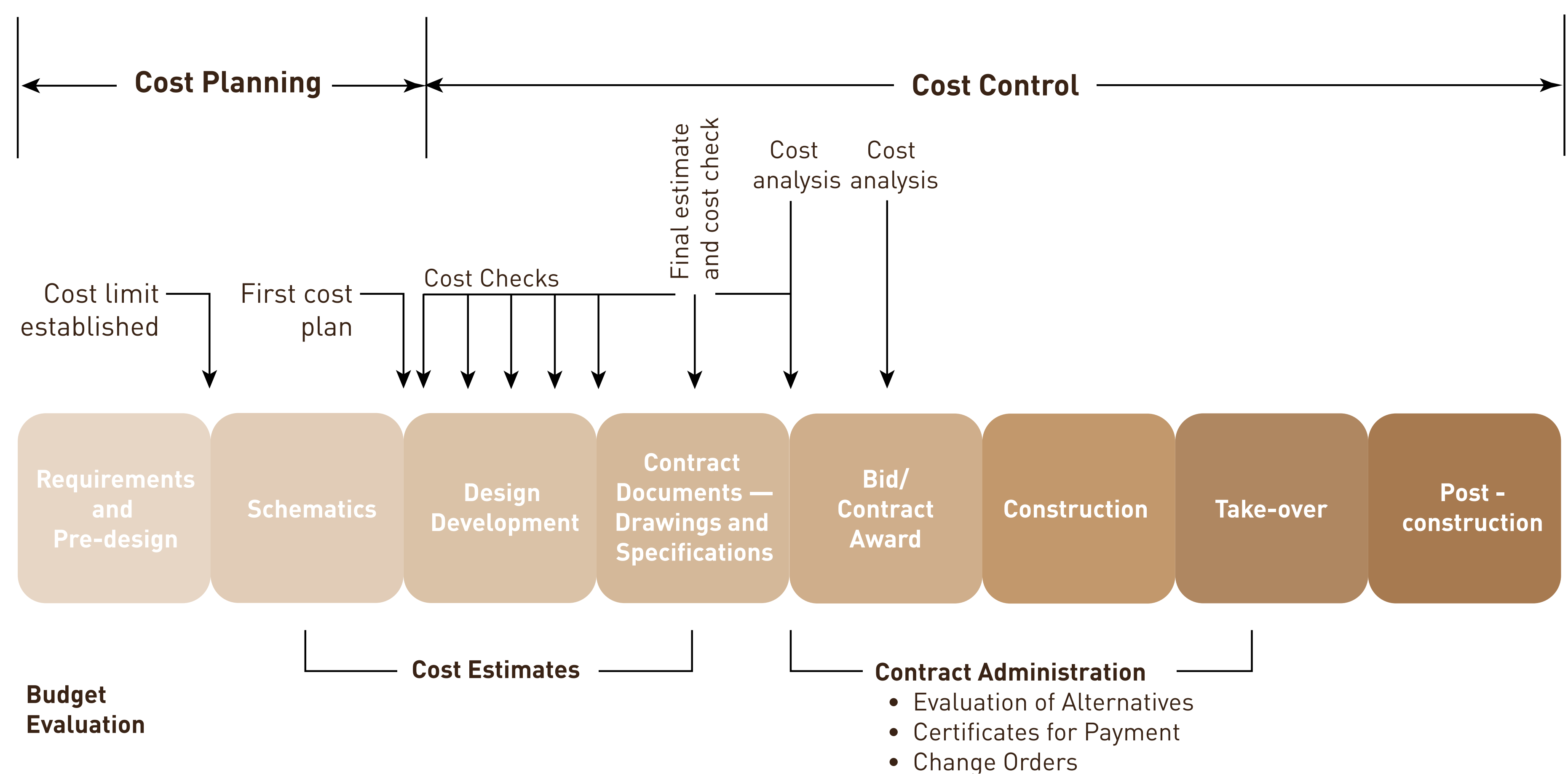
Traditional procurement models for mass timber building projects are unable to take advantage of the synergies between the design team, the mass timber supplier and the constructor working together at the early stages of design.



The core mass timber project team. *The owner/developer, architect, engineering consultants, constructor and mass timber product (MTP) supplier(s) must work closely within an integrated design process from the outset of the project to ensure an effective and economic design that meets all requirements. (Mantle314)*

Alternative solutions are required for almost every mass timber building project because prescriptive requirements for wood buildings in current building codes are quite restrictive. While the design and construction of wood buildings up to 12-storeys in height is permitted under the 2020 National Building Code, these requirements are premised on encapsulated mass timber construction. Anything outside the scope of these prescriptive requirements will require qualified consultants to prepare alternative solutions which are subsequently peer reviewed prior to submission for approvals. From a procurement and construction management perspective, it is not possible to confirm costing and scheduling until all of the alternative solutions have been approved and the time and cost associated with preparing and processing alternative solutions needs to be accounted for during the pre-construction stage.

Chain of custody refers to the responsibility for the proper shipping, storage and handling of mass timber, and it is extremely important to clearly delineate who holds the chain of custody from supplier to building site. There is no significant cost premium for establishing a chain of custody, but there may be serious costs incurred if the mass timber components are damaged or improperly protected from exposure to wetting that may lead to staining, possibly degradation. If off-site storage is the only practical means available due to a highly constrained building site, this restraint will involve additional costs for rental/leasing of the facility, providing security and shunting components to the site.



Cost planning and control begins at pre-design stage. *Cost planning and control begins in parallel with the development of the owner's project requirements (OPR). The resulting cost limit informs the schematic design process with checks throughout the design development and contract documents stages. Without the mass timber supplier at the table, it is not possible to conduct accurate and reliable cost planning and control. Design assist is a necessary aspect of mass timber building projects until such time as more cost data are available.*

Crane and staging coordination are key considerations because every mass timber supplier offers a proprietary system of mass timber components and these are not readily interchangeable between suppliers. Unlike concrete, which can be ordered to specification from a number of ready-mix companies in a given location, mass timber is comprised of highly prefabricated components that require a long lead time for their design, manufacture and shipping. Mass timber structures are essentially a kit of parts that is rapidly assembled on site and so the logistics of just-in-time delivery coordinated with hoisting (rigging) and assembly are critical.

The efficient delivery and rigging (hoisting) of mass timber components is critical to gain the mass timber advantage. *Efficient deployment of cranes and booms is an important erection strategy to optimize during the planning stage of a mass timber project. (Alex Schreyer/UMASS)*

In general, the type of core structure or lateral load resistance system and the rate at which these may be assembled largely dominate the schedule for the erection of the shell. Positioning cranes outside the footprint of the building is most advantageous, but site access may constrain the optimal deployment of cranes and lifts. Regardless, in order to minimize crane hanging time, connections for columns should be "drop and go" and for beams of the knife blade and/or slot and pin type. Time efficient connections minimize the hanging time and permit the crane to return to picking up the next component while workers complete fastening connectors.

The rental of scaffolding, staging, lifts and cranes can be very expensive if the mix and application of equipment are not optimized. Depending on the project, a large number of options are available:

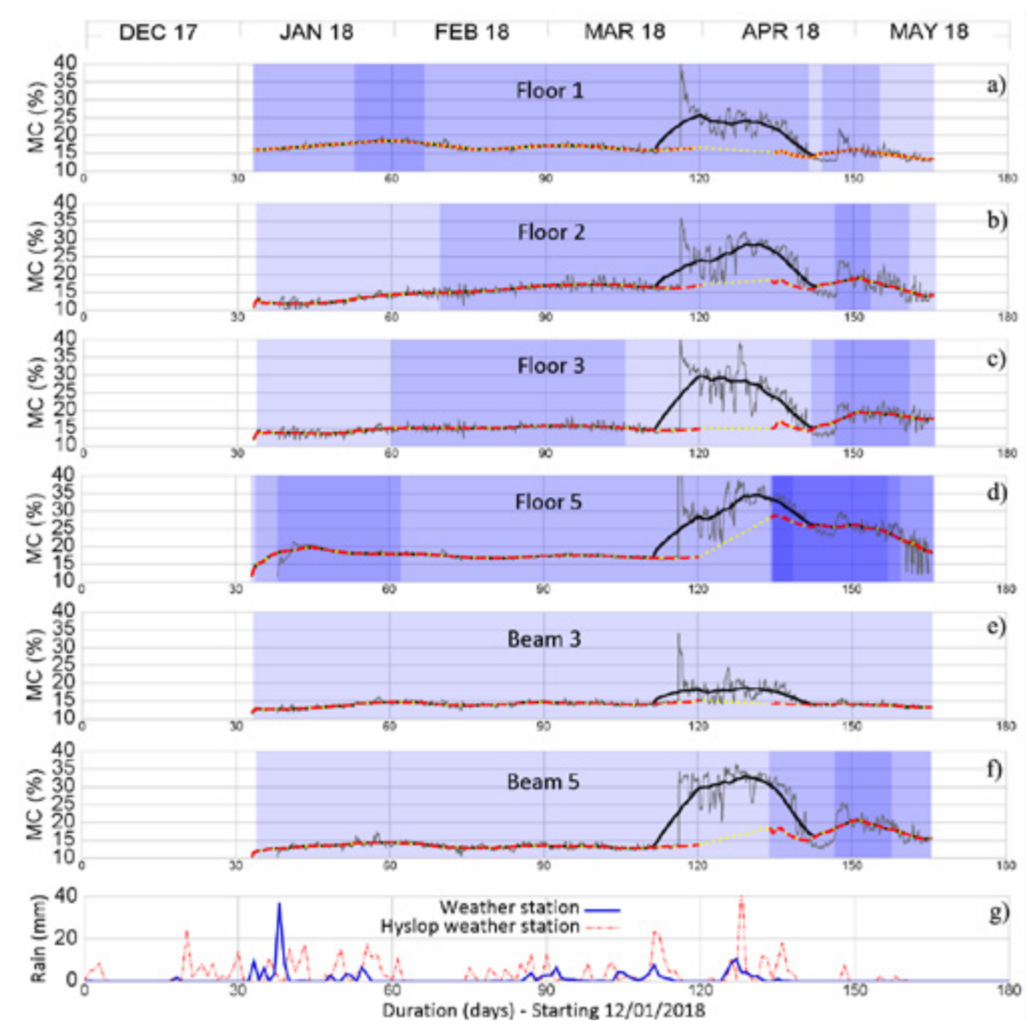
- Scaffolding/Swing Stage
- Mast Climbing Work Platforms
- Scissor Lifts / Articulating Lifts
- Telescopic Crane
- Tower Crane
- Truck Mounted Crane / Boom Lift (Cherry Picker)
- Rough Terrain Crane
- Loader Crane (Folding Boom or Knuckle Boom)

Minimize the number and duration of hoisting equipment rentals. *This construction site indicates a variety of cranes, lifts and scaffolding. A generous staging area beside the building and access behind the building allow cranes to work around the entire building without interference. Each project is different and considerable construction experience is needed to optimize the mix of hoisting equipment to efficiently execute the work. (Construction Canada)*

Moisture management for mass timber building projects is very important (see previous section). It is critical to delineate moisture management responsibilities and protocols among the constructor, supplier and sub-trades to ensure all aspects are fully addressed without duplication. From a procurement and construction management perspective, effective moisture management represents a prudent premium compared to the cost of remediation. Important factors to consider include:

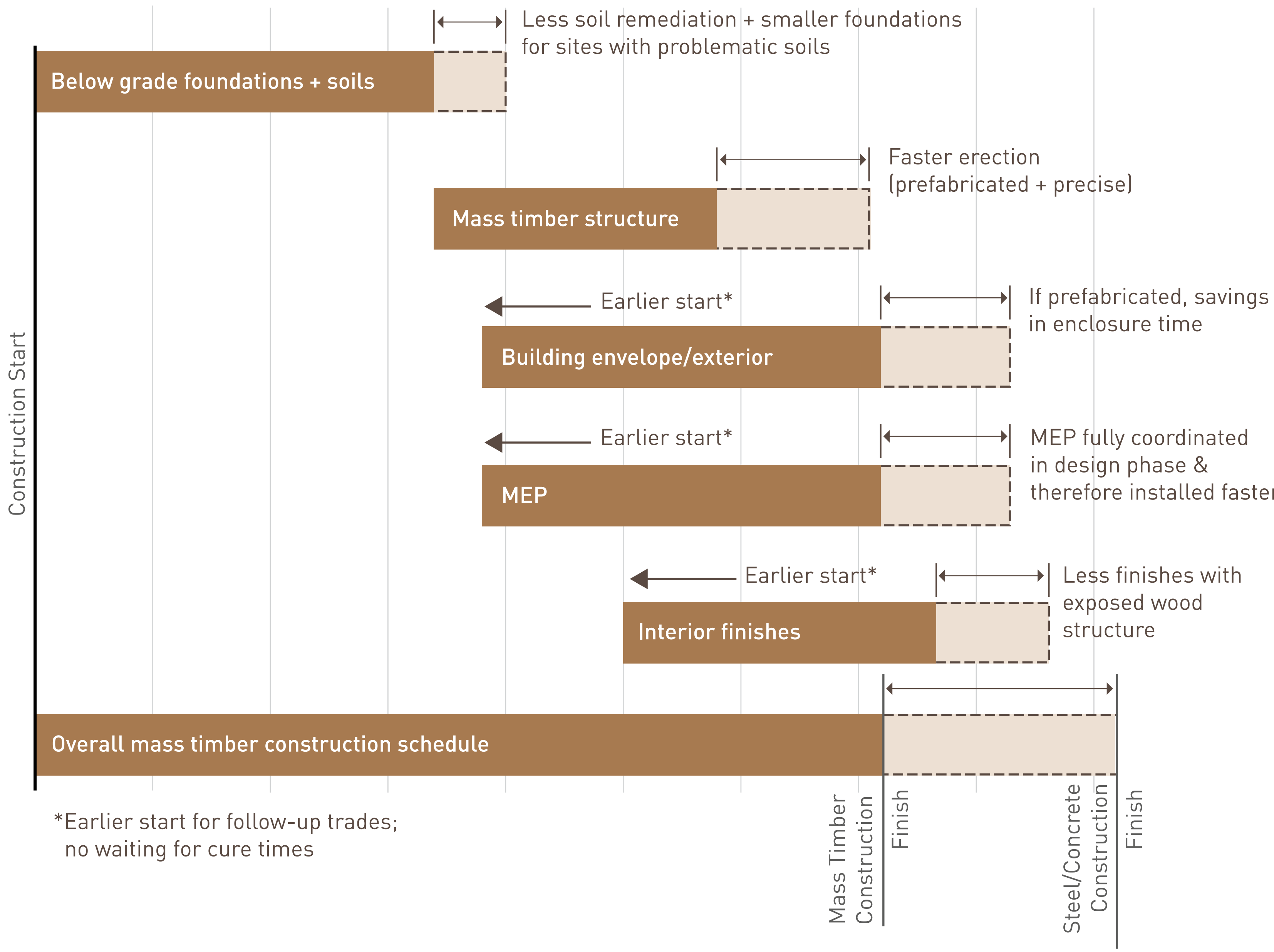
- delivery sequence
- storage protection
- tall vs extensive building typology and roof/wall sequence
- extreme rainfall measures (weekends, evening, holidays)
- supplier applied moisture protection
- mass timber type and packaging (wrapped vs unwrapped)
- coatings, tints to repel moisture and minimize UV fading

Commissioning is a highly recommended best practice (see next section) that ensures the actual performance is closely aligned with the predicted performance. In projects where façade mock-ups and testing are conducted, it is essential to ensure the site installation observes the critical details needed for the control of heat, air and moisture. Commissioning takes time and must be incorporated into the construction schedule.



In-situ moisture monitoring is a cost-effective form of commissioning. *The use of wireless moisture sensors installed in critical mass timber components provides constructors with a reliable indication of when a project can be closed in with interior finishes after a safe moisture content has been reached. This avoids potential costs and post-occupancy disruptions for the remediation of moisture-related performance problems. (Schmidt and Riggio - Buildings 2019, 9, 144)*

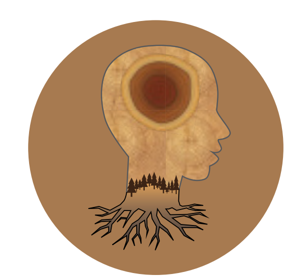
Currently, mass timber buildings represent a premium of 5% to 10% over conventional building types largely due to the need to observe a different code compliance path for most mass timber building projects. Consulting fees increase costs due to the time and complexity associated with documenting and peer reviewing alternative solutions required to get approval under the building code. Mass timber has the potential to deliver schedule savings, but this depends on a number of design and site access factors. The economy of mass timber building projects may be expected to change as more experience is gained and technological innovation evolves.



Mass timber may offer construction schedule savings over conventional materials and methods. *Based on recent experience, mass timber may not provide a significant schedule savings over structural steel. It is important to assess the total construction cycle schedule, but also to compare this with the total project time including delays due to design assist and code approvals. Compared to cast-in-place reinforced concrete, mass timber may save time when optimally coordinated and has the potential to reduce carrying costs and overheads while accelerating the ability to sell/lease the building. (WoodWorks)*

Procurement & Construction Management

- Conventional procurement models for mass timber buildings do not enable integrated planning, design and construction of mass timber buildings. Design assist involving the mass timber supplier is critical.
- Assemble a complete and well qualified project team and pay special attention to bonding, fire insurance, risk mitigation and the expediting of alternative solutions for code compliance.
- Establish the mass timber “chain of custody” up front and integrate it with the moisture management plan.
- Delivery and site logistics need to observe the project schedule while accommodating on-site quality monitoring and commissioning.
- Measurement and documentation of mass timber moisture content at the time of delivery and onwards are essential to product warranties.
- Handoff all product and equipment information, operations and maintenance instructions for facilities management.



Procurement and Construction Management
Click on this icon to download information related to procurement and construction management considerations for mass timber building projects.

Commissioning

Mass timber buildings represent an opportunity to engage in best practices. There is often a considerable difference between the construed and the constructed in contemporary buildings. Regardless of the quality of architectural design and engineering that is manifest in the drawings and specifications, the building will only perform as well as it has been constructed and subsequently operated, and this may not reflect how well it has been designed. The term used to describe what is often the unacceptable difference between what was intended or expected, and what is actually delivered, is the performance gap.

Modern buildings are made up from a wide range of materials, assemblies, components and equipment, held together and connected by countless fasteners, adhesives, membranes, and sealants, as well as ductwork, piping and wires. If all of these elements are not properly integrated by the constructor then serious performance problems can result. One of the most effective means to ensure that the building is constructed and operated as designed and specified is to invoke a process called whole building commissioning (Cx). In the past, only the mechanical and electrical systems, in particular the HVAC systems, were commissioned so that their proper operation could be confirmed prior to occupancy. Whole building commissioning involves both the active and passive systems constituting a building. The latest addition to the whole building commissioning process is termed building enclosure commissioning (BECx).

Commissioning is a quality-oriented process for achieving, verifying, and documenting that the performance of facilities, systems, and assemblies meets defined objectives and criteria.

The benefits of building commissioning are manifold and include:

- Assurance that design intent has been achieved;
- Delivery of a durable and resilient building asset;
- Congruence with societal sustainability objectives;
- Provisions of properly performing and functional building systems;
- Realization of energy and water efficiency targets;
- Balance between passive and active systems;
- Excellence across building performance rating systems;
- Properly informed and oriented building operators; and
- Comprehensive and cost-effective operations and maintenance procedures and protocols.

Commissioning is best suited to IPD (Integrated Project Delivery), Design – Bid – Build or Construction Management types of projects. It is least suited to Contractor Design & Build and any type of fast track project schedules. By fully integrating commissioning at the early stages of design and embedding it within the contract documents, it is possible to minimize and possibly eliminate the performance gap.

Commissioning Plan

Building commissioning is a quality-focused process for ensuring, verifying, and documenting that all performance aspects of facilities, systems, equipment, components and assemblies meet the objectives and criteria set forth in the Owner's Project Requirements. This set of requirements forms the basis for the Commissioning Plan.

Pre-Design Phase

- Select a Commissioning Agent(s)
- Pre-Design Phase commissioning meeting
- Begin development of Owner's Project Requirements (OPR)
- Development of initial Commissioning Plan outline

Design Phase
- Schematic Design
- Design Development
- Construction Documents
- Pre-Construction

- Design Phase commissioning meeting
- Design Review - passive and active systems
- Update Commissioning Plan
- Development of commissioning requirements in Specifications
- Begin planning for verification checklists, functional tests, Systems Manual, and training requirements

Construction Phase

- Construction Phase kick-off meeting
- Review submittals, monitor development of Shop and Coordination Drawings
- Review Operations and Maintenance (O&M) Manuals
- Conduct construction reviews, verification checks, diagnostic monitoring and functional testing
- Development of Commissioning Report and Systems Manual
- Development of Recommissioning Plan
- Verify and review training of owner's staff

Occupancy and Operations Phase

- Resolution of outstanding commissioning issues
- Perform seasonal/deferred testing
- Perform near warranty-end review
- Conduct measurement and verification
- Conduct post-occupancy evaluation

Commissioning is more than handing over an operational building. *This chart provides a helpful overview of a typical whole building commissioning process. Standards and protocols continue to evolve as commissioning is more widely implemented by building owners and developers that seek to avoid the performance gap in their projects. Proper commissioning plan guides this entire process.*

Commissioning Standards and Protocols

Building commissioning involves a number of standards and protocols that are typically referenced within specifications forming part of the contract documents for a building project. Currently in North America, the most commonly referenced standards, guidelines and test methods for commissioning are listed below.

- NIBS Guideline 3-2012 Building Enclosure Commissioning Process.
- ASHRAE Guideline 0-2019 The Commissioning Process.
- ANSI/ASHRAE/IES Standard 202-2018 The Commissioning Process for Buildings and Systems.
- ASTM E2947-16a Standard Guide for Building Enclosure Commissioning.
- ASTM E2813-18, Standard Practice for Building Enclosure Commissioning.
- CSA Z320-11 (R2016) Building Commissioning.
- CAN/ULC-S1001-11 (R2019) Standard for Integrated Systems Testing of Fire Protection and Life Safety Systems.

Within these standards and guidelines are found specific references to other testing and quality assurance standards, guidelines and protocols. The basic framework for a commissioning process considers:

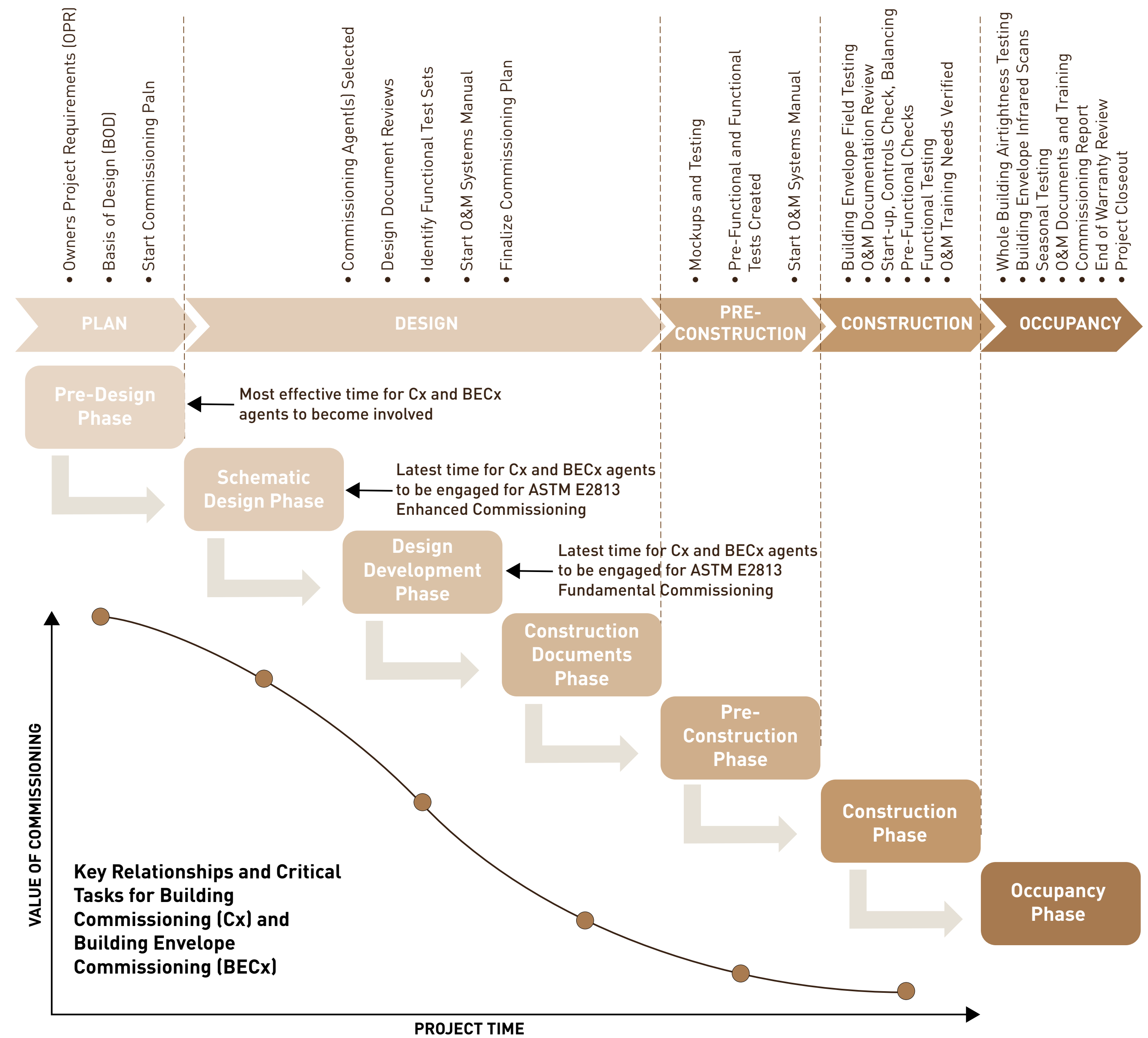
- Owner's Project Requirements;
- Basis of Design;
- Commissioning Plan;
- Pre-functional Checks of Facility Systems;
- Functional Tests;
- Systems Manual;
- Training Documents; and
- Final Commissioning Report.

Commissioning Plan

Operationally, a Commissioning Plan accomplishes the following:

- Assigns project team members and their respective responsibilities;
- Establishes objectives and criteria for quality, efficiency, and functionality;
- Sets out a commissioning scope and develops commissioning budgets;
- Establishes commissioning sub-plans (passive versus active systems);
- Delineates commissioning schedules, identifies testing and inspection protocols and procedures;
- Develops commissioning specifications;
- Determines special testing needs (e.g., mock-ups, performance measurement and verification);
- Defines operational staff training needs;
- Conducts post-occupancy evaluations; and
- Conveys all facility and supporting documentation to the owner, and facilities management personnel and operations staff

Important Note: For projects incorporating resilience measures, it is especially critical to identify all related protocols and procedures corresponding to associated emergency responses reflecting the nature of the emergency situation. In some cases, practice drills should be incorporated into the routine operations schedule.



Commissioning should start at the project planning stage. *The value that building enclosure commissioning (BECx) brings to any building decreases the longer implementation of this comprehensive quality assurance process is delayed. By establishing the owner's project requirements prior to the commencement of design, architectural and engineering resources can be more efficiently and effectively focused on well-defined targets.*

Building Enclosure Commissioning (BECx)

Building envelope commissioning focuses on performance related goals or objectives related to: water penetration resistance; condensation, insulation effectiveness (thermal bridging); air leakage; thermal comfort; sustainable materials; energy efficiency; level of inspection/maintenance required; and component service life.

Building enclosure commissioning reviews the materials, components, systems, and assemblies intended to provide shelter and environmental separation between interior and exterior, or between two or more environmentally distinct interior spaces in a building or structure. It is gaining in importance because the vast majority of performance problems, claims and litigation involve the enclosure. BECx has to be undertaken by specialists, with deep domain knowledge and experience. It should not be confused with routine quality assurance activities such as checking the moisture content of mass timber components arriving on site, even though such checks and measurements are an important part of the larger building envelope commissioning process. From the design office to the mass timber and façade supplier factory floor, on to the site and with a focus on the performance of materials, components, assemblies and whole systems, building enclosure commissioning requires holistic understanding of building science principles and applied enclosure technologies.

BECx has to be undertaken by specialists, with deep domain knowledge and experience.

The commissioning of buildings attempts to reflect the same quality assurance, product documentation, operations and maintenance instructions associated with other manufactured goods such as aircraft or automotive vehicles. For many common consumer goods, such as appliances and home electronics, more resources are typically devoted to their quality assurance than is provided in buildings, even though the latter may cost thousands of times more. Commissioning in all of its aspects, but especially BECx, should be viewed as an opportunity to bring the production of buildings into the 21st century.

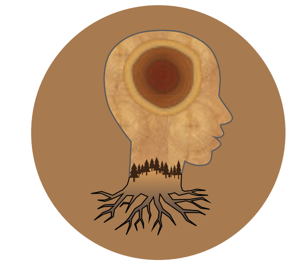
From a lifecycle performance perspective, building enclosure commissioning is a high yield investment that ensures value for money and buildings that perform as expected. It forms a critical part of the integrative design process and plays a role from the earliest beginnings of a building project until it is handed over to facilities management personnel.

Rx for Successful BECx

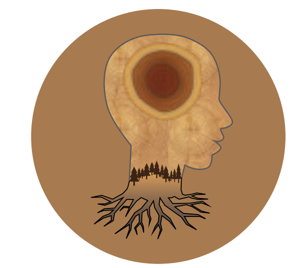
Key ingredients for a successful building enclosure commissioning recipe.

1. Make building enclosure commissioning a process everyone understands.
2. Retain an independent third party as BECx authority.
3. Define the owner's project requirements and develop the basis of design.
4. Align the building envelope commissioning scope with the OPR and to reflect the BOD and project's complexity.
5. Establish enclosure system performance metrics during the design phase.
6. Produce a written BECx plan.
7. Plan design reviews for all critical details and transitions between assemblies – arrange for mock-ups and testing as required.
8. Monitor construction early and often – conduct field testing as per the BECx plan, and factory inspections for all prefabricated assemblies.
9. Confirm performance after commissioning and occupancy – address defects as per provisions in the contract documents.
10. Architects should document all modified and rejected details and specs, then update / purge your technical archives accordingly.

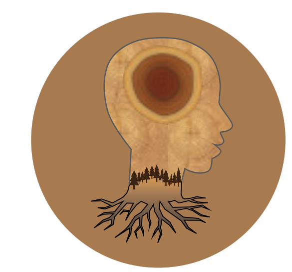
Adapted from *8 Strategies for Successful Building Enclosure Commissioning*. Emily Hopps and Peter Babaian, Simpson Gumpertz and Heger. Building Design & Construction, November 17, 2014.



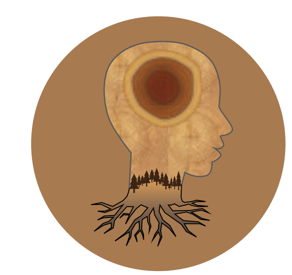
Thermal Bridging
Click on this icon to download information about best practices for reducing thermal bridging in building enclosures.



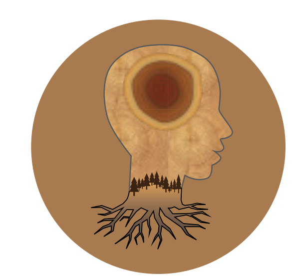
Airtightness
Click on this icon to download resources related to designing effective air barrier systems and achieving airtightness to manage heat and moisture transfer.



Durability
Click on this icon to download resources related to designing effective air barrier systems and achieving air tightness to manage heat and moisture transfer.



Commissioning
Click on this icon to download information about commissioning, quality assurance and site reviews.



Post Occupancy Evaluations
Click on this icon to download resources related to post occupancy evaluations and how these can improve design practice.

Facilities Management

The facilities management of mass timber building projects is in many ways no different than for any other types of buildings. The objectives of facility management are to operate the building facility as designed, constructed, and commissioned and to properly maintain it to ensure ongoing compliance with building and fire codes, and all associated environment, health and safety requirements.

- **Asset Management** – Involves project management, strategic planning, capital planning and construction/renovation;
- **Risk Management** – Observance of standards compliance, environmental, health and safety requirements, security and emergency management;
- **Business Management** – Human resources, financial management, contracts and procurement, and real estate dealings; and
- **Operations and Maintenance** – Technical services, occupant/tenant services, constructor/trades and utility interfacing, space management.

Facility management involves day-to-day operational and long-term capital planning activities. The scope of facility management encompasses managing and overseeing contracts and providers for cleaning, landscaping, maintenance, security, fire and life safety systems, and HVAC systems. The ultimate goal of these activities is to deliver a clean, safe, comfortable building supplied with basic utilities such as power, water, heating, cooling and ventilation to occupants. Failing to implement a strong, proactive facility management program can compromise the building's durability, lifespan and capital investment returns.

Key facilities management issues related to mass timber buildings: controlling indoor relative humidity; managing spills and leaks; and maintaining exposed exterior wood.

The key facility management issues with mass timber buildings are maintaining an acceptable relative humidity range, managing moisture, and maintaining exposed mass timber. Facility managers should consult the systems manual developed during the commissioning process to guide them in the management of these issues.

Relative Humidity

Maintaining the relative humidity of a mass timber building in an acceptable range is important to prevent checking and mold growth. Checking is longitudinal cracking that appears as the sap wood shrinks around the heart wood over time. It is an aesthetic issue, not a structural one, that occurs in wood when the environment is excessively dry for a prolonged period. To prevent checking in exposed mass timber, the relative humidity of the building must be maintained between the range of 35% to 50%. To avoid mold growth, the relative humidity must not be allowed to exceed 75% for extended periods of time. Understanding the acceptable relative humidity range, establishing appropriate HVAC set points, providing and adequate number of relative humidity sensors and monitoring their setpoints are essential for avoiding the problems of both checking and mould growth.

Moisture Management

Routine annual inspections and maintenance activities of the various building components that can introduce moisture damage should be integral to any facility management program. These activities include removing debris from roof drains and inspecting the roofing system, wall cladding, exterior projections (e.g., deck, balcony), fenestrations, and sealants and adhesives. Repairs to these components should be executed quickly to prevent moisture infiltration.

It is critical to address leaks, spills and floods immediately in any building, but most importantly in a mass timber building. Leaks can be the most challenging to deal with as they sometimes can go unnoticed for long periods before they are discovered. On the other hand, the evidence of spills and floods typically are visible shortly after an event occurs. Following a leak or flood, mold can form and produce potential indoor air quality issues. Depending on the wetting conditions of the wood and the duration of the wetting, structural decay can ensue. A facility manager needs to evaluate the moisture risk in relation to the building assembly that has been impacted by the leak or spill and determine adequate corrective actions. Obviously, shutting off the water source, removing standing water and employing drying techniques, such as heat and dehumidification, are key first steps. Care must be taken to avoid over drying the wood too quickly with too much heat or dehumidification resulting in checking. Currently, there are no industry-wide standardized protocols to deal with spill and leak scenarios with various mass timber building assemblies. Consultation with the structural engineer who designed the building, the wood supplier and/or the building science consultants who commissioned the building may be warranted depending on the situation.

The importance of a post-occupant moisture management protocol cannot be overstated. The personnel, equipment and procedures for dealing with different forms of moisture intrusion should be clearly documented so that a rapid response may be implemented anytime, including weekends and holidays.

Exposed Mass Timber - Exterior Applications

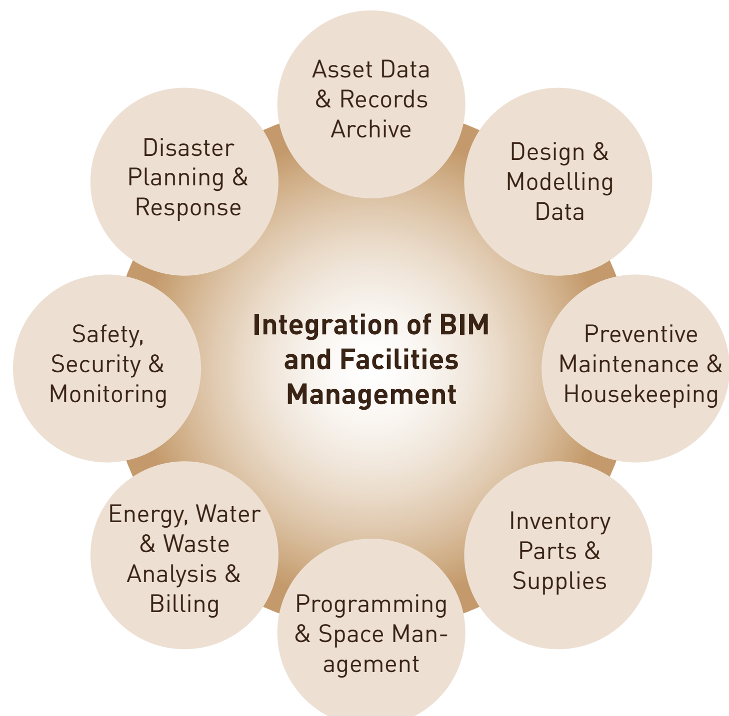
The major threats to mass timber in exterior applications are decay, weathering and black-stain fungi. To address these risks, facility managers should: (1) inspect exterior components annually, and hire a building science expert to inspect them closely at least every 5 years; (2) refinish wood coatings regularly rather than waiting until deterioration is present; and (3) remedially treat affected areas using diffusible preservative, and suitably repair any localized deterioration that may be detected.

The facility manager should also inspect the exterior mass timber components annually, and retain a building science consultant to follow up on any suspect areas. The facility manager's inspection should include observations related to cracking, flaking or thinning of coatings, discolouration of the underlying wood and areas of collapse or softness that could signal decay. Particular attention needs to be paid to end-grain, joints, upper horizontal surfaces, sites which may receive water drips, and places that abut concrete, soil and other moisture retentive building materials. If there is any doubt about the structural integrity of the assembly, the building owner should hire a structural engineer to conduct a thorough inspection.

Re-finishing of exposed exterior wood should be performed regularly rather than after deterioration has been observed. Once the coating has failed to the point where the underlying wood exhibits photo degradation (bleaching) or black-stain (greying) fungus growth, re-coating will never reach the same degree of adhesion and service life as a coating on fresh wood. The recoating interval should be based on the climate, the degree of exposure and manufacturers' recommendations. Generally, transparent and semi-transparent coatings can last from 6 months to 2 years, high solids opaque coatings 3 to 5 years, and paints can provide 6 to 10 years of acceptable service before refinishing.

BIM and Life Cycle Facilities Management

The design, fabrication and construction of mass timber buildings is highly dependent on building information management (BIM) technology. This makes them ideal candidates for integration with facilities management since a robust BIM model of the facility is normally generated and available.



Facilities management should integrate life cycle performance. *The combination of facilities management software platforms, BIM and building automation systems allow for a comprehensive and integrated approach to facilities management that both updates itself and anticipates proper operations and maintenance.*

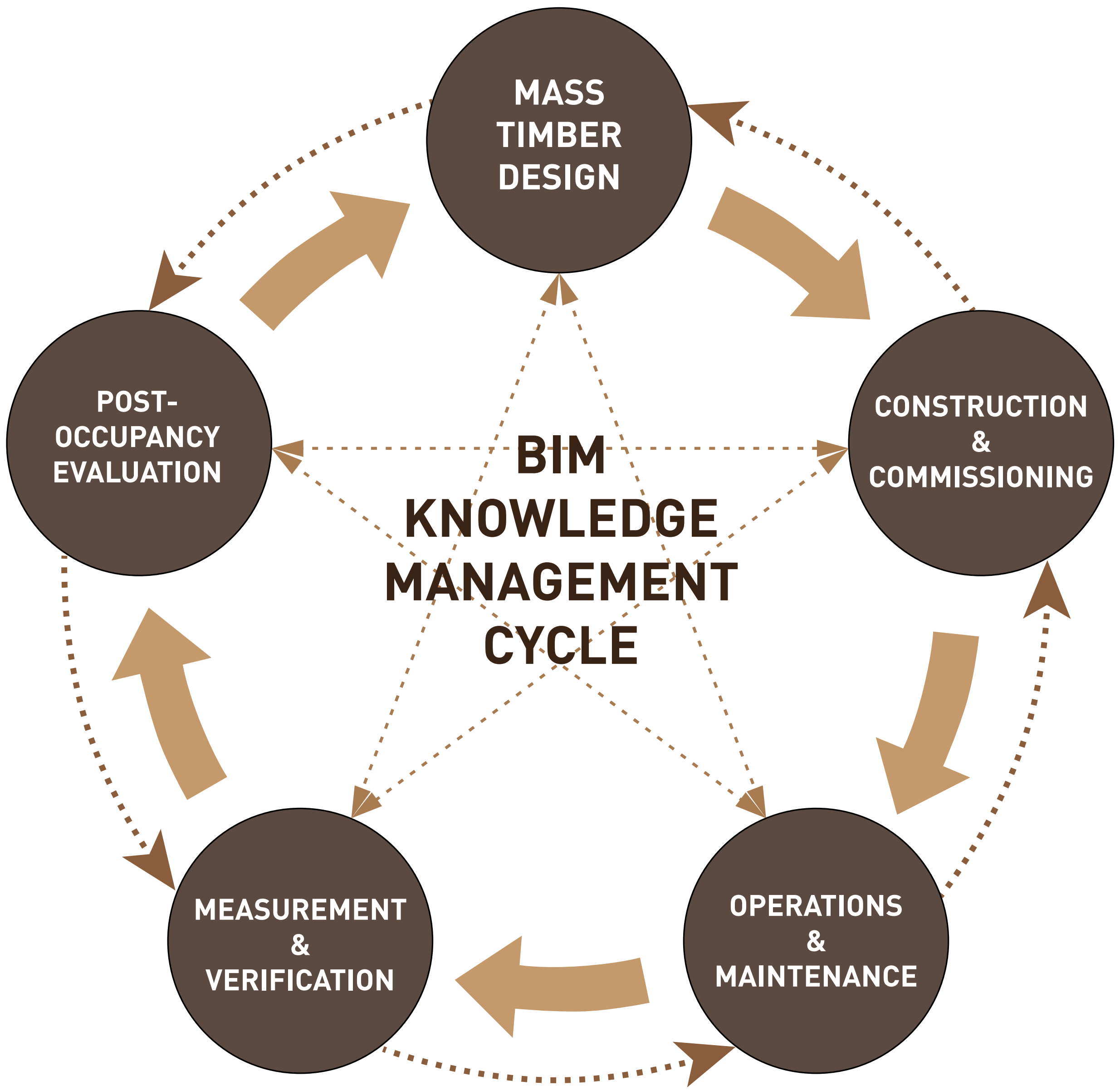
Buildings must be properly operated and maintained to achieve their performance objectives and realize their intended service lives. Commissioning enables proper operations and maintenance by ensuring the building is not defective and constructed in compliance with its design intent. Defective or deficient building equipment, components and assemblies will fail and require repair and replacement rather than routine maintenance. There is a significant difference in cost and disruption between routine maintenance and repair and/or replacement.

A proper and effective commissioning process (see previous section) makes the following positive contributions to operations and maintenance over the lifecycle of a mass timber building:

- **Complete Documentation** - warranties, manuals, protocols and procedures for operation and maintenance of the building, including services and site infrastructure;
- **Professional Facilities Management** - personnel who have appropriate qualifications, education and demonstrated experience in managing facilities;
- **Properly Trained and Qualified Building Operators** - staff who can operate and maintain the entire facility, including day-to-day operations (snow removal, recycling, garbage, landscaping, etc.);
- **Monitoring** - Measurement and verification of performance (energy, water, indoor air quality, etc.) and the adjustment of settings and schedules to maintain peak performance;
- **Comprehensive Maintenance, Repair, Replacement** - Evidence-based reserve fund studies that account for proper maintenance, prompt repair and proactive replacement;
- **Inhabitant Education and Engagement** - Working with the inhabitants and/or tenants so that they observe better housekeeping practices; and
- **Feedback and Continual Improvement** - Implement feedback mechanisms to inform designers, constructors, manufacturers, staff, management and inhabitants on how to improve the quality and performance of the building facility in general.

Ongoing or continuous commissioning, sometimes referred to as re-commissioning, represent facilities management best practices. By staying on top of all the passive and active systems that constitute a building, including its landscape, serious deterioration and breakdowns are avoided. Preventive maintenance is always more economical than letting things run down to the point of failure, but comprehensively commissioned facilities also retain their asset value over time.

Building designers do not typically avail themselves of the kinds of feedback that would improve and enhance the services they offer. The BIM knowledge management cycle is highly feasible for mass timber buildings and it provides numerous benefits for the continuous improvement of design services.

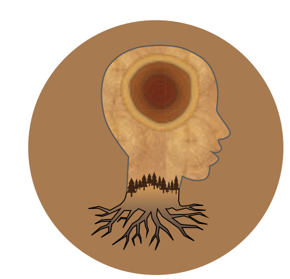


Knowledge management is key to improving design. *In the same way that BIM is an invaluable resource for facilities managers, it also provides architects and engineers with an opportunity to hold on to heuristics gleaned from various aspects of the project delivery cycle. Too often, faulty design details and specifications are not expunged, and design features that cause operations and maintenance headaches are not flagged. Measured performance data are not used to refine performance simulation models, and occupant evaluations of the completed facility are completely ignored. For the aerospace, automotive an electronics industry, these represent fatal business errors that our evolving building industry can no longer afford.*

Facilities Management & Mass Timber

Modern mass timber facilities must be properly managed to realize all advantages and benefits throughout their life cycle.

- For facilities managers, the management of data and information flows are key to the successful stewardship of mass timber buildings.
- Data and information begin with the digital design of the entire building using robust building information modelling (BIM) software that provides an invaluable asset long after the building project is completed.
- Special attention must be paid to controlling indoor relative humidity, managing spills and leaks, and maintaining exposed exterior wood.
- Preventive maintenance of exposed exterior wood involves regular visual inspections combined with cleaning and proactive refinishing.
- Continuous commissioning is a facilities management best practice that ensures the full value of the asset is realized over its entire life cycle.



Facilities Management
Click on this icon to download resources related to facilities management practices and protocols for mass timber buildings.

6 Looking Ahead

It is sometimes difficult to grasp that wood, one of the oldest building materials that is so familiar to people around the world over the ages, continues to face so many technical, regulatory, economic and environmental challenges. What would humans do if nature had not given us forests and wood?

Mass timber is made from wood, but it is an engineered wood product that in many ways exhibits properties that are so different from lumber and timber. If our forests could sustain the harvesting of large dimensional lumber and timber products so that we could continue constructing in a more traditional fashion, then there would be little need for innovation. However, the sustainability imperative in the face of climate change is demanding that we question just about everything we do in the building industry, most importantly our thinking.

The development of this primer publication reveals the many gaps in our building science knowledge. It also demonstrates that we have not applied all of our evidence-based knowledge in terms of better practices for designing, procuring, constructing, commissioning and operating and maintaining our buildings. Perhaps the mass timber revolution is our opportunity to hit the building industry's big reset button and get it right for succeeding generations.

An interesting perspective was provided by Dr. Anne Koven, Director of the Mass Timber Institute at the University of Toronto: *"climate change related to the carbon concerns of ecosystem functioning, the evidence for embodied carbon, and decarbonization processes, faster innovation, the stubborn and disheartening disparity gaps experienced by regional resource economies, environmental and professional ethics, participation and leadership by 'outsiders' such as Indigenous interests and the trades, and educating architecture, engineering, forestry students and early career professionals. Such questions require more research and collaboration to support the emerging mass timber industry."*

Our current state of building science knowledge around mass timber buildings is rapidly evolving as more building projects are construed and constructed. It will be important to verify if the recent round of mass timber buildings live up to their promise of comparatively superior environmental responsibility, indoor environmental quality and sustainable life cycle performance.

In countries like Canada, where high rates of population growth due to immigration are being witnessed and forecast to continue for decades to come, significant concerns have been raised about the carbon footprint of supporting infrastructure and buildings needed to accommodate that growth. Mass timber is a promising antidote to carbon intensive buildings and there is a growing need to be bold and innovative in our design thinking.

Zero carbon hybrid timber tower prototype. *This latest tall mass timber tower design innovation seeks to address the need to reduce the carbon footprint of buildings while promoting sustainable urban intensification. (DIALOG + EllisDon)*

But before mass timber buildings gain in their ascendancy, there are a number of questions that have to be answered and issues that need to be addressed.

- Starting with our forests, what exactly constitutes the sustainable harvesting of wood? How do we develop and enforce best forestry practices that exert a sustainable ecological footprint, not just in terms of carbon balance, but the promotion of biodiversity and protection of water resources?
- How will we equitably share the wealth created by mass timber among our Indigenous communities and empower them to pursue beneficial economic development paths?
- How do we instill life cycle design thinking and intergenerational equity concepts into our policies, codes and standards for buildings?
- How should we plan for and implement the training and education needs in schools of forestry, technology, engineering and architecture, as well as among the skilled trades, to sustain the mass timber revolution?
- What technology strategies are needed to advance bio-based materials research, development and production so that current building products embodying high global warming potential can be displaced by eco-friendly alternatives?
- How should mass timber suppliers (manufacturers) standardize their products so that these are as interchangeable as lumber and plywood building materials used in low-rise buildings?
- What can be done to advance the diversity and flexibility of acceptable solutions for mass timber buildings in our codes to avoid the time and expense associated with developing, documenting and peer reviewing alternative solutions?
- What are the more time and cost-effective procurement models for mass timber that support integrated early stage design assist and take advantage of building information modelling (BIM), design for manufacturing and assembly (DfMA), and modular offsite construction (MOC)?
- How do we institutionalize building performance evaluations and use this evidence-based feedback mechanism to design, build, commission, operate and maintain healthier and more sustainable buildings?

Mass timber innovation in support of sustainable natural resource education. *The Earth Sciences Building, University of British Columbia is the one of the largest panelized wood building and among the largest applications of cross-laminated timber in North America. It is critical that institutions and organizations that wish to advocate the goals of sustainable development adopt wood as the material of choice in their facilities. (Perkins + Will Architects, Structurlam – Martin Tessler)*

These are the big questions and issues that deserve immediate attention. Big technical gaps still exist in areas such as wood structural engineering, fire safety and acoustics. The durability and appearance of mass timber components through better moisture management protocols is yet another area that needs to be addressed. Prefabricated façade systems that can be rapidly installed to deliver high-performance in terms of thermal efficiency and durability also continue to challenge the mass timber industry. There is also a significant effort needed to research and develop bio-based materials with low carbon footprints that can substitute for more conventional insulation, sealant, adhesive and wood preserving and finishing materials.

For the building science field, most of the knowledge and expertise needed to deliver high-performance mass timber buildings already exists. It is much more a matter of using the tools modern building science has available, instead of developing yet more tools. It is the low diffusion rate of building science into the building industry rather than gaps in the knowledge base that hold back the achievement of well performing buildings.

Perhaps the mass timber revolution is our opportunity to hit the building industry's big reset button and get it right for succeeding generations.

Every size and type of building is suited to building with wood and wood engineering and building science can devise appropriate solutions to meet the various needs of the residential, commercial, institutional and industrial sectors. Mass timber is also known to provide a much-appreciated warmth of experience that can serve as a soothing respite from the harshness of concrete and steel urban environments.

It will be important to verify if the recent round of mass timber buildings live up to their promise of comparatively superior environmental responsibility, indoor environmental quality and sustainable life cycle performance.

Canada's canary in the mine is its Indigenous communities, where the chronically poor quality of housing has compromised health and well-being and foreshadows what is awaiting future generations of Canadians if the overwhelming evidence about the inadequacies of much of our current new housing is ignored. Mass timber is a sustainable path that will lead to socially and environmentally appropriate responses to our shelter needs.

Softening the urban fabric with mass timber. *The 100th branch of the Toronto Public Library, the Scarborough Civic Center Branch was designed to provide a sustainable natural oasis in its dense, urban environment. Combining structural innovation and design complexity, this audacious architectural achievement will serve the community's needs for generations to come. (LGA Architectural Partners, Blackwell Structural Engineers, NORDIC Structures)*

Mass timber for Indigenous communities. *Cardinal House is a prototype for a prefabricated mass timber home intended to help meet the housing needs of First Nations communities. Designed by renown Canadian architect, Douglas Cardinal, and manufactured by Element5, assembled by MCH, the prefabricated, modular design and mass timber construction delivers a high-performance, durable home that can be passed down through the generations.*

Onward

The building industry must finally enter the 21st century to more fully engage all of its issues and opportunities - this is the future challenge for all buildings, not just mass timber buildings. And those challenges will have to be overcome by our upcoming generation, who must be provided with access to education, training and meaningful internships, that will foster the career commitments needed to build a better world. The building industry needs vehicles to help educate, train, recruit and retain its best and brightest for a sustainable future.

The Mass Timber Institute at the University of Toronto is one such vehicle for supporting the research of our faculty colleagues and the education of our students, coming together to share a common future by enabling equitable access to the vast network of knowledge, expertise and personal relationships afforded by Canada's largest research-intensive university.

We are pleased to freely share this legacy with all of our university, community college, government and industry partners. For it is within this context that the MTI contributes to the advancement of mass timber, and it is through the pursuit of initiatives, such as this primer publication, that it shall continue to demonstrate its commitment.

MASS TIMBER INSTITUTE

UNIVERSITY OF TORONTO
JOHN H. DANIELS FACULTY OF ARCHITECTURE, LANDSCAPE, AND DESIGN

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Building Science & Mass Timber Futures

It is important to reiterate that building science alone is insufficient to drive the mass timber building revolution, but it is critical that the various stakeholders work together to advance the mass timber agenda and ensure the appropriate application of better building science.

- There remains a need to expand building science education for all design and construction professionals, their allied trades, facilities management personnel and all those involved in the regulations, codes and standards pertaining to mass timber buildings.
- If you can't measure it, you can't manage it. Monitoring and reporting building performance along with inhabitant feedback from post-occupancy evaluations are key to understanding and addressing performance problems.
- An open platform of technology transfer between researchers, innovators, manufacturers, educators, design professionals, tradespeople and regulatory officials is the path to continual progress and performance improvement.
- These are early days for mass timber and every project needs to apply the best available building science knowledge to deliver exemplary buildings that are safe, healthy, resilient and sustainable.

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