Tall Wood in Canada: Feasibility Study, Technical Guide, and Wood Innovation and Design Centre

Wood Innovation Design Centre Vancouver &
Machbarkeitsstudie 40 Geschosse in Holz

Wood Innovation Design Centre Vancouver & étude de faisabilité de bâtiments de 40 étages en bois
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1. Introduction

We are entering the age of Tall Wood buildings. Advances in timber engineering within Canada, and worldwide, make tall wood a possibility. High-performance materials like Cross Laminated Timber (CLT) and Laminated Veneer Lumber (LVL), composite systems such as Timber Concrete Composite (TCC), and modern mechanical and chemical connections are allowing us to achieve what was not previously possible. It is up to designers, builders, and manufacturers to start applying these amazing new technologies and push our buildings further than before, while respecting the strengths and limitations of this natural building material. Meanwhile, a changing climate means we need to adjust the status quo and find solutions and alternatives to the way we have been used to doing things in the past several decades.

Canada is well-placed at such a time of engineering growth. We are a country with vast forestry resources and world-class engineers, architects, wood suppliers, and builders. Building tall with wood is in Canada’s history. Our industrial brick and beam buildings date back to the early 1900’s, reaching up to 9 storeys tall. Timber is an abundant resource in Canada. Canada still has 91% of its original forest cover, with virtually zero deforestation in the last 20 years (FAO Advisory Committee on Paper and Wood products 2003). Nearly all of Canada’s forests, which make up 10% of the world’s forest cover and 30% of the world’s boreal forests (Statistics Canada 2009) are government owned and managed, less than 1% harvestation each year is permitted, and regeneration is mandatory. The Government of Canada imposes and enforces some of the toughest environmental laws on the forestry industry, ensuring that the forests are responsibly and sustainably harvested.

In the last few years, Equilibrium designed the groundbreaking Earth Sciences Building at UBC, a 5 storey hybrid timber and concrete building, using modern timber technologies, some of which were brand new to Canada. Equilibrium has since been involved in several initiatives which are bringing tall wood buildings to Canada. Eric Karsh of Equilibrium co-authored “The Case for Tall Wood Buildings” with Micheal Green, a feasibility study examining how a timber highrise could be built. Equilibrium has been among the contributors to the Canadian Technical Guide on Tall Wood Buildings, that is set to be published in the spring. And most notably, Equilibrium is the structural engineer for the Wood Innovation and Design Centre, a 27.5 metre tall 6 storey all-timber building in northern British Columbia that, once complete, will be the tallest modern all-wood building worldwide.

2. Background of Tall Wood in Canada

![Figure 1: 9-storey brick and beam building in Vancouver (WoodWorks)](image)

Construction in Canada in the mid 1800’s to the mid 1900’s took advantage of timber’s availability and abundance. Early industrial buildings were 6 to 9 storeys tall, built with brick perimeter walls and heavy timber post and beam interior frames. Examples of these
buildings can still be found in major cities throughout Canada. Some of these buildings are still in use, most converted to residential or commercial occupancies. Vancouver’s historical Gastown neighbourhood showcases some of these buildings.

Concerns over fires and advances in concrete and steel engineering techniques spelled the end for these original tall timber buildings. Building codes in Canada restricted the height of combustible buildings to 4 storeys, or 18m tall, and that limit has effectively stayed with us today. Two of the provinces, British Columbia and Québec, have recently allowed timber buildings up to 6 storeys tall. However, with stick framing, 6 storeys is likely the vertical limit, and to push taller, modern mass timber engineered materials are required.

The Canadian Building Code consists of two parts: A list of acceptable solutions with prescribed methods of achieving those solutions, and the relatively new and rarely used “alternate solution clause”. Under the Code, an alternate solution must meet the minimum levels of performance required under the code. In this way, the Code can be an objective- and performance-based document, rather than an entirely prescriptive document. Canadians pursuing Tall Wood projects must take it upon themselves to demonstrate how the performance can be achieved when stepping beyond the prescribed restrictions in the code.

3. Tall Wood Feasibility Study

![Building Developed for "The Case for Tall Wood Buildings"

Erik Karsh of Equilibrium Consulting and Michael Green of Michael Green Architecture (MGA) set out to develop a feasibility study describing how a tall timber building could be designed and built, and at what cost. With the intention of coming up with a design solution for 12 stories in timber, Karsh and Green instead found that they had developed a system that could reasonably be expanded to 20 storeys, and then to 30 storeys or higher. Out of this, “The Case for Tall Wood Buildings” was born, a collaborated effort demonstrating one possible solution of many that could be used to build tall wood within Canada, and worldwide.

This feasibility study introduced a design concept called Finding the Forest Through the Trees (FFTT). FFTT is both the acronym given to the specific structural system, and the guiding concept behind the study. The study stresses the value of not just the minutiae and the technical details, but the big picture concept. The Case for Tall Wood is an attempt to simplify the concept of using timber without forgetting the fundamental properties that make timber an advantageous choice. It argues why we should be considering wood for our high-rises. This document is not a stand-alone piece of engineering and architecture. It builds on what designers have come up with and achieved worldwide,
including CREE’s prefabricated LifeCycle tower system which can conceptually reach 30 storeys tall, London’s Stadhaus 9 storey all timber building, and ancient timber structures such as the Barsana Monestary (56m tall) and Japanese Pagodas. At the most fundamental level, the Californian redwood forests, with tree heights exceeding 100m tall, are the inspiration behind this effort, and a reminder that wood has an innate ability to be tall.

The study developed a series of prototypes to work through the engineering, architectural, code, and cost issues of specific buildings. The prototypical buildings are typically residential, though the feasibility study also provides options for open spaces more typical of commercial buildings. The inclusion of partitions in the structure, similar to what was done in London’s Stadhaus building, results in a stiffer structure that has a better resistance to lateral vibrations due to wind. A total of 4 prototypes were developed: A 12 storey, two 20 storey options depending on floor plan requirements, and a 30 storey option. These prototypes were compared to concrete benchmark 12, 20, and 30 storey buildings.

The prototype buildings are located in Vancouver, British Columbia (BC). BC is a hotspot of wood designers, researchers, and fabricators, and Vancouver has a density appropriate for a timber tower, with typical residential towers ranging from 10 to 20 storeys tall. Vancouver is also a high seismic region, therefore this study considers high seismic loads in addition to wind and gravity loads.
The structural system that this document presents was given the acronym FFTT. It is a tilt-up system that uses balloon-framed mass timber panels in a cost effective and simple way. The gravity loads are resisted with mass timber panels as the floors, walls, and building core, and engineered wood columns providing additional vertical support where necessary. The lateral load resisting system follows a strong column / weak beam approach, where mass timber panels make up the strong (and stiff) vertical supports, and steel beams integrated into the mass timber panels provide ductile beams that are designed to yield under seismic loads producing plastic hinges. However, initial analysis indicated that the ductility of the lateral load resisting system may not impact the final design significantly. Resistance to vibration from wind loading is the governing lateral load case for the taller buildings, even in high seismic zones. This is particularly apparent if concrete topping is omitted due to relatively low building mass. Regardless of whether wind governs the lateral behaviour or seismic governs, additional detailed analysis including static and cyclic testing of novel systems and assemblies would be required for this system to be implemented in a high-seismic zone.

The case study explores using solid wood panels for many of the structural elements in this building, but does not specify which product is required. There are multiple options, including Cross Laminated Timber (CLT), Laminated Veneer Lumber (LVL), and Laminated Strand Lumber (LSL) each with their own advantages and disadvantages. All of these mass timber panels provide excellent strength and stiffness, at a much lighter weight than concrete, and all are available in Canada.

Figure 5: Example of how a glulam column was designed to account for charring to achieve the necessary fire rating in “The Case for Tall Wood Buildings”

The Canadian Building Code categorizes wood as combustible, and except under very specific circumstances does not differentiate between the combustibility of light framing and of mass timber engineered products such as CLT. Canadian research is underway to demonstrate the fire resistance of mass timber engineered products, considering both charring and encapsulation. Combustible construction is not permitted in Canada for residential buildings over 6 storeys tall, so a performance-based alternative solution is required. Encapsulation is the typical option for providing fire-resistance ratings, however it reduces exposure of wood and it increases the carbon footprint, weight, and cost of a building. Charring, in combination with compartmentalization and modern suppression systems, is increasingly accepted as a method of providing fire resistance, by designing load-bearing members to include sacrificial or protective layers of wood. Smoke control and venting would need to be considered, and complete automatic sprinkler protection would be required, as these are standard requirement for the equivalent concrete building.

All timber elements would be pre-fabricated to optimize speed and ease of erection. Without needing to form and pour a concrete core, the limiting factor during construction would be the number of cranes available for lifting panels into place. The header panels can be built on the ground and “tilted up” several storeys at a time. The mass timber panel core could be erected first and used to brace the other walls and columns until
their connections are complete. Exposure to water during construction must be kept to a minimum. The estimated time savings between the timber prototypes and typical concrete buildings is on the order of 10 weeks, or 10-15% of the construction time.

A cost analysis in “The Case for Tall Wood” provided an initial estimate of the full project costs based on the preliminary drawings (see Figure ). The costs were compared to the concrete benchmark building, which is the typical construction type in Vancouver for high rises. Using FFTT with the charring method to achieve fire rating resulted in very similar costs as concrete, however encapsulation is pricier. These costs did not consider phasing of the work and accelerated schedule, so the improved schedule could have a favourable impact on the overall project cost. However, due to the novelty of this type of project, contractors would likely bid more to account for unexpected project risks.

![FFT T Project Costs for Vancouver](image)

Figure 6: Project Costs from "The Case for Tall Wood"

“The Case for Tall Wood Buildings” is published under the creative commons license and available freely online. The intent is to offer it as a starting point and a stepping stone to achieving tall wood buildings economically. This study is one possible solution of many, and is intended to be built from and used by designers, builders, and building officials worldwide to move forward the international development of what can be achieved in tall wood. The designs presented are conceptual only, based on preliminary calculations and computer modelling. To implement this design, more detailed analysis and laboratory testing will be required. Currently nonlinear analysis is underway at the University of British Columbia to further study the FFTT system.


4. **Technical Guide**

“The Case for Tall Wood Buildings” was an example of how a tall wood building technically could be built, however, it was intended to be an example, not a complete guide. There were still many questions left unanswered. The Canadian Wood Council is eager to have a flagship tall wood building in Canada, but this document did not provide the guidance and broad scope necessary to satisfy the performance requirements of the Canadian Building Code as an alternate solution.

In order to pave the way for a demonstration project in Canada, The Canadian Wood Council, along with Natural Resources Canada, put out a request for an expression of interest for high-rise wood demonstration projects, with a monetary grant available for the proponents selected. The grant is meant to encourage Canadian designers, builders, and manufacturers to safely and successfully demonstrate the use of wood as a viable structural element and system in a building of 10 storeys or more. However, to meet the
“alternate solution” requirements, a document was necessary outlining how equivalent performance could be achieved. That document is the “Canadian Technical Guide for the Design and Construction of Tall Wood Buildings.” This guide is to be used by designers to provide them with the tools necessary to design tall wood so that it is safe, durable, fire resistant, comfortable, and meets all necessary performance requirements. This guide outlines where additional work and research is needed before such buildings can be built. The guide is also intended to be used by building officials, authorities having jurisdiction, builders, developers, and planners to better understand tall wood and its advantages and challenges, and the state of research and design today.

The Canadian Wood Council hired a multidisciplinary team of consultants nationwide led by FPInnovations to assemble the guide. On this team were structural engineers, mechanical engineers, fire consultants, building envelope specialists, architects, cost consultants, and seismic specialists. The guide was partitioned into chapters that covered relevant issues to designers, owners, and building officials for a tall wood building. Through the latest research, design, and construction worldwide, this guide comprehensively covers issues relevant to tall wood buildings across the spectrum of disciplines.

Equilibrium played an integral role in the writing of this guide, as the lead author of the structural and serviceability chapter, and co-authors on many of the other chapters. Each chapter was peer-reviewed by independent consultants, ensuring that this document had the input from a considerable breadth of professionals country wide, from consultants to researchers to building officials. All in all 80 professionals from throughout Canada were involved in bringing this document together.

This guide was published jointly by FPInnovations as a 90% draft in 2013, to be released to those who were interested in submitting a project for the grant. The document is currently being updated and prepared for the publication of the first edition this spring. The first edition of the technical guide will be accessible online in the spring of 2014 through FPInnovations.

5. Wood Innovation and Design Centre

Independent from the work being done on the technical guide, but working closely with many of the consultants who were involved, Equilibrium moved forward on a 6 storey building (8 stories including the mezzanine and penthouse structures), which, at 27.5m tall, is slated to be the tallest modern all timber building in the world. Prince George, a small community of 72 thousand in Northern British Columbia, 786km north of Vancouver, will be home to the Wood Innovation and Design Centre, or WIDC. WIDC is currently under construction and expected to be completed by August 2014.

This building is meant to display BC’s ability to design and produce leading edge wood structures. Wood from all over the province will be showcased in this building, including Douglas-fir, cedar, hemlock, pine, and spruce. All of the engineered wood products are being produced in BC.

Figure 7: Rendering of WIDC (Image credit MGA)
The building will be used for research facilities and classes with the University of Northern British Columbia, office space for industry, and provincial needs. The program is provided to advance the province of BC’s Wood First agenda, which was created to celebrate the province’s resource, and to encourage its use locally.

5.1. Structure

In addition to being a showcase for innovation, WIDC is meant to be an example of how tall wood construction can be economically achieved in a timely way. Thus, the design is meant to be practical, cost efficient, and flexible enough that it can be repeated for other projects, and need not be limited to a demonstration building. A dry, wood-only system is used instead of cast-in place or precast wood concrete composite to minimize weight and speed up erection, a critical consideration for this project.

WIDC is a smorgasbord of modern timber technology. Included in the building are CLT walls, stick frame partition walls, glulam columns, PSL beams, CLT floors, and LVL columns. Connections include self-tapping screws, glued-in rods, glued-in HSK plates, and aluminum dove-tail connectors. Much of the timber is exposed to give the look and feel of a wood building and to properly showcase the local industry. Because of the exposed timber, the connections are typically hidden, improving fire performance and providing what will be a clean and simple look.

5.2. Post and Beam Frame

The structure uses CLT slab on glulam beams and glulam columns. Columns are typically on a 6m x 6m grid, supporting the CLT floor assemblies. The columns are spliced at each floor to simplify erection, and are end-to-end connected, transferring vertical loads in bearing parallel to grain and eliminating cumulative cross grain shrinkage. Steel shim plates are used to allow for height adjustment and eliminate the “comb” effect.

The beams frame into the column faces using the proprietary Pitzl™ connector – a pre-engineered aluminum dovetail connection system installed in the shop, which allows for fast and accurate erection. The connector is recessed and encapsulated by the surrounding wood material, and is therefore inherently fire resistant.

A number of column transfer beams are required, which will consist of 1200 or 965mm deep built-up Parallel Strand Lumber (PSL) beams that are bolted together. This product is dimensionally stable and has excellent shear and bending strength.
5.3. **Floor Deck Panel System**

The novel floor assembly developed for WIDC, shown in Figure 9, has CLT panels that are connected to one another with the HSK system, providing a fully composite corrugated structural section. Such an assembly allows building utilities to be run in the spaces between the 5-ply panels. Two advantages of this floor system over timber-concrete composite are maintaining a low carbon footprint by reducing the volume of concrete, and avoiding the shoring and waiting associated with allowing concrete to cure.

The mechanical penthouse at the highest level uses a timber concrete composite system to allow for higher equipment loads and fire rating.

5.4. **Connections**

There is no concrete above grade, except for concrete topping at the mechanical penthouse, and no structural steel members except for a handful of minor elements. As a result, nearly all connections are wood to wood, eliminating the need for wood to steel and wood to concrete connections above the foundation. Self-tapping screws provide most of the wood to wood connections throughout the building. They are hugely advantageous in this project given that they do not require pre-drilling in the shop, and can be installed on site with simple hand tools.

Additional connections used are glued-in rods and glued in HSK plates, both of which provide significant tensile capacity. Aluminum pre-engineered dovetail connectors are notched into columns for easy beam connections and fire safety.
5.5. Lateral Force Resisting System

Prince George has a high snow load, but low lateral demands, particularly low seismic loads. As a result, some of the tall wood challenges of buildings at other locations were not relevant for this building, particularly related to ductility of all-wood systems. Because of the lightweight structure, seismic is even less of a concern, and the lateral system is governed by wind.

Lateral loads are resisted entirely by the balloon-framed elevator core, built entirely of 5-ply and 7-ply CLT panels that are connected with self-tapping screws at lapped joints and steel brackets at floors. The balloon framing minimizes the number of inter-storey connections and increases the stiffness of the system. Hold-downs are provided using steel embeds and gusset plates using the proprietary HSK system, specifically proportioned to provide ductile behaviour. The hold-downs will be concealed and fire protected by the wall finishes. Inter-storey connections will be achieved with a combination of ring nail connections and shear keys. Ring nails are similar to timber rivets but provide a more ductile performance.

5.6. Glazing System

The typical glazing system will consist of pre-engineered glazing panels mounted on aluminum support sections, mounted directly onto LVL edge laminated window mullions, an innovative material. This product has been chosen for its great appearance, strength and dimensional stability. Edge-laminated LVL panels are also used for the canopies around the base of the building, and for the main lobby feature staircase.

Figure 11: Rendering of WIDC (Image credit MGA)

5.7. Fire Protection

Fire protection is provided through a fully engineered approach, relying on charring instead of the traditional encapsulation method. All posts, beams, loadbearing walls, and floor decking elements, including all connections, have been engineered, and oversized where required, to provide a one hour fire rating through charring throughout. All connections are typically protected by the surrounding timber material and will also achieve the required fire rating through charring.

6. What`s Next?

WIDC will be a huge achievement in Canada, North America, and the world for its innovative use of wood and efficient construction system. Using what has been learned from WIDC, “The Case for Tall Wood”, and the Canadian Technical Guide, we can move forward to further develop tall timber in Canada, and provide a global example of leading-edge technology and applications in the realm of tall wood buildings.