FIRE SAFETY IN TALL WOOD BUILDINGS

Jim Taggart

Over the past decade, Canada has been developing regulations to promote the use of cross laminated timber (CLT) and other mass timber products, in a variety of new and larger scale applications. This has required much research and testing to establish standards for structural strength, fire performance, thermal and acoustic behaviour. Large scale testing of CLT panels has generated consistent results and assured scientists that large mass timber buildings can be designed to the standards of life safety and structural stability required by the National Building Code of Canada.

Nonetheless, the perception of some municipal authorities, local fire marshals, building owners and developers does not yet comfortably differentiate between the fire performance of light wood frame structures and those made of mass timber. This same perception is evident in Europe where many Tall Wood buildings are still required to have concrete podiums, stair and elevator shafts.

The Legacy of the Chicago Fire

The reason is that almost all the large cities in Europe and North America had major fires in the 19th century that resulted in changes to the local building code, reducing the permissible height of wood buildings, or prohibiting them completely. However, the fire that devastated Chicago in 1871 impacted an entire continent.

Propelled by strong winds, the Chicago Fire destroyed 17,500 buildings, travelling from one to the next by igniting roof shingles, cladding, balconies and other exterior wood elements. More than 50 insurance companies declared bankruptcy and in response, the city of Chicago introduced a new bylaw requiring all new structures to be of ‘fireproof’ construction.

Loadbearing masonry became the default construction method, but within a decade, the emergence of reinforced concrete offered engineers and architects the possibility of high-rise structures with narrow columns and expansive glazing – a new aesthetic with instant and widespread appeal. With few exceptions, traditional timber building methods were eclipsed.

Cover: Canada's Earth Tower. Multi-storey winter gardens and selectively exposed wood structure bring nature into the tower form. Architect: Perkins and Will.
Above: Earth Sciences Building. One of the largest panelized wood buildings in North America at its time of construction, and a precedent for future mass timber projects. Architect: Perkins and Will. Photo Credit: Martin Tessler.
Right: Terrace House. Tall hybrid wood tower with flanking terraces that complement the Evergreen Building. Architect: Shigeru Ban. Credit: PortLiving.

In some cities, ‘brick and beam’ warehouses remained popular; the eight storey (one below grade) Landing building in Vancouver (1905), is one example that survives as testimony to the practicality and durability of heavy timber buildings in urban environments. However, as attitudes changed, much of the empirical knowledge about the design, construction and performance of heavy timber buildings was lost.

The Imperative for Reviving Tall Wood Buildings

For most of the 20th century, architects favoured industrial materials such as concrete, steel and glass when building in urban environments, a choice driven primarily by concerns for economy, utility and a Modern aesthetic. Little or no consideration was given to the environmental impact of buildings.

However, we now know that the construction and operation of buildings contributes approximately 40% of the greenhouse gas emissions in most developed countries. We also know that the world has a housing crisis; one that will require us to more than double the output of our residential construction sector if meaningful progress is to be made. Our current methods of construction, which rely heavily on reinforced concrete, concrete masonry and steel, may arguably address the housing crisis, but in so doing they will exacerbate climate change.
Concrete production is responsible for between 5% and 8% of global GHG emissions, while the manufacture of steel consumes 5% of the world’s electricity – much of which is still generated by fossil fuels. With the material content of a building being approximately 50% structure, it is crucial that we find substitutes for these carbon intensive materials. The only option currently available is mass timber.

Why Wood?

Living trees sequester carbon dioxide from - and release oxygen to - the atmosphere. They use the carbon to create cellulose which is the major component of wood fibre. Each cubic metre of wood contains approximately 0.9 tonnes of carbon, which is retained in the wood until it decays or is consumed by fire. Converting trees harvested from sustainably managed forests into durable building products and planting new trees in their place, maximizes both carbon sequestration and carbon storage – a fact confirmed in 2007 by the Intergovernmental Panel on Climate Change in its Fourth assessment Report.

In addition, the substitution of wood for other materials with a significant carbon footprint, such as concrete and steel, increases the net environmental benefit. On this basis, wood may be considered not simply as mitigating climate change, but contributing to its reversal.

The Evolution of Building Codes

As seen in the aftermath of the Chicago Fire, changes to building codes restricting the use of combustible construction generally happened quickly in response to such disasters. However, reversing these changes to reflect our emerging understanding of fire behaviour takes much longer.

The National Building Code of Canada (NBCC) was first published in 1941 and permitted heavy timber structures up to 22.5 metres. (For reasons unknown, one storey lower than The Landing). In 1953, the change to a risk assessment approach further reduced the permissible height to four storeys. This height was favoured by fire authorities, because it represented the tallest structure in which a fire could realistically be controlled and extinguished, given the fire detection systems, response times and firefighting equipment of the day. Paradoxically, this Code Change did not restrict combustible material in concrete buildings, nor require exposed steel to be protected. This height limit persisted until 2015 (2010 for residential construction in British Columbia) when it was raised to six storeys.

The NBCC began as a guide, but over time evolved into a prescriptive document. Only in 1996 did it introduce performance criteria that offered users some flexibility in their choice of construction, based on a system of equivalencies. In 2005, the NBCC moved to an Objective model, in which compliance is measured against Objective and Functional Statements. It offers two compliance paths: Deemed to Satisfy Solutions and Alternative Solutions. The former offers one or more prescribed solutions, whereas the latter requires proof that a proposed solution meets the criteria of the Objective and Functional Statements.

These Alternative Solutions are adjudicated on a case by case basis, are non-transferable and take a considerable length of time before being adopted into the Code as Deemed to Satisfy Solutions. In the case of a new construction material or technology, the rapid pace of scientific research can create a gap between proven performance and what is considered acceptable under current codes.

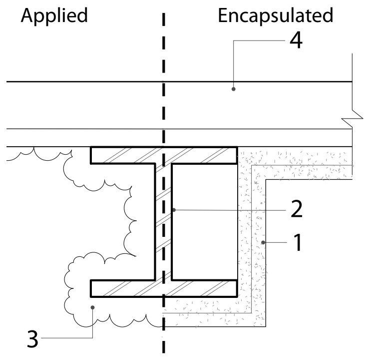
It is important to note that all buildings have inherent risks, both in terms of structural failure and fire related damage. Whatever the materials used in construction, building codes are designed to mitigate risk, rather than eliminate it altogether.

In the case of wood, igniting small members is relatively easy, whereas igniting mass timber components is virtually impossible in buildings in normal circumstances. This means light wood frame elements are almost always protected by layers of gypsum wallboard, while heavy timber elements generally extinguish when the source of heat is removed. Even in an intense fire, when heavy timber may continue to burn, it does so at a predictable rate. By adding thickness to the structural section, this phenomenon can be used to provide a specific fire resistance rating.

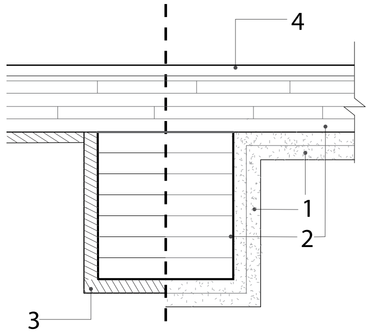
Fire Behaviour

The greatest risk to the integrity of a structure and the safety of its occupants comes from a fire that develops inside the building - a so-called compartment fire – rather than one that starts outside. The word ‘compartment’ carries a particular meaning, that of an interior space, or series of contiguous spaces, separated from other such compartments in the building by fire-rated floor and wall assemblies.

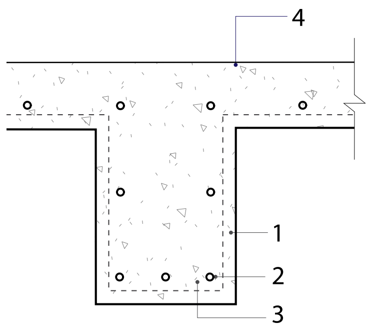
For a fire to start, three things must be present simultaneously: fuel, oxygen and a source of ignition. Fire is an exothermic reaction in which oxygen and fuel are consumed, and heat (together with by-products such as smoke) is produced.



STEEL



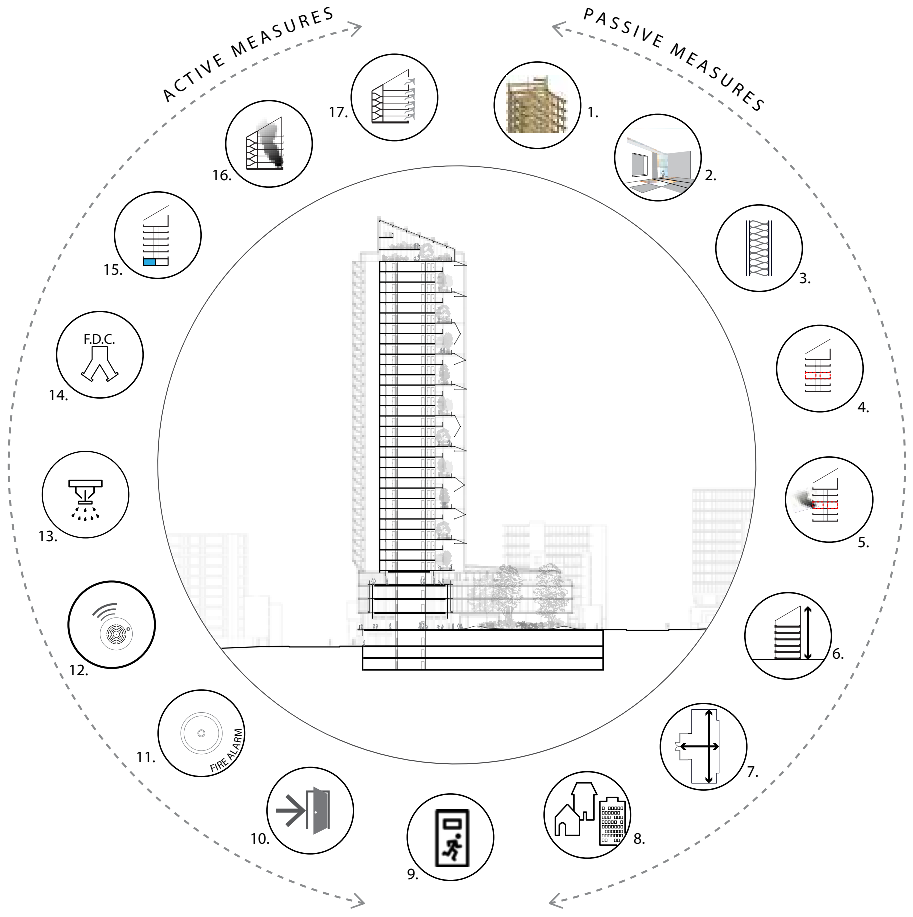
TIMBER



CONCRETE

Typically, a fire begins as an isolated phenomenon, but spreads and grows in intensity as it consumes the combustible contents and surfaces of the compartment. As the temperature increases, smoke will rise and spread across the ceiling of the compartment, then spread down the walls.

When the smoke layer reaches a temperature of approximately 600°C, the heat radiating from it will cause most of the combustible objects close to it to ignite simultaneously. This instantaneous transformation of a fire from localized to all-engulfing is called ’flashover’. In most cases it is the availability of fuel that determines how a fire develops in the early stages and the availability of oxygen that determines its growth after flashover.



FIRE SAFETY AND CONTROL SYSIEMS

1. Limit combustibility of structure
2. Limit combustibility of interior finishes
3. Limit combustibility of building components
4. Compartmentalization for fire
5. Compartmentalization for smoke
6. Scale limited by height
7. Scale limited by area
8. Use and occupancy type
9. Exit access
10. Exit protection
11. Heat detection through fire alarm
12. Smoke detection through smoke alarm
13. Fire suppression through sprinklers
14. Fire suppression through standpipes
15. Fire suppression through on-site water supply
16. Smoke suppression through pressurization
17. Smoke clearance through smoke venting

Design Objectives for Fire Control

The most important objectives of fire design are: to ensure the structural stability and integrity of a building for the duration required to enable the safe egress of building occupants and subsequent intervention by firefighters; and to ensure the life safety of occupants within the floor areas or compartments of a building.

For tall buildings, this structural fire resistance requirement is typically two hours. To ensure life safety for occupants within floor areas, measures must be taken to restrict the development of a fire within the compartment in which it started and to restrict the spread of heat or flames from that compartment to other parts of the building. Fire safety design combines both passive and active measures that together form a comprehensive strategy for detection, suppression and control.

Passive measures are concerned with physical building attributes such as material specification, compartment size, and the number and location of fire exits and firefighting access points. Active strategies include automatic heat and smoke detectors, fire alarms, sprinkler systems, smoke vents, backup generators, dedicated firefighting elevators, and in some cases, a dedicated on-site water supply for firefighters. Not all strategies will be required in all cases and fire simulation modelling can be used to determine the combination of strategies that will most effectively achieve the required level of performance. In the case of tall buildings, regardless of construction material type, sprinkler systems and fire alarms, and multiple exit paths, are mandatory.

These measures have reduced detection time to between 120 and 180 seconds and the arrival of firefighters to something less than ten minutes. Not only are 95% of fires restricted to the compartment in which they start, but many are extinguished before the building structure is seriously engaged. It is worth noting that sprinklers are one of the most reliable of today’s many building systems.

Above left: Typical fire safety design approaches for structural elements. Credit: Perkins and Will.
Above: Active and passive strategies for fire control in modern high-rise buildings. Credit: Perkins and Will.

Research, Testing and the Development of Codes and Standards

Canadian Standard CSA O86 is referenced in Part 4 of the NBCC and in provincial building codes. It provides criteria for the structural design and evaluation of wood structures or structural elements including CLT and was last updated in 2017. However, the breadth and depth of research on CLT structures, in particular, is outstripping the ability of codes and standards to keep up.

The 2020 editions of the National Building Code and National Fire Code will be based on past research and analysis conducted In British Columbia and Quebec and ultimately ratified by the Codes Canada Standing Committee on Fire Protection.

The Code will prescribe minimum dimensions for all timber members, encapsulation of the timber structure with two layers of 12.5mm Type X gypsum wall board, and floors finished with a concrete topping. Within the Deemed to Satisfy provisions of the new codes, there will be limited exceptions to encapsulation permitted.

Catching Up with the Research

Meanwhile, testing of fire behaviour in CLT structures has been ongoing at a variety of organizations, including Carleton University, the National Research Council of Canada, the Southwest Research Institute, the Forest Products Research Laboratory, the National Fire Protection Association and the Fire Protection Research Foundation.

Each organization has conducted multiple tests to compare the performance of alternative configurations of CLT compartments. The common objective was to determine how much wood can be exposed and still be safe in the scenario when sprinklers fail to control the fire and the fire service is unable to respond.
These tests have variously measured the effects of:

- The size of compartments
- The size of ventilation openings in the compartment
- The area and locations of exposed CLT elements (zero, one or multiple walls, none, part or all of the ceiling) with the remainder of the surfaces covered in two layers of 12.5mm Type-X gypsum wallboard
- The use of regular and heat resistant glues

Among the significant (and sometimes counterintuitive) conclusions have been that:

- Smaller ventilation openings lead to more intense, higher temperature fires
- Larger compartments (e.g. 22.4m x 4.8m x 2 .7m high) also result in less intense fires
- Exposed beams, columns and ceilings are unlikely to cause a significant increase in fire risk.
- The use of heat-resistant glues prevents the delamination and loss of the outer layer of Exposed CLT panels, and such panels may perform better than encapsulated CLT elements

Canada's Earth Tower, a tall hybrid wood project, envisionned for Vancouver.

Collectively, the tests have demonstrated fire performance for exposed CLT structures that is far superior to that previously supposed and to some degree blurs the boundaries between fully encapsulated, partially encapsulated and exposed CLT structures.

In reviewing the test results, Dr Steven Craft, who conducted the research at Carleton University concluded:

"Fire safe design of tall wood buildings is possible with the primary question being how much wood can be safely exposed. Based on changes to CLT adhesives, the Canadian and US codes are now very conservative on the amount of exposed mass timber that is possible. Many tall wood buildings currently being designed in Canada go beyond the 2020 NBCC provisions in height, occupancy and/or areas of exposed timber, as mass timber construction has progressed faster than code changes.“

In its commitment to advancing tall wood buildings, British Columbia has taken the lead, agreeing to implement NBC 2020 in the fall of 2019 for qualified jurisdictions like Vancouver. The Province has also announced its intention to permit fully exposed timber structures in buildings up to nine storeys with a requirement for two-hour fire resistance. Albeit belatedly, this will bring at least one Canadian province into line with the approach already being taken by two progressive jurisdictions at opposite ends of the world.

CASE STUDIES FROM AUSTRALIA AND NORWAY

25 King Street, Brisbane, Australia

Following the success of Forte, the country's first contemporary Tall Wood building in 2012, the Australian Building Code (ABC) was updated to include partially or fully encapsulated wood construction up to 25 metres in height in its Deemed to Satisfy provisions. Now, developer Lendlease has pushed the envelope for mass timber construction even further.

Designed by Bates Smart Architects, 25 King is a 10-storey commercial office complex with a total floor area of 16,446 square metres. When completed in the spring of 2019, it became the largest contemporary mass timber office building in the world.

Architecturally, 25 King is a glazed rectilinear volume through which can be seen its horizontal floor plates and exposed timber cross-bracing. The linear service core on the north side of the building is constructed entirely in wood. Structural engineers at Aurecon used glulam timber for the columns and beams, while the floor panels and walls of the service core were made from CLT. Glulam beams were also used for the diagonal bracing of the exterior bays of the building and for the V-shaped supports that form the retail colonnade on the ground floor.

Internally, fire engineers at Aurecon sized the exposed wood elements to include a 63-millimetre thick charring layer, designed to provide the required 90 minutes fire resistance, with an additional 7 millimetres assumed to have reduced structural performance under fire conditions. The same principles apply to the CLT floor and wall panels, their overall thicknesses of 220 and 240 millimetres also including a charring layer.

Mjøstårnet, Brumunddal Norway

This 18-storey, 85.4-metre, tower is located in the small town of Brumunddal, about 140 kilometres north of Oslo and is currently the tallest wood building in the world. Designed by Voll Arkitekter and completed in spring 2019, the mixed-use structure includes offices, 32 apartments, 72 hotel rooms, two restaurants and a rooftop terrace.

Engineered by Sweco, the interior structure consists of glulam columns and beams and a system of glulam and LVL sandwich panels for the floors. Testing by SP Fire Tech confirmed that the primary load bearing system meets the two-hour fire resistance requirement while secondary load bearing elements such as floors meet the 90-minute requirement. Fire resistance for the glulam structure is achieved through the charring method, with members being oversized by approximately 80-millimetres in each dimension. The floor panels are filled with mineral wool insulation.

Full sprinklering is a prerequisite for all tall buildings, but numerous other measures were also part of the fire design strategy. These included encapsulation of CLT in stair shafts, fire stopping of exterior cladding, fire retardant painted surfaces in escape routes, mineral wool insulation in the LVL and glulam floor panels and intumescent paint on some steel connections. Throughout most of the building, the glulam columns and non-loadbearing CLT walls remain exposed. With all the apartment units presold and the hotel fully booked, Mjøstårnet is a further demonstration that the market is ready for exposed wood buildings of considerable height.

Previous page: Top Right: 25 King Street, the largest contemporary mass timber office building in the world. Architect: Bates Smart Architects. Photo credit: Tom Roe.
Right: Mjostarnet, the tallest wood building in the world. Architect: Voll Arkitekter.

A Canadian Case Study? Canada's Earth Tower, Vancouver BC

At 35-40 storeys, and 31,500 square metres, the tower proposed near the Broadway corridor on the south side of Vancouver's False Creek, would set a global precedent for a hybrid mass timber building in terms of both size and height.

It has been conceived by architects Perkins+Will to be carbon neutral in both construction and operations. This has been achieved through the use of a mass timber structure of dowel-laminated timber and cross-laminated timber panels and glulam beams, and a building envelope that conforms to the Passive House standard. Concrete foundations, exit stairs and elevator core complement the timber structure.

Seen as the next stage in the evolution of Tall Wood structures under the Canadian Building Code, the degree of exposed wood at 8th and Pine will be determined by extensive large-scale fire testing. A comprehensive 'healthy materials' strategy will minimize the use of toxic (and combustible) petroleum-based products. Instead, natural materials such as mineral wool, stone, tile, glass and steel will strategically limit the amount of combustible materials available to burn inside the building.

The fire strategy will include enhanced sprinkler systems and fire alarm systems with greater reliability; an onsite water supply that will enable sprinklers to remain operational even if an earthquake disrupts water supplies; and recognition of the enhanced fire performance of mass timber components bonded with new heat-resistant glues The resulting design will undergo rigorous peer review by independent fire engineers and City of Vancouver staff.

Conclusion

The environmental arguments in favour of building with sustainably managed mass timber have been recognized around the world for a decade and were still a key motivation for the clients and architects of the 13 projects I researched for the book 'Tall Wood Buildings: Design, Construction and Performance in 2015'. Most of these architects also emphasized the important benefits of wood on occupant health through the reduction of airborne chemicals and particulates and humidity control.

What has emerged since, as I research the second edition of the book, is that the clients for most of the new projects stress the psychological benefits to building occupants of living or working in an environment with an exposed wood structure. These clients include international property developers like Lendlease and Hines and major corporations such as UK telecom giant Sky and Swiss-based Tamedia.

Canada's Earth Tower, residential interior view.
Credit: Perkins and Will.

If current plans are realized, these will be followed by global corporations such as Microsoft, Google, and Amazon. Here the environmental agenda is most assuredly running in parallel with an economic one that emphasizes the need to attract and retain high quality employees in a competitive market. This IS no isolated phenomenon. The 2018 Phase 3 Report from the World Economic Forum on the Future of Construction, identifies 'Societal and Workforce' as one of four mega-trends already influencing the future development of the industry.

"The construction industry is concerned with the health and safety not only of workers but also of the people who actually live or work in the buildings. Employee health and productivity are linked to the quality of the indoor environment, and that quality is largely determined by decisions made during project development and construction."

I have argued the case that exposed mass timber is the best material to meet this challenge. As far as Canada is concerned, an inability to deliver buildings of this calibre, that simultaneously address environmental, economic and social agendas, may affect the reputation of the construction industry,

In this case, however, it is not the quality of research, nor the willingness of designers and builders that is holding us back; rather it is the slow and bureaucratic nature of our code development process. In the face of this, the efforts of the Province of British Columbia and the City of Vancouver to advance the cause of Tall Wood buildings are to be applauded.

The Author:

Jim Taggart has written on wood architecture for more than 20 years. In addition to many case studies, his credits include the books 'Toward a Culture of Wood Architecture' (2011) and "Tall Wood Buildings: Design, Construction and performance (2017).

Acknowledgement

The author would like to thank Andrew Harmsworth, Principal, GHL Consultants, Vancouver and Dr. Steven Craft, Principal CHM Fire Consultants Ltd., Ottawa for their expert contributions to this article.