

Taller Wood Buildings and Fire Safety

Existing Evidence about Large Wood Construction



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Introduction

Recently, Vancouver architect, Michael Green, issued a report entitled *Tall Wood*, arguing that skyscrapers and other tall buildings should use more wood as a primary construction material. His argument is that wood is up to the task, is less polluting, and is more environmentally sustainable than the materials currently used. Green's (2012) buildings would employ "massive timber" elements such as cross laminated timber, laminated strand lumber, and laminated veneer lumber. Green is not suggesting that these tall buildings be of wood only. Rather, he is arguing that mass timber be integrated with other commonly-used structural materials such as concrete and steel.

While wood and wood-mix skyscrapers capture the imagination, extending the height of buildings with the more typical lighter-frame construction is perhaps a more practical concern. Currently, light frame construction tends to be limited to buildings of four storeys and less in North America. In some jurisdictions, this limit is mandated by building codes; in others, it is simply practice. Yet, the ability to construct acceptably safe timber structures with appropriate sprinkler and other technologies led Switzerland to change its fire codes in 2005 and allow the use of structural timber in medium-rise residential buildings of up to six storeys (Frangi and Fontana, 2010). Depending upon the application, mid-sized wood frame buildings can be a less expensive and more flexible alternative to other structures.

Despite the prevalence of wood frame structures throughout North America and parts of Europe, major concerns remain over the fire safety of such structures. This paper discusses some of the issues relating to wood structures and flammability.

The Issue

Wood is one of the world's most common and flexible building materials. Traditionally, its use has been restricted to smaller structures. The world's largest building, high rises and multistory mega complexes, are built of steel, stressed concrete and materials considered to have sterner properties. Recent advances in wood technology, however, have made it feasible to use wood products as the primary load-bearing component. Those products generally consist of some form of cross laminated timber where solid wood sheets or matrices of thin chips are formed into mass timber products. Those products gain their strength through lamination processes that place successive layers of wood fibers at 90 degrees to one another in combination with various adhesives and pressure.

Besides exhibiting additional strength, those products have other structural advantages over traditional wood products and other building materials. Despite these advantages, however, there has been reluctance to use mass timber to construct multistory buildings beyond four floors. Yet, it is possible to use these products to construct mid-rise buildings in the 1-12 story range and conceivably towers in the 30-storey range. Green's report has noted that 7- and 10-storey heavy timber buildings have stood for the last hundred years in Vancouver's Gastown. Furthermore, they report proposals for a 10- to 12-storey building in Melbourne, Australia, a 17-storey building in Norway, and a 30-storey hybrid timber and concrete building in Austria.

While there are several perceived issues relating to the structural integrity and performance of tall wood buildings, one of the primary concerns relates to fire resistance. As carbon-based products, ordinary lengths of wood burn in the presence of oxygen. This fact leads some to conclude that large wood-based structures would pose an inordinate safety risk particularly where egress might be limited, as is typically

the case in a high rise structure. Yet, all risks are relative and no structure is perfectly safe. As Frangi and Fontana (2010) note, “As achieving absolute safety is impossible, the level of acceptance is in general quantified by the authorities or with regard to financial losses with the owner of the insurance companies.” In extensive fire situations in “non-combustible” buildings, the weakest point is often the steel connection between the beams and the supporting posts. Superheated in a fire, steel will expand by twisting and elongating, and that process can cause joints to shear and the building to potentially collapse.

As the unfortunate circumstances surrounding the attack on the New York World Trade Centre in 2001 illustrated, buildings made of “incombustible” glass and steel can pose substantial risks under the appropriate circumstances. At sufficient temperatures, metal can melt, liquify, vaporize and eventually explode. While possible, the likelihood of this happening in most construction applications makes metal construction relatively but not absolutely safe. In the absence of being able to guarantee zero risk, the question is really one of relative risk. Thus, we might ask: “Can massive wood frame buildings be constructed to provide an acceptable level of fire resistance?”

Construction and Fire

While current tall buildings are constructed primarily of “non-combustible” materials such as concrete, glass and steel, there are several components within those buildings that have higher levels of combustibility. Many tall buildings contain wood trim, and most have highly combustible contents that make up floor and wall coverings and furnishings. Consequently, both construction materials and techniques are code mandated to limit the spread of fires and other incendiary events.

As Green’s (2012: 111) report states, code requirements are in place to ensure that:

...materials, assemblies of materials and structural members required to have a fire-resistance rating are intended to protect people and the building from fire or explosion progressing through the building, and prevent collapse of structural and non-structural members which could injure people or damage the building beyond the area of origin.

Just as residential wood frame structure can be made relatively fire resistant by using gypsum board cladding, rock-fibre insulation and closed joist construction procedures, so too can tall wood structures. It is suggested that tall wood building can be designed to provide a minimum 2-hour protection rating similar to most current code requirements.

Research suggests that fire safety, whether in a house or apartment, has little to do with the combustibility of the construction materials. It is generally the contents and behaviour of the tenants (smoking, cooking and having open fires) that poses the gravest danger. Furthermore, most casualties are caused by smoke inhalation.

Wood Components

Wood is generally a less homogenous substance than steel and other “non-combustibles,” and there is considerable variation in its properties based on the species and preparation procedures. Essentially, harder woods and woods with a smoother surface are more fire resistant than those with rougher surfaces (Babrauskas, 2002; Tondi, et al., 2012). Composite wood products are also affected by the type of resins

used in their preparation along with their density and shape. On the other hand, the fire resistant properties of relatively porous softwood lumber can also be changed through processing.

Overall, dense wood performs relatively well in fire situations. When exposed to fire, large wood beams char and that external coating act as an insulating barrier for the wood underneath. Furthermore, Tondi, et al. (2012) provide evidence that treating softwood Scots pine and beech products with inexpensive additives such as tannin, boric and phosphoric acid, can enhance the preservation of the wood, increase its mechanical properties by 10% to 30%, and significantly reduce the material's flammability. In their experiments, ignition times of treated lumber were reduced substantially and, in some situations, the boron and phosphorous compounds actually serve to extinguish localized flames.

Harada and his colleagues (2006) examined the insulation properties of thick plywood, particleboard and medium density fiberboard. Such materials are commonly used as flooring in Japan (as in Canada) and Japanese fire code requires a minimum 30-minute insulation performance. Their analyses supported the insulation value of those materials and they concluded that, "thick wood-based board is a suitable fire-preventive construction material." Again, the greater the density of the product, the higher its insulation performance.

Architectural Issues

One of the significant problems with examining the behaviour of building exposed to various sources of ignition is the fact that the outcomes are not simply a product of the component materials. "Wood" buildings are rarely 100% wood. Most structures are composites of various materials with various properties. A structure may have wooden joists supporting a cladding of plywood, corrugated iron, fibreglass or some other material. Walls may be solid wood (as in the case of log homes) or be of wood frame construction clad with gypsum board. Those combinations affect the flammability of the structure.

Similarly, construction techniques such as using "fire doors," rock-wool insulation, and joist barriers to prevent flame over all have an impact on how quickly a fire might ignite and spread from one part of the structure to another. Sprinkler systems have been shown to be one of the primary factors in limiting fatalities and fire damage in structures of all types including wood frame, single family residences (e.g., Richardson, 2001). Poor architectural design can increase fatality rates by making egress and evacuation overly challenging.

Closely connected with architectural design is the manner in which people actually use and behave while inside structures. As Kobe's and her colleagues note (2010) "the most critical aspect of a building's safety in the face of fire is the possibility of safe escape." This is the case whether the structure is on fire or if the issue is simply one of smoke generation raising the spectre of asphyxiation. Kobe's et al. (2010: 7) indicate that the efficiency of emergency staircases, for example, is influenced by such variable factors as their size, the population density, the ability of people to join the downward flow, small talk among evacuees, the size, weight and age of evacuees, the use of cell phones, the type of shoes they wear, and the counter flow of firefighters.

Other behavioural factors that influence the likelihood of personal injury or fatality include the fact that people rarely respond to appropriate procedures and regulations. For example, Kobe's et al. (2010) notes that in one study, 92% of fire escapees were unaware of the escape route signage. Furthermore, people

tend to use familiar rather than the closest, designated emergency exit, and a significant number of people ignore fire alarm bells although they will respond to verbal cues.

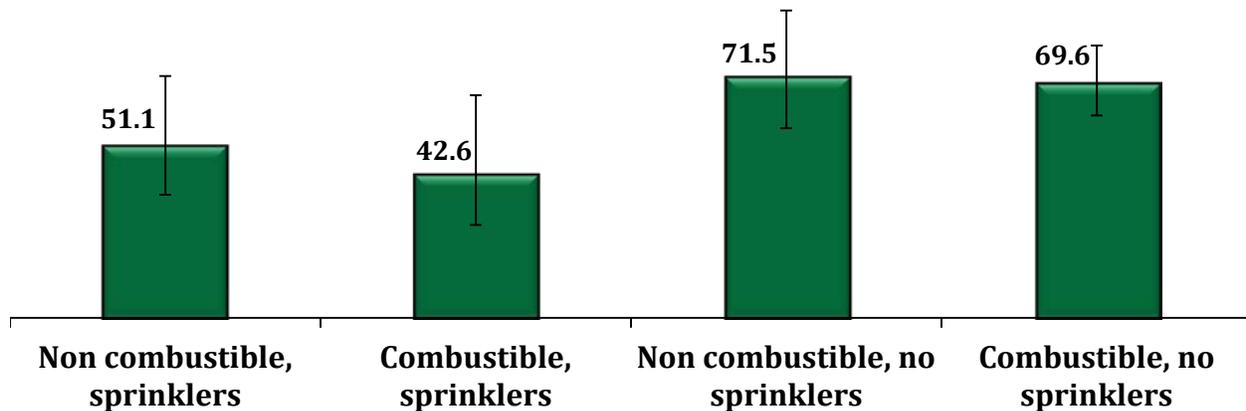
In the case of tall buildings it is reasonable to conclude that the likelihood of injury and loss is less related to structural material than the presence and functionality of sprinkler systems and smoke alarms, the composition of the contents, the engineering of the structure, and the manner in which the overall architectural design accommodates how people actually behave in an emergency situation as opposed to how they ought to behave (Buchanan, 2001).

Statistics

Obviously, the dearth of existing tall wood buildings makes it difficult to determine how well they perform in fire situations in comparison with other structural forms. It is possible, however, to gain some insight into how medium height buildings, in the 5-6 storey range, might behave in incendiary circumstances. Little data exist in Canada; however, it is possible to use the US National Fire Incident Reporting System (NFIRS) data. Both Canada and the US allow for wood frame buildings of up to four storeys to be used as hotels/motels although codes requirements are not completely comparable across jurisdiction. Richardson (2007) has aggregated fire incident data from 1980 to 1998 to examine the rate of injuries and value of property loss among three and four storey hotel/motel structures and presents the analysis according to whether the structures had sprinkler systems installed and the type of constructions. Specifically, construction type was classified as units made primarily of combustible or non-combustible components and level of protection or type of framing.

Richardson (2007) provided point estimates, however, he did not give estimate of the standard errors. Since we can expect some variation around those estimates depending upon a particular year or locality, it makes sense to generate those values. All things being equal, point estimates with small standard errors are more accurate and those with larger standard errors are less accurate. To help with the interpretation of the table, we have provided graphic charts reporting the estimated incidence rates of injuries (per 1,000 fires) and computed 95% confidence intervals (see Figure 1, below). Since some categories contained too few incidents, Richardson's categories were collapsed so that the buildings are crudely classified as either

FIGURE 1. INJURY RATES (PER 1,000 FIRES, PLUS 95% CONFIDENCE INTERVALS) BY SPRINKLER PROTECTION STATUS AND BUILDING MATERIAL COMBUSIBILITY



of combustible or non-combustible construction.¹ There are two items of particular note. First, while there is a slight tendency for the buildings constructed of combustible material to have a slightly higher rate of injuries, the differences are not statistically significant ($Z = -0.29$, $p > .1$, for the difference in injury rate as a function of combustibility, alone). Second, the presence of sprinklers had a greater impact than construction material, with the combined rate for injury was significantly lower as a function of sprinkler protection status regardless of combustibility of the construction ($Z = -2.57$, $p < .02$). The fact that sprinklers have a major impact on reducing injuries is not surprising. Richardson also looked at average dollar value of loss and found a similar pattern although the structures made of combustible materials generally sustained a greater dollar loss.

Summary

The issue of the fire susceptibility of taller wood buildings is complex. As we have learned by bitter experience, no structure is perfectly safe and given the right circumstances, almost anything can be subject to fire and collapse. Furthermore, non-structural factors such as the building's contents, the existence and functionality of sprinklers and smoke alarms, and the behaviour of potential evacuees all have an impact on the building's safety potential. Buildings made from wood components can be constructed to meet specific code requirements. The question is, are those minimums acceptable?

Furthermore, fire is but one risk to which building and their occupants are exposed. As we have seen time and again, non-combustible materials such as brick and stone, as well as steel and glass, can pose other hazards. Many traditionally constructed, non-combustible buildings, for example, fared poorly in earthquakes while well constructed timber frame buildings have survived for centuries (Gotz et al., 1989). For example, it is estimated that only two of Japan's 500 wooden pagodas—some as tall as 19 stories—have collapsed during the past 1,400 years despite being in one of the world's most active earthquake zones (Economist, 1997).

Ultimately, the decision regarding the most appropriate building material is a trade-off between susceptibility to competing hazards as well as other factors such as cost, resilience and architectural form. Building materials and construction techniques change over time. As with most of the durable goods we create, how we choose to design and construct our buildings is a blending of functionality, aesthetics, available materials and cost.

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¹For example, hotels with sprinklers of protected non-combustible construction had only one reported injury in 30 fires.

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