An Investigation of the New Opportunities of Wood in Mid-rise Construction in British Columbia

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Abstract

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With the preference to use reinforced concrete and steel structures in modern time, it is easy to forget that wood was once the material of choice for mid-rise construction. In January 2009, new BC Building Code requirements were modified to increase the maximum height of wood-frame residential construction from maximum height from four to six storeys [32]. This brings a new opportunity to re-consider wood as a popular building material. A list of factors have contributed to this decision, including the limited supply of developed land especially in the lower mainland, an overall fluctuation of material costs and land costs, tighter working schedules, and a growing awareness on using sustainable material. Construction projects tend to move forward if the buildings are easily to design and quick to build. With the relatively low material cost of wood and high design options of engineered wood, wood definitively fits into these two categories.

In 2011, there were approximately2.6 million people living in the Lower Mainland area, with about 2.3 million of them living in Metro Vancouver [10]. This number is up 9.2 % compared to a 2006 census which ranked Vancouver as third in the country [28]. As population has continued to increase, affordable housing has become a challenging topic to both immigrants and locals. In response to the massive growth in population, the lower mainland of BC is currently taking advantage of the recent code changes as mid-rise buildings are being rapidly developed and refined in cities such as Richmond,

Survey, and Langley. In 2012, the first six-storey wood frame condominium was built in Surrey which offered more affordable housing to homebuyers.

Despite all the advantages of light frame wood buildings, several key aspects of engineering designs and technical challenges should also be carefully considered when using wood. This includes fire resistance and fire safety, cumulative wood shrinkage potential, dead, live, wind and seismic load increases, and sound transmission. When the industry can overcome the above technical challenges, it will result in a better quality of sustainable neighbourhoods as height is no longer the limitation for wood buildings.

Keywords: Challenges, Mid-rise buildings, Sustainability, Wood frame buildings

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1.0 INTRODUCTION

The purpose of this report is to investigate new opportunities of using wood as primary building material for mid-rise building in British Columbia (BC). The first section of this report describes the chances under the new BC building code regulation and an overview of some traditional construction methods. The second section describes the general benefits of wood compared to other materials such as steel or concrete. The third section discusses some of the technical difficulties that the industry is trying to overcome. The last section describes an innovative building material-cross laminated timber (CLT) and how it can be beneficial in construction application. The main sources used in this report are from internet sources.

2.0 Technical Details of mid-rise wood frame building

2.1 Restrictions under new BC building code

Under the new building code regulation, mid-rise residential wood-frame buildings can be built to a maximum of six storeys [27]. However, there are other limits as seen in Figure 1.

- 7,200m^2 gross floor area if 1 storey in building height.
- 3600m^2 gross floor area if 2 storeys in building height.
- 2400m^{2}gross floor area if 3 storeys in building height.
- 1800m^{2}gross floor area if 4 storeys in building height.
- 1440m^{2}gross floor area if 5 storeys in building height.
- 1200m^{2}gross floor area if 6 storeys in building height.

In term of height restriction, all wood frame buildings are limited to less than 18 metres to the top floor and require non-combustible exterior cladding.

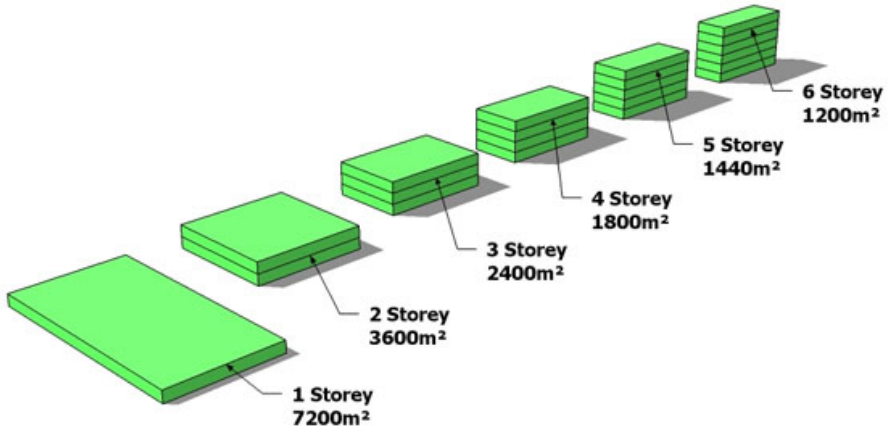

Figure 1: Regulation of the Minister of Housing and Social Development [38]

2.2 Building Methods

2.2.1 Ballroom framing

Ballroom framing is considered an old-fashioned framing method which was used primarily during the 19th century. It used long wood studs that go continuous from the base to the roof line, with flooring in between to separate each storey. It was a popular choice of construction method in Canada and the United States because of the direct available resources of long timber **[Fig2].**

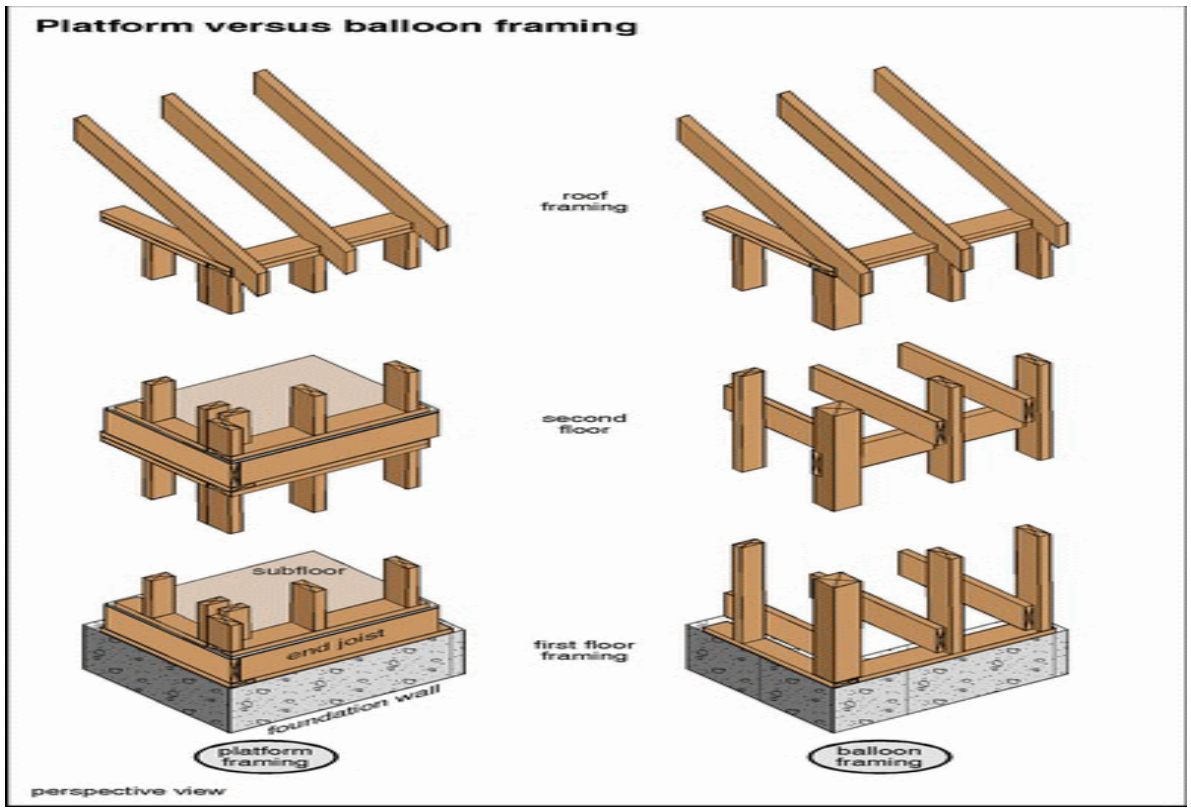

Figure 2: Platform framing verse Ballroom framing [39]

2.2.2 Platform framing

Today, multi-storey wood frame building is built typically under a platform framing method also known as “Stick framing”. The name is derived from its process, where once the foundation is set, the first platform can be added on top of the base and built upward one level at a time. Box and floor joints form the foundation of the structure and are placed under supporting structures such as sill plates, and headers. Normally, engineered plywood or oriented strand boards (OSB) are used to build for the exterior wall and sub-flooring, and interior walls are built above of the initial platform along with the ceiling and roof.

There are a few advantages of using platform framing over ballroom framing.

- Lower cost, as it does not require long wood studs
- Design flexibility
- Less time consumption
- Ease of installation

2.2.3 Skeleton framing

"Skeleton" framing is the term that often used to refer to light steel framing. It is a construction method that using steel as the primary building material to form the basic framework of the structure. The horizontal and vertical members are made from C-shaped studs because the shape of - C provides excellent structural support for the building due to its high strength to weight ratio, which is measured by the material's ultimate tensile strength before fracture (force per unit area) divided by its density. The higher the ratio, the higher the bending force the material can withstand before it fractures.

Advantages of using skeleton framing over other framing techniques

- High strength to weight ratio, meaning tall and complex building can be safety constructed
- Material consistency when compared to wood
- Higher durability due to low chemical reaction when compared to wood

Drawbacks of using skeleton framing

- High cost compared to modular or wood framing
- Requires skilled workers and installers
- Time consuming

3.0 BENEFITS OF WOOD FRAME BUILDING

3.1 Cost Comparison

Construction cost is an important factor when choosing wood as a building material. When compared with concrete or steel frame building, the performance of wood frame building is outstanding in terms of using available resources, reducing building costs, and increasing the speed of construction and. As indicated by Neill McGowan, a quality surveyor and partner at BTY Group in Vancouver, wood frame buildings generally have a 11% cost reduction compared to concrete and steel frames depending on various building characteristics [29].

3.1.1 Available Resources

With the appropriate forest management and certification programs, in place, the forest cover in Canada has been maintained at 348million hectares for the past twenty years. This represents 1/3rd of Canada's land [1]. BC is endowed with 55 million hectares of forest resource, which represents about 2/3rd of the province's land mass [1,36]. Most of the wood produced in BC is softwood, which is effectively utilized to make lumber and other wood products [4,41].

3.1.2 Building Cost

The locally available resources lower the material cost of wood as a building material. Wood frame building costs less than concrete or steel [4,41]. **Table 1** shows that light-wood frames are cheaper than cold-formed steel frames per square foot [41].

	Cost per square foot: Light WoodFrame	Cost per square foot: Cold Formed Steel
4-Storey	$79/sq. foot	$99/sq. foot
6-Storey	$82-85/ sq. foot	$95-97/sq. foot

Table 1: A comparison between light wood frame and cold formed steel in 4-storey construction and 6-storey construction [41].

Other important aspects of mid-rise wood frame buildings include lower labor cost, along with improvements in both construction speed and quality[29]. Dimensional lumber is mechanically shaped into different standard dimensions before it comes out of the sawmill [29]. While engineered wood is manufactured to precise specifications of a building design [41]. Additionally, wood structural panels that vary in thickness are used for sheathing in roofs, subfloors, and walls [42]. These building materials are light, tough, and easy to assemble [39]. With prefabricated wood as the main building material, the building process onsite is a lot easier. For this reason, there is a wider range of labor available, and the labor cost is lower for wood than other building materials [29].

The speed of wood frame construction is not comparable with other building materials. For example, using current construction methods, a complete foundation and wood structure of a typical wood frame villa can be done by three or four experienced construction workers in three or four weeks. However, the same villa built with a concrete frame will require a team of more than 40 workers and take roughly five months [9]. Thus wood frames are a more time-efficient construction method to be considered when building mid-rise residential housing.

The Remy apartments in Richmond, BC, are the first 6-storey wood frame residential housing after the new code of the province came out [41] [**Fig 3]**. According

to the Remy project developer, the company originally planned the building to be in concrete and steel structure, but the plan was shelved due to the 2008 economic downturn. However, when the Remy was built 6-storey with a wood frame, the company saved 12 per cent on construction cost, which was a saving of about $4.8 million [41].

Figure 3: The 6 storey wood frame building. The Remy, Richmond, BC [20].

3.2 Sustainability

The increased awareness of sustainability is reflected in every aspect of consumer life [17, 38]. More and more people choose environmentally friendly products over the others, and in response to this growing trend, government, real estate companies, and architects acknowledge the sustainability of wood and promote wood-frame building designs once more. Sustainability is a concept to maximize the utility of resources while minimizing waste, damage, and the risk of depleting resources. Wood is the only green building material [38].

3.2.1 Energy Efficiency

The most direct benefit of choosing wood-frame building is reflected in the reduction of energy bill charges. Wood framing can keep the room warm in winter and

cool in summer. Wood is less dense than concrete and steel, and the cellular structure of wood makes it a natural insulator [8,35]. The space inside the cellular structure traps air inside, which effectively lower the conductivity of wood. On the other hand, steel frame products have 400 times higher conductivity, while concrete products have 8.5 times higher conductivity when compared to wood [8] [**Table 2]**.

Table 2	Thermal Conductivity BTU×In/(h×ft^2×oF)
Wood (Softwood lumber at 12% moisture content)	0.7 ~ 1.0
Steel	310
Concrete	6

Table 2: Thermal conductivity of wood, steel and concrete.
Data obtained from American Wood Council [2].

High conductivity causes thermal bridging which means that heat will dissipate quickly across the surface. Thus, in winter more energy is needed to maintain room temperature in steel and concrete frame buildings, while in summer heat outside will be easily conducted into the room, most likely leading to the use of air conditioners or electric fans. In fact, the modern insulation technique of using cellulose on every kind of building material (wood, steel, or concrete) is based on the same principle: the shredded newsprint, which is made from wood products, is installed into the building for insulation because it effectively reduces the thermal conductivity [23]. This supports the advantage of wood frame building, as it both makes the residents comfortable and saves their energy bill.

3.2.2 Global Warming

The provincial government of BC recognizes global warming and its effect on BC's environment. For example, the Climate Action Plan established by the BC government indicates that BC has lost snow pack by up to 50 per cent, and seen an increase of annual precipitation by 20 per cent in the last fifty to one hundred years [14]. British Columbia: Climate Action for the 21st Century has raised the general public's awareness to climate change and sustainability. It has also addressed some of the key points that helped to shape the BC Lower mainland residential development change to rise wood frame building limit from 4 storeys to 6 storeys through the new code provision. For example, the action plan addressed the "Wood First" policy, and the goal of "Zero Net Deforestation" [7].

The "Wood First" policy requires all provincially-funded construction projects to use wood products as the primary building structure where possible, because wood is carbon friendly and reduces emissions [7]. This encourages commercial residential building companies to follow the trend and adopt wood design in mid-rise buildings. Wood has environmental merits in every step of its life cycle [38]. A healthy tree of large size can absorb 20kg of carbon dioxide annually, and produce oxygen that is enough to meet the needs of two people [14]. A healthy, growing forest can take in 1.4 tons of carbon dioxide and produce 1 ton of oxygen for every ton of wood. However, when a forest matures, the growth rate slows down, and the carbon dioxide absorption rate also drops off. Once the trees die, they will start to decay in the forest, and the carbon dioxide stored within it will be released back into the environment [7,14]. By harvesting a mature forest, carbon is locked into the wood. This means that a

wood frame house of 2,400sqft can sequester the amount of carbon from carbon dioxide in the wood that is roughly equivalent to seven years' emissions of a small, light-duty car [38]. Additionally, when old trees are taken down in a clear-cut method that resembles natural disturbances, this allows new forests to grow at a rapid rate and absorb more carbon dioxide [36,38].

The "Zero Net Deforestation" is a goal that requires any forest loss to be offset by an equivalent amount of tree planting [14]. This goal can be more easily achieved if the developers recognize the benefit of wood and use wood products for things such frame building, because this will plant more trees to keep their business going in the future [39]. The Canadian forest industry has a first-in-world certification commitment, in which products derived from the forest are under sustainable forest management (SFM) and certified to any of the three major SFM certification standards: Canada's National Sustainable Forest Management Standard (CSA), The Forest Stewardship Council's Principles & Criteria and/or Standards (FSC), or The Sustainable Forestry Board's Sustainable Forestry Initiative Program (SFI) [13]. When people are purchasing wood frame housing they can check for its wood product certification, so that they can know they are promoting sustainability in living in a wood frame residence.

Wood frame building also emits the least amount of green house gases during its construction, renovation, and destruction when compared to cement, glass, or steel [38].**[Fig 4]** This is due to the light weight of wood products. For example, when comparing the same weight of building materials, cement needs 5 times more energy than wood, glass needs 14 times more energy than wood and steel needs 24 times more energy than wood [38]. This comparison is called life cycle assessment (LCA), a

systematic way of assessing all the environmental issues connected with a product or service, from getting the raw material to waste removal [25]. When comparing wood, steel, and concrete construction, wood frame construction uses the least amount of total energy. It also scores the best index in green house gas, air pollution, solid waste, and ecological resource impact use [15].

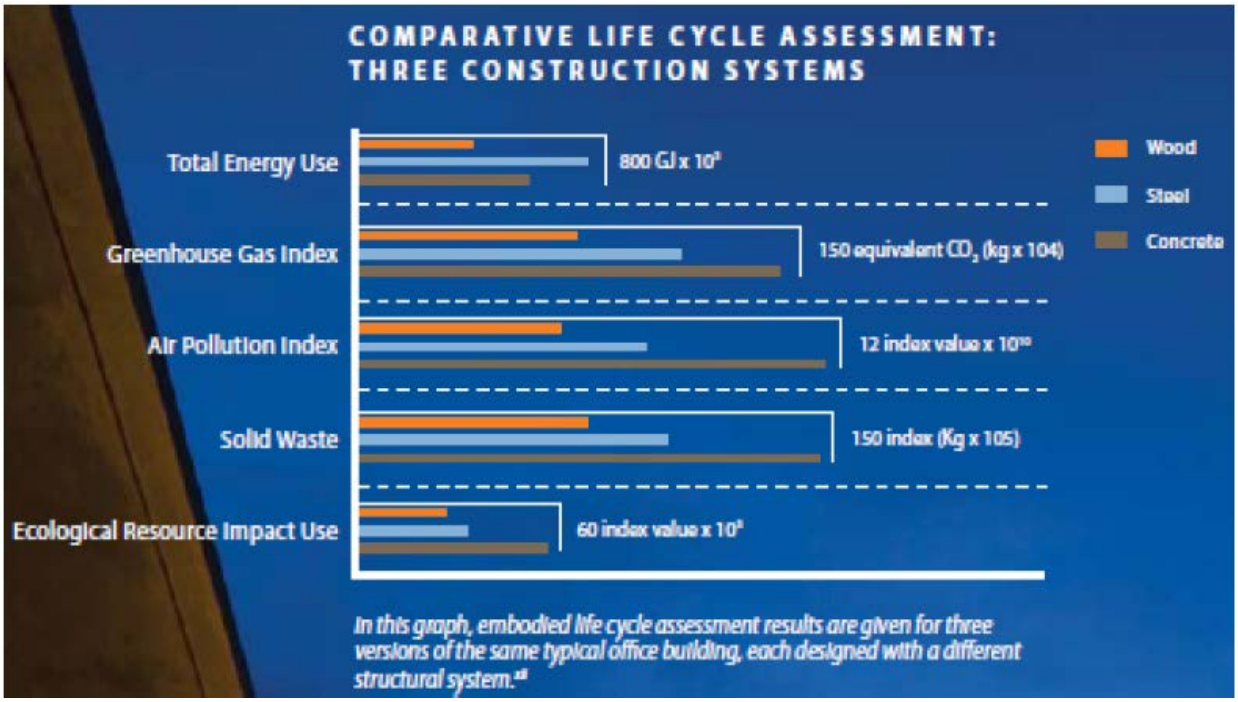

Figure 4: Wood frame construction system perform the best in a comparative LCA assessment in between wood, steel, and concrete [15].

3.3 Design Diversity and innovation

The longevity of a building is also an important feature for sustainability, as taking down an old building and reconstructing a new one will consume a lot of energy. A study was conducted in the city of Minneapolis/St. Paul to survey the buildings demolished between 2000 and 2003 [24]. Out of the 227 buildings surveyed, 63% of wood frame buildings were older than 50 years with majority of them felled in

between 76-100 years. Two thirds of the concrete buildings and 80% of the steel buildings did not last more than 50 years [24]. The long life span of wood frame buildings allows for more possibilities in design [14]. For example, wood trusses can have any shape a person can imagine [39]. In 2011, the renovation spending in BC was $7.6 billion, a number which is expected to grow to $7.8 billion in 2013[34]. This indicates that British Columbians are willing to perfect their home. Some buildings need to have part of them replaced due to damage; some buildings need to change the design to meet its owner's interest. Since wood is light weight and flexible, the cost and difficulty of renovating a wood frame building is much less than renovating a steel or concrete frame building. Although it is unlikely that the company will change the structural design once the construction of a 6-story wood frame commercial housing unit is completed [30], interior wood design can be creative and provide comfortable living for its buyers.

Wood frame building has 200 years of history [3]. There is a lot of expertise in the aesthetic design of wood products, and also a lot of researchers that help to develop new techniques and methods that improve the efficiency of wood frame construction, and the durability and strength of the wood product [39]. For example, engineered wood products such as LVL, PSL, and LSL provide better strength and long-term capabilities to a safe while cost-effective building [39]. Additionally, forestry research also helps in solving environmental and marketing issues. As a response to the urgent need to find alternative wood products due to mountain pine beetle infestation in BC, Lam *et al.* evaluated the performance of posts laminated with the blue-stained lodgepole pine lumber deposited by the mountain pine beetles and found

that post laminated blue-stained lodgepole pine (152mmx152mm) exhibited good structural performance compared to Select Structural Douglas-fir posts (140mmx140mm) [26]. This study provides insight into the maximizing of resources from damaged wood in wood product processing while minimizing the cost of wood construction.

4.0 Challenges of Wood Frame Building

The code of construction is to meet the requirement of a standard level of health and safety [39]. Wood frame building, with its natural physical properties, appropriate designs, and enhanced treatment can overcome problems such as shrinkage, and score high in the internal and external load, fire resistance, and sound transmission issues when compared to steel or concrete frame buildings.

4.1Shrinkage

Among all building materials, shrinkage and swelling are unique physical properties of wood, as wood is made up of dead cells [40]. These actions are related to the moisture content of wood: an increase in moisture content will make wood absorb water and expand. Likewise, a decrease in moisture content will make wood loses water and shrink [19]. Both shrinkage and swelling changes the dimension of the wood product, and affects the appearance of the product. However, shrinkage, especially after the wood has absorbed so much water, is of greater concern [33]. Each piece of wood product is often a combination of different wood elements: some have vertical grains and others have horizontal grains [30]. Studies have shown that wood shrinks much more across the grains than along the grains, and this will cause differential drying, resulting in an uneven and unappealing surface [33] [**Fig.5**].

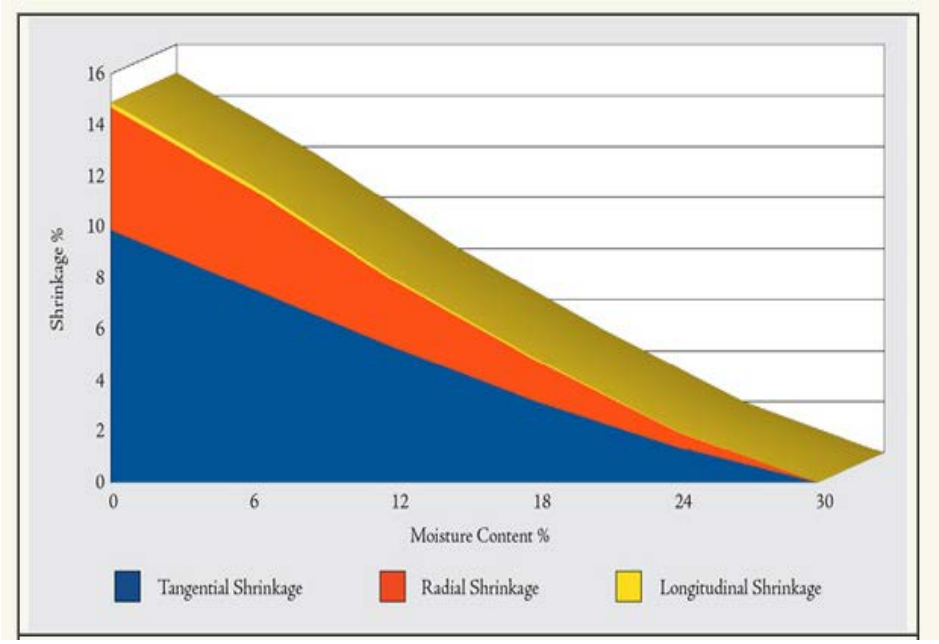

Figure 5: A hypothetical shrinkage curve of wood. The most shrinkage occurs tangentially across the wood circumference, or across the wood grains [33].

In mid-rise wood frame building, the vertical column elements are stacked on each other without beams in between. The beams are attached to the side of posts so the vertical stacking force will not cause deformation of the beams across its grains [33]. Thus, the dominant shrinkage is along the vertical direction of a mid-rise wood frame building, and the potential shrinkage effect increases significantly with each additional storey [30, 33]. To minimize the overall vertical shrinkage, the construction team can use engineered wood products such as I-joists or open-web floor trusses in place of dimension lumber joists [**Fig6**]. Some other approaches to prevent vertical shrinkage include the use of dimension lumber plates and floor joists that have moisture content reduced to 12%, or the use of 1-inch thick plywood as single or double base or top plates in wood frame construction[30].

Figure 6: I-joist wood building has reduced vertical shrinkage[21].

4.2Internal load and External load

4.2.1 Vertical load

The vertical load is associated with gravity, and includes all elements that are permanently attached to the structure [31]. The challenge of a wood frame building increases with height from low-rise to mid-rise, as at about 6-storey high, the dead weight from itself increases substantially [30]. The wood building also has to tolerate live loads, which includes snow, collected water, the people living inside, and furniture. [31] [**Fig 7**] The weight of people and furniture in a 6-storey wood frame housing also increases as the building provides more space for living. The vertical load has to be transferred effectively, using several approaches. For example, the construction team can use engineered wood products as the key column, beam locations, and critical blocking details [30]. The engineered wood products have high precision in their dimensions, and their good quality control strengthens the building's design that is aimed for better load transfer [30, 33].

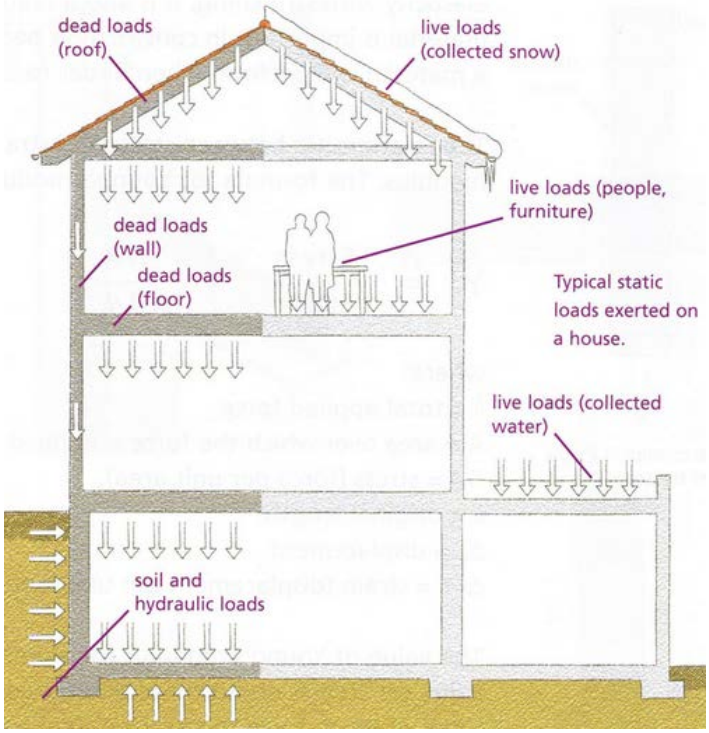

Figure 7: The vertical load imposed on a wood frame building [31].

4.2.2 Wind and seismic

Wind and earthquake are external forces that exert dynamic load on a building, and they mostly affect the increased lateral surface area as the height of the building increases [31]. Wood frame building has to be able to overcome these hazards to achieve target safety measures. In regions where the seismic activity is low, wind load governs the lateral design, whereas in regions where earthquake is frequent, the seismic load dictates the lateral design. Since winds and earthquakes usually strike the wall at an angle, the lateral load cumulates from the top of the building to the foundation [30, 33]. Thus, a strong shearwall in the lower storey of the building is needed. A solution to increase the lateral stability is to enhance the use of continuous self-adjusting steel tie-rod systems [**Fig. 8].** This system can calibrate the uplifting force

imposed by wind or earthquake, so that the building's assemblies are tightly held. In addition to this, there are many wood pieces and nail connections, which help provide back-up load paths that absorb and dissipate the energy of an external force [38].

Figure 8: Continuous self-adjusting steel tie-rod system is installed in a wood frame building at the end of a shearwall to increase the strength of the shearwall standing against lateral loads [30].

Figure 9: Seismic load exerts a lateral force on a building [12].

Wood frame construction in its nature has the highest safety measure in preventing earthquake damage, because it is strong and light weight, which means lower forces are exerted on the building [4]. The effect of the lateral load is shown in **Figure 9.** In 1995, the earthquake in Kobe, Japan killed 6,000 people and caused $100 billion in damage. However, wood frame housing using standard North American construction methods was largely unaffected [38].

4.3Fire resistance and safety

The major concern of the general public about wood frame building is the nature of wood being able to catch fire more easily, and the subsequent risk that comes with the heat and smoke inhalation for the occupants [4]. However, research and experience has indicated that fire safety has little to do with the combustibility of the structural materials; rather, the level of fire safety mainly depends on the occupants' own awareness of fire hazards [21]. Wood frame walls have an advantage over other walls because in a fire disaster, wood with large cross sections stays in place longer [38][**Table 3**]. The Remy project of 6-storey wood frame housing utilizes the "gypsum firewall system", which increases the fire resistance to a two-hour rating [38] **[Fig.10]**. Industrial pressure treatment and industrial chemical preservation to wood are other possible options to increase the fire resistance rating [32].

Table 3: Compare the performance of wood, concrete, and steel in fire[38]

Wood	Concrete	steel
Burns	Doesn't burn	Doesn't burn
-Meets fire safety provisions of building codes for use in walls, floors, and roofs -more likely to retain strength	-Subject to explosive spalling -once there is a fissure, fire can spread through	-Loses its strength at high temperature, -severely reduce the ability of sheet metal framed walls and roofs to stay in place and provide protection.

Figure 10: Gypsum firewall system [30].

4.4Sound transmission consideration

The sound insulation performance is higher in wood frame buildings when compared to concrete or steel framing [30]. The goal is to keep airborne noise, structural vibration, and impact sounds below the acceptable level, so that the homeowners enjoy comfortable living [30]. The low density structure of wood can reduce echoes [30] and in some surveys results have shown that more owners living in concrete and steel frame buildings reported concerns with noise and vibration when compared to owners living in wood frame buildings [21].

5.0 Future options and other innovations

5.1 Cross Laminated Timbers

Cross Laminated Timber (CLT) is a new building material which has been first introduced in Europe over a decade ago and it has now become a popular choice of material from the industry in North America. It is made up of multiple layers of wood panel board, with each layer stack on one another at 90 degree angles with alternative wood grain direction. It is glued together by hydraulic or vacuum hot press **[Fig11].**The major difference between CLT and normal engineer products such as plywood and oriented strand board is that the size of the panel is no longer a limitation. Traditional wood panels are produced with a size of 4 feet wide by 8 feet long, with a maximum thickness 1 inch. On the other hand, CLT panels can be made in any dimension that the builder wants, with the restriction being the size of the press and economies and feasibilities of transportation.

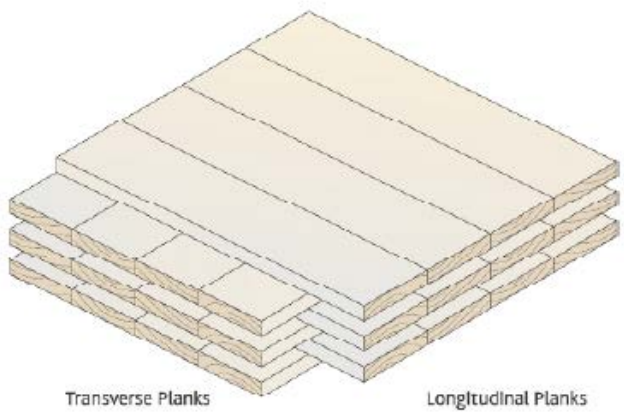

Figure 11: CLT panel configuration

One of the attractive advantages of CLT in multi-storey construction is its fire resistance performance. Due to its thick cross-section area, even when it is exposed

to fire, char occurs at a slow and predictable rate [16]. In addition to this, CLT construction has typically fewer combustible concealed spaces which can reduce the risk of fire spread and minimize the need for additional sprinkler heads within the building [22].

5.2 Hybrid Construction

In Europe, there are ongoing projects aimed at using CLT to build high rise building. The approach uses CLT as the post and beam of the building and mixes CLT with concrete or structural steel for elevator or stair shafts **[Fig12].**

Figure 12: Hybrid construction: Quebec City Genio Structure inc.

6.0 Conclusion

Today, steel and reinforced concrete are the two dominating building materials for mid-rise construction. However, relatively lower material costs, increased awareness on sustainability and innovative design diversity are driving factors that provide new opportunities for wood. Although there are still a few technical difficulties such as shrinkage, loading issues, fire resistance, and noise transmission, new innovative technology such as the development of CLT and improved construction methods, means that these problems will eventually be solved in the coming future and allow for taller construction to be build with lower cost and better performance.

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