The Possibilities of Building with Mass Timber:
The Case of the University of Toronto Academic Wood Tower

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Introduction

Climate Change and Reducing Greenhouse Gas Emissions

Rising greenhouse gas (GHG) emissions and subsequent climate change continue to be a growing threat to Canada and the rest of the world. In the Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment Report (2014), it was stated that in order to avoid irreversible and catastrophic damages, global GHG emissions must be reduced to maintain global warming below 2°C, relative to pre-industrial levels. Reaching this target will require an urgent and fundamental departure from business as usual. With regard to reducing emissions, the construction sector has received much attention. The energy required to produce various materials for the construction industry is contributing to rising GHG emissions and climate change. The dominant construction materials - steel and concrete - are extremely energy and emission-intensive and account for a great portion of total GHG emissions from material production in the building sector. The construction sector contributes about 36% of global energy use and 39% of energy-related carbon dioxide (CO^2) emissions, and it is estimated that concrete production is responsible for four to eight percent of the world's CO^2 emissions while the steel industry generates between seven to nine percent (Chen et al., 2020). Therefore, the building sector represents significant potential for reducing emissions and mitigating global climate change.

Rise of Mass Timber and its Possibilities

Luckily, a new building material is on the rise— one that has the possibility to challenge the current dominance of steel and concrete designs in the future and offer lower GHG emissions. Mass timber (MT) is a building material that is made up of multiple panels of wood, either glued or nailed together. Products in the MT family include cross-laminated timber (CLT), nail-laminated timber (NLT), glue-laminated timber (glulam), dowel-laminated timber (DLT), structural composite lumber (SCL), and wood-concrete composites (Yard, n.d.). Studies have shown that substituting traditional construction materials such as steel and concrete with wood or engineered wood products can substantially reduce CO^2 emissions.

MT not only has the potential to reduce GHG emissions as it is able to store large amounts of CO^2 in its panels, it also offers other benefits such as faster construction time with lower costs and waste, and benefits to human wellbeing (Yard, n.d.). However, despite recent excitement over MT, there are still many emerging problems that need to be addressed. Our group's objective is to research lessons learned from recently planned and constructed MT buildings to address whether MT is truly sustainable and to ultimately determine if the University of Toronto should pursue building with and advocating for MT. Our methodology for collecting data and information consists of two parts. We will first survey past examples of MT architecture and related existing literature and information covering our objectives. We will then examine specific case studies, with at least one domestic and one international example, to help us find unanticipated problems and environment-related risks. Our research specifically focuses on 4 main categories: environmental impacts, well-being, building performance, and economic costs of building with MT. This paper will first summarize and discuss these general findings before moving on to specifying how these scenarios can be applied in regard to the University of Toronto's Academic Tower.

Environmental Impacts

MT construction has been championed to be a solution for reducing GHG emissions and mitigating the effects of climate change. Timber products are not only a more sustainable substitute for traditional steel and concrete as it has a lower carbon footprint, but it also possesses the unique function of being able to sequester and store large amounts of carbon by tying it up in its building structure for decades or centuries (Figure 1). Furthermore, if the trees that are harvested for MT are replaced by newly planted trees in managed forests, carbon accumulation will continue in the new trees while the carbon sequestered by previous generations is stored in wood products, increasing the total amount of carbon that is accumulated over time (Chen, 2019). However, a recent study conducted found that total emissions from MT buildings "could arrive very close to the final emissions of the concrete design option if both worst-case sourcing and worst-case transport scenarios were realized" (FSC, 2019). Although MT has been demonstrated to reduce GHG emissions, several conditions must be met in order for it to be a sustainable viable option for climate change mitigation. These conditions are discussed below:

Sustainable Forestry

For any benefits of MT to be realized and maximized, sustainable forest management practices must be employed as emissions can vary widely depending on how the wood is obtained. In one study, it was found that poor forest management such as harvesting a "virgin" forest can lead to carbon loss that offsets any benefit of avoided emissions from the substitution of lumber for other building materials (Winchester & Reilly, 2020). However, if the harvesting is accompanied by sustainable forest management practices such as ones that seek to increase forest productivity, then these studies show that lumber use can be a viable low carbon alternative (Winchester & Reilly, 2020). Thus, wood for MT must come from a responsibly managed forest to realize any carbon benefits. Without explicit efforts focused on sourcing, there is no assurance that conventional wood products will yield climate-smart MT and help reduce GHG emissions. Although sustainably managed land does not have to be certified, forest certification can help companies provide additional assurance to customers that their wood products come from legal, responsible sources. The Forest Stewardship Council (FSC), Sustainable Forestry Initiative (SFI), Canadian Standards Association's Sustainable Forest Management Standards (CSA) are three internationally recognized certifications that can contribute to credibility and make positive contributions to forest sustainability (Ward & Patterson, 2019).

In addition to sustainable forestry practices, it is recommended that the wood is sourced and produced locally to further reduce GHG emissions. Chen (2019) found that there could be up to a 95% reduction in global warming potential (GWP) associated with lumber transportation when a closely located sawmill is used to supply 100% of the lumber for CLT manufacturing in comparison to one that was farther away.

End-of-Life Management for MT Products

The end-of-life (EOL) for MT begins when the building is demolished, and its EOL scenarios mainly include recycling, reprocessing/ reusing, disposal in a landfill, or being burned for bioenergy. Although wood is considered to be carbon neutral, it does not mean that they are emissions-free as emissions can occur in any of these EOL scenarios because energy input is required to process and transport the wood materials. The amount of emissions released depends on its EOL treatment. To avoid unnecessary GHG emissions, it is recommended that MT components avoid landfill or incineration at EOL. When disposed of in landfills or incinerated, timber products can emit methane, carbon monoxide, and many other substances (Chen, 2019), and its methane emissions tend to be higher than concrete as the wood decomposes at a higher rate (Chen, 2019). Under both of these scenarios, the carbon that was once stored inside the wood would also be released.

To avoid higher methane emissions and reduce overall GHG emissions, it is recommended to increase wood recycling and reuse during EOL for MT products. Just by reusing 36% of MT materials (specifically CLT), it was found that this can substantially reduce its environmental impacts compared to landfill disposal or incineration (Chen, 2019). As most MT buildings are assembled with mechanical fasteners due to them being built off-site (Ross, n.d.), this construction method aligns with the Design for Disassembly method, where MT panels can be harvested from an old structure and reused in a new building so that the material can be returned to the industry for next use as part of the circular economy (Ross, n.d.). If for some reason the timber panels are not reusable for future MT building construction, they can also be transformed into raw materials for products such as pellets, pulp, and composite panels. (Chen, 2019). In Denmark, Danish firm TrÆls takes in wood from the demolition of old buildings and upcycles them into new outdoor furniture for sale and rent (Vestergaard & Craig, 2019). These scenarios are much less carbon-intensive than sending them to landfills or burning them as a fossil fuel alternative. Additionally, when wood products are reused, transport distance can be shorter because wood is recovered in large urban centers and can be reused locally (Bergman et al., 2013), reducing emissions that are associated with the transportation sector. However, it must be noted that despite these emissions, MT materials still produce lower CO^2 emissions compared to concrete in a scenario where all building materials are disposed of in landfills.

Well-being

MT buildings have the potential to improve human wellbeing through physiological wellness and psychological wellness. When panels are left exposed, building aesthetics are greatly enhanced, "as the exposed timber provides a warm sensation" (Harte, 2017). For physiological wellness, a 2014 research conducted by UBC found that undergraduate students exposed to wood have lower sympathetic nervous system responses (Naturally:wood, 2018). Other studies have also found that increased presence of wood in the building could reduce flu outbreaks as well as contribute to a lower heart rate compared to concrete facilities (Naturally:wood, 2018). Apart from that, the wood itself as a hypoallergenic material is easier to clean, which means that could prevent the buildup of dust and other pollutants causing allergies (Naturally:wood, 2018). This can result in better indoor air quality and creates an environment for better study performance for both students and teachers.

In regard to psychological wellness, research shows that incorporating wood and other natural materials into our buildings can reduce stress and contribute to good mental health (Fell, 2010). This research by Fell chose 120 students and divided them into four different groups in rooms with or without the presence of both wood and plants, and the results show a lower level of skin conductance (which is moderated by the sympathetic nervous system) in the rooms with the presence of wood. Exposed timber in schools and health care buildings has been shown to have psychological benefits with reduced heart rates and stress levels, higher levels of concentration in schoolchildren, and faster recovery rates for patients (Harte, 2017). Another study in Australia surveyed more than 1000 workers and found that satisfaction at work is directly related to the presence of wood in their workplace; these workers who had wood in their workplace were also found to have higher levels of concentration and improved productivity (Knox & Parry-Husbands, 2018). This study showed that people in workplaces with less than 20% natural wood surfaces were up to 30% less satisfied with both their working life and physical workplace compared to those with a high proportion of wood (over 60%) (Knox & Parry-Husbands, 2018). Apart from their satisfaction, concentration and productivity, the workers in an environment with over 60% of wood also show a 20% higher confidence and 16% more optimism about the future than those working under 20% wood coverage (Knox & Parry-Husbands, 2018).

Building Performance

Moisture

Moisture is an important factor when it comes to MT construction because of the material properties of wood. "Elevated moisture levels can cause dimensional instability, microbial attack, and fastener corrosion" (Finch, 2020), as well as leading to biodegradation and fungi growth (Wang et al, 2018). Because moisture exposure is common in North American construction, attention is required in all steps from manufacturing to post-construction to prevent unwanted moisture, allow time for drying, and design for moisture to escape. MT material can be protected from moisture before and during construction using sheets and barriers, as shown in the appendix (AIAS, 2019). Wood treatments such as glue line additives, pressure treatment, and dip/spray coatings can also prevent decay as well as insects or mould (Wang et al, 2018). In addition, moisture can be monitored in the buildings for further prevention and proper water-shedding design and drying mechanisms can greatly improve the moisture performance (Wang et al, 2018). Moisture can be a minimal influence on the durability of a building when there is proper risk management and maintenance.

Fire safety

There are three general approaches to fire protection in wood buildings. The first one is *full encapsulation*, an approach that fully encapsulates the wood elements of the building in fire-resistant material, such as gypsum wallboard (Green & Taggart, 2020). However, this strategy will tend to cover all indoor exposed wood surfaces, decreasing benefits for human well-being. The second and less conservative approach is *partial encapsulation*, where some of the massive timber elements are left exposed within the building. In this case, the structure itself is considered to be the most critical aspect of the fire protection effort and would remain mostly concealed to help maintain fire safety (Green & Taggart, 2020). As ceilings are the most important factor in fire safety as it is where the smoke accumulates and heats up, ceilings are more likely to be covered up than walls in partial encapsulation. The third approach is *non-encapsulation construction*, which leaves as much wood as possible exposed and uses fire simulation modelling to comply with all relevant regulations and performance criteria (Green & Taggart, 2020). The fire resistance, in this case, can be achieved by calculating the depth of the "sacrificial" layer of the wood to keep the structure safe from fire damage. The thickness of this layer depends on the type of wood and charring rate, usually at 40mm per hour. Thus, in a non-encapsulated situation, an extra layer of 40mm is required to protect the structural section from damage and withstand one hour of fire.

Other fire safety challenges associated with high-rise MT buildings include the contribution of exposed timber to room fires, connections between timber components, and service penetration. In the case of fire, exposed timber can help fuel fire significantly. However, the outer layer of the wood will be burned to char at around 300 °C, which creates a protective layer for the layers below (Barber & Gerard, 2015). The installation of gypsum boards can increase the fire resistance time for wood elements significantly, and a single layer can add 30 minutes to fire resistance (Barber & Gerard, 2015). Compared to timber connections, metal connectors perform better under fire (Schmid & Fragiacomo, 2019). Thus, metal connectors should be used in the building to connect timber components. Service penetrations are one of the weaknesses in MT buildings, since it allows fire and smoke to pass through.

Acoustics

As the overall mass of MT is significantly lighter than that of concrete or steel, sound is able to transfer more easily through walls, creating more noise. However, with proper acoustical design, it is possible to achieve a similar level of privacy in MT buildings as steel and concrete buildings. Four solutions are recommended to help minimize sound transfer in MT buildings.

Determine the Correct MT Option:

Before building construction, the type of MT must be considered as not all MT products are created equal. Acoustic testing found that CLT performs slightly better than other MT options (DLT, glulam, NLT etc.), as the laminates are cross-oriented in a panel and have lower susceptibility to small holes and cracks (Preager, 2019).

Add Decouplers:

Decouplers are products that break direct connections between finishes on one side of an assembly and the other which reduces the amount of noise that is able to travel (McLain, 2018). In MT floor and ceiling systems, the most common decoupling products are rubber floor underlayment and mats placed between MT panels (McLain, 2018; Preager, 2019). The type and thickness of material vary, but the purpose remains the same: to break the direct connection between finishes on one side of an assembly and the other.

Minimize Flanking:

Flanking is when sound travels through the walls, floors, ceiling, gaps and cracks. Wood buildings are more susceptible to noise issues due to the number of flanking paths where sound travels through assemblies other than the wall itself. One way to minimize flanking paths is to use resilient connection isolation and sealant strips. These products are able to provide sound isolation and the strips can also act as decouplers (McLain, 2018). The alternative is additional layers for the walls, ground, and ceiling to avoid sound getting into the floor and transferring structurally via vibration to the horizontally adjacent rooms (Preager, 2019).

Increase Mass:

Another way to achieve better noise control is to increase the mass of MT buildings to achieve the same sound levels expected from steel and concrete. One way to increase mass is to incorporate a hybrid design, combining MT with a heavier material such as concrete. Another option is to add a poured concrete or gypsum-based topping on top of MT panels to enhance thickness and mass (McLain, 2018). However, both approaches diminish the environmental benefits of wood construction as well as the positive impacts on the well-being of the building’s inhabitants (Di Bella & Mitrovic, 2020).

Earthquakes

Ontario's Tall Wood building reference describes earthquake performance as "an area of ongoing research" (Ontario, 2017). Tall MT buildings are to be designed to avoid brittle failure to prevent loss of life during the event of an earthquake (Ontario, 2017). Mid to high rise wood buildings also require modelling and dynamic analysis that takes into account the interaction between different materials in the building (Ontario, 2017). OBC B-4.1 outlines the regulations concerning loads and earthquake-related concerns (Ontario, 2017). Overall, the building must be structurally sound, but earthquakes do not currently pose an outstanding problem in Toronto because of the city being located on a stable part of the North American plate with very little seismic activity.

Building Code

The 2012 building code in Ontario, amended in 2015, only covers wood buildings up to 6-storeys (Ontario, 2017). In Vancouver and Quebec, tall wood building projects were able to be built above the 6-story limit through exemptions from parts of the provinces' building codes. In Vancouver, the building was issued a "site-specific regulation known as the UBC Tall Wood Building Regulation", with specific exemptions ensuring equal or improved performance with current codes (Ontario, 2017, p.3). In Quebec, the Tall Wood building was approved through a publication outlining allowances for MT buildings up to 12 storeys, written around the design framework of a Quebec tall wood demo project (Ontario, 2017).

In Ontario, tall wood buildings such as the UofT academic building require the adoption of an "alternative solution that achieves at least the same level of performance as required by the acceptable solutions" in the OBC division B (Ontario, 2017). This involves developing a solution similar to the requirements of a tall building with non-combustible materials, introducing "mitigating features", and addressing specific aspects related to combustible structure", such as fire and seismic performance (The Canadian Wood Council, 2018). "Approval [from the municipal building department] of an alternative solution depends on a strong and well-documented building application package along with a strong design team that addresses all compliance issues" (Ontario, 2017).

Economic Cost

Building with MT has been found to be more economically advantageous than building with traditional steel and concrete building. Not only does it lower overall building costs, but it also has the potential to stimulate economic activity and development in rural areas. Although MT materials such as CLT are more expensive per unit than steel or concrete, construction costs are considerably lower as timber panels are prefabricated and assembled on-site, reducing construction timelines by 25% and construction traffic by 90% (Mass Timber Institute, n.d.). In addition to reducing construction costs, MT production can help spur economic development and investment in the forest sector, providing economic opportunities to disadvantaged northern and remote communities that rely on the manufacturing of forest products for jobs and economic resilience (MT Institute FAQ, n.d.; Evans et al., 2018). In research conducted by Scouse et al. (2020), it was found that building with MT generated larger economic impacts than traditional concrete construction when sourcing supplies and workers locally. However, when construction required importing wood product elements from manufacturers outside the study area, net economic impacts of MT and concrete frame scenarios become relatively similar.

Case Studies

Mjøstårnet

Mjøstårnet is an 18-storey MT building situated by Lake Mjøsa in Norway, which currently holds the record for the world's tallest MT building at 85.4 metres tall (Figure 2) (Moelven, n.d.a). The initiative to build Mjøstårnet came from investor Arthur Buchardt who wanted to build the world's tallest timber building using local resources, local suppliers, local competence, and sustainable wooden materials (Abrahamsen, 2018). That vision was realized as the majority of Mjøstårnet's timber components originated from nearby sustainable forests and the glulam panels have been produced at Moelven's glulam factory only 15 km from the building site (Abrahamsen, 2018).

For installation, Moelven employed a completely new and untested assembly technique. At Mjøstårnet the individual components were transported directly to the building site without any form of trial assembly (Abrahamsen, 2018). The beams arrive fully processed and pre-drilled and are assembled at ground level in sections 4–5 storeys high before being lifted into place (Vestergaard & Craig, 2019; Moelven, n.d.a). This construction method ensured a quicker production process and made it possible to build Mjøstårnet faster and cheaper. Mjøstårnet's building structure is almost completely composed of glulam and the only significant elements of the structure to be made from concrete are the floor slabs for levels 12-18 to ensure mass and the building's stability in strong winds (Guinness World Records, n.d.). Fire safety has also been of paramount importance for Mjøstårnet. Each floor forms its own fire compartment, which is designed to restrict fire from spreading, sprinklers systems covers the building inside and out, outer wall elements have been treated with a fire retardant material, and fire strips are put in place protect the steel sheets and dowels in the junctions and joints (Moelven, n.d.b)

Mjøstårnet serves as a contributor to future sustainable development and is a demonstration that it is possible to build large, complex timber buildings. Projects that focus on local supply chains such as Mjøstårnet are able to build even faster and reduce emissions from the transport of materials, with added benefits of boosting jobs and expertise in the local economy.

Brock Commons

The University of British Columbia recently constructed one of the tallest MT buildings in the world at 18 storeys and a height of 53 metres— Brock Commons (Fast & Jackson, 2017). Before the construction, workers built a full-scale mock-up building to validate the constructability of the proposed design. Site construction began in November 2015 and completed in July 2017. Around two floors were built per week, which was significantly faster compared to the amount of time that is used to build traditional concrete buildings (Crockett, 2016). The panels for construction were also prefabricated and constructed off-site, resulting in fewer on-site mistakes and saving total construction time. This has proven to be cost-competitive compared to concrete and steel buildings.

However, building Brock Commons was not without challenges. The first challenge was due to building codes as the British Columbia Building Code limits the height of wood buildings to six stories. Thus, two independent structure peer reviews had to be completed to make sure Brock Commons complies with all codes and standards. The project was only approved based on a Site-Specific Regulation which is only applicable to this specific project and site. Fire protection was also a challenge due to its height. To combat this, all exposed wood was covered with multiple layers of Type X gypsum board to achieve a 2-hour fire-resistance rating. The building is also fully equipped with sprinklers and fire extinguishers provided on each floor. In addition, there is a 20,000-litre backup water supply tank at the basement of the building which has the capacity to supply the entire sprinkler system for 30 minutes (Pilon et al., 2016).

T3 Bayside

T3 Bayside is a 10-storey MT building complex in Toronto and is projected to be the tallest timber office building in North America after its completion in 2023 (Cogley, 2019). 3XN, the designer of this building chose to build with MT due to its low environmental impacts, reduced construction time, the possibility of future disassembling and reusing of building material, and the fact that products can be sourced locally (Cogley, 2019).

The building is expected to store 3886 metric tons of CO^2 which is equivalent to the emission of 2708 cars (T3 Bayside, 2020). The building will also only be built using young trees rather than old-growth ones, making T3 more sustainable (T3 Bayside, 2020). Both the interior and exterior parts of the building will be built using MT (Murray, 2020). Fire safety in T3 is expected to outperform concrete and steel, as the timber beams will char rather than burn, maintaining their integrity as steel buildings can often become deformed in fires (T3 Bayside, 2020). Despite concerns regarding acoustics, T3 is expected to have sound insulation similar to concrete and steel buildings by using sound mats, creating better sound insulation (T3 Bayside, 2020). Although there is a six-storey limit building code restriction in Ontario, T3 Bayside has received its site-specific exemption because of its innovative development concept that was granted recently and began its construction (Landau, 2020).

Toronto Tree Tower

The Toronto Tree Tower is set to be an MT high-rise building with 18 storeys around 62 metres tall. 4500 square meters of its area is for residential use, while the other 500 is for public space (Işık et al., 2020). The building is planned to be built with predominantly CLT panels as it is more fire-resistant and can help improve the indoor climate (Işık et al., 2020). Construction involves off-site assembly of the wood pieces, which are then built in a "modular building process" (Figure 6.2) to help reduce construction time, noise pollution, and waste (Howarth, 2017). The Tree Tower also plans to add large plants on its balconies to serve as private gardens and provide more privacy to residents, a major concern for high-rise residential buildings (Designing Building Wiki, 2020). It has also been found that the combination of wood and plants can also increase well-being (Fell, 2010). The building is set to become the world's tallest hybrid timber structure and a model for sustainable construction (Howarth, 2017). However, the construction of this residential building has not begun and whether or not the building codes will make an exemption is uncertain.

Origine

Origine (Figure 7) is a 13-storey residential project in Quebec City, standing 40.9m tall, with 12 floors and a 100% wood structure on a concrete podium (Nordic, n.d.). It is innovative as it is the tallest wood building in eastern North America, especially with a lateral resistance system made entirely of wood (Cecobois et al., 2018). In this project, designers had to work around the 4-storey limit of the Quebec Construction Code with an alternative solution called "equivalent measures", similar to Ontario's alternative solution pathway (Cecobois et al., 2018). This process showed that the code's "performance goals and functional statements were being respected" and was approved by the Quebec RBQ (Cecobois et al., 2018.). In the design of the floors, the load resisting system is made by the CLT shear walls, CLT load-bearing walls, glulam post and beam axes, and floors that transfer lateral loads from the load-bearing walls to the shear walls (Cecobois et al., 2018.). For fire safety, the design team for Origine performed various tests to measure the fire resistance of the materials and compositions (Cecobois et al., 2018). This involves separation walls that prevent fires from spreading, as well as high performing structural elements which provide 2 hours of fire resistance through the charring process (Cecobois et al., 2018.). More precautions are taken with fire-resistive insulating material on the structure, balconies, and exterior cladding (Cecobois et al., 2018.). The design team also tested the acoustic performance of different compositions of walls and floors and were able to achieve performance goals by placing acoustic membranes between floors and through testing (Cecobois et al., 2018.). Specific challenges and solutions can be found in Figures 7.1 to 7.3 in the Appendix.

Environmental impacts wise, this building uses 3.111 m^3 of FSC-certified wood from the province, it sequesters about 2295 metric tons of carbon dioxide and avoids about 1000 metric tons of carbon through the use of wood in place of other materials (Cecobois et al., 2018). Additionally, thermal performance is improved in the building by "reducing thermal bridges" which saves on energy use (Cecobois et al., 2018).

Concluding Thoughts and Recommendations for the Academic Tower

This paper has examined both the benefits and challenges of constructing with MT. Not only does MT have the ability to reduce GHG emissions, but it is also able to lower construction costs and time and enhance well-being for individuals residing in the building. Challenges to constructing with MT include achieving required performance levels for fire resistance, acoustics, and moisture because of the material properties of wood. This paper has also outlined ways in which designers and past case studies can and have found solutions for MT to perform as well as or better than non-combustible building material. Despite the challenges, the benefits of MT construction have shown to outweigh these adversities.

The University of Toronto should also have a vested interest in building the Academic Wood Tower, as it would push the university to the forefront of MT construction and sustainable initiatives in Canada. Wood buildings over 6 storeys are not yet included in Ontario's building code, so the Academic Tower would be a front runner in the province and can pave the way for more innovative use of the material and more buildings being built. It is also "expected to be the tallest MT and concrete hybrid building in North America" (Levine, 2018). The benefits of MT are also of special concern to the university, because they directly impact students and staff in terms of wellbeing. The design of libraries and workspaces on campus can either positively or negatively impact student experience as most students prefer to study at places that are more comfortable and aesthetically pleasing. Thus, the possibility of having MT buildings on campus with exposed wood panels can help greatly enhance study sessions and improve the student experience on campus in comparison to studying in traditional steel or concrete buildings such as Robarts. The Academic Wood Tower and future MT buildings could help promote both physical health through better indoor air quality and mental health by adding more timber elements inside the building.

For the University of Toronto to undertake a new path to sustainability, the building of the Academic Wood Tower should follow these specific guidelines based on our research:

- To reduce GHG emissions and ensure that the Academic Wood Tower is as sustainable as possible, the University of Toronto must source its timber products locally and from sustainably managed forests (look for third-party verification such as the FSC). Further, the building should also be built in a way to assure that it can be disassembled with ease, increasing the chances of being able to recycle or reuse old timber panels.
- To enhance student and faculty member's wellbeing, it is recommended that as much wood as possible is left exposed in the building interior without jeopardizing fire safety.
- To ensure fire safety, exposed surfaces of the ceiling should be covered with gypsum while leaving the walls exposed at most. If possible, the University of Toronto should attempt to achieve fire safety while leaving all panels exposed. Further, the Academic Wood Tower should be fully sprinklered with a water tank on site, like Brock Commons.
- It is vital that the University of Toronto utilize decouplers and minimize flanking to achieve sound insulation. Although the University could choose to pursue increasing mass with concrete or gypsum, that could diminish well-being effects for students and faculty members. It is also recommended that the University of Toronto build with CLT as it is found to perform better than other MT products in terms of sound insulation.
- Finally, timber panels should arrive on-site prefabricated and fully processed to ensure a quicker construction time. This would help reduce economic costs significantly. Costs can also be reduced if timber products are sourced locally, which decreases transportation costs and helps spur economic development in the surrounding regions.
- The Academic Wood Tower should be built with as much timber products as possible. However, if it is not possible to achieve stability through only MT, concrete and steel should be incorporated into the higher storeys to ensure mass and the building's stability in strong winds.

Appendix

Figure 1: Carbon stored in MT vs. concrete and steel

Source: Işık, Bisht & Mikovcák, 2020

Figure 2: Types of moisture prevention treatment of MT

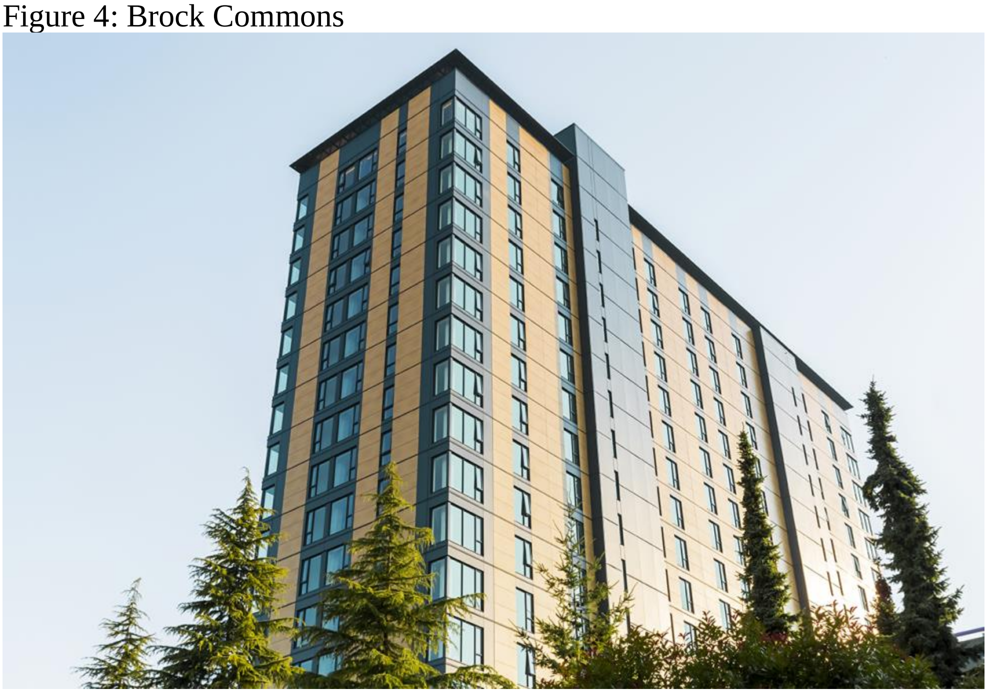
Treatment	Benefits	Limitations	Notes
Fully Adhered Vapor-Permeable Sheet	◊ Generally keeps bulk water out ◊ Water will not travel far in case of breaches ◊ Generally spans checking or cracks	◊ May be slick for walking (depending on material used) ◊ Liquid water sitting on upper surface for extended periods of time will migrate through as vapor	Some degree of vapor permeability is preferred, but this should not be considered waterproofing.
Liquid-Applied Weather Barrier	◊ Generally keeps bulk water out ◊ Water will not travel far in case of breaches	◊ Water and temperature application limitations ◊ Application in factory is preferred ◊ Limited ability to span cracks or checks	Options have ranges in vapor permeability, including: ◊ Silicone ◊ Urethane ◊ STPE ◊ Acrylic
Wood Sealers	◊ Inexpensive ◊ Can be sprayed ◊ Maintains wood appearance	◊ Weather and temperature application limitations ◊ Requires drying time and multiple coats	Benefits are similar to liquid treatment, but not as robust.
Edge Treatment Only	◊ Less labor time to install	◊ Only shields the end grain ◊ Requires more diligence to keep surfaces dry	Tapes or sealants.

Source: AIAS, 2019

Figure 3: Mjøstårnet

Source: Moleven, n.d.

Figure 4: Brock Commons



Source: UBC Housing, n.d.

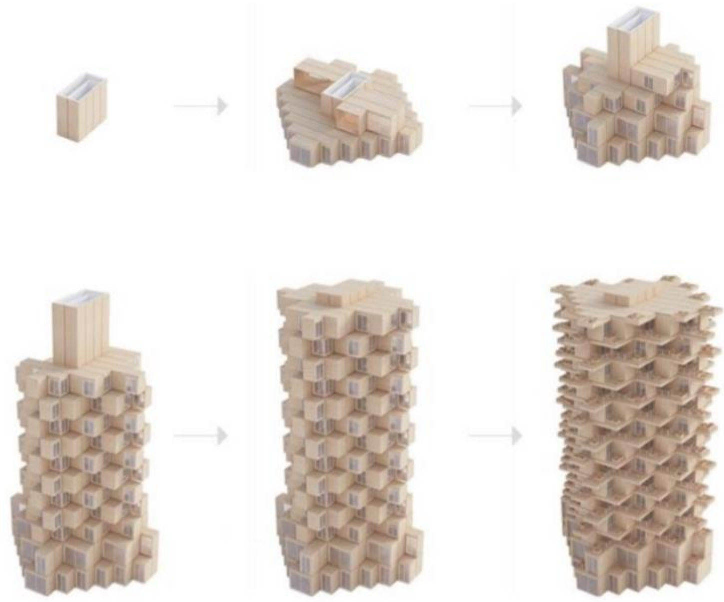
Figure 5: T3 Bayside

Source: T3 Bayside, 2020.

Figure 6.1 Toronto Tree Tower

Source: Designing Buildings Wiki, 2020

Figure 6.2: Tree Tower Construction



Source: Designing Building Wiki, 2020.

Figure 7: Origine Render

Source: Yvan Blouin Architect (Cecobois et al., 2018)

Challenges	Innovative Solutions
Transfer of lateral loads in the floor diaphragm	Lateral loads to be transferred in the diaphragm on the top floor are enormous. A plywood element wouldn't have been enough to transfer the load between the panels running north to south so the designers used CLT strips to transfer the heavy load.
Transfer of shear stresses between shear wall panels	Using shear keys meant there was no need to install large nailed-on metal plates. This reduced installation costs.
Vertical assembly of CLT panels	Metal junction plates with oblong holes allow the building to resist shear stresses without restricting tensile stress.
In-plane resistance of CLT panels	The "true" in-plane shear value for CLT panels was unknown. It had been calculated with a safety margin built in. Following tests carried out at FPInnovations, the factor was reduced by three, providing optimal design for the shear walls.
Fastening to the ground	The designers came up with a system of metal fasteners that worked with shear keys anchored in concrete to transfer forces at the base of the shear walls.
Speed of assembly	Using CLT meant that the wall panels were 3 storeys high, reducing installation time.

Figure 7.1 (Cecobois et al., 2018, p.11)

Challenges	Innovative Solutions or Original Features
Demonstrating the mechanical strength of the gravity load resisting system for two hours of fire resistance	Wood elements were sized to provide one hour of fire resistance and the elements were covered with Type X gypsum boards for one additional hour of protection. Fire resistance was also demonstrated in large-scale tests.
Demonstrating the integrity and insulation of floors, load-bearing walls, and other fire separation walls	Fire resistive systems for joints and technical elements passing through fire separation walls were devised and tests were carried out in accordance with Standard CAN/ULC-S115.
Demonstrating fire resistance	Tests were performed in accordance with Standard CAN/ULC-S101, as required by the Building Code. The calculation method (Annex B of the CSA 086 standard) had not yet been published at that time.
Confounding the skeptics	A large-scale demonstration test simulating an extreme case of fire was carried out.

Figure 7.2 (Cecobois et al., 2018, p.17)

Challenges	Innovative Solutions or Original Features
Choosing floor and wall assemblies to ensure good acoustic performance	Carrying out tests on assemblies with many variations, to determine optimal solutions.
Ensuring acoustic comfort	Ensuring the quality of implementation and performing in-situ tests to confirm acoustic performance.

Figure 7.3 (Cecobois et al., 2018, p.19)

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