The Development of Mass Timber as a Substitute for Structural Steel

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction

Steel is a common building material because of its design versality, ease of prefabrication, durability, and strength-to-weight ratio. But the manufacturing process has a substantial carbon footprint. Designers have tried to mitigate this impact by using recycled steel, but the environmental effects are still severe. The U.S. consumption rate of construction materials exceeds the world sustainable usage rate, meaning we are at risk of material shortages (Horvath, 2004). This has led to the exploration of alternative materials with comparable stiffness and strength to steel, but lower net carbon emissions during production. Mass timber is a new type of building material that can serve as this solution.

In this research paper I describe the environmental impacts of timber manufacturing and explore the history of mass timber technology. Then I analyze the fire performance of large timber members since that is a common concern for designers. Then I explore how different organizations—such as trade associations, lobbyist groups, environmental advocacies, government agencies, and sustainability associations —have either hindered or helped its development. I also analyze why designers could be apprehensive about using timber instead of steel as their primary structural material. My research has led me to conclude that mass timber construction projects perform as well as steel buildings but have the added benefits of carbon capture & storage, aesthetics, and construction efficiency. This new material can aid in the fight against climate change without sacrificing the advancement of new infrastructure. But analysis software will need to be developed further to aid the design process, new lobbyist groups will need to emerge to combat the steel industry's influence on policy, and more grants will have to be issued to fund large-scale mass timber projects.

Environmental Impacts of Timber Manufacturing

Mass timber, a material made from layering and gluing together structural lumber boards, is a cost-competitive alternative to steel. Because of its ability to sequester carbon, mass timber has lower net carbon emissions, and the cross-laminating of the wood layers makes it just as strong. Prakash Nepal & co-authors found that a 100% market adoption scenario estimated a reduction of 497-825 million tons of CO_2 emissions from mass timber building construction from 2020 to 2070. The projected carbon benefit was based off the emission difference between mass timber and concrete during raw material extraction and construction/installation, and the estimated amount of carbon stored in mass timber over its life cycle (Nepal et al. 2024). Tait Bowers & co-authors conducted a life-cycle impact analysis on 1 m^3 of glulam timber and discovered a reduced reliance on fossil fuels and an increase in renewable energy compared to typical construction materials. It also showed the amount of carbon sequestered in the wood far exceeded the number of emissions produced during the manufacturing process (Bowers et al. 2017). Nepal & co-authors concluded from published life-cycle analysis results that mass timber manufacturing results in more greenhouse gas emissions than standard lumber and wood panels, due to the energy needed for material transport, drying, cutting, gluing, assembling, etc. But the emissions produced are less than that for steel and concrete (Nepal et al. 2024). Also, the most common adhesives used for panel construction are formaldehyde free (Mohammad et al.). Due to the variation material properties of mass timber members, analytical models of these structures can be unreliable. As a result, a more conservative design approach would have to be used.

Mass timber is often produced from fast-growing trees in a monoculture farm so they can be harvested and quickly replaced, so as to not contribute to deforestation. But harvesting from homogenous forests still leads to degradation, which can decrease biodiversity, fragment wildlife habitats, and release carbon dioxide that was sequestered in the trees. It can also worsen the soil’s ability to absorb water, which leads to erosion and flooding. Unfortunately, just replanting the trees is not a sufficient replacement for an older, diverse forest. Many large corporations that manufacture lumber have little accountability for the sustainability of their lumber harvesting process. To combat this, the Forest Stewardship Council (FSC) is developing a certification system to create more transparency and ensure the wood is harvested responsibly (NRDC, 2024).

History of Mass Timber Construction

Cross-laminated timber (CLT) was first introduced in Austria and Germany in the early 1990s, after Austria undertook an industry-academia joint research effort resulting in developing this new wood product. Mass timber rose in popularity throughout the early 2000’s due to the efficiency of fabrication, delivery, & construction, the reduction of construction noise, the aesthetics of exposed wood, and the lower net carbon emissions. There are currently more than one hundred CLT projects in Europe, and the implementation of CLT is still gaining momentum in North America (Mohammad et al.).

The National Design Standards (NDS) for Wood Construction recently added mass timber to the code book. It defines structural glued laminated timber, commonly referred to as glulam, as “an engineered, stress-rated product of a timber laminating plant, comprising assemblies of specially selected and prepared wood laminations bonded together with adhesives” (AWC, 2023). This distinguishes glulam from typical heavy timber, which doesn’t have the same strength as built-up mass timber members. Another type is cross-laminated timber (CLT), which NDS defines as “a prefabricated engineered wood product consisting of at least three layers of solid-sawn lumber or structural composite lumber where the adjacent layers are cross-oriented and bonded with structural adhesive to form a solid wood element” (AWC, 2023). The main difference is the grains of glulam laminations are parallel longitudinally, as opposed to angled in cross-laminated timber.

There have been many success stories of mass timber design in the United States has it's been rising in popularity. For example, Apex Plaza in downtown Charlottesville is Virginia's first and tallest high-rise mass timber building, containing 151,000 square feet of office space and 6,800 square feet of retail space. The eight-story frame is made of cross-laminated timber harvested from fast-growth wood, which has a quick life cycle and thus doesn't contribute to deforestation. The CLT was sourced from Nordic Structures in Montreal, Canada, and the final project used 2,200 tons of finished product. The largest columns are 18"X23" weighing 100 pounds per linear foot, and the largest beams are double 12"X25" weighing 75 pounds per linear foot. The building is estimated to have a carbon benefit of 3,000 metric tons compared to traditional construction approaches. Hourigan broke ground on Apex Plaza in 2019 and the building opened in December 2021. Their commitment to sustainability was evident from the CLT framework, the 875 solar panels, and the green roof which promotes biodiversity and storm water retention (Hourigan, 2022). Pictured below are photos taken by Hourigan of the building during construction, and the finished interior which features exposed wood.

Figure 1: Apex Plaza wood frame during construction and after completion of the project.

Analysis of Fire Performance of Timber Members

One common concern for using mass timber in high-rise construction projects is fire safety. Since timber can increase the initial fire growth rate more than noncombustible structural materials, it can potentially overwhelm the fire protection systems and result in more danger for occupants of the building. Because of this the designer needs to develop a fire protection strategy based on charring rate, visibility, temperature, and toxicity of the exposed timber. Some potential failure modes are gypsum failure and delamination of the CLT (Brandon, 2018). Previous tests measured the heat release rate based on the charring rate of compartments with noncombustible materials versus exposed CLT. The quantity of exposed timber varied from 21% to 100% of the surface area of the walls and ceiling (Brandon, 2018). Table 1 shows a slightly elevated HRR for the compartments with exposed wood.

Table 1: Predicted and measured average heat release rates (Avg. HRR) for the duration of the reference test.

Test	Reference test		Test with exposed timber				Error
	Avg. HRR reference test during *period a* (MW)	Duration of the fully developed phase of the reference test, *period a* (min)	Charring rate during *period a* (mm/min)	Area of exposed surface (m^2)	Avg. HRR during *period a* (MW)	Predicted Avg. HRR during *period a* (MW)	
1-3	8.5	21.7	1.00	24.6	10.0	10.1	-0.2%
1-4	5.8	30.0	0.76	41.9	7.5	7.8	-4.1%
1-5	5.8	30.0	0.61	24.6	6.6	6.8	-2.8%
1-6	5.8	30.0	0.58	66.4	7.9	8.2	-4.5%
I5	4.1	15.3	0.67	53.8	6.6	6.3	4.1%

Due to the ventilation control in both compartments, there was no significant temperature difference during the peak phase of the fire. Failure of the gypsum boards can be mitigated by using thicker layers of fire-rated gypsum and fastening with screws of a sufficient depth. Cracks can also lead to failure but tend to be smaller as the distance between screws decreases.

Compartment tests observed that gypsum fall-off occurs when the temperature reaches 300°C, so this value is assumed when predicting structural damage. (Brandon, 2018).

A common misconception is that timber structures have poor fire endurance, but they perform well and often only require sandblasting away char as a method of repair. Yet the industry has shifted to emphasize noncombustible materials, which can confuse the public. Many believe that these materials won't endure fire damage since they don't burn, which is not true (AF & PA, n.d.). Most structural steel will lose its strength at approximately 800°F and fail at 1200°F. Wood loses its strength as the cross section shrinks due to charring, so the use of a large, built-up member such as mass timber is a method of fire protection itself. The Southwest research Institute in San Antonio, Texas conducted a test to determine the comparative performance of exposed timber and steel roof framing members in fire temperatures (AF & PA, n.d.). The results of the test are as follows:

Table 2: Deflection of a loaded steel beam when exposed to fire temperatures.

Time Exposed to Fire (min)	Temperature (°F)	Deflection (inches)
6	894	2
14	1194	8.25
20	1279	11.75
29	1422	35.50

The unprotected steel failed after 30 minutes of exposure but had lost its structural integrity before the test was completed. A glue-laminated timber beam reached a maximum deflection of 2.25 inches after 30 minutes of fire exposure. After the test was completed, the cross section revealed a char depth of 0.75 inches on each side and 0.625 inches on the bottom, as well as shrinkage of individual adhesive laminations. It was estimated that 75% of the wood was undamaged and still managed to support the design load (AF & PA, n.d.). This analysis demonstrated that susceptibility to fire is no greater risk than that of a high-rise building comprised of structural steel.

Organizations Involved in the Adoption of Mass Timber

There are multiple environmental groups that advocate to reduce global carbon emissions, and a possible solution is the incorporation of mass timber into new construction. One participant is the Natural Resources Defense Council (NRDC), a sustainability advocacy group that "works to safeguard the earth—its people, its plants and animals, and the natural systems on which all life depends" (NRDC, 2024). The NRDC doesn't oppose wood construction if it is sourced legally and harvested using methods that protect forest species, the local water quality, and the rights of indigenous people. They claim the best practice is to buy recycled lumber and request documentation of its source from the seller (MacMillan, 2016). The NRDC also supports policies to advance "carbon capture and storage," a technique to capture CO_2 pollution and permanently bury it underground (Doniger, 2018). Mass timber buildings have this same effect naturally. Another participant is American Forests, an environmental advocacy whose mission is to "create healthy and resilient forests...that deliver essential benefits for climate, people, water, and wildlife" (American Forests, 2024). Their stance is that forests are the best solution for climate change because they capture and store almost 15% of the country's carbon emissions. They support mass timber construction because wood as a building material has the same carbon-storing capacity (American Forests, 2019).

Some trade associations include the International Association for Mass Timber Construction, the first global group that offers training, certifications, and education in order to promote the mass timber construction movement (IAMTC, 2024). Mass Timber Strategy provides technical guides for mass timber construction, embodied carbon & life cycle analyses, and biophilic design. They also founded Mass Timber Marketplace, which consolidates contacts for mass timber providers into one website (MTS, 2021). Boston Mass Timber Accelerator invests in mass timber construction projects, raises public awareness of its economic and carbon benefits, and introduces practitioners to the feasibility of mass timber design and construction (BPDA, 2024). The Mass Timber Construction Management Program from Woodworks provides one-on-one assistance with wood construction projects and offers tools to help improve design and management. It includes two elements: a project management curriculum and a mass timber installation training (Woodworks, 2024). The American Wood Council (AWC) creates the national design specifications for wood design, and just added the Mass Timber AMM Guide in 2023 to be used with the Florida Building Code. They provide guides for fire safety, acoustics, connections, energy efficiency, green building, resilience, etc. Other tools include a carbon calculator, reused wood directory, and forest product data visualization (AWC, 2024). They were the first industry to develop third-party verified environmental product declarations that describe the environmental impact of their materials. They market wood as a “carbon-friendly solution to existing structural materials” (AWC, n.d.).

A significant participant in the mass timber movement is the American Insitute of Steel Construction (AISC). They market structural steel as a sustainable choice, claiming it’s “93% recycled content and is 100% recyclable, making it a material that is circular for generations” (AISC, n.d.). Since all hot-rolled sections in the U.S. are made in electric arc furnaces, “the American steel industry is the least carbon-intensive of all major steel-producing countries” (AISC, n.d.). The major American steel mills have emphasized their commitment to the decarbonization of the structural steel industry. Nucor pledges to reduce greenhouse gas intensity by 35% by 2030, Steel Dynamics pledges to go carbon neutral by 2050, and Cleveland Cliffs pledges to reduce greenhouse gas emissions by 25% by 2030. AISC supports structural steel as the most sustainable choice because it “is the most recycled material on the planet” (AISC, n.d.).

Another influential participant is the U.S. Green Building Council (USGBC), who created the LEED rating system. According to USGBC, “LEED certification provides a framework for healthy, highly efficient, and cost-saving green buildings, which offer environmental, social and governance benefits” (USGBC, 2024). Their goal is to reduce the contribution to climate change, enhance individual human health, protect water resources, enhance biodiversity, promote sustainable material cycles, and enhance community quality of life. A project can achieve LEED certified, silver, gold, or platinum status based on points earned during a review by Green Business Certification Inc (GBCI). The credits address carbon, energy, water, waste, transportation, materials, health and indoor environmental quality. The USGBC also provides online courses, memberships, and credentials for designers. They also require AISC to submit environmental product declarations to ensure the environmental impact of the steel products is accurate and transparent. The USGBC supports the use of mass timber in new construction because it “helps with our shift to renewable resources” (Holt, 2017). They claim the economic benefits include off-site fabrication, shorter construction time, and lower material costs. The aesthetics of exposed wood also resulted in higher occupant satisfaction since “humans are attracted to natural shapes, forms, and textures” (Holt, 2017). However they address the challenges of adopting a new material, such as a limited supply of mass timber in North America, limited industry experience, and lack of testing data.

The United States Environmental Protection Agency (EPA) is an organization that writes regulations that explain the technical, operational, and legal details necessary for Congress to implement laws. Their primary goal is to protect the environment and public health, and they monitor compliance of their policies with audits, credentials, and inspections. The EPA developed the Sustainable Materials Management (SMM) Strategic Plan to advance the built environment over the years 2017-2022 (EPA, 2025). Their plan covers a variety of construction materials such as steel, concrete, wood, glass, stone, aluminum, etc. One of their suggestions is to use secondary materials from construction demolitions. They also started the C-MORE Grant Program, whose goal is to "improve transparency and disclosure of embodied greenhouse gas (GHG) emissions data associated with construction materials and products to facilitate the steady reduction of embodied carbon" (EPA, 2025). The EPA selected 38 businesses, universities, and nonprofit organizations for this program, totaling $160 million in funding. They purposely selected projects that support the advancement of environmental product declarations (EPDs) and other sustainability verification tools. The American Wood Council (AWC) was awarded a grant to advance life-cycle data collection, create an EPD generator tool, and enhance transparency within the wood industry (EPA, 2025). The EPA has not stated that any specific construction material has the best effect on the environment, but has instead made efforts to reduce carbon emissions for all common materials.

Challenges to Mass Timber Development

There are several obstacles inhibiting the replacement of structural steel with mass timber. One of the most prominent challenges for the adoption of mass timber as a primary structural material is the standardization of codes. The North American CLT product standard was published in December 2011, then the American Wood Council included the material design standard in the NDS. Another necessary step for broad public acceptance is the CLT design standard being referenced in the International Building Code (IBC) (Mohammad et al.).

Another potential hindrance is that The American Iron & Steel Institute founded a political action committee called SteelPAC, whose “purpose is to help elect candidates to the U.S. Congress who support AISI’s goals of making steel the material of choice and to enhance the competitiveness of the American steel industry” (AISI, 2025). They lobby for political legislation that supports their agenda and organize “grassroots” coalition building. Their stance is that steel and other manufacturing industries “create significant benefits for society, including good-paying jobs, investment in research and development, critical materials for our national defense, and high-value exports” (AISI, 2025). One of their policy recommendations is for steel to only be produced domestically to address unfair foreign trade practices, eliminate currency manipulation, and create new jobs. Because of this, AISI supports President Trump’s “America First” trade policy, and encourages his administration to reinvigorate his steel tariff program established in 2018. AISI also claims there are several regulations set by the Environmental Protection Agency (EPA) that threaten the global competitiveness of the steel industry and need to be reconsidered. They urge congress to “ensure that regulatory decision-making by the EPA is based on sound science and technological feasibility” (AISI, 2025), which indicates they believe the current rules are too strict and exaggerate the negative environmental impact of steel manufacturing. The American Institute of Steel Construction (AISC) and the American Iron and Steel Institute (AISI) currently market steel as a sustainable choice since it is technically a recyclable material, but don’t advertise the significant amount of carbon dioxide released into the atmosphere as a product of manufacturing. Until there is a significant political donor that can promote mass timber to the same extent, it will be difficult to enact policies that support mass production and implementation of timber design.

Sustainability rating systems such as LEED are somewhat helpful in the mass timber initiative but don’t provide a significant enough reward to motivate a project manager to use a new material they are unfamiliar with. It can provide tax benefits and good publicity but not much else. The LEED scorecard allows buildings to earn their certification without using a lot of innovative ideas in their design. Points can be earned from being close to public transit, adding bicycle racks, reducing parking capacity, assessing the site, using recycled materials with known life-cycle information, incorporating natural light, etc. Since it is fairly easy for a steel structure to earn its accreditation, rating systems aren't doing much to push the industry towards mass timber design.

Conclusion

Mass timber construction has the potential to expand our infrastructure without severely depleting our resources. The greenhouse effect from steel manufacturing is severe, so it is necessary to consider other options. Many can be reluctant to transition from steel to mass timber because of the fear of higher costs, lack of knowledge and/or experience, insufficient data, and unwillingness to change their practices. In order for designers and engineers to become more comfortable with alternative materials, we need more developed analysis software, new editions of building code books and design criteria, free educational seminars for those in the industry, and the incorporation of wood design into university curriculums. Timber manufacturing companies and environmental advocacy groups are pushing for the spread of wood-based construction but are undoubtedly being met with obstacles from the steel industry. But as mass timber grows in popularity, the transparency of the lumber industry will have to keep up and follow best practices set by environmental agencies. New projects will require government support, adequate funding, and widespread advertising to promote mass timber as a "green" alternative to structural steel.

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