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Mass Timber in Construction: A Bibliometric Network Analysis and Qualitative Review of Trends, Challenges, and Opportunities

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Abstract

This paper explores the growing significance of Mass Timber Construction (MTC) in sustainable building practices. Employing a systematic search strategy across leading databases including Web of Science, ScienceDirect, and Lens.org, it analyzes peer-reviewed research from 2014 to 2024 using VOSviewer® software to identify key themes, methodologies, and research gaps. The review explores various Mass Timber products, such as Cross-Laminated Timber, and their applications, highlighting environmental benefits such as reduced embodied emissions, structural advantages, improved occupant well-being through biophilic design, and enhanced efficiency via prefabrication technologies. Case studies showcasing successful MTC projects from the U.S., Canada, Japan, and Chile further illustrate these advantages. The review acknowledges existing challenges such as technical limitations, regulations, higher upfront costs, and a lack of industry familiarity in MTC management, while exploring recent innovations and future trends. This knowledge aims to empower construction professionals to manage and lead Mass Timber projects effectively, fostering the adoption of sustainable building practices. The paper concludes that while MTC presents significant environmental and operational advantages, its broader adoption will require collaborative efforts from policymakers, industry stakeholders, and educational institutions to address existing challenges and promote sustainable building practices. This comprehensive review offers valuable insights for the construction industry, paving the way for the successful integration and implementation of MTC, ultimately contributing to a more environmentally responsible built environment.

Keywords

Mass Timber, Cross-Laminated Timber, Construction, PRISMA, VOSviewer®.

1. Introduction

The incorporation of sustainable and innovative building materials and methods has become imperative in modern construction practices. As the construction industry seeks to minimize its environmental impact and address climate change concerns, there is a growing emphasis on adopting construction techniques that reduce carbon emissions, promote energy efficiency, and enhance the overall sustainability of built environments (Hough, 2019). Among these emerging approaches, Mass Timber Construction (MTC) has gained significant attention due to its remarkable environmental benefits, structural integrity, and aesthetic appeal (Brandner, et al., 2016).

Mass Timber refers to a category of massive, engineered wood products that are composed of large, solid wood panels or beams, such as Cross-Laminated Timber (CLT), Glue-Laminated Timber (Glulam), Nail Laminated Timber (NLT), Dowel Laminated Timber (DLT), and Structural Composite Lumber (SCL) (Harte, 2017). These materials offer numerous advantages over traditional construction materials, including their renewable and low-carbon nature, lightweight yet robust properties, enhanced fire resistance, and potential for prefabrication and modular construction (Brandner, et al., 2016; Mayo, 2015; Harte, 2017; Crawford & Cadorel, 2017; Gray & Sadoughi, 2021). Mass Timber structures have been demonstrated to reduce greenhouse gas emissions by sequestering carbon, as the wood used in their production acts as a carbon sink, and reduce energy consumption in comparison to steel and concrete (Abed, et al., 2022; Crawford & Cadorel, 2017; Liu, et al., 2016).

Recognizing the growing significance of MTC, it becomes essential to equip future construction professionals with the necessary knowledge and skills to effectively manage and lead Mass Timber projects (Leonard, et al., 2019). The adoption of MTC faces challenges due to limited knowledge in areas such as performance, regulations, fire safety, and the scarcity of local manufacturers (Zaman, et al., 2022; Hossain, et al., 2020). As MTC represents a relatively new and evolving field (Ahmed & Arocho, 2020), a literature review can be effective in preparing industry professionals and construction stakeholders in the construction industry by providing them with a comprehensive understanding of Mass Timber applications in construction, benefits, challenges, innovations, and future trends.

There are a number of systematic reviews in the wood and Mass Timber area that provide insights into Australian government procurement policies, timber construction as a solution to climate change, and wooden multi-story market development (Milestone & Kremer, 2019; Tupenaite, et al., 2023; Jussila, et al., 2022). However, in this study, the focus is on the preparation of industry professionals and construction stakeholders in adopting MTC, exploring its application, and showcasing successful MTC case studies. To address these needs, this paper presents a comprehensive literature review of Mass Timber in construction. The review utilizes systematic search strategies, inclusion criteria, and data analysis to synthesize current knowledge and identify areas for future research. This structured approach ensures a thorough examination of the topic, providing valuable insights for advancing the adoption and implementation of Mass Timber in the construction industry.

2. Research Objectives and Methodology

2.1 Research objectives

The objective of this study is to explore the applications of Mass Timber in construction and identify gaps in the current literature and suggest areas where further research is needed. By addressing these objectives, this literature review aims to provide a comprehensive and insightful analysis of MTC, contributing to the knowledge base and supporting the ongoing evolution of sustainable building practices.

2.2 Search Strategy

A comprehensive search was conducted to gather relevant literature on Mass Timber in construction. This involved utilizing multiple academic databases known for their extensive coverage of scholarly articles, including Web of Science (WoS), ScienceDirect, and Lens.org. The literature database search in WoS was conducted using the "All Fields" feature, ensuring retrieval of all entries where the specified keywords appeared in any fields or in the title, abstract, or author-defined keywords. The search strategy was carefully designed to ensure a wide-ranging collection of relevant studies. Keywords used in the search included "Mass Timber," "Cross-Laminated Timber," or "CLT," and "Mass Timber Construction," among others. These keywords were selected to capture the various aspects and terminologies associated with Mass Timber, ensuring that the search encompassed all relevant research articles.

2.3 Inclusion/Exclusion Criteria

Included studies were peer-reviewed journal articles, conference proceedings, and reviews published within the selected range of 2014 to 2024. This range was chosen to capture the most recent developments and historical context of Mass Timber in construction. Exclusion criteria were applied to maintain focus and quality; non-peer-reviewed articles, non-open access articles, data papers, book chapters, dissertations, and studies not directly related to Mass Timber were excluded. Starting with an initial pool of 342 papers identified through the search strategy, the inclusion and exclusion criteria were applied, followed by the PRISMA screening process (see Fig.1). This process determined the eligibility of the papers, ultimately resulting in the inclusion of 43 papers for review in this study.

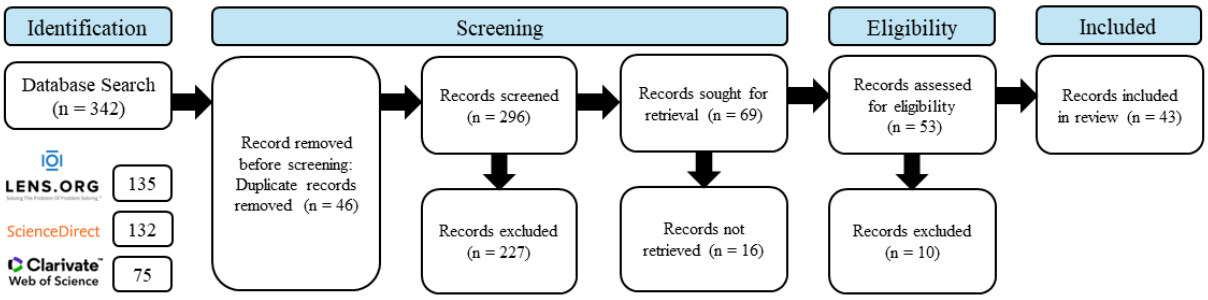

Fig. 1. PRISMA flow diagram of the systematic review process.

2.4 Analysis

The literature was analyzed for recurring themes, methodologies, findings, and gaps. This involved a detailed examination of each study to identify common patterns and significant differences. To enhance the analysis, VOSviewer®, a software tool for constructing and visualizing bibliometric networks, was used. This tool allowed for the mapping of relationships between different studies, highlighting key areas of focus and emerging trends within the field of MTC. Bibliometric analysis was also employed to quantify publication trends and research impact. By using VOSviewer, the review was able to provide a visual representation of the literature landscape, making it easier to identify and discuss the major themes and gaps in the current research. Additionally, a qualitative analysis of the literature was performed to uncover current trends in MTC, examine case studies, and identify future opportunities for its application.

3. Bibliometric and Qualitative Analysis of Literature

3. 1 Bibliometric Analysis

Bibliometric analysis provides a quantitative evaluation of publication trends, revealing the growing academic and research interest in MTC and identifying key journals and conferences contributing to the field. The bibliometric analysis of the publication frequency of the 43 papers reviewed revealed a sharp increase in academic and research interest in MTC in 2022 (see Fig. 2). Although Mass Timber has been utilized in construction since the early 1990s, the analysis of the papers reviewed in this study highlighted a notable rise in scholarly attention over the past decade, indicating a recent acceleration in research activity. This surge corresponds with the industry's heightened focus on sustainable construction practices and the adoption of innovative building materials.

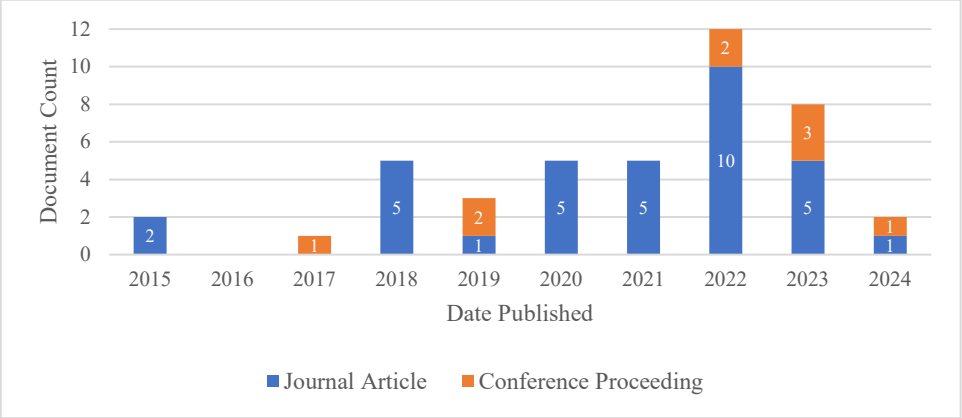

Fig. 2. Scholarly works overtime of records reviewed in this study (Journal Article includes both articles and review articles).

The analysis identified key journals and conferences (Table 1) contributing to the discourse, highlighting a diversification of research topics, including structural performance, environmental impact, and regulatory challenges. The "*Journal of Building Engineering*" and "*Sustainability*" contain the highest number of publications in the MTC area, indicating that these two journals are leading sources of academic and research contributions in this field.

Visualizing keywords co-occurrence from a set of publications can reveal the main topics and how they are related, helping in identifying research trends and gaps. Based on the search settings and inclusion criteria, it was anticipated that "Mass Timber", "Cross- Laminated Timber," and "Mass Timber Construction" would be the most frequently used keywords by the authors in their publications. Fig. 3 demonstrates the keyword co-occurrence in the selected papers for review, using the fractional counting method in VOSviewer. Aside from Mass Timber, CLT, and MTC, researchers frequently use keywords such as "Life Cycle Assessment" (LCA), "Climate Change," and regulation-related terms like "Fire Resistance," "Tall Timber Buildings," and "Seismic Design," indicating concerns in these areas. Additionally, cost-related keywords such as "Circular Economy" and "Deconstruction and Reuse" and construction management-related terms such as "Change Orders" are prevalent in MTC literature.

Overlay visualizations are also a powerful tool for illustrating changes and developments over time. These visualizations allow multiple data sets to be displayed simultaneously on the same graph or chart, making it easier to compare trends, patterns, and relationships between different variables. As illustrated in Fig. 4, the graph, which is scored based on publication dates, indicates that Mass Timber research has been progressively shifting towards CLT and, ultimately, LCA, regulations, and durability of the structure, demonstrating the existing area of concern.

Table 1. Key journals and conferences (emphasizing the frequent appearance of relevant papers in these sources).

Publication Title	Number of Publications	Impact Factor	Percentage	Publication Type
Journal of Building Engineering	6	6.7	14%	Journal Article
Sustainability	5	3.3	12%	Journal Article
Buildings	3	3.1	7%	Journal Article
Mass Timber Construction Journal	3	1.5	7%	Journal Article
World Conference on Timber Engineering (WCTE 2023)	3	–	7%	Conference Paper
Engineering Structures	2	5.6	5%	Journal Article
Wood and Fiber Science	2	1.1	5%	Journal Article
Construction Research Congress	2	–	5%	Conference Paper
Modular and Offsite Construction (MOC) Summit Proceedings	2	–	5%	Conference Paper
Journals with only one publication – combined	13	–	30%	Journal Article
Conferences with only one publication – combined	2	–	5%	Conference Paper

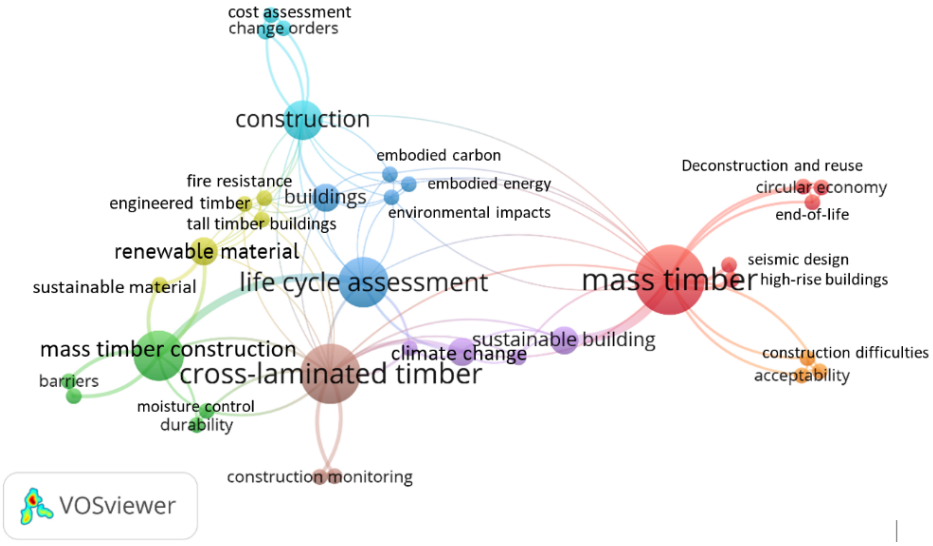

Fig. 3. Keyword co-occurrence using VOSviewer®.

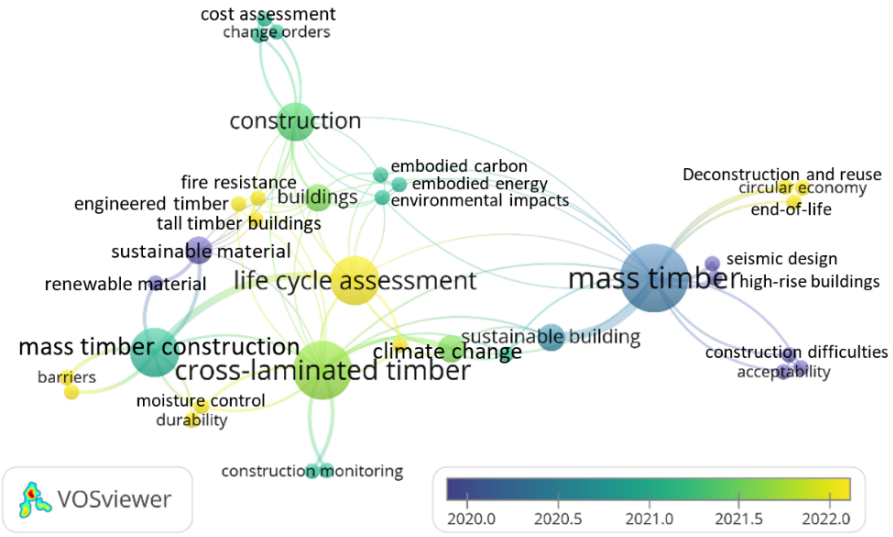

Fig. 4. Overlay visualization using VOSviewer®.

3.2 Trend Analysis

3.2.1 Sustainable Construction and Mass Timber

Numerous research studies have consistently emphasized the sustainability attributes of timber constructions, particularly due to their capacity to sequester carbon dioxide within the wood structure (Pittau, et al., 2019; Crawford & Cadorel, 2017; Liu, et al., 2016). The inherent properties of wood, along with the comparatively simpler manufacturing processes required for producing wood-based construction materials, contribute to its reputation as a sustainable alternative to masonry, steel, and concrete (Vanova, et al., 2021; Abed, et al., 2022; Budig & Mlote, 2022). Additionally, Mass Timber buildings have the advantage of reduction in emissions throughout the building's lifespan (Nuñez Avila & Blanca-Giménez, 2022). Another benefit of MTC is the reduction in construction waste. Brisland et al. (2019) note that prefabricated wood panels, manufactured off-site in controlled environments, result in minimal on-site material waste. These panels are precisely engineered and cut to size, significantly decreasing the amount of waste generated during construction. (Brisland, et al., 2019).

Mass Timber extends beyond being solely characterized as a sustainable material. According to Fell (2013), MTC offers significant aesthetic and biophilic design benefits. Timber provides a visually warm aesthetic that fosters a positive social experience for individuals occupying timber-based buildings (Fell, 2013). The natural beauty and warmth of wood in Mass Timber buildings foster a connection with nature, enhancing occupant well-being, productivity, and satisfaction, and promoting biophilic design principles that encourage a positive relationship between humans and the natural environment (Montjoy, 2022). In summary, MTC provides a sustainable and environmentally friendly approach to building structures. Its renewable nature, carbon sequestration potential, lower embodied energy, reduced greenhouse gas emissions, energy efficiency, waste reduction, and promotion of biophilic design principles make it an attractive choice for those seeking environmentally conscious building practices.

3.2.2 Current Trends and Adoption of Mass Timber in The Construction Industry

The use of Mass Timber in the construction industry is emerging as a significant trend and a sustainable alternative to traditional materials (Aboulnaga & Elsharkawy, 2021). In a study conducted by Ahn et al. (2022), the authors demonstrated that prefabricated Mass Timber panels, such as CLT and Mass Plywood Panels (MPP), have revolutionized timber utilization in construction through innovative integrated building technology. These panels serve as structural components for load-bearing floors and walls, offering a versatile and environmentally friendly solution (Ganey, et al., 2017).

Typically, panel thickness ranges from 3.5" to 12", with the potential to produce panels as thick as 20" (American Wood Council, n.d.; Abed, et al., 2022). Panel widths vary from 8' to 12', while lengths span from 20' to 60' (The Beck Group, 2018). The size limitations are influenced by the capacity of the press used for panel production and logistical considerations during transportation (Canadian Wood Council, n.d.). However, the panels are custom-made to meet the specific requirements of individual projects, with wall panels capable of spanning multiple stories (The Beck Group, 2018). The manufacturing process necessitates specialized facilities equipped with automated machinery to produce panels of such significant dimensions. These panels are fabricated as finished building elements and assemblies, enhancing efficiency and streamlining the construction process (Ahn, et al., 2022).

Prefabrication is a critical requirement rather than an optional choice in MTC. Due to the substantial size of the elements, on-site cutting is impractical (Michael Green Architecture, 2017). Consequently, these components are prefabricated and transported to the construction site for assembly using basic equipment. A variety of connectors are utilized in Mass Timber panel construction, including screws, steel plates, and specialized connectors. These connectors can be pre-installed off-site and rapidly assembled on-site with screws or bolts. According to Polastri et al. (2017), this approach facilitates efficient and streamlined construction processes, ensuring the precise and secure joining of Mass Timber panels. They have shown that the connectors play a crucial role in facilitating in-plane connections of timber panels, as well as connections at various angles, such as between walls and floors. Although a direct comparison of material unit costs currently places Mass Timber products at a slight disadvantage compared to steel and concrete, their utilization of renewable raw materials and their low carbon footprint during manufacturing and construction provide significant competitive advantages over traditional building industries (Kremer & Symmons, 2015). These sustainability factors enhance the appeal and viability of Mass Timber as a construction material in the long run (Ahn, et al., 2022).

In conclusion, these panels have revolutionized traditional building practices by introducing innovative integrated building technology, offering a sustainable and versatile solution for modern construction projects. While the initial adoption of Mass Timber may present challenges and slight cost disparities compared to traditional materials

like steel and concrete, its utilization of renewable resources and low carbon footprint make it an attractive long-term investment for the construction industry. By emphasizing sustainability and environmental awareness, Mass Timber emerges as a competitive and forward-thinking choice, aligning with the industry's growing focus on eco-friendly building practices and addressing the global imperative for sustainable development. Consequently, future trends in MTC are expected to prioritize sustainability, technological integration, and market expansion.

3.3 Case Studies

The reviewed papers collectively highlight the significant environmental and operational benefits of MTC while also addressing the challenges and opportunities associated with its broader adoption. Mass Timber buildings, such as those in the U.S. Pacific Northwest and central Chile, demonstrate lower greenhouse gas emissions and better recycling potential compared to conventional concrete buildings, with Mass Timber structures showing up to 73% recycling potential versus 34% for concrete (Sun, et al., 2022; Liang, et al., 2021; Felmer, et al., 2022). Additionally, MTC projects in Canada and Japan emphasize the adaptability and sustainability of modular Mass Timber systems, which can be prefabricated to meet specific design and environmental standards, such as Passive House certification, and reduce construction waste (Passarelli, 2022; Lang, et al., 2019). However, challenges such as higher initial construction costs, regulatory hurdles, and a lack of familiarity with Mass Timber scheduling and management persist (Mirando & Onsarigo, 2022; Zaman, et al., 2022; Ahmed & Arocho, 2021). Despite these barriers, the potential for Mass Timber to contribute to global sustainability goals, such as net-zero emissions by 2050, is significant, provided that efforts are made to improve regulatory frameworks, fire safety understanding, and cost competitiveness (Zaman, et al., 2022; Fischer, et al., 2023). The studies also highlight the importance of educational initiatives and industry collaboration to bridge knowledge gaps and promote the adoption of circular design principles in higher education (Passarelli, 2022). Overall, while MTC presents clear environmental and operational advantages, overcoming the existing challenges will require concerted efforts from policymakers, industry stakeholders, and educational institutions.

4. Discussion and Recommendations

MTC offers substantial environmental and operational benefits, primarily due to its renewable nature, carbon sequestration capabilities, lower embodied energy, and reduced greenhouse gas emissions. The prefabrication of timber panels minimizes construction waste, while the biophilic design advantages of timber improve occupant well-being by fostering a connection with nature.

The bibliometric and trend analysis reveals a growing interest in MTC, driven by technological advancements such as the prefabrication of CLT and MPP, which enhance efficiency and sustainability in construction. Despite these advancements, MTC adoption faces challenges, including higher initial costs, regulatory hurdles, and a lack of industry familiarity with Mass Timber techniques. The global adoption of MTC is influenced by regional regulatory frameworks and market conditions, with supportive policies and incentives playing a crucial role in its success. To overcome existing barriers, policymakers, industry stakeholders, and educational institutions need to collaborate to improve regulatory frameworks, enhance fire safety understanding, and promote educational initiatives. Future research should focus on addressing performance, regulatory, safety, and cost efficiency challenges to further enhance the viability and appeal of Mass Timber in the construction industry.

This paper recommends several strategies to promote the adoption of MTC. Key among these is the need for collaboration between academic institutions, industry stakeholders, and government agencies to innovate and share knowledge. Investment in research should address fire safety, durability, and the development of new applications. Additionally, promoting cost competitiveness through financial incentives like subsidies and tax benefits can help reduce the initial construction costs, making Mass Timber more appealing compared to traditional materials like steel and concrete.

Educational initiatives are essential to bridge knowledge gaps in MTC. Integrating Mass Timber knowledge into academic curricula and offering professional training programs, including upskilling and specialized training modules, will equip future construction professionals with the necessary skills. Industry collaboration is equally important, fostering innovation and standardizing best practices through partnerships among architects, engineers, builders, and manufacturers. Continuous research should address performance, regulatory, and safety challenges, exploring new materials, construction techniques, and design practices. These combined efforts will advance sustainable and environmentally friendly building practices, leveraging Mass Timber’s benefits to meet global sustainability goals.

5. Conclusions

MTC represents a transformative approach to sustainable building practices, offering significant environmental and operational benefits. The renewable nature of timber, coupled with its carbon sequestration capabilities, lower embodied energy, and reduced greenhouse gas emissions, makes it an attractive alternative to traditional construction materials. Technological innovations in prefabrication and integrated building systems have further enhanced the efficiency and sustainability of Mass Timber projects.

However, the literature review indicates that the adoption of Mass Timber faces challenges, including higher initial construction costs, regulatory hurdles, and a lack of industry familiarity. Addressing these challenges requires collaborative efforts from policymakers, industry stakeholders, and educational institutions. By improving regulatory frameworks, enhancing fire safety understanding and durability of the material, and promoting educational initiatives, the construction industry can overcome these barriers and advance the adoption of Mass Timber.

The reviewed case studies demonstrate the global potential of Mass Timber to contribute to sustainability goals, such as net-zero emissions by 2050. Continued research and innovation in this field will be crucial in realizing the full potential of Mass Timber as a sustainable and competitive building material. By prioritizing sustainability and environmental consciousness, Mass Timber can play a pivotal role in shaping the future of the construction industry.

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