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Social, economic, and policy aspects of cross-laminated timber: A review of emerging literature and future research needs

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ABSTRACT

Production of Cross-laminated timber (CLT), which is the most widely used mass timber product, for use in large-scale building construction has been increasing as an alternative to traditional building materials. While knowledge on the environmental and engineering aspects of mass timber, such as CLT, has been well documented in wood science and engineering literature, little is established regarding the social, economic, and policy aspects. Peer-reviewed publications were examined to establish current knowledge and future research gaps for cross-laminated timber and mass timber systems. Research on these aspects of mass timber is emerging but remains isolated and sporadic. This article synthesizes current research on these topics and identifies future research needs. Remaining gaps include product and lifecycle cost, regional impacts, recyclability, carbon credit potential, small diameter timber and hardwood lumber utilization, policy and incentive programs, and current public perception of cross-laminated timber and mass timber in general. Findings from this study will benefit researchers and other stakeholders in the wood industry and offer guidance on future research opportunities.

1. Introduction

Cross-laminated timber (CLT) is part of the mass timber family of engineered wood products that are manufactured by gluing, nailing, or doweling wood products in various layers resulting into large panels, post, and beams with improved strength and structural performance (Oval, 2024; Atkins et al., 2024). CLT and mass timber wood construction system has seen traction in the building, architecture, and engineering sectors in recent decades (Brandner et al., 2016; Harte, 2017; Ahmed and Arocho, 2021; WoodWorks, 2025). With climate change, interest in using sustainable building materials such as mass timber in place of traditional materials (e.g., steel and concrete) has been growing. Sustainable building materials offer a potential way to mitigate greenhouse gas (GHG) emissions from the built environment, which is responsible for about one third of the global GHG emissions (United Nations Environment Program, 2024). Unlike traditional building materials such as concrete and steel, mass timber materials offer notable GHG emission mitigation benefits in at least two main ways. First, mass timber serve as long-term carbon stores, retaining carbon in its materials throughout a building's service life, and continuing to store majority of that carbon in landfills beyond end of life. Second, the use of mass timber materials displaces high-emission materials such as concrete, resulting in lower overall carbon footprint of mass timber buildings than their traditional counterparts (Kumar et al., 2024; Nepal et al., 2024).

Mass timber buildings are achieving environmental certifications, such as LEED (Leadership in Energy and Environmental Design), likely due to their compatibility with other sustainably conscious structural systems. These certifications showcase and act as industry benchmarks for sustainable and environmentally conscious building practices (Mirando et al., 2024).

The most common mass timber product in use today is cross-laminated timber (CLT) with other products such as glued laminated timber (a.k.a. glulam or GLT), nail-laminated timber (NLT), dowel-laminated timber (DLT), and mass plywood panels (MPP) also gaining market acceptance (Atkins et al., 2024). These mass timber components are used in construction for ceilings, floors, walls, and support beams of buildings and in other large-scale applications such as crane mats or in bridge construction. These mass timber components can be

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prefabricated and constructed off-site, lowering potential transport cost and associated climate impacts compared to traditional construction materials (Ahmed and Arocho, 2021; Abed et al., 2022; Taylor et al., 2023; Kumar et al., 2024). This prefabrication also lowers the amount of manpower needed for installation, as the panels only need to be raised and secured into place (Harte, 2017). Recent studies have shown that construction companies, engineers, and architects are becoming more familiar with mass timber (Vlosky et al., 2019; Ahmed and Arocho, 2021; Penfield et al., 2022). With this increased familiarity many large-scale CLT and mass timber projects have already been completed and hundreds more are in the design and planning stages across the United States (WoodWorks, 2025).

CLT is the primary focus of this study as it is the fastest growing mass timber product, already representing a large proportion of recent and new mass timber construction (Horx-Strathern et al., 2017). As CLT is a mass timber product, this study also examines and discusses the greater context of mass timber as it relates to CLT. Technological advancement in CLT production is advancing rapidly in North America though novel material sourcing, and integration of digital automation. Emerging businesses including Mercer Mass Timber are using design software to streamline engineering, code compliance and manufacturing and thereby make CLT more accessible and scalable. In terms of supply and demand, historic production capacity in North America has lagged, due partly to supply bottlenecks and reliance on imports; recent government support and industry investment have helped fill some of that gap (Brashaw, 2025). At the same time, the number of mass timber projects in the United States has risen sharply over the past decade, with data indicating substantial year-over-year growth in both proposed and completed projects (WoodWorks, 2025). Looking ahead, growing low-carbon mandate in construction, combined with shifting market preferences are expected to contribute to continuous and robust growth of global CLT demand in future (Mordor Intelligence, 2025).

With agreements such as the United Nations Sustainable Development Goals or SDGs, increasing consideration for environmental implications is heavily influencing global politics and international relations (United Nations Environment Program, 2024). Human-caused climate change has seen global atmospheric CO_2 [carbon dioxide] levels rise almost 40 % since the 18th century (Lindsey, 2025). The production of steel and concrete is one of the primary contributors to the rise in global CO_2 levels, equating to 13.5 % of all annual human emissions (Fennell et al., 2022). Use of CLT shows potential in lowering CO_2 levels by acting as a substitute to high emission steel and concrete, releasing less CO_2 during manufacture, and as a source of stored carbon (Nakano et al., 2020; Tellnes et al., 2020; Chen et al., 2022; Greene et al., 2023; Kumar et al., 2024; Nepal et al., 2024). Growing adoption of mass timber systems is likely to positively contribute to the climate change mitigation efforts in the construction industry (Tellnes et al., 2020). Traditional building components that use steel and concrete negatively impact climate through the release of CO_2, and increases in ocean acidification, city smog, waterway eutrophication, and heavy metal leachate in soils (Junnila and Horvath, 2003; Kumar et al., 2024). More recent studies suggest that mass timber products, such as CLT, have the potential to lower GHG emissions by almost up to 100 % when they are used in place of traditional reinforced concrete or structural steel construction systems, especially when reuse/recycling of mass timber materials after the end of their first service lives is considered (Greene et al., 2023; Kumar et al., 2024).

In May 2022, the Biden administration announced allocating $44 million toward improving research and development of climate-smart wood products and to help establish future wood-based markets (USDA, 2022). This investment showcases some of the recent policy and investment placed on promotion of mass timber products in the U.S. Job creation and market opportunities play a key role when considering the economic benefits of mass timber. With the decline in market for traditional forest products such as paper and pulp across the United States, many jobs have been lost. CLT and other mass timber show potential for job creation particularly in these struggling wood product sectors (Scouse et al., 2020; Brandeis et al., 2021). A specific example is the closure of pulp and paper-based industries in Tennessee and surrounding states leading to a negative impact on rural communities by limiting the avenues for landowners to sell their stumpage (Brandeis and Guo, 2016; University of Kentucky Forestry Extension, 2015). This shows a need for the establishment and development of new industries that can create a market for the timber stock of these landowners and revitalize rural economies impacted by the decline of these traditional wood product markets (Poudyal et al., 2017; Adhikari et al., 2023). Some concerns have been raised regarding the possibility of larger mass timber industry harming traditional tradeperson jobs (e.g., carpenters, roofers). However, such a concern has been addressed by a recent study which concluded that a larger mass timber industry would instead add jobs to the market and raise household incomes in the economically impacted areas without harming traditional tradesperson jobs (Abed et al., 2022).

Most research on CLT or mass timber, thus far, has focused on engineering and life-cycle environmental impact assessment aspects, although some sporadic studies have also investigated social, policy, and economic aspects. Much of the research in these areas has remained sporadic and are discipline specific with no clear consolidation of findings or information. For instance, research into economic implications surrounding CLT has grown greatly in recent years but, findings have not been synthesized into a concise format. For this study, economic research relates to job creation, industry investment, product cost, market supply and demand, and building cost. Studies examining societal and policy implications are also limited and what has been done has not been synthesized (Scouse et al., 2020; Ahn et al., 2022; Liu et al., 2023). For this study, social research is defined as research about public acceptance, mental and physical well-being, psychological factors and perception regarding aesthetic, safety, eco-friendliness, greenness etc. Policy research refers to research on product standards, building codes, market assurances, subsidies, grants, policy formation, and implications. The need exists to integrate findings from various disciplines including engineering, environment, economic, social, and forestry sciences to better understand the current state of mass timber knowledge. Summarizing available knowledge as well as identifying future research needs is vital for promoting increased use of CLT. This synthesized knowledge is important because it enables individuals and forestry professionals, researchers, forest landowners, wood products manufacturers, builders, architects, environmental groups, local and federal government agencies, and policymakers to make better informed decisions, develop effective policies, and adopt practices that support not only sustainable forest management but also promote responsible use of wood products and healthy climate.

This study had three objectives. The first objective was to establish a review and synthesis of current research surrounding the economic, social, and policy implications of CLT and mass timber in general. The second objective was to identify gaps in knowledge and establish potential future research questions to advance the domestic CLT and mass timber sector. Findings from those two objectives led to our third objective, which was to assess the opportunities and barriers for utilizing small diameter timber and hardwood lumber in manufacturing of CLT. Most of the current manufacturing of CLT utilize higher grade softwood lumber as raw material. The potential for utilizing small diameter timber and/or hardwood lumber has been less explored. Studying these aspects of mass timber is important for various reasons. Social acceptance is a key factor in promoting the use of mass timber. Insights into public opinion and familiarity can help shape targeted educational initiatives and campaigns to increase awareness and support. Similarly, policy aspects is important because well-informed policies are essential for standardizing and regulating mass timber practices. Research into existing policies and their successes or shortcomings can guide effective policymaking, ensuring the safe and sustainable implementation of mass timber systems. Likewise, social research sheds light on how mass timber systems affect communities, whether in terms of safety perceptions, aesthetic value, or mental and physical well-being. This helps tailor designs and applications to better suit societal needs. Finally, economic studies often delve into subsidies, grants, market assurances, and building codes, all of which significantly influence the economic viability of mass timber products and new investment in market. Understanding these aspects can aid stakeholders in optimizing economic benefits. Overall, mass timber has the potential to align with eco-friendly initiatives and reduce the carbon footprint of the construction industry. Social and policy research ensures that this alignment is effectively communicated and supported through legislative frameworks. This multifaceted understanding enriches the conversation around mass timber, providing actionable insights for researchers, industry professionals, policymakers, and communities. It's an integral part of fostering a balanced and sustainable approach to its adoption.

2. Materials and methods

A narrative review methodology was used to assemble and synthesize the current state of knowledge related to the social, economic, and policy aspects of CLT. Narrative reviews offer broad contextual overview for fields with scattered literature and research. The culmination of these sources are then presented in a narrative form in order to guide the reader through the literature and provide broad summaries and conclusions (Baumeister and Leary, 1997; Sukhera, 2022). This approach is similar to the widely adopted SALSA (Search, Appraisal, Synthesis, and Analysis) framework (Grant and Booth, 2009), which begins with the initial stage of searching (with a pre-determined set of keywords of interest), appraising (or screening for relevance, quality etc.), synthesizing, and analyzing.

To develop this study's narrative review, relevant journal articles, technical reports, conference papers, news reports, and other scientific articles were gathered using various search databases. These materials were then examined for recurring themes, methods, and findings, and subsequently categorized into key areas of knowledge related CLT and mass timber. The categorization of these knowledge areas was determined based on their prevalence in the literature and the discretion of the research team. Primary search databases included Scopus, Web of Science, CABI Digital Library, and the U.S. Forest Service TreeSearch. Due to the majority of mass timber research emerging in the past decade, all relevant articles and publications were considered independent of article age. A total of fifty-five articles used in analysis were identified: thirty-five economics articles, ten policy articles, and ten social articles. Thirty-seven articles were published from 2020 to 2024 with twenty-three articles published between 2015 and 2019 (Fig. 1). Primary focus of this study is the United States. However, studies from other countries or regions have been included when they offer complementary perspectives or provide context, examples, or insight that help illuminate potential implications to US markets and enrich the discussion.

Search terms were broken up by social economic and policy and each term was searched in each of the databases listed above. Common search criteria included primary terms such as “mass timber” and “cross-laminated timber” combined with secondary terms. Due to an over-abundance of engineering-related results showing up exclusions were made for engineering-related criteria such as mechanical engineering civil engineering industrial engineering etc. Search databases used and the excluded and included search terms are summarized in the table below (Table 1). All terms were used in searches across each database. Search terms were used to search through article titles abstracts and keywords. Each article was then examined and only excluded if we felt the article did not fit into the scope of research for this project. However CABI Digital Library and Forest Tree Service Tree Search yielded a limited number of results making excluded term unnecessary. Conversely excluded terms were added to Scopus and Web of Science to lower the number of sources that are out of scope and unsuitable until the searches resulted in a relevant and manageable number of results. Scientific articles and publications were analyzed and selected based on the research team's assessment of how closely the resources fit the above-mentioned social economic and policy categories

It should be noted that while adding broader terms, particularly

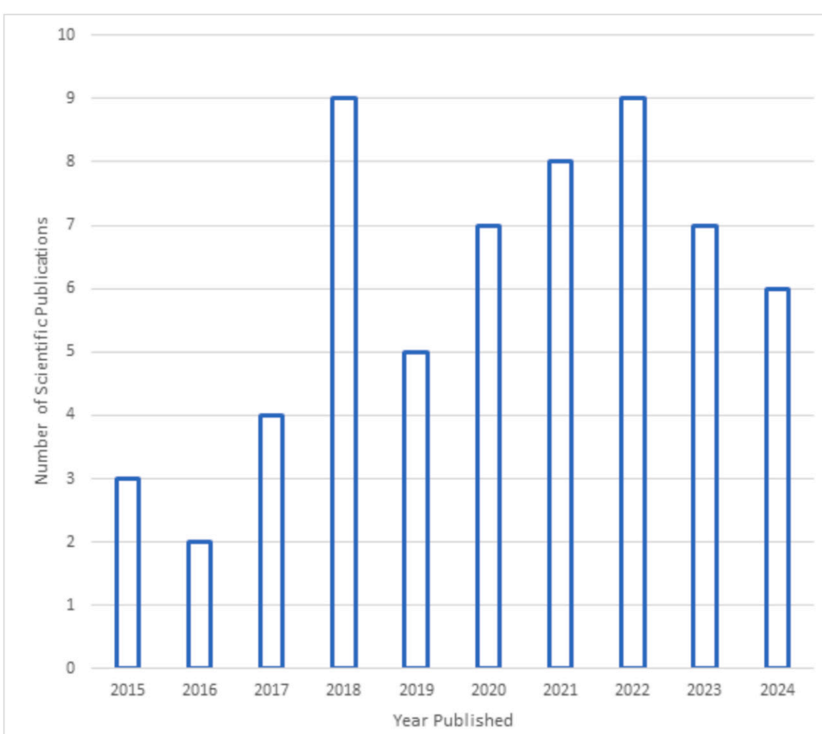

Fig. 1. Frequency of publications by year on social, economic, and policy aspects of mass timber and mass timber systems research. Publications were compiled from Scopus, Web of Science, CABI Digital Library, and the U.S. Forest Service TreeSearch.’

Table 1
Databases and terms used during the literature review process.

Search Database	Excluded Terms	Included Terms
Web of Science	"Engineering Civil", "Engineering Mechanical", "Engineering Geological", "Engineering Multidisciplinary", Engineering", "Electrical", "Electronic", "Engineering Industrial", "Engineering Manufacturing", "Metallurgy", "Metallurgical", "Engineering"	"econom*", "job creation", "investment cost", "production cost", "supply", "building cost", "market demand", "production standard", "building code", "market assurance", "subsid*", "grant", "acceptance", "mental well-being", "physical well-being", "aesthetic", "safety", "eco-friendly", "perception"
Scopus	"Engineering", "Chemical Engineering"	
CABI Digital Library	None	
Forest Service Tree Search	None	

Note: Asterisk (*) at end of search terms indicates a multiple character search (e.g., econ* = economy, economic, economics, etc.…).

social and political, would have made our search more comprehensive, we consider this to be a very minor bias, if any, for two reasons. First, the studies on social science aspects of mass timber are just emerging, rare and extremely limited. If our review study was about a topic (e.g., tree mortality, fire ecology) that with a substantial literature already, it would have made a significant difference but in our case of relatively understudied topic, we do not consider that being a significant issue. Second, during our search of relevant literature on social aspect of mass timber during this study and another related study (Bremner et al., 2025), we have not seen any other publications that were not detected by our search protocols. Nonetheless, we note that like in any review studies, search terms we used may not necessarily be an entirely exhaustive list.

Research gaps were established based on the review of the information presented in the collected literature. Areas or topics with few or no articles were noted and researched further. The identification of these missing or unexplored topics was established through the literature compiled during the literature review process in order to gain insight into gaps in research on mass timber systems. These research needs and gaps are further expounded upon in the discussion section.

3. Results

The research related to CLT has been sporadic, especially in the areas of economic, policy, and social research. Gathering and synthesizing what knowledge is presently available will be valuable for the industry moving forward. A summary of what is currently known on the economic, policy, and social aspects of mass timber is listed in the following sections. The following section discusses these aspects in depth and can be used as a general resource for the current state of mass timber research and knowledge.

3.1. Economics

The economic aspects of CLT were the most widely researched in scientific literature when compared to policy and social aspects. Final product cost, utilization of novel low-quality wood materials, consumer willingness to adopt, supply and demand, carbon credit potential, and novel hardwood utilization are all discussed in the following section and table below (Table 2).

Cost consideration heavily impacts whether an industry is willing to adapt to a newer technology. A U.S. study examining a 12-story mass timber building made from softwood timber found that although front-end costs would be 26 % higher, the mass timber building would provide

Table 2
Summary of current knowledge and references on economic aspects of CLT.

Knowledge area	General findings	References
Cost Consideration	The current upfront cost of CLT and mass timber construction may be higher, but the long-term life-cycle cost is low	Rajagopalan and Kelley, 2017, Brandt et al., 2019, Gu et al., 2020, Ahmed and Arocho, 2021, Ahn et al., 2022, Balasbaneh & Sher 2022, González-Retamal et al., 2022
Small-Diameter and Low-Quality Lumber	Limited research and utilization of small-diameter lumber in CLT and mass timber components has shown potential with projects and research continuing to develop	Fredriksson et al., 2015, Crovella et al., 2019, Wu et al., 2021, Azambuja et al., 2022, Vaagen Timbers, 2024
Willingness to Adopt	The U.S is likely between the evaluation and trial stage of a successful adoption with architects in particular becoming more familiar with CLT and mass timber. Although familiar, many are still hesitant toward full adoption at this stage.	Laguarda Mallo and Espinoza, 2015, Strobel et al., 2017, Evison et al., 2018, Nepal et al., 2021, Ahmed and Arocho, 2021, Penfield et al., 2022,
Supply and Demand	The likely impact on the forest resource base for CLT and mass timber is minimal given the higher growth-to-drain ratio	Brandt et al. 2021, Comnick et al., 2021, Nepal et al., 2021, Nepal et al., 2024
Stored Carbon	Stored carbon in CLT and mass timber has positive environmental and economic potential through reduced greenhouse gas emissions and carbon credit incentives	Lehmann, 2012, Kremer and Symmons, 2015, Ahmed and Arocho, 2021, Chaggaris et al., 2021, Liang et al., 2021, Pasternack et al., 2022, Taylor et al., 2023, Kumar et al., 2024, Nepal et al., 2024
Hardwood Mass Timber	Hardwood CLT shows potential in mechanical testing and to alleviate struggling hardwood markets but will likely remain a niche product with higher cost and limited supply compared to traditional CLT products	Liao et al., 2017, Ehrhart and Brandner, 2018, Crovella et al., 2019, Adhikari et al. 2020, Brandeis et al., 2021, Comnick et al., 2021, Abed et al., 2022, Ettelaei et al., 2022, Azambuja et al., 2022, Norris et al., 2024, Hassler et al., 2024

a cost saving of 2.4 % over its life cycle, especially when the end-of-life salvage values of mass timber was factored in (Gu et al., 2020). A U.S. based review study established a similar results with mass timber building costs likely higher than steel and concrete across examined studies. The study did state that adding carbon offsets likely shifts this value consideration in favor of mass timber. The same study found that limited research on the economic cost of mass timber was a factor affecting their ability to establish a definitive answer (Ahn et al., 2022). A recent non-U.S. based study has concluded that mass timber buildings showed competitive costs when compared to multi-story buildings constructed of conventional materials like concrete and steel (González-Retamal et al., 2022). A study calculating the manufacturing cost of CLT in the northwestern U.S. stated that a hypothetical CLT plant could produce panels at an average cost of $536/m^3$ of finished product. The price range was calculated at between $518/m^3$ and $652/m^3$ depending on facility size and location. The economic analysis in this study was conducted on a cost base year of 2015 (Brandt et al., 2019). The lack of a widespread market and availability of CLT in many regions of the U.S. likely plays a large role in the current high cost of these mass timber systems (Rajagopalan and Kelley, 2017; Ahmed and Arocho, 2021). A study from 2022 looking at the potential for increasing mass timber use in Malaysia found that the life-cycle-cost of dowel-laminated timber and nail-laminated timber wall assemblies were lower when compared to CLT (Balasbaneh and Sher, 2024). As concluded by a U.S. based stakeholder survey study (Bremner et al., 2025), these cost and market availability considerations will play a major role in the adoption and utilization of mass timber going forward. Continued research on the economic and life cycle cost of mass timber buildings will need to be conducted to alleviate concerns from investors, engineers, and architects on the economic viability of mass timber construction.

Small-diameter timber or lower-quality lumber in CLT panel construction may be a way to lower cost and increase timber availability. Small-diameter timber is often a bioproduct of timber harvest operations and is frequently used in pulp, biofuel, or particle board. A study tested small-diameter timber as structural members and found that these components performed sufficiently for several light frame construction purposes (Wu et al., 2021). An earlier study tested small-diameter lumber in CLT construction utilizing a novel trapeze edging method. They concluded that this method was feasible and increased small-diameter lumber yield. A drawback to this method is that it would require changes to sawmill operations, edging machinery, and specialized CLT production equipment to fully utilize small-diameter lumber (Fredriksson et al., 2015). Vaagen Timbers, a mass timber producer in Washington, has successfully specialized in small-diameter lumber in their production process. Currently, their website lists the use of logs smaller than 8 in. in diameter in their CLT and glulam panels (Vaagen Timbers, 2024). Researchers at Washington State University are working on a project funded by a USDA Forest Service wood innovations grant to model the characteristics, press loads, and performance of small-diameter timber feedstock for use in CLT panels (U.S. Forest Service, 2022). Testing into utilizing low-quality lumber in CLT panels has been optimistic surrounding its mechanical effectiveness. A study examining a variety of species found that low-grade red maple and white ash met PRG 320 guidelines, but low-grade white pine did not meet the requirements (Crovella et al., 2019). A more recent study tested yellow poplar No. 2 common boards in CLT panel construction. They concluded that a large portion of these low-quality yellow poplar boards can be effectively utilized in CLT panel construction under PRG 320 guidelines (Azambuja et al., 2022). Utilizing small-diameter or low-quality timber stock in mass timber systems shows potential to lower cost and increase lumber availability; however, further research and testing is needed to form conclusive results.

A consumer's willingness to adopt plays a key role in the acceptance of a new or novel product. Mass timber products are still relatively new, especially compared to other traditional construction methods and materials. For a new construction material like CLT to be accepted and utilized by architects and engineers, there needs to be both demand for the product as well as sufficient manufacturing capacity to supply the product (Evison et al., 2018). Successful adoption of new products like mass timber requires awareness, interest, evaluation, trial, repeat purchase, and finally full adoption by consumers (Laguarda Mallo and Espinoza, 2015, Nepal et al., 2021). Another study found that a majority (58 %) of U.S. architecture firms surveyed in their study were still unfamiliar with CLT as of 2015. A follow-up study that surveyed U.S.-based engineering firms found a similar observation with 59 % of the firms not being familiar with CLT (Laguarda-Mallo & Espinoza 2018). More recent studies suggest that overall awareness about mass timber among architects has improved over time (Ahmed and Arocho, 2021; Penfield et al., 2022). For example, 70 % of U.S. architects surveyed as of 2021 had participated in some capacity with mass timber but that 45 % of those surveyed architects had less than 1 years of experience. When the researchers asked about design difficulties, lack of stakeholder awareness was listed as one of the most frequent answers given by architects surveyed (Ahmed and Arocho, 2021). Positive environmental impacts have been shown to increase a consumer's willingness to utilize or adopt a new wood-based product. Although this plays a key role in the positive perception of these products, cost is still the primary factor when indicating whether a consumer will purchase or utilize a wood-based product (Strobel et al., 2017). Another aspect influencing adoption is the perceived susceptibility of mass timber to fire. Current research is favorable toward mass timber fire performance with many studies concluding mass timber has adequate fire resistance for use in construction. Fire remains one of the key concerns surrounding mass timber use, likely impacting adoption (Abed et al., 2022). This will require a continued effort on the side of researchers to communicate the fire safety of mass timber.

Supply of and projected demand for mass timber is important for establishing the economic viability of these products. A U.S. based study found that by the year 2030 market penetration of CLT would be estimated at 24 % and the demand will be higher in some states (California, Washington, and Arizona) than in others. Their results showed that given the current CLT production capacity, manufacturing supply would not exceed demand until 2026 or 2028 depending on the scale of operations. Maximizing production to match capacity tends to generate the best economic viability given the large, fixed cost of mass timber manufacturing facilities. The economic viability of mass timber also depends on the supply of its raw material – lumber, which is processed using roundwood timber as input. Looking at lumber supply and assuming current production capacity, the researchers concluded that the total lumber supply required to feed these CLT manufacturers was modest, between 1.6 % and 1.8 % of the total U.S. lumber supply (Brandt et al., 2019). A similar U.S. based study examined the potential impacts on sustainable timber supply given an increasing mass timber demand. The researchers split the U.S. into North, South, and Western and estimated impacts on demand up until 2035. The only region that under conservative estimates might see demand exceeding timber supply is that of the Western U.S. with the North and Southern U.S. able to supply projected demand under all scenarios (Comnick et al., 2021). Another study evaluated the impacts on global wood products markets of projected mass timber demand in multiple countries, which also suggested smaller impacts on global timber supply (harvests), with varying impacts on individual countries. However, they found that higher global lumber demand for mass timber production would lead to a diversion of lumber consumption away from the traditional construction industry (e.g., light-frame construction), suggesting a likely strong market competition for lumber between mass timber and traditional construction use. Depending on the demand scenarios, they projected that increased demand for mass timber globally could drive up lumber prices by 2 % to 23 % by 2060, suggesting likely increased costs of both mass timber and traditional constructions (Nepal et al., 2021). Although the current literature surrounding timber supply is limited, a few studies that have been published on this topic are optimistic. It seems unlikely that an expanding CLT or mass timber market would run into timber supply limitations any time soon.

Stored carbon in mass timber components is a major factor when considering the positive environmental impact and economic potential of increasing mass timber use in construction (Lehmann, 2012; Ahmed and Arocho, 2021; Chaggaris et al., 2021; Pasternack et al., 2022). A U.S.-based survey of architects and building contractors showed that the low-carbon emission aspects of mass timber were a primary factor when architects and builders were considering these components for construction projects (Ahmed and Arocho, 2021). Positive carbon impacts and potential for carbon storage as well as lower greenhouse gas emission potential have been discussed extensively in much of the recent scientific literature (Kremer and Symmons, 2015; Ahmed and Arocho, 2021; Liang et al., 2021; Kumar et al., 2024; Nepal et al., 2024). The creation of economic incentives for the stored carbon and emission reductions in mass timber products creates a potential for carbon credit systems to be established. A recent study concluded that the potential economic and monetary compensation for stored carbon in mass timber products could be significant, depending on carbon prices. These credits could be provided based on mass timbers' intrinsic storage of carbon as well as an alternative for other high GHG emitting construction materials, thus avoiding carbon emissions in two ways (Taylor et al., 2023).

Carbon credits for mass timber use have the potential to address some of the cost concerns discussed in the previous section. An established mass timber carbon credits system would offset some of the operating costs associated with a mass timber building by providing a potential source of continued financial compensation over the building's lifespan.

To date, lumber in U.S. CLT manufacturing has come from softwood species (Comnick et al., 2021). Studies surrounding the performance of hardwood use in CLT have shown positive results in mechanical and performance tests. Mechanical rolling shear strength has been tested using European hardwoods with positive results (Ehrhart and Brandner, 2018). A similar study using American red maple, ash, and Eastern white pine in the U.S. reached similar conclusions with both hardwood species meeting strength requirements for CLT construction (Crovella et al., 2019). Scientific literature surrounding hardwood CLT fire resistance has been optimistic about these CLT panels meeting fire and safety construction requirements (Abed et al., 2022). Scientific testing surrounding hardwood CLT mechanical performance seems to be hopeful about the future of hardwood use in mass timber products. The literature is still limited, and future testing will be required to confidently establish performance parameters and standards.

Utilization of hardwood timber stock for mass timber components such as CLT shows potential to recover declining hardwood markets. For 2023, Hardwood Market Report (2024) reported the lowest annual eastern U.S. hardwood sawmill production of 5.54 billion board feet since at least 1960, a huge decline from years pre-pandemic. In addition, pulpwood, paper, and paperboard industries in the U.S. have shown a general decline in consumption and production since the 1990s (Brandeis et al., 2021). Another recent U.S. study examining the regional and economic impacts of mass timber in the state of Oregon discussed local vs non-locally sourced wood in a CLT building (Scouse et al., 2020). Through a regional economic analysis, this study found that constructing a 12-story CLT building constructed with locally sourced wood could generate a net economic benefit of $4.8 million, compared to traditional 12-story concrete frame building. In contrast, using non-local wood reduced the benefit to $1.09 million. A survey study of current CLT manufacturers in the U.S. stated that quality, quantity, and grading standards were the main concerns of these manufacturers. They further state that CLT manufacturers are hesitantly optimistic about hardwood use in mass timber products such as CLT (Adhikari et al., 2023). Hardwood utilization in mass timber products such as CLT shows potential to remediate some of these lost economic sectors and support rural community timber markets. The mechanical testing surrounding hardwood use in CLT is optimistic; however, the economic and logistics of utilizing hardwood species on a large scale is still up for debate.

A potential barrier to utilizing hardwood in CLT or mass timber is the cost differences between hardwood and softwood lumber (Bremner et al., 2025). Hardwood lumber in the U.S. is on average two to three times that of comparable softwood lumber (Timber Update 2023). A potential solution is the utilization of low-grade and/or small-diameter hardwood species. Several studies have evaluated low-grade or small-diameter hardwood lumber from species such as poplar, ash, oak, and maple and concluded the CLT panels met strength requirements (Crovella et al., 2019, Azambuja et al., 2022, Norris et al., 2024, Hassler et al., 2024). Low-density yellow poplar has also been tested; however, the CLT panel did not meet structural requirements. The researchers did note that when the low-density yellow poplar was combined with traditional softwood species the panels exceeded strength requirements (Kramer et al., 2014). This was an early study from 2014 with the potential for replicating the study with modern adhesives and techniques. Small-diameter Chinese and European eucalyptus has been tested in CLT panel construction with positive mechanical results (Liao et al., 2017, Ettelaei et al., 2022). However, it is not clear how applicable these tests are to American hardwoods given the unique fast-growth characteristics of eucalyptus.

3.2. Policy

Many of the studies on the policy aspects of mass timber in the U.S. have been conducted in the last several years. Policy formation outside of the U.S. is more developed with several countries establishing programs in the late 90's. Policies adopted outside of the U.S. were considered in order to add perspective and potential insight to inform policy making in the U.S. Examining these foreign policy, including their successes and failures, could help guiding the development or further improvement of U.S. based policy efforts. This non-U.S. policy as well as U.S. specific policy and subsequent policy adoption and cost in the U.S. is discussed in the following section and table (Table 3).

Government policies and regulations play a key role in the production and use of all products including CLT. A study from 2016 found that the first policies surrounding CLT and mass timber were enacted by Germany, Austria, and Switzerland in 1998 with policies for the rest of Europe following in 2006 (Brandner et al., 2016). After this initial wave of policy introduction in European countries, other countries including Canada, China, Japan, New Zealand, Norway, and the United States started to research and enact policies and construction standards surrounding mass timber (Brandner et al., 2016, Su, 2018, Nakano et al., 2020, Wahlstrøm, 2020). A study in 2016 looking at the state of CLT research in North America found that building code acceptance and standardization of design methods were the most pressing research needs at the time (Pei et al., 2016). In 2010, the Japanese government enacted policies to greatly support the production and implementation of wood in building construction, where CLT has become a major push with direct government incentives and subsidies offered to companies that either produce or use CLT in construction projects. These policies led to an increase in the number of structures in Japan utilizing CLT from 26 in 2015 to 300 in 2018 (Nakano et al., 2020). These Non-U.S. mass timber policies highlight the positive potential for CLT policy implementation and offer valuable insights for sharping related policies in the U.S.

In the United States, policy formation surrounding tall mass timber buildings gained traction in 2012 with organizations such as the American Wood Council (AWC) establishing a five-year plan with support from the Softwood Lumber Board and U.S. Endowment for Forestry and Communities to expand the International Building Codes (IBC) current guidelines on tall timber building construction (Stegner and Fotheringham, 2022). The IBC is a code and guideline standard created

Table 3
Summary of current knowledge and references on policy aspects of CLT and mass timber.

Knowledge area	General findings	References
Non-U.S. Policies	Policy surrounding mass timber started in the late 90's with many countries enacting new programs to push mass timber adoption and utilization	Brandner et al., 2016, Su 2018, Nakano et al., 2020, Wahlstrøm, 2020, Pei et al. 2016, Nakano et al., 2020, Pasternack et al., 2022
U.S Policies	U.S policy formation surrounding mass timber started in 2012 with the International Code Council (ICC) continuing to evolve the International Building Codes (IBC) with expanded fire safety and exposed CLT guidelines	Kouarti 2017, Gu & Bergman 2018, International Code Council 2020, Stegner and Fotheringham, 2022, International Code Council 2023, University of Massachusetts Amherst 2023, International Code Council 2024
Policy Adoption and Cost	New and upgraded mass timber facility costs are likely more economically feasible than many local governments have found leading to positive potential for incentive policy programs	Milestone & Kremer 2019, Riddle 2023, WoodWorks 2024

by the International Code Council (ICC) for building construction in the United States, Puerto Rico, and the U.S. Virgin Islands. These codes include building codes for all buildings, excluding townhouses up to three stories as well as one- or two-family homes. These codes are released on a three-year cycle with individual states and municipalities choosing whether to adopt the current IBC guidelines or remain under a previous version (International Code Council 2024). In 2012 the AWC proposed changes to the 2015 IBC that aided in the establishment of guidelines specifying CLT use as a heavy timber building (type IV-HT) element in the IBC 2015 guidelines (Stegner and Fotheringham, 2022). It was under the IBC 2015 guidelines that the first design plans were developed such as the Framework building proposed by Lever Architecture in Portland Oregon and the John W. Olver Design Building proposed by Leers Weinzapfel Associates in Amherst Massachusetts (Kouarti 2017, Gu and Bergman 2018, University of Massachusetts Amherst 2023). These changes were proposed and spearheaded by the AWC in collaboration with the Softwood Lumber Board and the U.S. Endowment for Forestry and Communities as well as an Ad Hoc Committee on Tall Wood Buildings approved by the ICC Board of Directors in 2015. The Committee established research and testing needs and tests were conducted to support new safety and performance guidelines for CLT construction. Fourteen mass timber code changes were approved for the 2021 version of the IBC guidelines (International Code Council 2020). These changes established three types of mass timber building construction categories: Type IV-A classified as wood buildings up to 18 stories with noncombustible protection over mass timber, Type IV-B classified as wood buildings up to 12 stories with limited exposure of mass timber ceiling panels, and Type IV-C classified as wood buildings up to 9 stories with completely exposed mass timber with 2-h fire ratings. The AWC and ICC Committee on Tall Wood Buildings put forward changes again during the 2021 IBC development phase which were later approved and have now appeared in the 2024 version of the IBC guidelines (International Code Council 2023). The major changes in this 2024 version included new fire safety guidelines allowing for Type IV-B mass timber buildings to have all interior floors and ceiling areas constructed of exposed CLT (International Code Council 2023, Stegner and Fotheringham, 2022).

One of the main factors for local governments' hesitancy or barriers to adopting mass timber building policy is the lack of knowledge on cost. A 2019 study found that governments and councils might find mass timber use more economically feasible than previous assumptions and recommended local cost-benefit analysis (Milestone & Kremer 2019). New mass timber facility costs and costs associated with upgrading current facilities have been a general concern limiting mass timber adoption. In 2018 the U.S. Farm Bill introduced the Community Wood Energy and Wood Innovation program to facilitate wood-utilizing industries. One of these applications is the Innovative Wood Product Facilities grant, which provides cost share for innovative wood facilities, which include mass timber facilities (e.g., sawmills, mass timber manufacturing). These grants can cover up to 30 % ($1 million cap) of a facility's cost. However, few mass timber-related projects have been funded under this program (Riddle 2023). WoodWorks provides education for the AEC community through its outreach activities on non-residential construction, primarily CLT and other mass timber systems (WoodWorks, 2025).

3.3. Social

Social aspects of CLT were organized into three categories of public opinion, psychological and physiological well-being, and willingness to adopt and are listed in the table below (Table 4). Psychological and physiological well-being associated with wood have the most references; however, it is noted that none of these studies are CLT or mass timber specific. Willingness to adopt is likely the most widely studied social aspect of CLT. However, these studies are still limited compared to other non-social aspects. Many barriers surrounding willingness to adopt for CLT have been listed in various studies over the last decade.

Table 4
Summary of current knowledge and references on social aspects of CLT and mass timber.

Knowledge area	General findings	References
Public Opinion	The most recent studies looking at public opinion on CLT and mass timber showed limited familiarity with public opinion being generally positive about environmental aspects and safety concerns.	Larasatie et al., 2018, Montague et al., 2021, Debnath et al., 2022, Stegner and Fotheringham, 2022
Psychological and Physiological Well-Being	Studies surrounding exposed wood use in building construction are extensive with long-term support for the positive psychological and physiological aspects of wood	Sakuragawa et al., 2005, Nyrud A. & Bringslimark T. 2010, Burnard et al. 2015, Strobel et al., 2017, Yin et al., 2018, Jo et al., 2019
Willingness to Adopt	Economic risk, awareness, cost, comparability to other materials, sustainability, code standards, performance, fire safety, and durability are the primary factors affecting engineers, architects, and contractors' willingness to adopt CLT	Laguarda Mallo and Espinoza, 2015, Zelinka et al. 2021, Ahmed and Arocho, 2021, Abed et al., 2022, Penfield et al., 2022, Ricco et al. 2023

The most recent study directly examining public opinion on mass timber assessed the opinions on CLT of millennials and showed participants had a positive but limited knowledge (Montague et al., 2021). The study concluded that information campaigns will be vital to communicate the properties and potential benefits of CLT to this younger demographic. An indirect recent study by in 2022 looked at public perception on social media. However, this study took a meta-analysis approach and did not ask direct questions about mass timber (Debnath et al., 2022). The most concrete research on public opinion and mass timber was conducted by a study in 2018. In this study, the researchers found that limited familiarity was common among the survey respondents. The neutral responses given by the participants prompted the researchers to emphasize education as a positive strength for advancing future initiative. Participants stated mass timber construction was seen as having better environmental performance while also stating concerns surrounding deforestation, fire risk, and uncertainty surrounding earthquake (seismic) risk. This study was pivotal in establishing many of the currently held perceptions of what the public thinks about CLT and mass timber (Larasatie et al., 2018). However, the questionnaire for this study was administered throughout 2017, making the information and conclusions gathered, over half a decade old. Social pressures surrounding building-oriented climate action are prominent on social media platforms and online discussions. These pressures influence the perception and discourse around recent international climate agreements and climate mitigation policies such as the 2015 Paris Agreement, EU Green Deal, and the 2017 UN Climate Change Conference (Debnath et al., 2022). A more study involving attitudes and perception of stakeholders found some promises for CLT from hardwood species in terms of mechanical effectiveness, supply and aesthetic value that can be added with hardwood, but note that higher cost of raw materials, liability issues and lack of establishing lumber grading could be potential barriers in growth of hardwood CT products (Brember et al. 2025). Further research into the social implications including public awareness, knowledge, attitudes, acceptability, and preference of CLT and mass timber is limited. Recent research by Montague et al. (2021) and Debnath et al. (2022) has shown the importance of acquiring these perspectives as well as establishing the link between social perception and environmental policy support surrounding CLT and mass timber use. The dated nature of available information creates a need for up-to-date research and surveys on public opinion surrounding CLT and mass timber in general. Given how far the policy and construction guidelines have come in the last five years (Stegner and Fotheringham, 2022), it is reasonable to assume that the public's opinion on CLT and mass timber has likely shifted since the last in-depth surveys were administered.

The connection between the natural environment and human well-being in constructed spaces has been well-established in the physiological and psychological scientific literature (Sakuragawa et al., 2005, Nyrud and Bringslimark, 2010, Burnard et al. 2015, Strobel et al., 2017, Jo et al., 2019). Some early studies of note concluded that interior wood wall panels decrease depression and lower blood pressure (Sakuragawa et al., 2005). Similarly, Bringslimark (2010) showed that participants perceived interior wood panels as "natural" and "healthy" as well as quantifying physiological benefits. Traditionally constructed non-wood-utilizing indoor environments have been shown to lessen a person's ability to recover emotionally and are linked to psychological drain (Burnard et al. 2015). The use of natural building components, such as wood, has been shown to improve people's emotional and physical well-being in these constructed environments (Sakuragawa et al., 2005; Yin et al., 2018). People report decreased levels of stress, improved memory, and improved emotional state when natural biophilic components are incorporated into building construction (Yin et al., 2018). The wood used in interior spaces can influence a person's perception of ambiance and elicit feelings of positivity and connectedness to nature (Strobel et al., 2017). These psychological and physiological considerations are important when establishing potential benefits to increased use and adoption of CLT.

An early study considering mass timber production and market acceptance found that economic risk and uncertainty were driving factors in Architecture, Engineering and Construction (AEC) firms' willingness to adopt mass timber (Laguarda-Mallo & Espinoza 2015). A survey of industry professionals at a 2018 North American Mass Timber Research Needs Assessment Workshop found that the top concerns about mass timber adoption included the need for studies related to cost-effectiveness, comparability to other materials, environmental and carbon implications, and establishment of codes and construction standards (Zelinka et al. 2021). A recent study resulting from the 2022 North American mass timber research needs assessment workshop found that many questions related to fire performance, building durability, architectural considerations, structural performance, sustainability, and infrastructure applications require extensive future investment and research (Ricco et al. 2023). Each section of the workshop proposed questions to participants with results broken down into a matrix examining the research and investment effort compared to the perceived or expected impact. These topics varied greatly in perceived effort and impact, but few proposed future steps fell into the low effort and high impact category (Ricco et al. 2023). Another survey of building contractors, architects, and mass timber manufacturers found that awareness and hesitancy were still primary factors driving whether a construction practitioner was willing to use mass timber products as of 2021 (Ahmed & Arocho 2021). There has likely been a shift in architect and building engineer awareness of CLT as a more recent survey conducted in 2022 by Penfield et al. (2022) showed that 100 % of architects and engineers were familiar with CLT. Both architects and engineers agreed that CLT shows advantages in environmental aspects but only architects stated CLT is more effective when compared to traditional building materials. Compatibility with traditional building materials was not seen as an issue for either architects or engineers. Disseminating information on the current state of mass timber construction codes, safety testing, and economic potential to building contractors, architects, engineers, and manufacturers has the potential to alleviate the current hesitancy toward mass timber products such as CLT (Penfield et al., 2022).

4. Discussion

Mass timber research has made considerable progress in recent years, but many aspects and areas of knowledge are yet to be explored. These knowledge gaps are listed in the table below (Table 5). Specifically, questions related to economic viability, policy and regulation needs, and social acceptance aspects of CLT are yet to be answered. Establishing and discussing this knowledge gaps will better guide future research and help to add to the continued knowledge around CLT and mass timber in general.

4.1. Economics

Although several publications discuss the cost of CLT and mass timber use in building construction, there is limited literature on how a CLT industry would impact local and state economies. The forest-based economic markets in the U.S. have declined in recent years, leading to a need to replace lost economic potential (Brandeis and Guo, 2016, University of Kentucky Forestry Extension 2015, Brandeis et al., 2021). Many hardwood states such as Tennessee have seen closures of pulp and paper mills removing these markets that local landowners relied upon to sell their timber (Brandeis and Guo, 2016; Poudyal et al., 2017). CLT shows potential to alleviate some of these economic losses. Research into specifics of these market implications such as the investment needed to establish CLT plants, and the expected regional economic impacts (i.e., multipliers of jobs, GDP, tax implications) will be vital to justify new investment for CLT production and secure support from stakeholders in the forest products industry. This economic potential will likely dictate regional acceptance of CLT with struggling markets more likely to adapt to novel products such as CLT. Continued research into which regions will likely benefit most from an expanded CLT market will help to achieve a clearer picture of the total economic potential of CLT.

Studies have examined the direct cost of CLT and mass timber in large-scale building construction and as an individual finished product (Brandt et al., 2019; Gu et al., 2020; Ahn et al., 2022; González-Retamal et al., 2022). However, these studies have been limited in scope and lacked definitive supporting economic research to confidently state conclusions. Ahn et al. (2022) stated limited research is a negative factor in definitively establishing the economic competitiveness of mass timber when compared to traditional building materials such as steel and concrete. A study in Japan found that CLT slabs utilized in bridge construction would be significantly more expensive than currently used reinforced concrete methods. Greenhouse gas emissions could be lower than reinforced concrete but only if CLT without waterproofing was used (Iwase et al., 2020). Future research into regional economic impacts, financial feasibility over time, increasing product availability and cost, and utilization of more cost-effective lumber resources will likely have varied but major impacts on the economic feasibility of future projects utilizing CLT. Research into other applications such as in large-scale residential, commercial, and parking garages, or more research into utilization in bridge construction has the potential to create new avenues for CLT that may be more suited to overcome the economic hurdles currently in place.

Recyclability and salvageability of CLT and mass timber components at the end of a building's life cycle have been discussed in several scientific publications (Robertson et al., 2012; Vamza et al., 2021; Hassegawa et al., 2022; Greene et al., 2023). Studies specifically looking at the economic impacts of recyclability are limited (Liang et al., 2021). A study by Vamza et al. (2021) states that recycling CLT into a mycelium insulation material shows the most potential followed by wood pellet production. Even though this study covered the environmental and feasibility implications of recycling CLT well, it did not get into the economic benefits. Further research into ways to recycle CLT and other mass timber components will be vital if economic circularity and environmental factors are to be positively addressed. Research into the economic benefits of recycling CLT has the potential to shift the

Table 5
Summary of knowledge gaps for economic, policy, and social aspects of CLT and mass timber.

Knowledge area	General findings	References
Economic		
Regional Economic Impact	There has been a decline in forest-based markets in the U. S. However, research into the direct economic impacts of CLT mass timber has been limited, showing potential for research into new ways to support and revitalize declining markets.	Brandeis and Guo, 2016, University of Kentucky Forestry Extension 2015, Poudyal et al., 2017, Scouse et al., 2020, Brandeis et al., 2021
Cost and Availability	Current literature lacks definitive answers on CLT cost and availability, likely due to regional complexities in resources and infrastructure. Studies have stated this uncertainty as a primary factor in the inability to establish mass timbers' economic competitiveness.	Brandt et al., 2019, Iwase et al., 2020, Gu et al., 2020, Ahn et al., 2022, González-Retamal et al., 2022
Recyclability	Most studies into the recyclability of CLT and mass timber are newer and continued efforts into novel end-of-life uses need to be pursued.	Robertson et al., 2012, Liang et al., 2021, Vamza et al., 2021, Hassegawa et al., 2022, Greene et al., 2023
Small-Diameter/ Low-Quality Timber	Two studies have shown positive results when looking into small-diameter timber use in CLT. Utilization of small-diameter lumber could aid declining industries, but more research is needed to support the current findings and research new timber species viability.	Fredriksson et al., 2015, Crovella et al., 2019, Azambuja et al., 2022, U.S. Forest Service 2022, Vaagen Timbers, 2024
Carbon Credit Potential	Carbon credits for CLT and mass timber show the potential to shift the economic feasibility of large-scale mass timber use and increase stored carbon. However, carbon credits for CLT and mass timber is a new concept that will require further research into the benefits, drawbacks, and consequences if implemented.	Chaggaris et al., 2021, Taylor et al., 2023, Georgia Forestry Commission 2024
Impact on Wood Markets	The current research is confident that current timber markets can supply a CLT industry. However, research into the specifics of supply and demand and impacts on product prices has been limited.	Comnick et al., 2021, Nepal et al., 2021, Atkins et al. 2023
Aesthetics and Perceptions	The positive impact of wood aesthetics and human perception in literature is well supported. However, no studies have directly examined if CLT or mass timber show the same positive impacts as other wood products.	Sakuragawa et al., 2005, Burnard et al. 2015, Yin et al., 2018, Harju et al. 2022
Incentives and Cost Share	Incentives and cost-share programs, such as the successful ones implemented in Japan, show the potential to support U.S. industries in an emerging CLT market. Studies into the economic impacts of these programs will be vital to establish if U. S. markets will benefit from new or expanded CLT and mass timber incentive programs.	Nakano et al., 2020, Riddle 2023
Hardwood Mass Timber	Hardwood CLT is a novel product gaining traction in the wood products field. Uses of low-quality and small-diameter feedstock may increase the economic viability of these products. There is potential for these products to alleviate some of the economic struggles felt by declining hardwood markets.	Crovella et al., 2019, Brandeis et al., 2021, Azambuja et al. 2022, Norris et al., 2024, Hassler et al., 2024
Policy		
New Policy Programs	The research into CLT and mass timber policy formation and implementation has been limited. The few U.S. policy programs that are in place have likely not been sufficiently utilized. New research into expanding current programs and creating new policies will be vital to support an expanding CLT sector.	Nakano et al., 2020, Riddle 2023, Taylor et al., 2023
Synthesis of non-U. S. Policy	Testing to establish U.S. construction standards and regulations must take place in the U.S. However, further research and examination of CLT and mass timber programs, such as those in Japan, could bring insight and help guide U.S.-based policy efforts.	Nakano et al., 2020, Stegner and Fotheringham, 2022
Social		
Public Attitudes and Preferences	Research into what the public thinks of CLT has been limited. Research has shown that the public is generally unaware of CLT or mass timber. Further research into current perception and education and outreach programs will be vital to gain a clearer picture of the social acceptance and public attitude toward CLT.	Larasatie et al., 2018, Luo et al., 2018, Montague et al., 2021, Poratelli et al., 2023,
Environmental Opinion	Positive environmental impacts of a product are often a leading driver toward public support. Studies show positive public opinions toward CLT and mass timber. Further studies and research will need to be done as the CLT industry grows to establish current public perceptions and opinions.	Larasatie et al., 2018, Montague et al., 2021, Abed et al., 2022, Debnath et al., 2022
Exposed Wood	The benefits of exposed wood are heavily supported in the literature. However, no studies have been done directly examining the impacts of exposed CLT or mass timber on study participants. Further studies	Sakuragawa et al., 2005, Nyrud and Bringslimark, 2010, Burnard and Kutnar, 2015, Strobel et al., 2017, Jo et al., 2019

(continued on next page)

Table 5 (*continued*)

Knowledge area	General findings	References
	will be needed to establish the psychological and physiological impacts of exposed mass timber on building inhabitants.	

economic feasibility. Additionally, recycled CLT could be used for new structural applications, further showing the economic feasibility of these components. If possible, this could lower the demand for new CLT components as recycled components would continue to be utilized well beyond the original structural application. New and novel ways of utilizing CLT and mass timber at the end of a building life-cycle will need to be researched to establish a clearer picture of the true lifetime cost of CLT building construction.

Low-quality softwood and hardwood lumber is not currently being utilized in structural applications. These lumbers often come from young or low value timber stands. Some studies have been conducted on the use of low-quality and small-diameter hardwood lumber for CLT construction (Crovella et al., 2019, Azambuja et al., 2022). Some studies have been done and shown that small-diameter lumber has potential both in terms of strength and production (Fredriksson et al., 2015; Wu et al., 2021). Although these studies show positive results, Azambuja et al. (2022) and Crovella et al. (2019) assessed limited species and Fredriksson et al. (2015) stated several potential barriers in implementing small-diameter lumber in CLT. Some companies such as Vaagen Timber have even adopted manufacturing models to make use of these low cost small-diameter lumber stocks showing a successful economic model can be achieved (Vaagen Timbers, 2024). A deeper investigation is needed to determine if other low-quality softwood or hardwood lumber is financially viable for use in CLT products. The U.S. Forest Service has continued to support advancements in new and novel wood products through their wood innovation grants (U.S. Forest Service 2022). Further utilizing these programs to promote and expand the knowledge surrounding small-diameter and low-quality lumber feedstock in CLT will likely be pivotal to successfully implementing these products. The use of under-utilized timber has the potential to revitalize struggling economies as well as bring down the potential cost of CLT or other mass timber products. New and novel ways of manufacturing CLT may be specifically developed to make use of these types of low-grade lumber.

Since CLT and mass timber structures store carbon in their wood biomass while simultaneously acting as alternatives to other high GHG-intensive materials, there is a potential for carbon credit generation (Chaggaris et al., 2021, Taylor et al., 2023, Georgia Forestry Commission 2024). However, our current understanding of the effectiveness and logistics of carbon credits for CLT and mass timber use in construction is limited. Further economic analysis is needed to quantify the value of such carbon credits, demonstrate that they meet all eligibility criteria (e.g., additionality, permanence), and propose feasible market protocols (e.g., commitment, payment vehicles, beneficiaries, monitoring, and verification) and models for their trade in the market. Perhaps, existing models of trade in other commodities (e.g., biochar, agriculture soil carbon) may be evaluated for their replicability in the context of CLT. Overall carbon credits show great potential to both promote and further highlight the economic feasibility of CLT.

Although research has shown that the current timber supply can adequately support the continued growth of CLT manufacturing (Comnick et al., 2021, Nepal et al., 2021, Atkins et al. 2023), this does not mean that there will be no impact on wood markets. The potential for increasing CLT manufacturing to raise demand in timber markets has potential to raise prices and create supply scarcity. These increased prices and scarcity have the potential to negatively affect traditional wood-utilizing markets (Nepal et al., 2021). However, given the current size of the CLT and mass timber industry, as well as its projected growth, it is unlikely that traditional wood markets will be significantly impacted. National forest growth has exceeded harvest since the 1940's. According to Comnick et al. (2021), total harvestable forest demand would only equate to 82 % of national forest supply even under high estimates of CLT and mass timber utilizing. This does not consider regionality with areas such as the Western U.S. likely more susceptible to demand exceeding forest growth (Comnick et al., 2021). Research into these impacts will likely need to be done on a local and regional scale and replicated across a variety of different models before a clear picture of CLT' impact on forest resources can be understood.

Positive aesthetics play a key role in how people perceive wood products through increased attractiveness as well as positive emotional, physical, and psychological well-being (Sakuragawa et al., 2005, Burnard et al. 2015, Yin et al., 2018). A review by Harju et al. (2022) states that environmental impacts, health implications, perceived naturalness, and symbolism all influence whether a consumer is willing to make an economic decision based on wood characteristics. However, no studies have directly examined if CLT in particular shares the same emotional, physical, and psychologically positive attributes as the previous studies have suggested. It is possible that a structure made entirely of CLT could have diminished, neutral, or expounded effects on people's willingness to adopt CLT. It is likely that perceptions surrounding the positive aesthetic aspects of CLT will be a large driving factor for the promotion of these products moving forward. New and novel mass timber products will likely develop with visual and exposed components being the largest draw for prospective buyers.

Incentives and cost-sharing policies are another avenue for future research to consider. A policy establishing incentives like those discussed by Nakano et al. (2020) in Japan could be implemented in the U. S. to help promote and spur CLT and mass timber adoption. In 2014 Japan initiated a program to expand CLT production as an expansion of a previous 2010 plan to promote wood use in public buildings. This plan involved the subsidizing of CLT production facilities and has seen the expansion from 26 facilities in 2015 to 300 by 2018. These policies could be nationwide efforts or enacted by state, county, or city governments to promote adoption in specific regions. Cost share programs could influence whether a person, company, or organization would utilize CLT in building construction. Future studies to examine the potential impacts of different levels of incentives, regionality of implementation, length of incentive programs, and mode of payment (e.g., direct payment, tax break, cost-share) could help derive a predicted future demand under different scenarios. These studies could be quantitative economic analyses or implemented under qualitative methodologies such as gathering stakeholder opinions and perceptions under differing scenarios.

Hardwood CLT has gained attention in recent years as a potential way to address struggling hardwood lumber markets. These markets have declined in recent years with sawmill production levels at the lowest point since 1960 (Hardwood Market Report, 2024). Add to this the general decline of paper, pulpwood, and paperboard and this decline becomes even more prevalent (Brandeis et al., 2021). A new product such as hardwood CLT could create a new avenue for hardwood lumber and alleviate some of the burden on these struggling industries. Hesitancy toward the use of hardwood in mass timber often forms when discussing the cost increase between hardwood and the more available softwood options. It is true that hardwood lumber is on average two to three times that of softwood lumber (Timber Update 2023). However, studies have been conducted in areas that show potential to lower this cost and make hardwood CLT more competitive (Crovella et al., 2019, Azambuja et al., 2022, Norris et al., 2024, Hassler et al., 2024). These studies show that hardwood CLT may show potential to be economically competitive under specific scenarios. More studies into these aspects of hardwood CLT and other mass timber products will be vital to establish a clearer picture of the true potential of this novel product. Although hardwood CLT will likely not be a one product solution to these struggling hardwood markets, any increased demand for hardwood lumber can be seen as a positive.

4.2. Policy

In the U.S., current incentive programs directed toward CLT, and mass timber have been limited with no direct CLT-specific policies in place. Riddle (2023) suggests several measures for increasing the adoption of CLT and mass timber including expanding research grants and programs, specifying requirements for government buildings to utilize CLT and mass timber wholly or partially in new construction, monetary incentives for utilizing CLT and mass timber in construction projects (e.g., tax incentives, access to credit), and direct federal timber harvest to support CLT and mass timber manufacturing facilities' lumber requirements. Expansion of current programs to incorporate more CLT and mass timber would likely be the simplest solution as several programs in the Wood Innovation Grant Program have already supported CLT and mass timber projects. Requirements for new construction to utilize CLT and mass timber either partially or wholly have been successful in other countries such as Japan found by Nakano et al. (2020). Monetary incentives (e.g., tax incentives, access to credit) have been successful in other similar industries and may show positive results if applied to the CLT industry. California's Buy Clean California Act in 2017, and the U.S. Department of Agriculture's Partnership for Climate-Smart Commodities Program are examples of U.S.-based policies pushing for cleaner manufacturing and material use (Taylor et al., 2023). The potential for CLT manufacturers to utilize federal timber stock could address some of the cost and lumber availability concerns surrounding current CLT and mass timber systems. Research into the viability and potential of these measures would better inform policymakers when considering options for increasing CLT adoption.

The United States and other countries interested in promoting the CLT and mass timber should assess the feasibility of some of the successfully implanted CLT and mass timber policy incentives elsewhere (e.g., Japan) (Nakano et al., 2020). It is not guaranteed that success will translate to other countries, but future research could examine the factors that contributed to the success and adapt similar or reasonably modified models that fit the local conditions. Although this paper examines and discusses research in other countries its primary focus is on policy implications in the United States. Regulations and construction standards such as the U.S.-specific IBC guidelines have been discussed. Testing for mass timber component properties must take place in the U.S. to be considered as evidence for updating the IBC guidelines (Stegner and Fotheringham, 2022). Although non-U.S. studies may not be directly applicable to the specific manufacturing and construction parameters in the U.S., the synthesis of quality scientific testing in other countries can better shape and direct U.S.-based efforts toward successful CLT adoption.

4.3. Social

How the public and potential consumers of CLT products view mass timber is largely unknown. Support for public policies and demand for and adoption of CLT and mass timber products will largely depend on public attitudes toward the product and its availability. Limited social research thus far (Larasatie et al., 2018; Montague et al., 2021) has not considered consumer willingness to pay for CLT products. These types of studies are vital when evaluating wood products and a consumer's likelihood and willingness to adopt new or novel wood product solutions. Environmentally certified timber products are similar to CLT concerning the environmental considerations and potential for consumers to value the eco-friendly aspects. A recent study found that consumers are willing to pay a premium price for environmentally certified timber products due to the environmentally conscious management behind them (Poratelli et al., 2023). A study looking at consumers' willingness to pay for modern wood buildings in China and Japan showed differences between the two markets and helped to establish a lack of consumer knowledge as a factor impacting willingness to pay for modern wood buildings (Luo et al., 2018). Establishing willingness to pay for CLT products from architects and engineers as well as building owners or project funding agencies will be vital if the adoption of CLT systems is to increase. Future research needs to be done to fill this knowledge gap as well as gain further perspective on consumers' willingness to adopt CLT.

Environmental concerns and considerations have been shown to impact the perception of and support from the public on the use of CLT and mass timber systems and products (Larasatie et al., 2018; Montague et al., 2021; Debnath et al., 2022). This public concern aligns well with the current scientific literature on CLT and mass timber, particularly when examining environmental impacts. Improved sustainability and environmental benefits over traditional construction materials such as steel are some of the driving factors behind the scientific communities' positive stances toward the increased adoption of CLT and mass timber products (Abed et al., 2022). Better communicating these positive environmental and sustainability aspects of CLT will be vital to gaining public and social support. This social support will be vital particularly when considering the establishment of governmental policies that have the potential to subsidize and promote the use of CLT products. Further research is needed on the connection between the current public and consumer perception of the environmental aspects of CLT and how these aspects will impact willingness to pay and willingness to adapt.

The current research on the psychological and physiological benefits of wood exposure in the built environment has been stated in a substantial amount of scientific literature (Sakuragawa et al., 2005, Nyrud and Bringslimark, 2010, Burnard et al. 2015, Strobel et al., 2017, Jo et al., 2019). However, none of these publications examined the direct psychological and physiological impacts of CLT products on experiment participants. As such, only indirect conclusions can be made on the potential positive end-user experience-based benefits of CLT products. This creates a need for research on the direct psychological and physiological impacts of CLT use in large-scale building construction. It is likely exposed wood will become a major selling point for CLT moving forward. However, it is difficult to state certainties when no studies have been done on these psychological and physiological aspects of CLT.

Considering everything, several key implications as stated below, can be drawn to summarize the discussion of knowledge generated and strategic directions needed to advance CLT production.

- Target investments strategically: Societal benefits of CLT could be maximized by focusing CLT investments in regions with declining forest-product markets and conduct region-specific feasibility analyses.
- Expand and diversify markets: Developing new CLT applications and products, including hardwood CLT, can improve competitiveness and reduce reliance on single or limited market.
- Optimize raw material use: Policy initiatives at the next level should prioritize leveraging low-quality, small-diameter, and under-utilized timber to reduce production costs and strengthen supply chains.
- Leverage sustainability benefits: This may be realized by capturing value from carbon storage credits and emphasizing CLT's environmental advantages to market these benefits to the builders, consumers etc.
- Manage supply and price risks: The economic shocks from market uncertainties may be addressed by monitoring regional timber availability and secure long-term procurement strategies (e.g., future contracting options)
- Differentiate through design and aesthetics: Manufactures may see benefit and even receive price premium by greater use of exposed wood and design quality to enhance CLT's market acceptance.
- Engage policy and stakeholders: Institutions interested in promoting manufacturing and use of CLT need continuous advocacy for incentives and education of policymakers, professionals, and consumers to increase adoption.

5. Conclusions

The CLT and most other mass timber products are still a novel wood product system and many questions about its economic, policy, and social aspects are yet to be answered. Discipline-specific research thus far has resulted in sporadic and isolated knowledge lacking coalescence between disciplines. This study synthesized the current body of knowledge and research related to the economic, policy, and social aspects of CLT and mass timber, in general. Informed by this review, it also established the need for several potential directions for future research, which will benefit researchers, policymakers, and stakeholders in the wood products industry interested in promoting CLT adoption. Additionally, limited research has addressed the chronological evolution of mass timber production and use. Also unknown is regional variation in mass timber knowledge, perception of risk and benefits, use in construction or manufacturing of wood-based products, and adoption as well as effectiveness of policies adopted to promote mass timber products. While this study was a first attempt to qualitatively synthesize the emerging knowledge on CLT but as the literature on mass timber continues to grow, future studies could utilize a more quantitative research approach such as meta-analysis, quantitative multiple regression modeling to investigate and quantify effect of various co-variates.

Mass timber, CLT in particular, offers significant opportunities for consumers and developers by creating new market for underutilized lumber, providing long-term carbon storage benefits, adding aesthetic and resident well-being, and most importantly, supporting regional timber economy. Policy incentives and growing consumer awareness and appetite for environmentally sustainable building materials may enhance the market potential. However, widespread adoption may still be constrained by several barriers such as limited research on economic feasibility, costs, recyclability and uncertainty surrounding building codes and regulations.

CLT shows promise both as a financially sensible product and with added potential for future incentives such as carbon credits to further incentivize adoption. Governmental assistance and incentive programs (e.g., innovation grants, tax incentives, research grants) have seen positive results for other wood product industries but limited programs have been directly applied to CLT. The social aspects surrounding CLT show that stakeholders are becoming more aware of CLT and mass timber as well as supporting the continued expansion and utilization of CLT in projects and designs. Policy, regulation, and guidelines in the U.S. have expanded greatly in the past decade and continued efforts are still underway to develop new policies toward expanding CLT adoption. Because CLT building systems are still relatively novel, it will take continued development over many years before they can reach a point of mainstream acceptance and adoption.

Research into the economic aspects surrounding CLT has been the most explored to date, with policy and social aspects fairly limited in the current literature. However, economic research gaps are still extensive and include regional availability and cost, recyclability and end-of-life solutions, utilization of low-grade or low-cost lumber, and carbon credit potential. Policy research gaps include expanding current cost-share and incentive programs, development of new policy programs and their impacts, and synthesis of non-US-based policy programs to inform U.S.-based policy formation efforts. Social gaps include research into current public opinion on CLT, public perception of environmental and sustainability considerations, and specific research on the physiological and psychological impacts of different mass timber systems. CLT shows great potential, but the growth of this industry will likely be slow given the competitive hurdles when compared to long-supported traditional building materials.

CRediT authorship contribution statement

Alexander Bremner: Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Neelam C. Poudyal:** Writing – review & editing, Writing – original draft, Supervision, Funding acquisition, Conceptualization. **Prakash Nepal:** Writing – review & editing, Funding acquisition, Conceptualization. **Consuelo Brandeis:** Writing – review & editing. **Adam Taylor:** Writing – review & editing. **Richard Bergman:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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Data availability

No data was used for the research described in the article.

References

Abed, Joseph, Rayburg, Scott, Rodwell, John, Neave, Melissa, 2022. A review of the performance and benefits of mass timber as an alternative to concrete and steel for improving the sustainability of structures. Sustainability 14 (9), 5570. https://doi.org/10.3390/su14095570.

Adhikari, Ram K., Poudyal, Neelam C., Consuelo, Brandeis, Nepal, Prakash, 2023. Identifying optimal locations for hardwood CLT plants in Tennessee: Application of a spatially explicit framework. For. Prod. J. 73 (3), 219–230. https://doi.org/10.13073/FPJ-D-23-00010.

Ahn, Namhyuck, Ambrose Dodoo, Mariapaola Riggio, Lech Muszynski, Laurence Schimleck, and Maureen Puettmann. "Circular Economy in mass timber construction: state-of-the-art, gaps and pressing research needs" J. Build. Eng. 53, (2022): 104562. doi: https://doi.org/10.1016/j.jobe.2022.104562.

Ahmed, Shafayet, Arocho, Ingrid, 2021. Feasibility assessment of mass timber as a mainstream building material in the US construction industry: level of involvement, existing challenges, and recommendations. Am. Soc. Civil Eng. 26 (2). https://doi.org/10.1061/(ASCE)SC.1943-5576.0000574.

Atkins, Dave, Anderson, Roy, Dawson, Emily, Moonen, Peter, Muszynski, Lech, 2024. International Mass Timber Report 2023. https://www.masstimberreport.com.

Azambuja, Rafael da Rosa, DeVallance, David B., McNeel, Joseph, 2022. Evaluation of low-grade yellow-poplar (*Liriodendron tulipifera*) as raw material for cross-laminated timber panel production. For. Prod. J. 72 (1), 1–10. https://doi.org/10.13073/FPJ-D-21-00050.

Balasbaneh, Ali Tighnavard, Sher, Willy, 2024. Economic and environmental life cycle assessment of alternative mass timber walls to evaluate circular economy in building: MCDM method. Environ. Dev. Sustain. 26 (1), 239–268. https://doi.org/10.1007/s10668-022-02707-7.

Baumeister, Roy F., Leary, Mark R., 1997. Writing narrative literature reviews. Rev. Gen. Psychol. 1 (3), 311–320. https://doi.org/10.1037/1089-2680.1.3.311.

Brandeis, Consuelo, Guo, Zhimei, 2016. Decline in the pulp and paper industry: Effects on backward-linked forest industries and local economies. For. Prod. J. 66 (1–2), 113–118. https://doi.org/10.13073/FPJ-D-14-00106.

Brandeis, Consuelo, Taylor, Marcus, Abt, Karen L., Alderman, Delton, Buehlmann, Urs, 2021. Status and trends for the U.S. Forest products sector: a technical document supporting the Forest Service 2020 RPA Assessment. In: Gen. Tech. Rep. SRS 258. U. S. Department of Agriculture Forest Service, Southern Research Station, Asheville, NC. https://doi.org/10.2737/SRS-GTR-258.

Brandner, R., Flatscher, G., Ringhofer, A., Schickhofer, G., Thiel, A., 2016. Cross laminated timber (CLT): overview and development. Eur. J. Wood Wood Prod. 74 (3), 331–351. https://doi.org/10.1007/s00107-015-0999-5.

Brandt, Kirstin, Wilson, Alex, Bender, Donald, Dolan, James D., Wolcott, Michael P., 2019. Techno economic analysis for manufacturing cross-laminated timber. Bioresources 14 (4), 7790–7804.

Brashaw, B., 2025. Scaling up mass timber: Closing gaps, fueling innovation. USDA Forest Service. Available online at https://www.fs.usda.gov/es/node/773896300?utm_source=chatgpt.com.

Bremner, Alexander, Poudyal, Neelam C., Nepal, Prakash, Brandeis, Consuelo, Taylor, Adam, 2025. Stakeholders' attitudes and perceptions regarding the viability of hardwood cross laminated timber (CLT). J. For. https://doi.org/10.1007/s44392-025-00050-z.

Burnard, Michael D., Kutnar, Andreja, 2015. Wood and human stress in the built indoor environment: a review. Wood Sci. Technol. 49 (5), 969–986. https://doi.org/10.1007/s00226-015-0747-3.

Chaggaris, Rachel, Pei, Shiling, Kingsley, Greg, Feitel, Alexis, 2021. Carbon impact and cost of mass timber beam-column gravity systems. Sustainability (Basel, Switzerland) 13 (3), 12966. https://doi.org/10.3390/su132312966.

Chen, Cindy X., Pierobon, Francesca, Jones, Susan, Maples, Ian, Gong, Yingchun, Ganguly, Indroneil, 2022. Comparative life cycle assessment of mass timber and concrete residential buildings: a case study in China. Sustainability Basel, Switzerland 14 (1), 144. https://doi.org/10.3390/su14010144.

Comnick, Jeff, Rogers, Luke, Wheiler, Kent, 2021. Increasing Mass timber consumption in the U.S. and sustainable timber supply. MDPI Sustainability 14 (1), 381. https://doi.org/10.3390/su14010381.

Crovella, Paul, Smith, William, Bartczak, Jacek, 2019. Experimental verification of shear analogy approach to predict bending stiffness for softwood and hardwood cross-laminated timber panels. Constr. Build. Mater. 229, 116895. https://doi.org/10.1016/j.conbuildmat.2019.116895.

Debnath, Ramit, Ronita Bardhan, Darshil U. Shah, Kamiar Mohaddes, Michael H. Ramage, Michael R. Alvarez, and Benjamin K. Sovacool. "Social media enables people-centric climate action in the hard-to-decarbonise building sector." Sci. Rep. 12, no. 1 (2022): 19017–19,017. doi: https://doi.org/10.1038/s41598-022-23,624-9.

Ehrhart, T., Brandner, R., 2018. Rolling shear: test configurations and properties of some european soft- and hardwood species. Eng. Struct. 172. https://doi.org/10.1016/j.engstruct.2018.05.118, 554–472.

Ettelaei, A., Taoum, A., Shanks, J., Lee, M., Nolan, G., 2022. Evaluation of the bending properties of novel cross-laminated timber with different configurations made of Australian plantation Eucalyptus nitens using experimetnal and theoretical methods. Structures 42, 80–90.

Evison, David Craig, Kremer, Paul D., Guiver, Jason, 2018. Mass timber construction in Australia and New Zealand—Status, and economic and environmental influences on adoption. Wood Fiber Sci. 50, 128–138. https://doi.org/10.22382/wfs-2018-046.

Fennell, Paul, Driver, Justin, Bataille, Christopher, Davis, Stevn J., 2022. Cement and steel – nine steps to net zero. Nature (London) 603 (7902), 574–577. https://doi.org/10.1038/d41586-022-00758-4.

Fredriksson, Magnus, Bomark, Peter, Broman, Olof, Grönlund, Anders, 2015. Using small diameter logs for cross-laminated timber production. Bioresources 10 (1), 1477–1486. https://doi.org/10.15376/biores.10.1.1477-1486.

González-Retamal, Marcelo, Forcael, Eric, Saelzer-Fuica, Gerardo, Vargas-Mosqueda, Mauricio, 2022. From trees to skyscrapers: holistic review of the advances and limitations of multi-storey timber buildings. Buildings 12 (8), 1263. https://doi.org/10.3390/buildings12081263.

Grant, M. J. and A. Booth. "A typology of reviews: an analysis of 14 review types and associated methodologies." Health Inf. Libr. J. 26(2):91–108.

Greene, Jonah M., Hosanna, Robert H., Willson, Bryan, Quinn, Jason C., 2023. Whole life embodied emissions and net-zero emissions potential for a mid-rise office building constructed with mass timber. Sustain. Mater. Technol. 35, e00528. https://doi.org/10.1016/j.susmat.2022.e00528.

Gu, Hongmei, Liang, Shaobo, Bergman, Richard, 2020. Comparison of building construction and life-cycle cost for a high-rise mass timber building with its concrete alternative. For. Prod. J. 70 (4), 482–492. https://doi.org/10.13073/FPJ-D-20-00052.

Hardwood Market Report. "Hardwood Market Report." Fastmarkets Volume CII Number 2. Accessed January 12, 2024. https://hmr.com/about-hmr.

Harte, Annette M., 2017. Mass timber - the emergence of a modern construction material. J. Struct. Integr. Maint. 2 (3), 121–132. https://doi.org/10.1080/24705314.2017.1354156.

Hassegawa, Mariana, Karlberg, Anna, Hertzberg, Magnus, Verkerk, Pieter Johannes, 2022. Innovative forest products in the circular bioeconomy. Open Res. Eur. 2, 19. https://doi.org/10.12688/openreseurope.14413.1.

Hassler, Curt C., Young, Matt, Denes, Leve, Bencsik, Balazs, McNeel, J.F., 2024. An evaluation of low-grade red oak and soft maple as raw material for cross-laminated timber panel production. For. Prod. J. 74 (2), 107–120. https://doi.org/10.13073/FPJ-D-23-00058.

Horx-Strathern, Oona, Varga, Christiane, Guntschnig, Georg, 2017. The futre of timber construction CLT - cross laminated timber. Storaenso. Accessed April 15, 2025. https://www.storaenso.com/-/media/documents/download-center/documents/product-specifications/wood-products/clt-technical/stora-enso-the-future-of-timber-construction-en.pdf. International Code Council. "2021 International Building Code (IBC).

Iwase, Tetsuya, Sasaki, Takanobu, Araki, Shogo, Huzita, Tomohumi, Kayo, Chihiro, 2020. Environmental and economic evaluation of small-scale bridge repair using cross-laminated timber floor slabs. Sustainability (Basel, Switzerland) 12 (8), 3424. https://doi.org/10.3390/su12083424.

Jo, Hyunju, Song, Chorong, Miyazaki, Yoshifumi, 2019. Physiological benefits of viewing nature:a systematic review of indoor experiments. Int. J. Environ. Res. Public Health 16 (23), 4739. https://doi.org/10.3390/ijerph16234739.

Junnila, Seppo, Horvath, Arpad, 2003. Life-cycle environmental effects of an office building. J. Infrastruct. Syst. 9 (4), 157–166. https://doi.org/10.1061/(ASCE)1076-0342(2003)9:4(157).

Kramer, Anthonie, Barbosa, Andre R., Sinha, Arijit, 2014. Viability of hybrid poplar in ANSI approved cross-laminated timber applications. J. Mater. Civ. Eng. 26 (7). https://doi.org/10.1061/(ASCE)MT.1943-5533.0000936.

Kremer, Paul D., Symmons, M.A., 2015. Mass timber construction as an alternative to concrete and steel in the australia building industry: a PESTEL evaluation of the potential. Int. Wood Prod. J. 6 (3), 138–147. https://doi.org/10.1179/2042645315Y.0000000010.

Kumar, Vaibhav, Marco Lo Ricco, Richard Bergman, Prakash Nepal, and Neelam Poudyal."Environmental impact assessment of mass timber, structural steel, and reinforced concrete tall residential structures based on the 2021 international building code provisions." Build. Environ. 251 (2024): 111195. doi: https://doi.org/10.1016/j.buildenv.2024.111195.

Laguarda Mallo, M.F., Espinoza, O., 2015. Awareness, pereceptions and willingngess to adopt cross-lamintated timber by the. architecture community in the United States. J. Clean. Prod. 94 (1), 198–210.

Larasatie, Pipiet, Guerrero, Jose E., Conroy, Kendall, Hall, Troy E., Hansen, Eric, Needham, Mark D., 2018. What does the public believe about tall wood buildings? An exploratory study in the US Pacific Northwest. J. For. 116 (5), 429–436. https://doi.org/10.1093/jofore/fvy025.

Lehmann, Steffen, 2012. Sustainable construction for urban infill development using engineered massive wood panel systems. Sustainability (Basel, Switzerland) 4 (10), 2707–2742. https://doi.org/10.3390/su4102707.

Liang, Shaobo, Hongmei, Gu, Bergman, Richard, 2021. Environmental life-cycle assessment and life-cycle cost analysis of a high-rise mass timber building: a case study in Pacific Northwestern United States. Sustainability (Basel, Switzerland) 13 (14), 7831. https://doi.org/10.3390/su13147831.

Liao, Y., Tu, D., Zhou, J., Zhou, H., Yun, H., Gu, J., Hu, C., 2017. Feasibility of manufacturing cross-laminated timber using fast-grown small diameter eucalyptus lumbers. Constr. Build. Mater. 132 (1), 508–515.

Lindsey, Rebecca, 2025. Climate Change: Atmospheric Carbon Dioxide. Accessed April 24, 2023. https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide.

Liu, Mengyuan, Huzita, Tomohumi, Murano, Akito, Goh, Chun Sheng, Kayo, Chihiro, 2023. Economic ripple effects analysis of cross-laminated timber manufacturing in Japan. Forests 14 (3), 492. https://doi.org/10.3390/f14030492.

Luo, Wen, Mineo, Keito, Matsushita, Koji, Kanzaki, Mamoru, 2018. Consumer willingness to pay for modern wooden structures: a comparison between China and Japan. Forest Policy Econ. 91, 84–93. https://doi.org/10.1016/j.forpol.2017.12.003.

Mirando, Anthony, Onsarigo, Lameck, Krsteska, Ivana, 2024. Determining the sustainability of mass timber structures through third-party sustainability assessment systems. In: Proceedings of 60th Annual Associated Schools of Construction International Conference, 5, pp. 405–413. https://doi.org/10.29007/xtnr.

Montague, Iris, Kassandra Stout, and Rubin Shmulsky. "Love it or leave it: what domillennials really think of wood products?" For. Prod. J. 71, no. 2 (2021): 150–160. doi: 10.13073/FPJ-D-21-00009.

Mordor Intelligence, 2025. Cross Laminated Timber Market Growing at 11.45% CAGR. Avaialble Online at. https://www.prnewswire.com/news-releases/cross-laminated-timber-market-growing-at-11-45-cagr-2025-2030-says-mordor-intelligence-302562965.html?utm_source=chatgpt.com.

Nakano, Katsuyuki, Koike, Wataru, Yamagishi, Ken, Hattori, Nobuaki, 2020. Environmental impacts of cross-laminated timber production in Japan. Clean Techn. Environ. Policy 22 (10), 2193–2205. https://doi.org/10.1007/s10098-020-01948-2.

Nepal, Prakash, Johnston, Craig M.T., Ganguly, Indroneil, 2021. Effects on global forests andwood product markets of increased demand for mass timber. Sustainability 13 (24), 13943. https://doi.org/10.3390/su132413943.

Nepal, Prakash, Prestemon, Jeffrey.P., Ganguly, Indroneil, Kumar, Vaibhav, Bergman, Richard D., Poudyal, Neelam C., 2024. The potential use of mass timber in mid-to-high-rise construction and the associated carbon benefits in the United States. PLoS One 13 (19), e0298379. https://doi.org/10.1371/journal.pone.0298379.

Norris, Jonathan R., Hassler, Curt C., Denes, Levente, Oporto, Gloria, Bencsik, Balazs, McNeel, Joseph F., 2024. Producing hardwood cross-laminated timber (HCLT) mats from low-grade red oak lumber. For. Prod. J. 74 (1), 88–97. https://doi.org/10.13073/FPJ-D-23-00061.

Nyrud, Anders Q., Bringslimark, Tina, 2010. Is interior wood use psychologically beneficial? A review of psychological responses toward wood. Wood Fiber Sci. 42 (2), 202–218. Accessed June 28, 2024. https://www.researchgate.net/publication/286055653_Is_interior_wood_use_psychologically_beneficial_A_review_of_psychological_responses_toward_wood.

Oval, R. O. "Mass timber and taller wood construction." Accessed January 17, 2024. https://www.naturallywood.com/topics/mass-timber/.

Pasternack, Rachel, Wishnie, Mark, Clarke, Caitlin, Wang, Yangyang, Belair, Ethan, Marshall, Steve, Hongmei, Gu, Nepal, Prakash, Dolezal, Franz, Lomax, Guy, Johnston, Craig, Felmer, Gabriel, Morales-Vera, Rodrigo, Puettmann, Maureen, Van den Huevel, Robyn, 2022. What is the impact of mass timber utilization on climate and forests? MDPI Sustain. J. 14 (2), 758. https://doi.org/10.3390/su14020758.

Pei, Shiling, Douglas Rammer, Marjan Popovski, Tom Williamson, Philip Line, and John W. Van De Lindt. "An overview of CLT research and implementation in North America." World Conf. Timber Eng. Accessed June 22, 2023. https://www.fpl.fs.usda.gov/documnts/pdf2016/fpl_2016_pei001.pdf.

Penfield, Patrick, Germain, Rene, Smith, William B., Stehman, Stephen V., 2022. Assessing the adoption of cross laminated timber by architects and structural engineers within the United States. J. Green Build. 17 (1), 127–147. https://doi.org/10.3992/1943-4618.17.1.127.

Poratelli, Francesca, Blanc, Simone, Pippinato, Liam, Zanchini, Raffaele, Bruzzese, Stefano, Brun, Filippo, 2023. Willingness to pay for certified wooden products: a critical literature review. For. Stud. Metsanduslikud uurimused 76 (1), 46–63. https://doi.org/10.2478/fsmu-2022-0003.

Poudyal, Neelam C., Joshi, Omkar, Taylor, Adam M., Hodges, Donald G., 2017. Prospects of wood-based energy alternatives in revitalizing the economy impacted by decline in pulp and paper industry. For. Prod. J. 67–8 (7), 427–434. https://doi.org/10.13073/FPJ-D-17-00004.

Rajagopalan, Neethi, Kelley, Stephen S., 2017. Evaluating sustainability of buildings using multi-attribute decision tools. For. Prod. J. 67 (3–4), 179–189. https://doi.org/10.13073/FPJ-D-16-00028.

Robertson, Adam B., Lam, Frank C.F., Cole, Raymond J., 2012. A comparative cradle-to-gate life cycle assessment of mid-rise office building construction alternatives: laminated timber or reinforced Concrete. Buildings (Basel) 2 (3), 245–270. https://doi.org/10.3390/buildings2030245.

Sakuragawa, Satoshi, Miyazaki, Yoshifumi, Kaneko, Tomoyuki, Makita, Teruo, 2005. Influence ofwood wall pane ls on physiological and psychological responses. J. Wood Sci. 51 (2), 136–140. https://doi.org/10.1007/s10086-004-0643-1.

Scouse, Adam, Kelley, Stephen S., Liang, Shaobo, Bergman, Richard, 2020. Regional and net economic impacts of high-rise mass timber construction in Oregon. Sustain. Cities Soc. 61, 102154. https://doi.org/10.1016/j.scs.2020.102154.

Stegner, Heather, Fotheringham, Nikki, 2022. Research and testing lead to historic code change. For. Prod. J. 72 (4), 226–234. https://doi.org/10.13073/2376-9637-72.4.226.

Strobel, Kristen, Nyrud, Anders Q., Bysheim, Kristian, 2017. Interior wood use: linking user perceptions to physical properties. Scand. J. For. Res. 32 (8), 798–806. https://doi.org/10.1080/02827581.2017.1287299.

Su, J.Z., 2018. Fire safety of CLT buildings in Canada. Wood Fiber Sci. 50, Special issue, 102–109. Accessed June 28, 2024.

Sukhera, Javeed, 2022. Narrative reviews: flexible, rigorous, and practical. J. Grad. Med. Educ. 14 (4), 414–417. https://doi.org/10.4300/JGME-D-22-00480.1.

Taylor, Adam, Hongmei, Gu, Nepal, Prakash, Bergman, Richard, 2023. Carbon credits for mass timber construction. Bioprod. Bus. 8 (1), 1–12. https://doi.org/10.22382/bpb-2023-001.

Tellnes, Lars G.F., Saxegård, Simon A., Johnsen, Fredrik Moltu, 2020. Cross-laminated timber constructions in a sustainable future - transition to fossil free and carbon capture technologies. In: IOP Conference Series: Earth and Environmental Science, 588, p. 42060. https://doi.org/10.1088/1755-1315/588/4/042060 no. 4.

U.S. Forest Service. Process Modeling for Cross Laminated Timbers Using Small Diameter Timber Feedstock. Accessed March 25, 2024. https://apps.fs.usda.gov/nicportal/WOODINNOVATIONS/dspProjectDetailReport.cfm?id=439.

Vaagen Timbers. Sustainably Created Cross Laminated & Glue Laminated Timber Products. Accessed April 15, 2024. https://vaagentimbers.com/.

United Nations Environment Program, 2024. “2022 Global Status Report for Buildings and Construction” Accessed January 12. https://www.unep.org/resources/publication/2022-global-status-report-buildings-and-construction.

University of Kentucky Forestry Extension. “Economic impact of the closing of the Verso pulp and paper facility in Wickliffe, KY” Accessed January 17, 2024. https://forestry.ca.uky.edu/files/ky_verso_mill_closure_uk_ces_forestry_combined.pdf.

USDA, 2022. Biden Administration Announces $32 Million to Advance Climate-Smart Mass Timber Construction, Expand Wood Markets. U.S Department of Agriculture. Accessed August 5, 2023. https://www.usda.gov/media/press-releases/2022/05/27/biden-administration-announces-32-million-advance-climate-smart.

Vamza, Ilze, Valters, Karlis, Luksta, Ilze, Resnais, Peteris, Blumberga, Dagnija, 2021. Complete circularity in cross-laminated timber production. Environ. Clim. Technol. 25 (1), 1101–1113. https://doi.org/10.2478/rtuect-2021-0083.

Vlosky, Richard P., Parajuli, Rajan, LeBlanc, Mason T., Gale, Charles B., 2019. Digitalization and circular economy: forestry and forestry based industry implications. In: P. 321–325 in Proc. of conf. on Influencer Perceptions of Cross-Laminated Timber in the U.S. South, 12th International Scientific Conference. WoodEMA.

Wahlstrøm, Simen, 2020. Methods for creating CLT Construction Guidelines. EDP Sci. 172, 10005. https://doi.org/10.1051/e3sconf/202017210005.

WoodWorks, 2025. Building Trends: Mapping Mass Timber. Accessed July 23, 2024. https://www.woodworks.org/resources/mapping-mass-timber/#:~:text=In%20the%20U.S.%2C%202%2C205%20multi,projects%20from%20design%20to%20completion.

Wu, Guofang, Zhu, Enchun, Ren, Haiqing, Zhong, Yong, Gong, Meng, 2021. Use of small-diameter round timber as structural members in light frame construction. J. Asian Architect. Build. Eng. 21 (3), 1029–1039. https://doi.org/10.1080/13467581.2021.1929241.

Yin, Jie, Zhu, Shihao, MacNaughton, Piers, Allen, Joseph G., Spengler, John D., 2018. Physiological and cognitive performance of exposure to biophilic indoor environment. Build. Environ. 132, 255–262. https://doi.org/10.1016/j.buildenv.2018.01.006.