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Views of Cross-Laminated Timber (CLT) Manufacturer Representatives around the World on CLT Practices and Its Future Outlook

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Abstract: Due to its recent emergence, there is a limited body of global market research available on CLT. Presently, the literature lacks comprehensive understanding regarding the present state, varied uses, and future outlook of CLT construction at a global level. The objective of this article is to address this knowledge gap by conducting semi-structured, in-depth interviews with CLT manufacturer representatives around the world, including Austria, Italy, Czech Republic, Sweden, Norway, Finland, Japan, Canada, and Uruguay. Critical findings emphasized that (1) the predominant mention was about the insufficient knowledge and experience within construction professionals; (2) a clear need for heightened expertise and training in the domain of CLT was underscored; (3) CLT was regarded as a favorable choice in efforts to combat climate change; (4) CLT was deemed highly appropriate for settings marked by variable climatic conditions; (5) CLT producers, particularly those with comprehensive, vertically integrated operations encompassing the entire processing cycle, remained unaffected by the rise in raw material costs; (6) the COVID-19 pandemic generally yielded positive impacts on the CLT market; (7) primary application of CLT, as emphasized by most manufacturers, is in residential and institutional projects; and (8) most manufacturers noted the expansive and boundless opportunities within the market, especially considering the climate crises as potential future avenues for the utilization of CLT. This article aims to advance the widespread adoption of CLT within the global construction sector. It will achieve this by elucidating the obstacles, possibilities, and forthcoming prospects associated with CLT.

Keywords: wood/timber; cross-laminated timber (CLT); practice; future outlook; experts; international

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1. Introduction

The construction industry is a significant contributor to greenhouse gas emissions on a global scale, placing high demand on natural resources [1,2]. Presently, the construction sector is responsible for approximately 40% of carbon dioxide (CO_2) emissions and consumes about 35% of the total global energy [3,4]. The Paris Agreement sets the target of reducing worldwide CO_2 emissions by 50% by 2050 compared to the levels observed in the 1990s, aiming to limit the global temperature increase to below 2 degrees Celsius [5,6]. Considering the current annual global CO_2 emissions [7], it is imperative to mitigate the climate consequences arising from the construction industry as a crucial step towards achieving this objective. Within the current construction industry, there are two main approaches implemented for the purpose of minimizing environmental effects [8]: (i) the adoption of eco-friendly construction materials [9], and (ii) optimizing energy usage throughout the operational lifespan of structures [10].

Progress in building technologies plays a crucial role in attaining sustainability objectives within the construction industry [11]. This entails exploring solutions at the construction material level that enable either a reduced utilization of the same materials or the adoption of alternative environmentally friendly materials [12,13]. Concrete and steel,

the predominant building materials in contemporary construction practices, exhibit a high carbon footprint due to their carbon-intensive nature [14,15]. As reported by the International Energy Agency (IEA), the production of one ton of steel results in the direct release of approximately 1.4 tons of carbon dioxide into the atmosphere [16,17]. Cement production, on the other hand, contributes to more than 4 billion tons annually, with emissions of carbon dioxide ranging from 250 kg for high-mix cement to 930 kg for regular Portland cement per ton produced [18,19]. It is well established that when make making comparisons to conventional non-renewable choices such as steel or concrete, bio-based building materials such as engineered wood products (EWPs) exhibit superior environmental attributes [20–22].

EWPs are experiencing growing utilization as structural materials due to their diverse mechanical benefits, such as uniform strength, rigidity, and environmental characteristics [23,24]. Moreover, EWPs are increasingly emerging as a feasible option, particularly in the construction of high-rise buildings [25,26]. These products are frequently fabricated by laminating smaller boards or lamella into larger structural components, offering exceptional structural properties and enabling the construction of intricate timber structures [27]. In 2022, EWPs' market attained a valuation of nearly USD 18.5 million, and it is anticipated to exhibit a compound annual growth rate (CAGR) of almost 9.4% throughout the forecast period. This growth trajectory is expected to lead to a market size of about USD 32 million by the year 2028 [28].

CLT occupies a significant position within the category of EWPs [29]. CLT, a prefabricated multilayered EWP, is produced by applying pressure and adhesive to bond the surfaces of a minimum of three panels together, arranged in a 90° configuration [30]. Having originated in the early 1990s, CLT has witnessed substantial growth in production on a global scale, with a particular emphasis on its expansion within Europe [31]. By 2017, around 70% of the worldwide CLT production within Europe [32] was accountable for this notable increase. The prevalence of CLT in Europe has captured the interest of construction researchers and industry professionals worldwide (e.g., [33–35]).

Additionally, particleboard is an EWP produced by combining wood chips with a synthetic resin or an appropriate binder, subjected to elevated pressure and temperature through a hot press [36]. It constitutes a significant component of international wood-related commerce, with both its demand and production exhibiting a positive trajectory in recent times. The worldwide particleboard market achieved a total valuation of USD 21 billion in the year 2020. The group foresees a CAGR of 4.4% over the subsequent six years [37].

Moreover, medium-density fiberboard (MDF), characterized by a density falling within the range of 500 to 1000 $kg \cdot m^{-3}$ [38], finds diverse applications, including (but not limited to) furniture (constituting over 50% of its usage), construction and flooring, interior design, and various other purposes. The global market size of MDF amounted to USD 38.25 billion in 2020 [39]. Projections indicate a growth trajectory, with the market expected to increase from USD 39 billion in 2021 to reach about USD 57 billion by the year 2028.

On the other hand, wood-based composites (WBCs) are produced using various derivative materials derived from wood products [40], including timber or lumber that has been processed into boards, as well as wood waste or wood chips [41]. These materials can be strategically engineered to form composite products. WBCs are experiencing notable growth in diverse industrial sectors, with widespread applications encompassing furniture, pallets, panels, structural frameworks for architectural designs, bridges, and more [42]. Nevertheless, the predominant market for WBCs resides in both residential and commercial building applications. An overwhelming 95% of residential housing in the United States relies on WBCs for construction, with these materials also being extensively utilized in the industry for non-structural applications [43].

It is also worth noting that while adhesive bonding and metal fasteners are acknowledged for their reliability and demonstrated long-term efficacy [44,45], there exists a requirement for a more environmentally friendly alternative in joining timber components within multi-layer wooden beams and panels [46,47]. In recent times, various adhesive-

free methods for connecting multi-layer beams and panels have been introduced [48]. These techniques encompass the following: (1) joining multi-layer timber with wooden dowels [49] (such as untreated hardwood dowels [50], thermo-hydro-mechanical densified wooden dowels [51], and rotary-welded wooden dowels [52]); (2) dowel-laminated timber (DLT) [53]; (3) wooden nails [54]; (4) dovetailed panels [55,56]; and (5) linear wood-welding technology [57]. Nevertheless, challenges associated with these products exist. For instance, with respect to DLT products, it is imperative to channel further research and development efforts towards the available materials. Additionally, the introduction of a certification process is crucial to facilitate the entry of a construction product into the market. Technical guidelines aligning with national design codes play a pivotal role for manufacturers, designers, and contractors.

Main current trends in CLT technology encompassed the following points:

(a) Increased acceptance and adoption [58]: CLT has been gaining acceptance worldwide as a viable alternative to traditional construction materials, such as concrete and steel. More architects, engineers, and builders have been incorporating CLT into their projects.
(b) Research and innovation [59]: Ongoing research and development have been focused on improving the manufacturing processes [60], strength [61], fire resistance [62], and sound insulation [63] of CLT. Innovations in adhesives [64], coatings, and manufacturing techniques aim to enhance the performance of CLT in various applications.
(c) Tall timber buildings [65–67]: CLT has been increasingly used in the construction of tall timber buildings, challenging the dominance of steel and concrete in high-rise construction. This trend is likely to continue as new design concepts and construction methods are developed.
(d) Digital technologies [68]: The integration of digital technologies, such as building information modeling (BIM) [69], has been helpful in the design and construction of CLT structures. Digital tools help optimize the use of materials and improve the efficiency of the construction process.
(e) Sustainability focus: CLT is often promoted as a sustainable building material due to its renewable source (wood) and its ability to sequester carbon. Sustainable forestry practices [70] and certifications [71] play a role in ensuring the environmental benefits of CLT.
(f) Building codes and standards [72–75]: The development and updating of building codes and standards related to mass timber construction, including CLT, have been ongoing. As CLT becomes more widespread, regulatory frameworks will adapt to ensure safety and reliability.

Due to its recent emergence, there is a limited body of global market research on CLT [76]. Currently, there is a lack of extensive knowledge in the literature regarding the current status, diverse applications, and future projections of CLT construction on a global scale. This article seeks to address this research gap by conducting interviews with CLT manufacturer representatives around the world, focusing on the following key themes: (1) general overview; (2) material properties; (3) ecology; and (4) market condition. Through our work, we aim to provide valuable insights, data, and recommendations that can aid in enhancing the understanding, utilization, and acceptance of CLT as a prominent construction material on a global scale. By addressing both potentials and limitations of CLT, we hope to encourage its widespread integration into construction projects worldwide, ultimately contributing to a more sustainable and efficient construction industry.

The aim of this article is to bridge this information deficiency through the execution of semi-structured and comprehensive interviews with representatives from CLT manufacturers across the globe. The research questions were structured to comprehensively grasp the prominent factors, potentials, and impediments influencing the planning and implementation of CLT structures within the global context. These were formulated as follows: (1) What is the current state of CLT construction worldwide? (2) What are the principal driving forces and obstacles associated with the utilization of CLT in wooden

construction? (3) What does the foreseeable future hold for the utilization of CLT on a global scale?

The subsequent sections of the article are organized as follows: The initial section outlines the historical development of CLT construction, followed by a presentation of the comprehensive literature survey on global CLT industry. Afterward, materials and methods employed in this study are provided. Subsequently, the findings obtained from interviews conducted with CLT manufacturer representatives around the world are presented, leading to an extensive discussion section. Consequently, this article concludes with a section that encompasses future prospects, recommendations, and limitations of this research paper.

2. The Concise Historical Background of CLT Construction

CLT is a structural building material made by stacking layers of timber at right angles and bonding them together with adhesives. It has gained popularity as an environmentally friendly and sustainable alternative to traditional construction materials, such as concrete and steel. Here is a detailed history of CLT construction [77–79]:

a. Early development of EWPs: The concept of EWPs dates back to the early 20th century. Laminated timber products were developed to enhance the structural performance and efficiency of wood as a building material.
b. Introduction of glued laminated timber (Glulam): Glulam was developed in the 1930s. It involved bonding layers of timber together with adhesives to create large, strong, and versatile structural components [80].
c. Layered wood panels: The concept of layering wood panels in a perpendicular fashion, a precursor to CLT, which emerged in the 1970s. This technique involved creating panels by bonding layers of wood at right angles to each other to improve the structural performance of timber [81].
d. First modern CLT panel prototypes (1980s): The modern concept of CLT emerged in Europe during the 1980s. Austrian and German researchers and engineers began developing and experimenting with CLT panel prototypes, using a combination of thin layers of timber and adhesives [82].
e. Research and innovation (1990s): In the 1990s, research and innovation in CLT technology accelerated, focusing on improving panel strength, fire resistance, and manufacturing techniques. Researchers and industry professionals in Europe played a significant role in refining and promoting CLT [83].
f. Commercialization and adoption (early 2000s): By the early 2000s, CLT gained commercial viability and started to be used in a variety of construction projects, including residential, commercial, and institutional buildings [84]. Its popularity was fueled by its structural performance, sustainability, and speed of construction.
g. Global expansion (mid-2000s and beyond): CLT gained traction globally, particularly in Europe, North America, and Australia. Architects, engineers, and builders increasingly recognized the benefits of CLT, leading to a surge in its adoption for various building types, from tall wooden buildings to schools, hotels, and office complexes.
h. Tall timber buildings and landmark projects (2010s): In the 2010s, CLT gained recognition for its potential in constructing tall timber buildings. Landmark projects such as the Forté building in Australia and the T3 building in the United States showcased the feasibility and sustainability of using CLT for high-rise structures [85].
i. Regulatory and standards development (2010s): During this period, regulations and standards specific to CLT were developed or revised to ensure safe and compliant use of CLT in construction projects. Various organizations, including building codes and standards bodies, recognized CLT as a viable construction material.
j. Ongoing research and advancements (2020s): Research and development in CLT continue in the 2020s, focusing on improving the performance, fire resistance, acoustics, and sustainability aspects of CLT. The industry is also exploring digital fabrication and integration with other construction methods.

3. Literature Survey

Numerous studies have been conducted on the global CLT industry, as evidenced by the following list; however, only a limited number of these studies offer a comprehensive global outlook on this sector.

Among the prominent research on the CLT industry, De Araujo and Christoforo [86] conducted a systematic literature analysis and a sectoral investigation of its major players. It was reported that the number of CLT manufacturers in North America and Europe is limited, and these manufacturers have been found to inadequately promote the environmental advantages of CLT. Instead, their primary focus appears to be on serving their respective local markets.

Two modern transformation practices in the construction sector have been examined by Hamalainen et al. [87], namely the acceptance of CLT and the improvement of digital transformation. Their conclusion emphasized the importance of an internal organizational perspective to guide the actors involved in the construction of CLTs.

The study conducted by Liu et al. [88] examined the influence of CLT on economic fluctuations in Japan. Their research revealed that unclassified operations, lumber, logs, road freight, and wholesale commerce were the top five categories with the most significant financial impact on CLT production in the country.

Benedetti et al. [89] presented the integration of a manufacturing model to facilitate the expansion of CLT manufacturing, accompanied by a comprehensive financial analysis in situations where the product and its attributes are not widely recognized. The results indicated that CLT production utilizing low-capacity plants can be advantageous, but a high degree of integration is crucial for achieving optimal outcomes.

Hassler et al. [90] conducted a thorough examination of the challenges faced in improving and establishing the market for CLT in the United States. Two key issues were addressed: (1) the certification approval of hardwoods, particularly yellow poplar, according to the USA standards, and (2) the production of structurally graded boards using conventional lumber manufacturing methods commonly employed in the hardwood industry to meet specific production level requirements.

A scientometric analysis of CLT and the effects of the fourth industrial revolution on the building industry was carried out by Martinez Villanueva et al. [91]. Their findings indicated that the implementation of Industry 4.0 in CLT is still in its nascent stages.

Larasatie et al. [92] conducted a comprehensive global survey on the CLT industry, incorporating updates from 2020. The survey identified a total of 66 CLT manufacturers, out of which only 12 companies were subjected to a thorough interview process guided by a formal survey.

Muszynski et al. [93,94] directed their scientific investigation towards the CLT industry, highlighting the relatively recent emergence and lack of familiarity in numerous present markets, particularly when timber was employed in the construction of buildings.

Brandner et al. [95] delivered a comprehensive report that showcased the latest advancements in various aspects of CLT, with a particular focus on manufacturing, technology, material characteristics, and connectivity. In their report, they proposed the establishment of a comprehensive set of globally standardized norms for wood engineering. Their recommendation aimed to broaden the scope of CLT applications and strengthen its competitiveness against solid mineral-based construction materials.

Vatanen et al. [96] conducted an interview-based study in Finland, exploring the prospective utilization of CLT. The findings revealed that CLT is perceived positively and holds significant potential as an environmentally friendly alternative for future sustainable construction endeavors.

4. Research Methods

This article draws on literature review and interviews with CLT manufacturer representatives worldwide. These approaches were substantiated by leveraging insights from prior studies [97–100], with the details presented in Table 1. The selection of representatives

from diverse countries, including Austria, Italy, Czech Republic, Sweden, Norway, Finland, Japan, Canada, and Uruguay, for extensive interviews aimed to incorporate a wide range of perspectives and provide insights into CLT practices and its future outlook in the world.

Table 1. Interviewees from CLT manufacturers by their position/title and experience.

	Interviewee 1 (Austria)	**Interviewee 2 (Italy)**	**Interviewee 3 (Czech Republic)**	**Interviewee 4 (Sweden)**	**Interviewee 5 (Norway)**
Position/title	Managing Director	Chief Executive Officer (CEO)	Business Development and Sales Manager	Marketing Director	Sales Director
Experience	Long-term experience in mass timber research and production	Long-term experience in CLT construction and production	Long-term experience in building materials production and technology	Long-term experience in forest product industry	Long-term experience in CLT construction and production
	Interviewee 6 (Finland)	**Interviewee 7 (Japan)**	**Interviewee 8 (Canada)**	**Interviewee 9 (Uruguay)**	
Position/title	Business Development and Sales Manager	Sales Manager	Vice President	Engineering and Design Manager	
Experience	Long-term experience in building materials production and technology	Long-term experience in CLT production	Long-term experience in CLT construction and production	Long-term experience in engineering and design of mass timber	

To consolidate qualitative data regarding global CLT practices, in-depth interviews were conducted with CLT manufacturers' representatives. This research employed a qualitative approach, focusing on detailed individual interviews with a small group of participants, as exemplified in [101,102]. Additionally, this article used semi-structured interviews due to its appropriateness and potential to reveal new themes [103–105]. Each interview session had a duration of approximately one hour. The interviews were conducted through video conference software. After the interviews, the video recordings underwent thorough examination, and the resulting findings were shared with the interviewees for their additional review and input via email.

The interview questions were meticulously crafted through a comprehensive approach, drawing upon a synthesis of similar studies such as [86], an exhaustive exploration of the CLT industry, insights gleaned from additional research endeavors focused on wood construction, invaluable advice from industry experts, and in-depth discussions with authors possessing a profound understanding of both the current landscape of the wood construction market and the intricate nuances of the wood research field. This multifaceted methodology ensured that the interview questions were not only informed by the existing literature and empirical evidence but also enriched by the nuanced perspectives and expertise of key stakeholders in the CLT industry and the broader realm of wood-related research. Furthermore, the interview format was designed to foster open dialogues, facilitating the gathering of information through predetermined questions and responses. It also encouraged the exploration of new inquiries, capitalizing on the extensive expertise of the professionals involved. The individuals chosen for interviews were primarily drawn from the most skilled, experienced, and knowledgeable professionals working at the largest or the second largest CLT production facilities in their respective countries, as seen in Table 1.

A comprehensive outreach effort was undertaken between June and September 2023 to engage with a total of more than 20 CLT manufacturers, which included the largest entities situated in various countries. The initiation of contact was facilitated through email

correspondence or by utilizing the contact forms on their respective websites. In an attempt to ensure effective communication and engagement, a series of up to 10 reminder emails were sent to each manufacturer. Despite the concerted efforts to establish connections with all manufacturers, it was observed that meetings with company representatives materialized for only 9 of them. This outcome highlights the varied responsiveness within the industry, underscoring the importance of persistence in communication strategies when seeking collaboration or information from CLT manufacturers on a global scale.

In addition to the mentioned countries above, invitations for interviews were extended to significant CLT manufacturers in various countries, including China. However, despite multiple follow-up emails, no responses were received. It is pertinent to mention that challenges arise in the process of locating the accurate contact email due to the absence of English websites for CLT manufacturers in certain countries, such as Japan. Overall, attempting to contact CLT manufacturers in different countries presents challenges related to language barriers, information accessibility, cultural differences, responsiveness, accuracy of contact information, and industry dynamics.

Table 2 and Appendix A present the themes and associated questions used in this study.

Table 2. Main themes, corresponding subsections, addressees, and main purposes of the interview questions (Appendix A).

Main Themes		Corresponding Subsections	Addressees	Main Purposes
Topics	**Subtopics**			
General overview	Familiarity of CLT	5.1	Experts with long-term experience in CLT production industry	Identifying views of CLT manufacturing experts
	Increasing CLT knowledge	5.2		
	Building types	5.8		
Material properties	Variable climatic conditions	5.4		
	Weak points	5.9		
	Best wood species	5.11		
Ecology	Climate change	5.3		
	Sustainable forest management	5.5		
Market condition	Effect of raw material prices	5.6		
	Effect of the pandemic	5.7		
	Effect of standards	5.10		
	Future outlook	5.12		

Maintaining ethical standards and safeguarding the privacy of the interview participants was of utmost importance. In order to achieve this imperative, stringent measures were implemented to keep their identities confidential. Every effort was made to withhold and protect any information obtained from the interviews that had the potential to disclose their identities. This commitment to strict confidentiality underscored our dedication to upholding ethical principles and respecting the privacy rights of the individuals involved in this study.

5. Results: Interviews

As mentioned earlier, the outcomes of the interviews were categorized into specific themes, aiming to offer an inclusive comprehension of the prevailing status, progress, and future prospects of the CLT industry on a global scale. These themes were observed across various contexts within the interviews, irrespective of the question posed or the individual being interviewed. The interview findings were organized into distinct categories, shown in Tables 1 and 2, denoted as (1) general overview; (2) material properties; (3) ecology; and (4) market condition.

5.1. Familiarity of Professionals in the Construction Industry with CLT

The interviewed representative from the Austrian CLT manufacturer stated that a notable level of expertise exists in Austria. Within the country, architects, engineers, and construction firms possess substantial knowledge in effectively incorporating CLT into their designs.

The interviewed spokesperson from the Italian CLT manufacturer underlined that investors, end-users, and numerous stakeholders are well versed in this technology. However, architects, engineers, and technical experts frequently do not possess a strong acquaintance with CLT. Typically, they attempt to persuade the client to opt for concrete or steel technology when constructing a new building due to their lack of knowledge about timber-based solutions.

The envoy interviewed from the CLT manufacturer based in the Czech Republic emphasized that the market for CLT is in an early stage of development, although it is evidently on the rise. There is existing knowledge in the region, and notable large-scale projects are already in the planning stages. The potential for CLT in this part of Europe is significant, and its successful utilization entails not only awareness of its advantages but also a deeper understanding of its application by contractors.

The interviewed specialist from the CLT manufacturing firm in Sweden provided insights into the expanding adoption of CLT construction practices in Sweden. They noted a growing number of pioneers in the field, including architects and engineering companies, who are familiar with and increasingly specifying CLT in their projects. However, the CLT market share remains relatively modest, and there is considerable pressure on architects and engineers to explore transitioning from traditional materials, such as concrete and steel, to CLT, although it presents a challenging endeavor.

The interviewed official from the CLT manufacturer in Norway mentioned that most construction professionals are not well acquainted with CLT, but this is evolving as the market is growing. Only individuals who fall within the innovators and early adopters category, possessing expertise and experience in CLT construction, are truly knowledgeable about it.

The representative from the Finnish CLT manufacturer stated during the interview that CLT is fairly recognized among architects, engineers, developers, and contractors in Finland. However, despite this familiarity, it is not comprehensively understood or universally acknowledged by every designer or developer. Nonetheless, there has been a notable surge of interest in CLT in recent years, with regulatory initiatives playing a significant role in fostering this interest.

According to the interviewed professional from the CLT manufacturer in Japan, a significant portion of construction industry professionals in the country lack familiarity with CLT construction. This includes architects, civil engineers, clients, and builders, who generally have limited knowledge and expertise regarding CLT construction methods.

The interviewed emissary from the Canadian CLT manufacturer conveyed that their familiarity with mass timber is not as extensive as their understanding of concrete and steel—traditional materials—despite timber's antiquity in comparison. Within the architectural community, suggestions to utilize mass timber in construction projects are made to clients, and the subsequent challenge is to garner support from engineers, given their relatively limited knowledge of this technology in North America. In the context of general contractors, 15 years ago, there was a notable reluctance to adopt mass timber in construction; however, over time, contractors gradually began undertaking smaller-scale projects involving mass timber. Presently, major general contractors across North America possess substantial experience with mass timber, signifying a positive trajectory. The industry is witnessing an upswing in projects incorporating mass timber, and numerous significant corporations are championing the use of mass timber as their primary building material.

The interviewed expert from the CLT manufacturer in Uruguay reported that construction professionals in Uruguay currently have limited awareness and understanding of CLT. In response to this, we have undertaken the initiative to arrange comprehensive

meetings, with a particular focus on engaging architects and engineers, in order to provide them with in-depth education and insights regarding CLT construction methods.

5.2. Increasing CLT Knowledge among Construction Professionals and Lay People

The interviewed representative from the Austrian CLT manufacturer stated that significant progress was made in this area, but there is a substantial need for more information and training, akin to the processes involved in working with materials such as concrete and steel. Enhancing our understanding of wood usage in construction, whether it involves mass timber or wooden frames, should be a priority.

The interviewed specialist from the Italian CLT manufacturing entity emphasized a substantial surge in knowledge acquisition within the last decade. This surge is attributed to a notable increase in construction activity, particularly in large-scale projects, and heightened investor interest. Additionally, considerations regarding rapid construction and earthquake safety in Italy have contributed to this trend. However, it is acknowledged that a significant amount of work lies ahead in the forthcoming years.

The professional interviewed from the Czech Republic-based CLT manufacturer stressed that there is a partial comprehension of CLT within the public sector. However, there is a need for additional educational efforts. Increasingly, representatives from municipalities and the public sector should be engaged and informed about the potential opportunities offered by CLT.

The interviewed expert from the Swedish CLT manufacturing company conveyed that efforts have been made to educate professionals through the creation of educational materials and resources. Customers are increasingly interested in incorporating CLT into their buildings. The manufacturer organizes training courses for architects and engineers, aiming to address concerns related to climate change and promote the positive aspects of building with wood. They emphasized the importance of enhancing education among specifiers, architects, and engineers to dispel biases regarding wood, particularly concerning sound insulation, fire safety, and other associated concerns.

The interviewed official from the Norwegian CLT manufacturer pointed out the paramount importance of ensuring safety and comprehensive product knowledge in the widespread adoption of CLT. Anticipating a heightened demand for sustainable buildings and residences anchored in renewable solutions driven by both the public and inhabitants, there is an escalating need for enhanced expertise among professionals. It is essential to recognize that transitioning from a concrete/steel construction to a CLT construction without modifying the structural geometry is generally not an optimal approach. CLT can effectively serve in both load-bearing and partition walls.

The spokesperson from the CLT manufacturer in Finland highlighted in the interview that there is a well-defined emphasis on timber use in construction, particularly within the public sector. The Finnish Ministry of Environment has initiated a wood program, advocating for timber utilization and providing education to numerous municipalities and representatives. These entities often take the lead in launching new school projects. However, there remains an opportunity for further education and knowledge dissemination throughout the entire construction value chain. The objective is to ensure that everyone involved comprehends the potential benefits of integrating timber into construction practices.

Based on insights provided by the interviewed representative from the CLT manufacturer in Japan, it is evident that the successful adoption of CLT within construction projects relies heavily on the active involvement and collaboration of key stakeholders. Among these stakeholders, construction companies, architects, and structural engineers stand as primary pillars.

The interviewed authorized person from the Canadian CLT manufacturer reported that, presently, approximately 75% of their team possesses a strong foundational understanding or substantial awareness when working with EWPs. However, it is acknowledged that the journey is ongoing, necessitating extensive training. Comprehensive knowledge is

imperative, encompassing aspects such as fire safety, acoustic properties, and the building envelope, as well as principles of building physics.

The interviewed spokesperson from the CLT manufacturer in Uruguay emphasized the need for a substantial boost in CLT awareness within both the construction industry and the general public. It was mentioned that they are currently offering numerous courses and have also integrated CLT education into university curricula.

5.3. CLT as a Building Material in the Fight against Climate Change

The interviewed expert from the Austrian manufacturer specializing in CLT emphatically reiterated the significant role that timber-based construction, particularly leveraging CLT, plays in actively mitigating the pressing climate crisis. The merits of employing CLT extend beyond structural functionality, encompassing substantial environmental benefits that are vital for our sustainability agenda.

The interviewed specialist from the Italian CLT manufacturer stressed the potential benefits of aligning with the European Commission's strong inclination towards promoting biomaterials. The spokesperson underscored the necessity of implementing regulations focusing on carbon footprint, highlighting its potential to incentivize investors financially and suggesting various approaches for public institutions to extend their support.

The interviewed professional from the CLT manufacturer in the Czech Republic emphasized that the construction industry grapples with a significant challenge pertaining to materials. CLT, being an industrially scalable and existing product, presents a valuable opportunity in the battle against climate change, addressing a critical aspect of sustainability within the industry. The interviewed representative from the Swedish manufacturer specializing in CLT expressed that CLT is anticipated to gain prominence as a building material in future construction endeavors aimed at combating climate change. They underscored the significance of carbon sequestration, highlighting that CLT serves as a viable and advantageous substitute for concrete and steel due to its ability to effectively store carbon.

The interviewed authority from the Norwegian CLT manufacturer emphasized that CLT stands out as a superior building material in the context of climate change. They highlighted its attributes of sustainability, renewable sourcing, and efficient natural CO_2 storage. It was pointed out that the lightweight nature of CLT leads to increased efficiency in transport and assembly compared to concrete and steel, resulting in fewer trailers on the roads.

The specialist interviewed from the Finnish CLT manufacturing sector highlighted a notable challenge concerning construction materials in the industry. They underscored that CLT, being a product with industrial scalability and existing infrastructure, represents a valuable prospect in combating climate change. It effectively addresses a crucial facet of sustainability within the construction industry.

According to the interviewed representative from the Japanese manufacturer with expertise in CLT, it is increasingly evident that the incorporation of timber-focused construction techniques, especially those utilizing CLT, holds a pivotal position in effectively alleviating the ongoing climate crisis. CLT, being a versatile and sustainable material, not only enables the construction of structurally sound buildings but also serves as a crucial tool in the fight against climate change.

The interviewed spokesperson representing the Canadian CLT manufacturer conveyed that CLT, as a construction material, actively contributes to the combat against climate change. Timber stands out as the sole carbon-negative material, and there is a growing imperative to mandate the adoption of clean materials for construction. It was underlined that timber is unequivocally poised to emerge as the material of choice for the future.

The interviewed official from the Uruguayan CLT manufacturer highlighted the increasing prevalence of CLT in future construction endeavors aimed at combatting climate change. They pointed out the abundance of public policies and substantial government incentives in place to support this initiative against climate change.

5.4. Suitability of CLT for Environments with Highly Variable Climatic Conditions

The interviewed representative from the Austrian CLT manufacturer pointed out that CLT is appropriate for settings characterized by fluctuating temperatures, humidity, and weather conditions. However, the importance of subjecting critical projects to scrutiny by third-party experts was stressed. As an illustration, it was cited that successful CLT deliveries are completed to diverse countries, including Singapore, which experiences both high temperatures and humidity. Despite these conditions, the manufacturer has not encountered any problems, emphasizing that the choice of adhesive used can potentially be a factor to consider.

The interviewed consultant from the Italian CLT manufacturing company emphasized that CLT is well suited for places with fluctuating climatic conditions. The company has gained expertise in deploying CLT in diverse climates, including deserts, the Alps, Nordic countries, Australia, and New Zealand. Ultimately, the end-user experiences high satisfaction with their living environment.

The individual interviewed within the sector of CLT manufacturing in the Czech Republic and underscored that CLT exhibits exceptional suitability for environments characterized with considerable fluctuations in temperatures, varying levels of humidity, and unpredictable weather conditions. This adaptability makes CLT an excellent choice for structures to withstand and thrive in such diverse environmental scenarios.

The interviewed specialist from the Swedish manufacturer with expertise in CLT emphasized that the applicability of CLT is contingent upon its utilization. In the interview, the specialist indicated that CLT is well suited for diverse geographic locations worldwide, depending on how it is strategically employed in construction.

The interviewed spokesperson from the Norwegian manufacturer specializing in CLT stated that due to wood's hygroscopic properties, CLT is well suited for locations experiencing varying climatic conditions. However, achieving optimal engineering and assembly requires individuals with a high level of CLT expertise. The utilization of melamine urea–formaldehyde (MUF) glue is viewed positively, as it allows the hygroscopic effect to permeate throughout the entire cross-section of an CLT element. Careful attention must be given to managing the capillary effect during the engineering and assembly phases, especially when CLT is exposed to damp conditions. It is worth noting that a vapor barrier is not necessary for CLT elements, as they inherently possess this function. Typically, exterior joints are sealed with tape unless veneer joint plates are employed.

The professional interviewed from the Finnish CLT manufacturing sector emphasized that CLT demonstrates outstanding appropriateness for settings marked by significant temperature variations, fluctuating humidity levels, and unpredictable weather patterns. This versatility positions CLT as a superb selection for constructing buildings that can endure and flourish in a wide array of environmental circumstances.

According to the interviewed expert from the Japanese CLT manufacturer, addressing security concerns, particularly for outdoor or exterior wall applications, is a prevalent topic. Protective measures can be implemented on the surface, often involving the incorporation of specific chemical substances.

The interviewed official from the Canadian CLT manufacturer stated that timber can be utilized in various environmental conditions, but that proper water treatment is crucial. Neglecting the necessary precautions and protective measures can lead to rapid deterioration. Therefore, it is essential to incorporate durability considerations into the initial design phase, as retrofitting can be highly impractical. This applies to a wide range of projects, including buildings, arenas, and pools. Particular attention should be paid to water-related issues and the meticulous design of column bases.

The interviewed specialist from the CLT manufacturer based in Uruguay has reported that, through extensive observations and analyses, CLT showcases remarkable compatibility across a diverse spectrum of climatic conditions. This adaptability of CLT is a testament to its structural resilience and performance under varying environmental circumstances.

5.5. Sustainable Forest Management for the Implementation of CLT Construction

The interviewed spokesperson from the Austrian CLT manufacturer highlighted that all forests in Austria are sustainably sourced and certified by the Programme for the Endorsement of Forest Certification (PEFC), amounting to 100% compliance.

The interviewed expert from an Italian manufacturer specializing in CLT emphasized that in the northern region of Italy, where their company is based, the majority of forests are PEFC-certified. This certification is vital due to the various requirements from clients, such as LEED and BREEAM certifications, necessitating proof that the timber originates from sustainably managed forests.

The individual interviewed from the CLT manufacturer in the Czech Republic emphasized that sustainability is not merely an aspect but the very core of our operational philosophy. Our dedication is centered on prioritizing sustainability, and in doing so, we provide an enduring and renewable solution for forest management.

The interviewed specialist from the Swedish CLT manufacturing firm stressed the sustainability of forestry practices in Nordic countries, specifically highlighting Sweden. They acknowledged the challenges related to biodiversity but emphasized the long-standing commitment to sustainable forestry. In Sweden, there has been a well-established law for over a century that guides reforestation efforts following harvesting activities.

The interviewed official from the Norwegian CLT manufacturing company affirmed that exclusively PEFC-certified timber is utilized, ensuring a 100% adherence to this standard. The timber utilized typically originates from forests within a radius of approximately 200 km around their CLT production facility.

The expert interviewed from the Finnish CLT manufacturing sector emphasized that their approach involves utilizing third-party environmental sustainability certifications, such as a PEFC certification. These certifications serve as assurances that the forests are managed, harvested, and replanted in a manner that aligns with sustainability principles.

As per the interviewed specialist affiliated with the Japanese CLT manufacturer, Japan possesses abundant forests, albeit not strongly linked with sustainable forestry practices. However, the expert emphasizes the necessity for increased efforts toward sustainable forest management in the future.

The interviewed representative from the Canadian CLT manufacturer affirmed that both Canada and the United States maintain highly rigorous forest management practices, amounting to a 100% compliance rate. The harvesting operations span 15 million acres of land, all of which hold the Forest Stewardship Council (FSC) certification, underscoring the paramount significance of sustainability.

The interviewed expert from the CLT manufacturing company in Uruguay emphasized their steadfast commitment to sustainable forestry practices, underscored by a robust framework of comprehensive certifications. This dedication to sustainable forestry manifests as a cornerstone of their operations, promoting responsible environmental stewardship and ensuring the long-term health and viability of the forests from which they source their timber.

5.6. Effects of Wood Raw Material Prices on CLT

The interviewed representative from the Austrian CLT manufacturer pointed out that the sales price of mass timber, particularly laminated timber, is significantly influenced by the expenses associated with raw materials. Determining the available market capacity and the required volume are pressing concerns.

The interviewed specialist affiliated with the Italian CLT manufacturing company stressed that up to the beginning of 2021, the price exhibited notable stability. However, from March 2021, a substantial surge in pricing was observed. Due to the erratic nature of timber price fluctuations, many investors opted for concrete, which clients readily approved to mitigate risk. Investors found an unpredictable price scenario for their projects in the subsequent year unacceptable.

The professional interviewed from the Czech Republic's CLT manufacturing industry stated that despite the inherent price fluctuations of construction materials, their reliance on proprietary forests and a highly efficient material sourcing system—drawing from both private forest owners and integrated sawmills within their CLT production—ensures that they are relatively less affected by variations in raw material prices.

The interviewed expert from the Swedish CLT manufacturing firm highlighted that during the pandemic, when raw material prices tripled, the CLT industry remarkably maintained its stability. Despite likely thin profit margins, they managed to sustain their business without significant losses. This resilience was attributed to the general inflationary trend affecting all building materials, ensuring that CLT remained competitively priced compared to alternative construction materials.

The interviewed spokesperson from the Norwegian CLT manufacturing firm confirmed that the core CLT construction processes remained unaffected, adhering to the established technical standards. The impactful events stemmed from an extraordinary superprofit scenario engendered by sawmills. This scenario led to market uncertainty due to steep price hikes, resulting in a shift of sentiment among key stakeholders, such as architects, civil engineers, clients, builders, and contractors, in the early majority. They either postponed or exhibited considerable skepticism toward utilizing CLT due to the escalated costs. Consequently, the company faced substantial financial challenges, which were exacerbated by the prolonged repercussions of the COVID-19 pandemic and escalating raw material expenditures.

The representative interviewed from the Finnish CLT manufacturing sector affirmed that, regardless of the fluctuations observed in the pricing of building materials, their confidence in in-house forest resources and a highly effective material acquisition process, which includes sourcing from private forest owners and the integration of sawmills within their CLT manufacture, ensures a reduced sensitivity to variations in raw material costs.

In line with the interviewed expert associated with the Japanese CLT manufacturer, prices in Japan have been experiencing a notable upswing. The cost of timber, a crucial factor affecting CLT pricing, has also been on the rise. Notably, this trend is observed across various building materials, not exclusive to CLT.

The interviewed professional from the Canadian CLT manufacturer stated that the connection between the pricing of dimensional lumber, a fundamental component of CLT, is evidently strong. This relationship is particularly noticeable when purchasing lumber from the open market, where prices can fluctuate significantly within a short timeframe—increasing by as much as 25% in a week. In recent years, there have been instances where lumber prices reached peak levels. The manufacturing company follows a distinctive business model, characterized by vertical integration encompassing harvesting, sawmilling, and mass timber production. This integrated approach allows the company to offer comprehensive turnkey solutions for most of their projects. While the company's pricing does not heavily impact the overall market, it holds significant implications for those procuring lumber from the open market—a subject deserving of a separate and nuanced discussion.

The interviewed official from the Uruguayan CLT manufacturing company communicated that in their particular situation, they possess an integrated setup encompassing a sawmill and the complete processing chain from tree to CLT. Consequently, fluctuations in raw material prices do not impact their operations. However, in contrasting scenarios, where such integration is absent, changes in timber prices have a direct and proportional effect on CLT pricing.

5.7. The Impacts of the COVID-19 Pandemic on CLT Construction

The interviewed spokesperson from the Austrian CLT manufacturer highlighted the significant adverse effects that they experienced over a year. The repercussions were notable due to the closure of construction sites, causing delays in ongoing projects. These projects were not scrapped but rather postponed, resulting in a tangible reduction in

annual production across the industry. This situation was exacerbated by multiple factors, including the impact of the COVID-19 pandemic. Additionally, escalating costs of raw materials and the fiber used in CLT production further contributed to a substantial price hike for CLT.

The interviewed expert associated with the Italian CLT manufacturer emphasized that the COVID-19 pandemic had a positive effect in terms of public perception, distinct from industrial considerations. As individuals were compelled to spend extended periods in their residences due to the pandemic, they gained a heightened appreciation for the significance of comfortable housing. Consequently, clients and people in our vicinity began engaging in extensive discussions about environmentally friendly and health-promoting housing.

The individual interviewed from the CLT manufacturer in the Czech Republic reported that their organization encountered a favorable impact attributable to the COVID-19 pandemic. This favorable effect was reflected in a notable surge of new projects, demonstrating an evident increase in demand and opportunities for their CLT products during this period.

The interviewed specialist from the Swedish CLT manufacturing firm pointed out that the COVID-19 pandemic had a notably positive impact on the utilization of wood. There was a surge in popularity for creating additional decking, working on garden projects, and renovating houses, although these trends did not directly translate to significant benefits for the CLT industry.

The interviewed representative from the Norwegian CLT manufacturing company affirmed that the primary consequence was the notable expansion of the highly profitable market segment. While there were challenges related to physical access to construction sites and some limitations in on-site follow-ups during assembly, these factors did pose certain issues.

The spokesperson interviewed from the Finnish CLT manufacturing sector affirmed that, even amidst the pandemic, a substantial number of public buildings were constructed in Finland. Remarkably, the preceding two years during the pandemic proved exceptionally advantageous for CLT sales in the Nordic region, resulting in a notable increase in our market presence in the Nordic region during that period.

In accordance with the insights provided by the interviewed authority affiliated with the Japanese CLT manufacturer, the emergence of the COVID-19 pandemic has presented a transient challenge concerning the acquisition of wood resources. Despite this initial challenge, they express a current outlook devoid of foreseen major impacts or disruptions in the prevailing operational landscape. It is anticipated that the challenge related to wood procurement will be managed effectively, and the CLT manufacturing processes will continue without significant impediments in the foreseeable future.

The interviewed specialist associated with the Canadian CLT manufacturer noted that the impact of COVID-19 was quite minimal due to our geographical location. While office projects were paused as a result of widespread remote work adoption, COVID-19 did not directly affect the production or construction of the materials. The company is involved in diverse projects, including sport complexes, institutional and office buildings, and commercial edifices, along with collaborations with esteemed universities. These projects remain on schedule, with universities maintaining their momentum owing to sustained demand. There was a strategic shift from office projects to institutional and other building types to adapt to the changing landscape.

The interviewed spokesperson from the Uruguayan CLT manufacturing company shared that their company recently commenced its operations in the domain of CLT production. Given this recent initiation, they emphasized that the ongoing pandemic has not affected or impeded their operational processes, allowing them to continue their endeavors in manufacturing CLT without disruptions stemming from the global health crisis.

5.8. The Most Common Building Types Constructed with CLT

The interviewed specialist representing the Austrian CLT production company underscored the versatility and applicability of CLT across three primary sectors: residential, hospitality, and commercial buildings. Within the residential sector, CLT has gained recognition and popularity for its use in various housing types, ranging from single-family homes to multi-unit buildings.

The interviewed authority associated with the Italian CLT producer mentioned an increasing emphasis on employing CLT in the construction of multi-residential buildings, typically spanning five to six floors. The rationale behind this focus lies in the material's remarkable structural properties and efficiency, which enable the realization of mid-rise structures that prioritize sustainability and a reduced carbon footprint.

The expert interviewed from the CLT manufacturer in the Czech Republic conveyed that within the Czech Republic, the prevalent category of buildings constructed using CLT predominantly includes public schools and residential structures.

The interviewed specialist from the Swedish CLT manufacturer noted that within the realm of public CLT structures, schools and gymnasiums stand out as the most commonly adopted applications. Furthermore, they highlighted a growing trend of utilizing CLT in the construction of hotels and private residences, indicating a broader acceptance and integration of CLT in various building types.

The interviewed spokesperson from the Norwegian CLT manufacturing firm confirmed their capability to construct diverse building typologies, encompassing recreational facilities, public edifices, residential structures, office complexes, and even high-rise buildings, all utilizing CLT as a primary construction material.

The representative interviewed from the Finnish CLT manufacturing industry emphasized that in Finland, the majority of CLT buildings that are delivered encompass public infrastructure, such as schools and kindergartens. This is closely followed by office buildings and commercial structures.

As per the interviewed official affiliated with the Japanese CLT producer, the prevalent utilization of CLT is observed in office buildings featuring two or three stories. This trend is primarily driven by the inherent limitations of CLT related to indoor conditions and stringent fire protection regulations, which are rigorously enforced in Japan.

The interviewed expert linked to the Canadian CLT manufacturer observed that prior to the COVID-19 pandemic, the primary domains of CLT usage were office spaces and institutional establishments, with some presence in sports facilities, such as arenas, pools, tracks, or soccer stadiums. However, in the present context, a significant proportion, likely around 75%, is dedicated to institutional projects. The prevailing market trend is heavily leaning towards mid-rise constructions.

The interviewed representative from the CLT manufacturing company in Uruguay disclosed that their primary construction focus involves luxury housing and multi-family buildings utilizing CLT. However, they do not typically engage in social housing projects due to the limited cost competitiveness of CLT, which is driven by substantial labor costs and high construction taxes. Nevertheless, the company has been engaged in various government-sponsored projects, such as schools and institutional buildings for universities, showcasing the versatility of CLT in diverse construction contexts.

5.9. Possible Weak Points of CLT Structures

The interviewed expert representing the Austrian CLT production company stated that from a structural perspective, the weak aspect of CLT lies in its lightweight and slim design. Nevertheless, with regard to construction, there are no inherent weaknesses. Moreover, when utilized appropriately in accordance with proper design principles, there are no vulnerabilities. Challenges arise when inexperienced workers handle the material, yet this challenge is applicable to all construction materials.

The interviewed representative linked to the Italian CLT manufacturer stressed that timber industry, on the whole, comprises numerous small-scale enterprises, lacking signifi-

cant players for large-scale projects. This constitutes a notable disadvantage. Moreover, weaknesses in CLT construction encompass cost considerations, durability, moisture susceptibility, and a dearth of expertise, particularly concerning general contractors and their aptitude for correct implementation and technical intricacies. Furthermore, certain regions, such as the Middle East, exhibit overly stringent fire regulations due to inadequate awareness, while Central Europe adopts a performance-based approach to fire design.

The professional representing the CLT manufacturing sector in the Czech Republic underscored a major weak point they are facing. This challenge revolves around a critical shortage of knowledge pertaining to the efficient utilization of CLT within specific market segments. This knowledge deficit has emerged as a formidable barrier, hindering the ongoing expansion and development of the CLT market in the region.

The interviewed agent from the Swedish CLT manufacturing company emphasized certain vulnerabilities in CLT structures. It was mentioned that building sway poses a weakness for CLT constructions, necessitating the integration of concrete elements to enhance stability, particularly in taller buildings. Additionally, material inefficiency was highlighted as another drawback, with CLT requiring a significant amount of wood, often comprising 3–7 layers of boards. Hollow sections were suggested as a potential solution to address this issue. Moreover, the expert noted that some builders opt for measures to protect the construction site from rain during the building process, albeit this practice can increase the overall project cost.

The interviewed official from the CLT manufacturing company based in Norway affirmed that employing good engineering and precise assembly significantly minimizes potential vulnerabilities. When utilizing an MUF adhesive, there are fewer concerns compared to using a PUR adhesive, particularly concerning fire-related issues. A polyurethane reactive (PUR) adhesive is associated with an elevated risk of delamination and the release of additional energy and toxic gases in the event of a fire.

The envoy interviewed from the Finnish CLT manufacturing industry highlighted a significant challenge: a knowledge gap in certain market areas where adequate understanding of efficient CLT utilization is lacking. This knowledge gap is a primary impediment to the market's further development.

According to the interviewed spokesperson affiliated with the Japanese CLT manufacturing company, the central challenge in advancing CLT construction lies in the imperative need to enhance cost competitiveness.

The interviewed specialist associated with the Canadian manufacturer of CLT remarked that the market size is likely a vulnerability of mass timber, although it is continuously expanding, especially with the substantial construction market in North America. Collaborative efforts are essential to accommodate the construction of numerous buildings. Certain European suppliers are making efforts to enter the North American market; however, the logistical challenge of shipping materials across vast distances, both within the continent and across the ocean, poses a considerable obstacle.

The interviewed expert from the CLT firm in Uruguay revealed that CLT construction involves significant wood consumption, and in certain scenarios, an alternative approach could utilize less wood, such as combining post and beam structures with CLT floor slabs. In the context of high-rise buildings (six stories or more), employing CLT may be a favorable choice. However, for structures below six stories, it might not be the optimal solution due to the considerable weight of CLT. This necessitates the use of machinery on the construction site for lifting CLT components, eliminating the possibility of manual installation only. Consequently, this factor contributes to an impact on construction costs.

5.10. The Impacts of Standards in the Construction Industry on the CLT Market

The interviewed specialist representing the Austrian manufacturer of CLT mentioned that there is no discernible impact since standard practices involve adhering to the Eurocode in Austria, making it business as usual.

The interviewed spokesperson from the Italian manufacturer of CLT emphasized the interest in obtaining PRG 320 for the US market due to increasing demand. There is the flexibility to operate within Europe, excluding France; however, compliance with specific technical requirements is mandatory, should we consider entering the French market.

The expert within the CLT manufacturing sector in the Czech Republic mentioned that adhering to the Eurocode, which constitutes standard practices, has resulted in an absence of observable influence. Furthermore, they possess the prestigious European Technical Approval (ETA) for CLT, empowering them to supply CLT across a broad spectrum of geographic regions.

The individual interviewed representing the CLT manufacturing company in Sweden underscored that when comparing construction using concrete for a five-story building to utilizing CLT, it becomes apparent that adhering to building standards, acoustic considerations, and other factors can lead to a notable drawback. This drawback primarily manifests as increased costs associated with accommodating a limited number of stories, such as five, at the same vertical elevation as opposed to the potential for six stories.

The interviewed agent from the Norwegian-based CLT manufacturing entity stated that obtaining a CE marking has not posed a challenge in Norway. However, compliance with the PEFC certification is a requirement, along with the necessity of an Environmental Product Declaration (EPD).

The spokesperson from the CLT manufacturing sector in Finland underscored a pivotal point: their possession of ETA for CLT significantly broadens their ability to provide CLT to a wide array of geographic regions. This accreditation, authorizing compliance with European technical standards, positions them as a reliable supplier capable of meeting the CLT needs of diverse and geographically dispersed markets.

As indicated by the interviewed official associated with the Japanese CLT manufacturer, Japan has implemented a carbon-neutral policy that encourages the utilization of wood in public construction projects. However, this policy lacks penal provisions. In adherence to this approach, the company follows the Japan Agriculture Certificate (JAS) standard, a national benchmark for assessing wood products broadly.

The interviewed expert associated with the Canadian CLT manufacturer noted that all construction products in North America necessitate certifications. Compliance with either the North American APA or PRG 320 certification is obligatory for CLT. This stringent requirement serves as a significant entry barrier due to the specialized adhesive required for achieving the essential fire rating. Therefore, obtaining a certification is challenging, primarily due to its technical demands rather than its associated costs.

The interviewed representative from the CLT manufacturing company in Uruguay disclosed that they currently do not possess specific CLT-related standards. As an illustration, they employ Eurocode for computational purposes and adhere to various European standards in their operations.

5.11. Best Wood Species for CLT Production

The interviewed specialist affiliated with the Austrian manufacturer specializing in CLT affirmed that among the array of wood species available, spruce stands out as the most suitable and efficient choice for optimal CLT production.

The interviewed representative from the Italian manufacturer of CLT stressed that the versatility of CLT allows for the utilization of various wood species readily available within one's local environment, with a particular focus on fast-growing tree species.

The delegate representing the CLT manufacturing sector in the Czech Republic highlighted the prevalent and primary use of spruce as the primary material in the production of CLT. This emphasis was placed to emphasize the significance and widespread adoption of spruce within the CLT production process.

The interviewed professional from the Swedish manufacturer of CLT stressed the superiority of Norwegian spruce and pine for creating CLT boards. Currently, spruce

overwhelmingly dominates the CLT market due to its remarkable strength, making it preferable for builders.

The interviewed expert from the CLT manufacturing entity based in Norway asserted that, within Nordic countries, spruce proves to be a cost-effective choice in terms of both strength and manufacturing efficiency. Through the application of superior quality and strength classification T22, there lies the potential for achieving reduced volume or thickness and longer spans.

The representative from the CLT manufacturing sector in Finland emphasized the primary use of spruce in CLT production. Furthermore, they mentioned that, as per the approval, there is an option to incorporate a limited quantity of pine within specific internal layers of CLT. It was also mentioned that we are actively involved in numerous research and development initiatives aimed at exploring the use of various species, including hardwood, in our processes.

According to the interviewed official affiliated with the Japanese CLT manufacturing entity, Japanese cedar stands out as the optimal material for CLT production due to its abundant availability in Japan.

The interviewed spokesperson linked to the Canadian manufacturer specializing in CLT observed that within North America, the primary wood species utilized is SPF (spruce–pine–fir), with a prevalence of black spruce. On the West Coast, Douglas fir is also notably prominent. In the design foundation for numerous projects, particularly in the mentioned region, architectural specifications necessitate the use of Douglas fir owing to its distinctive reddish-hued fiber, meeting specific aesthetic requirements.

The interviewed envoy from the CLT manufacturing company based in Uruguay revealed that, among the diverse selection of wood species at hand, pine distinguishes itself as the most appropriate and effective option for achieving optimal CLT production.

5.12. Opportunities and Challenges for the CLT Market in the Future

The interviewed expert from the Austrian CLT manufacturer asserted that a significant transformative influence is anticipated through the Green Deal initiative within the European Union. This initiative is expected to fundamentally alter the financing and construction landscape, particularly emphasizing sustainability in building products. Universities can play a pivotal role in imparting knowledge and training to construction companies, architects, and engineers, emphasizing standardized approaches and mass production techniques over current prevalent prototypical methods. The overarching objective is to enhance standardization within the industry. The primary challenge lies in accelerating the growth and augmenting the structural strength of CLT to compete effectively with conventional products such as concrete, given the niche nature of CLT.

The interviewed spokesperson from the Italian CLT manufacturer emphasized the potential of hybrid solutions. Recognizing the value of strong alliances, integrating efforts with concrete and steel companies presents a promising avenue. The discourse primarily involves spruce and pine, and diversifying beyond these key species poses a challenge. However, this challenge represents a significant opportunity for growth and innovation. Establishing new standards becomes imperative for incorporating diverse species. The timber sector has exhibited robust growth, yet the looming impact of climate change, leading to heightened forest insect activity, forewarns a potential decline in the next decade. To navigate this, exploring alternative wood species necessitates substantial investment facilitated through regulatory provisions from the European Commission.

The representative from the CLT manufacturing sector in the Czech Republic emphasized extant CLT solutions that can efficiently assist the industry and the country in achieving emission targets and establishing enduring carbon storage. Over the years, the production capacity in the Czech Republic has expanded to meet the rising demand.

The interviewed professional from the Swedish CLT manufacturing company highlighted the challenging state of the building market in Sweden due to elevated interest rates and inflation issues, resulting in a downturn in building activities. However, they

expressed optimism that once the building sector returns to normal activity levels, the potential for CLT to expand its market share is promising. They anticipate an increased utilization of CLT in combination with steel and concrete, especially in high-rise buildings, to enhance structural stability.

The interviewed specialist from the CLT manufacturing organization located in Norway affirmed their focus on addressing challenges related to achieving extended structural spans. The organization frequently employs rib decks but has yet to extensively utilize cassette decks for this purpose. Additionally, concerns regarding fire safety, vibrations, and acoustics necessitate the development and adoption of preapproved solutions within the industry.

The individual from the Finnish CLT manufacturing industry pointed out that existing CLT solutions can effectively contribute to the industry and the country in achieving emission targets and establishing long-term carbon storage. Additionally, the expert highlighted the support of Green Deal finance in Europe, specifically endorsing the utilization of sustainable and renewable resources.

As per the interviewed representative from the Japanese CLT manufacturer, the present narrative has shifted markedly, addressing climate change through construction practices. Anticipating the future, this trend is expected to intensify, garnering more attention and emphasis. The main obstacles encompass cost competitiveness and consumer preferences. Many individuals tend to favor cost-effective materials, contributing to the continued perception of wood construction as relatively expensive in Japan. Large-scale wood construction remains a relatively novel concept in the market, necessitating heightened regulatory standards. Furthermore, modifications and alignment with fire safety codes are imperative for the successful integration of larger wood-based constructions.

The interviewed official from the Canadian CLT manufacturer remarked on the vast and boundless potential of the market. With the current focus on climate change, achieving low-carbon construction is imperative for sustainability. Canada possesses extensive forest resources; however, responsible and sustainable harvesting practices are crucial. Foreseeing the future, a primary challenge for the master industry in the upcoming decades lies in significantly augmenting the existing production capacity.

The interviewed envoy from the CLT manufacturer Uruguay disclosed that the adoption of CLT hinges on cost-effectiveness. Governmental incentives, such as tax exemptions promoting wood construction, could significantly influence its utilization. Highlighting the urgent need to combat climate change, the representative underscored wood as the optimal material in this endeavor. However, a major challenge lies in the limited knowledge and expertise within the timber industry. They estimated a developmental timeline of approximately 10 years to bridge this knowledge gap, expressing optimism in the ongoing progress. In South America, the advantage of short tree lifecycles presents an opportunity for faster CLT production in the future.

5.13. Other Opinions or Comments

The interviewed spokesperson from the Austrian CLT manufacturer conveyed that the integration of CLT into construction is an ongoing development. It heavily relies on robust backing from governmental authorities and entities such as the European Union for broader adoption. The main obstacle lies in customary construction practices of major industry players, such as construction companies. These entities are accustomed to working extensively with steel and concrete, making the transition to CLT a significant challenge.

The interviewed representative from the Italian CLT producer emphasized that there is a need for a shift in the client's mindset, particularly focusing on sustainability within this context. They highlighted a gap within our industry: a lack of influential European institutional bodies dedicated to advocating for timber, engaging with the entire industry effectively.

The interviewed professional from the Swedish CLT manufacturing company stressed that Sweden is currently experiencing a significant expansion in its CLT production capacity.

They anticipate a few years of surplus supply and predict an increased prevalence of CLT in various applications during this period.

The interviewed official from the Norwegian CLT manufacturer pointed out a disparity compared to other industries. Public subsidies for construction with sustainable and renewable materials are notably absent. CLT is yet to be fully embraced by architects and consulting engineers, who remain predominantly engaged with concrete and steel suppliers. This could be attributed to the perception that discussions around wood and CLT may not be as captivating for politicians compared to the focus on innovations related to electric cars, wind turbines, and energy storage solutions such as batteries.

The interviewed specialist from the Canadian manufacturer specializing in CLT highlighted the critical need for well-crafted and comprehensive regulations focused on advancing sustainable and carbon-neutral practices within the construction industry. These regulations would play a vital role in shaping the industry towards environmentally responsible construction methods, aligning with global sustainability goals and minimizing the carbon footprint of the built environment.

According to the interviewed expert from the CLT manufacturing firm in Uruguay, there is no standardized protocol specific to CLT in place. The company adheres to European Union (EU) regulations, primarily EUROCODE 5, but recognizes its outdated nature. They emphasized the necessity for extensive research and a substantial presence of researchers specializing in CLT to advance and establish updated standards and practices.

6. Discussion

By conducting thorough semi-structured in-depth interviews, this study delved into the perspectives of global representatives within the CLT manufacturing sphere, including Austria, Italy, Czech Republic, Sweden, Norway, Finland, Japan, Canada, and Uruguay. The investigation encompassed their viewpoints on current CLT practices and their insights regarding the prospective trajectory of CLT within the industry, considering the key themes of the general overview, material properties, ecology, and market conditions.

The perspectives of the interviewed experts exhibited uniformity, endorsement, and mutual reinforcement. Highlights regarding views of CLT manufacturer representatives around the world on CLT practices and its future outlook include the following:

(1) Many CLT manufacturers commonly highlighted the deficiency in knowledge and experience regarding CLT within the broader spectrum of construction industry professionals, encompassing architects, engineers, and other technical experts. Notably, no specific professional group was emphasized in this observation. This phenomenon was notably evident in countries where the CLT market is in its nascent stages of development, as exemplified by the situations observed in nations such as Japan and Uruguay. In these regions, the distinct characteristics of an emerging CLT market were prominently discernible, with indicators such as evolving industry practices, limited widespread adoption, and an initial phase of market establishment. Furthermore, the Canadian CLT manufacturer conveyed that recommendations within the architectural community for incorporating mass timber in construction projects are extended to clients. The ensuing challenge lies in securing support from engineers, as their familiarity with this technology in North America is relatively limited.
(2) CLT manufacturers emphasized a pronounced demand for increased CLT expertise and training, underscoring the prevailing familiarity with traditional materials such as concrete and steel.
(3) A consensus among all manufacturer representatives was reached, affirming that CLT stands as an optimal building material in the battle against climate change.
(4) While it was asserted that CLT is well suited for environments characterized by highly variable climatic conditions, the importance of factors such as thorough project preparation and supervision, as well as the selection of suitable adhesives, was underscored.
(5) Sustainable forest management practices for CLT construction were in place in all manufacturing countries, except for Japan.

(6) It was reported that CLT producers, especially those with a fully integrated operation covering the entire processing cycle, were not affected by the increase in raw material prices, while other manufacturers were directly affected.
(7) According to manufacturers, the COVID-19 pandemic led to a significant increase in the utilization of wood, and CLT. However, during that period, the construction sector experienced a slowdown due to factors such as project delays.
(8) Most manufacturers emphasized that CLT finds its primary application in residential construction, particularly in the realm of private and high-end residential structures, and in public and institutional building projects.
(9) Regarding the drawbacks of CLT structures, deficiencies were noted in terms of cost competitiveness, the necessity for incorporating concrete to mitigate building sway due to its lightweight nature, and the overconsumption of wood.
(10) Specifically, European manufacturers assert that established construction norms, such as the CE marking, do not present any impediments to the CLT market.
(11) While European CLT manufacturers predominantly asserted that spruce is the most suitable wood species for CLT production, Japanese, Canadian, and Uruguayan manufacturers stated that Japanese cedar, SPF (spruce–pine–fir) with a predominance of black spruce, and pine, respectively, are the optimal choices for CLT production.
(12) The Finnish CLT manufacturer stated that we are actively immersed in a range of research and development initiatives, demonstrating a dedicated commitment to the exploration and examination of various timber species for integration into their manufacturing processes. Their proactive involvement underscores a dynamic approach to understanding and harnessing the potential of hardwood and other timber types. This concerted effort signifies a forward-looking perspective within the industry, as these manufacturers seek to broaden their knowledge base, optimize production techniques, and potentially enhance the versatility and sustainability of their CLT products.
(13) Many manufacturers observed the extensive and limitless prospects within the market, particularly when considering the climate crises as potential avenues for the future usage of CLT.

This study's results confirmed numerous findings previously documented in other research (e.g., [87,96]).

The unanimous agreement reached among representatives from the manufacturing sector underscores the pivotal role that CLT plays in addressing the urgent need to combat climate change. This consensus was not only confined to a localized context but found resonance in broader discussions, as evidenced by the study conducted by Vatanen et al. [96]. In their research, 18 Finnish specialists specializing in CLT construction emphasized the environmentally conscious attributes of CLT, positioning it as an ideal choice for future sustainable building practices. The positive perception of CLT as an eco-friendly alternative, highlighted by the Finnish specialists, and echoes the sentiment that CLT is gaining traction as a material with inherent sustainable qualities. In a parallel vein, Duan [106] accentuated the viability of employing CLT buildings as a pragmatic and effective strategy for combating climate change within the context of China. This assertion suggests that the implementation of CLT structures holds practical significance and represents a tangible means to contribute positively to environmental sustainability in the Chinese construction landscape. However, a noteworthy discrepancy emerged during interviews with manufacturers, echoing the findings of Vatanen et al. [96]. Manufacturers acknowledged the environmental benefits of CLT but also revealed a limited understanding and expertise when it comes to its practical implementations. This knowledge gap among manufacturers regarding CLT is further underscored by the research conducted by De Araujo and Christoforo [86], who reported that many CLT manufacturers are predominantly concentrated in North America and Europe. Despite their presence in these regions, there is a notable discrepancy in their advocacy for the environmental advantages of CLT. Manufacturers, as observed in the interviews, tend to concentrate primarily on their local markets, perhaps neglecting to

amplify the broader environmental benefits of CLT on a global scale. The research by Hassegawa et al. [107] shed light on critical factors influencing the broader adoption of CLT. Regulatory frameworks play a crucial role in facilitating the acceptance and integration of CLT into mainstream construction practices. Moreover, this study suggests that a growing level of consumer awareness is pivotal in encouraging the widespread adoption of CLT. These insights highlight the need for manufacturers to not only enhance their understanding of CLT but also actively participate in promoting its environmental advantages on a global scale, as underlined in the studies by [108–110].

The study conducted by Hurmekoski et al. [111] shed light on the intricate network of inter-organizational relationships within the CLT industry, highlighting a prevailing sense of fragmentation. Notably, their research identified a simultaneous trajectory of ongoing progress aimed at bolstering collaborative efforts. This observation aligns closely with our own findings, indicating a distinct absence of influential European institutional entities singularly dedicated to championing the cause of timber and effectively engaging with the broader industry. In contrast, Hamalainen and Salmi [68] contributed to the discourse by emphasizing the existence of robust cooperative interactions among stakeholders within the CLT sector. Their insights underscored the critical importance of effective communication, particularly with design teams, and advocated for the establishment of interconnected networks as catalysts for advancing CLT construction methodologies. An interesting facet of their work was the recognition of digitalization as a potent force with the capacity to augment the utilization of CLT in building structures. Nevertheless, the study acknowledged a crucial need for collaborative efforts cutting across organizational boundaries and sectors to fortify the digital transformation within the broader CLT business network.

Hamalainen and Salmi's research [68] illuminated a distinctive characteristic of the construction process involving CLT that sets it apart from traditional on-site construction methods. The pivotal insight gleaned from their work emphasizes the paramount importance of effective collaboration throughout the various stages of CLT construction, with a particular emphasis on engagement with not only the design team but also the CLT manufacturing and construction firms. This study underscores the notion that the success of CLT projects hinges significantly on the seamless cooperation between diverse stakeholders. Particularly, forging strong collaborative ties with the design team is identified as a critical factor in ensuring the efficacy and efficiency of the CLT construction process. By establishing a symbiotic relationship with CLT manufacturing and construction firms, a holistic approach to project planning and execution is envisioned, which becomes instrumental in mitigating potential errors and challenges. Hamalainen and Salmi's research posits that errors occurring during the planning phase can have cascading effects, potentially leading to unfavorable outcomes in the production and implementation of CLT. This aligns seamlessly with our own interview findings, which corroborate the idea that when CLT is utilized correctly and in adherence to appropriate design principles, the susceptibility to errors and negative consequences diminishes significantly. The implicit message is that the proper integration of CLT into construction processes requires meticulous planning, cooperative efforts, and adherence to established design principles to ensure optimal outcomes [112,113].

As articulated by Shigue [114], a critical impediment to the widespread adoption of CLT lies in consumer misunderstandings surrounding wood. Shigue highlights a prevalent perception of wood as a low-grade material, tarnished by misconceptions related to its perceived high maintenance demands and outdated beliefs regarding its durability, fire safety, and its purported link to deforestation. These misjudgments, if left unaddressed, have the potential to act as significant barriers to the comprehensive acceptance and utilization of CLT in construction projects. Echoing this sentiment, our own interview findings corroborate the notion that there exists a pressing need to rectify and challenge these misconceptions, particularly among key stakeholders such as specifiers, architects, and engineers. The emphasis on improving education emerges as a crucial theme, with the understanding that dispelling preconceived notions about wood is instrumental in paving

the way for the increased adoption of CLT. Specifically, our interviews underscored the importance of targeted education initiatives aimed at challenging prevailing misconceptions about wood. Specifiers, architects, and engineers were identified as pivotal players in this narrative, as their understanding and endorsement significantly influence material choices in construction projects. As emphasized in the studies by [115–117], the need for a nuanced educational approach becomes evident, focusing on aspects such as sound insulation, fire safety, and other related considerations to provide a comprehensive understanding of the capabilities and advantages offered by CLT.

Numerous CLT manufacturers identified extensive and limitless opportunities within the market. This is particularly evident when contemplating the climate crises, as these circumstances present potential pathways for future applications of CLT that can contribute to achieving emission targets and provide a means for long-term carbon storage. The recognition of CLT's potential in addressing environmental challenges underscores its significance as a sustainable and versatile construction material in the context of mitigating climate change and promoting carbon sequestration. Likewise, a multitude of additional studies, as referenced by [118–122], have investigated the role of CLT in contributing to a sustainable future. This collective body of research underscores the ongoing interest and exploration of CLT as a pivotal element in advancing sustainable practices within the construction industry. In the course of our interviews, European producers underscored the Green Deal as a notable advantage, as documented in [123]. Nevertheless, they expressed concerns regarding the insufficiency of robust institutional support for timber within Europe and the lack of public subsidies for construction projects involving sustainable and renewable materials, as highlighted in [124]. The prospect of hybrid solutions, including elevated incorporation of CLT in conjunction with steel and concrete, was also underscored by several producers interviewed. A multitude of recent studies found in the existing literature delve into the exploration and analysis of hybrid structural solutions that incorporate CLT, exemplified by references [125–127].

Potential research areas within CLT construction could encompass (a) exploring strategies to bridge the knowledge and experience gap among construction professionals regarding CLT through targeted education and training programs; (b) investigating policy frameworks and regulations at a global level that either hinder or support the adoption of CLT in the construction sector, and propose recommendations for policy improvements; and (c) conducting surveys and studies to understand consumer perceptions, preferences, and acceptance of CLT-built structures, and their willingness to adopt this construction method. By delving into these research areas, a deeper understanding of CLT and its potential in the construction industry can be achieved, promoting its widespread adoption and addressing knowledge gaps identified in the summary.

While this research provides valuable insights into the state and potential of CLT construction globally, it is important to note several limitations: (i) findings are based on interviews with CLT manufacturer representatives and could potentially introduce a sampling bias towards their perspectives and experiences; (ii) the research focuses primarily on interviews conducted in specific countries, which likely limits the generalizability of the findings to a broader global context; (iii) since this study mainly addresses the perspectives of CLT manufacturers, the views of other stakeholders such as architects, engineers, or consumers are likely to be overlooked. Addressing these limitations in other future studies as well as further diversifying data sources may increase the robustness and applicability of this study's findings and recommendations.

7. Conclusions

The findings from our research could offer intricate policy insights and regulatory recommendations concerning the market dynamics of CLT in the worldwide construction sector. These insights are poised to enhance comprehension, particularly for significant experts such as designers, specifiers, producers, and various stakeholders in the CLT

construction domain. This is vital given the current market demands and the imperatives posed by regulatory and legal frameworks, influenced by pertinent decision makers.

Additional public CLT initiatives should be implemented, focusing on creating sustainable business models that receive legal and financial backing from government bodies. Moreover, it is vital to foster robust partnerships involving local governments, contractors, suppliers, and architectural firms. Furthermore, enhancing inter-organizational collaboration, particularly with design teams and CLT firms, will enhance expertise and facilitate a wider global adoption of CLT.

Providing essential academic and practical guidance on the utilization of CLT is of paramount importance, necessitating comprehensive instruction within academia and the construction sector. Additionally, legislators bear significant responsibilities in shaping the regulatory landscape governing aspects that will influence the trajectory of the global CLT market.

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Appendix A. Interview Questions

1. How familiar are you with CLT production and construction?
2. How familiar do you think CLT is to other professionals (e.g., architects, civil engineers, clients, builders) in the construction industry?
3. Should knowledge of CLT be increased among professionals in the construction industry, or the public and inhabitants?
4. Is CLT a building material that will be seen more in future construction in the fight against climate change?
5. Is the CLT suitable for environments where temperature, humidity, and weather conditions are highly variable?
6. How much sustainable forest management is implemented in the CLT timber construction industry in your country/continent?
7. How did changes in wood raw material prices affect CLT construction?
8. What impact has the corona pandemic had on CLT construction?
9. What kind of buildings (e.g., leisure-time, public, residential, office, high-rise) do you build most with CLT?
10. What are the possible weak points of the CLT structure?
11. How do the standards in the construction industry in your country (such as CE marking across Europe) affect the CLT market?
12. Which wood species do you think are best suited for CLT production?
13. What opportunities and challenges would you assess for the CLT market in the future?
14. Other opinions or comments?

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