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Published in:
Environmental Research Communications

DOI:
10.1088/2515-7620/adaf0f

Published: 01/02/2025

Document Version
Publisher's PDF, also known as Version of record

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To cite this article: Oana Iliescu *et al* 2025 *Environ. Res. Commun.* **7** 025007

Environmental Research Communications

PAPER

Drivers and challenges for wood-based construction in urban areas

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Keywords: sustainable construction, stakeholder perception, low-carbon construction, wood building, timber building

OPEN ACCESS

RECEIVED
11 November 2024

REVISED
14 January 2025

ACCEPTED FOR PUBLICATION
27 January 2025

PUBLISHED
6 February 2025

Abstract

Wood-based construction (WBC) has gained prominence as a sustainable alternative to traditional construction, offering significant environmental benefits such as carbon storage and reduced greenhouse gas emissions. Its importance lies in its potential to contribute to climate change mitigation while supporting economic growth and innovation in the construction industry. Therefore, understanding the drivers and challenges of WBC is essential for its future development. This study, at the first stage, conducted a literature review to identify the key drivers and challenges associated with WBC, categorizing them into environmental, technical, economic, and perception and policy aspects. Then, based on these findings, we conducted 20 semi-structured interviews with WBC experts from Finland in the construction industry, public administration and academia to compare theoretical perspectives with practical insights. Results revealed that literature often focuses on matters such as life-cycle assessments, policy development, and renewable resource management. On the other hand, interviewees emphasize practical concerns like technical feasibility, economic viability, and client perceptions. Climate considerations are acknowledged by interview participants as important but are often viewed as external expectations rather than core business drivers. This study highlights the gap between academic research and industry practice.

1. Introduction

1.1. Background

Reducing greenhouse gas (GHG) emissions, mitigating, and adapting to climate change have become essential actions to ensure a sustainable future. Nonetheless, the building sector is not changing fast enough to achieve its sustainability goals by 2030 or even by 2050, according to the 2024 UNEP's Global Status Report for Buildings and Construction [1]. Currently, it accounts for an estimated 21% of all global GHG emissions [2]. Additionally, as the population grows and increasingly moves towards urban areas, our demand for new construction activities also rises [3]. Thus, the need for more robust solutions is more significant than ever.

In recent years, numerous environmental measures on a building level have focused on lowering the GHG emissions from the operational phase [4–6]. These measures target energy efficiency improvements in the building envelope (e.g., better insulation, more efficient windows, etc); renewable energy integration, water management, building automation etc As a result, the relative share of GHG emissions from the operational phase has decreased, while the embodied emissions have become a more significant factor in the overall lifecycle emissions. Research notes that in energy-efficient buildings, embodied GHG emissions range from 45–50% to over 90%, in some very rare cases [7–9]. Thus, adopting low-carbon material solutions on a larger scale could help steer the industry toward carbon neutrality, reducing the embodied emissions of a building.

Wood represents such a solution. It is a renewable material, provided it is sourced sustainably from well-managed forests. Rapid urbanisation and the resulting demand for new infrastructure and housing present an opportunity for wood construction to play a pivotal role in reducing environmental impacts within cities. Unlike conventional, carbon-intensive building materials, i.e., concrete or steel, wood building materials can significantly lower the embodied carbon footprint of urban development while offering comparable structural and aesthetic qualities [1, 10–12]. By integrating wood into multi-story housing, commercial buildings, and

public spaces, cities can achieve GHG reductions [13–16]. Moreover, wood materials serve as a long-term carbon storage solution by retaining the carbon dioxide absorbed by trees [17, 18]. Wood's adaptability to modular pre-fabricated construction methods supports faster development and shorter construction time, an essential benefit in densely populated urban areas. Accordingly, wood-based construction (WBC) in urban areas could reduce the carbon footprint of buildings, becoming one possible pathway for sustainable and resilient cities.

Traditionally, wood has been widely used as a construction material for single-family houses, especially in the Northern countries [19], where it accounts for more than 80% of building frames [20]. Nowadays, the development of engineered wood products such as glued laminated timber (glulam), cross-laminated timber (CLT), or laminated veneer lumber (LVL) allows for the use of wood as a structural element in multi-storey buildings [18–21]. However, to significantly contribute to sustainability in construction, the use of wood elements in both structural and non-structural capacities must be substantially higher across all building types, scales, and heights [17].

Research notes further beneficial aspects of WBC beyond its climate mitigation potential. EWPs have an advantageous strength-to-weight ratio compared to alternative construction materials [22, 23]. They are well-suited to prefabrication, leading to more time- and cost-efficient installations on site, fewer disruptions to the surrounding environment, as well as safer and more standardized working conditions for the operators (ibid). From the user perspective, there is a growing body of literature investigating wood-centric environments in residential buildings. The studies focus on possible air quality improvements and a relaxing atmosphere, leading to well-being and health benefits [24–28]. However, researchers note that these aspects are more difficult to quantify due to numerous subjective factors. Whether driven by environmental benefits or other advantages, the growing interest in WBC is increasingly evident across the industry [29].

The challenges associated with the development and growth of wood-based construction are also quite diverse. Construction in general is a slow-changing industry, based on a multitude of standards and regulations, on international (e.g., EU-wide) and national levels. At present, these standards favour well-established, traditional construction materials. Additionally, users and construction professionals have varying perceptions of wood durability, fire resistance, acoustic performance, and moisture control [30]. These perceptions might affect the acceptance and appeal of wood as a building material. Consequently, the cost competitiveness of WBC across different markets varies. Overall, the WBC industry is a multifaceted subject regarding both its potential and limitations.

1.2. Aim and scope

Although the benefits of WBC are well-established, the industry's growth has been slower than anticipated. The research generally includes perspectives from one set of stakeholders in the WBC value chain and it focuses on their position within the industry [31, 32]. There is a need for a holistic view from multiple perspectives which would clarify the state and future development of the sector. This article aims to examine the drivers and challenges of WBC from theoretical and practical perspectives. Towards that goal, this article proposes the following research questions:

RQ1: What are the key drivers and challenges for large-scale adoption of wood-based construction proposed in the scientific literature?

RQ2: How does the wood-based construction sector in Finland, as a forest-rich country, perceive the drivers and challenges in wood-based construction?

This study is focused on Finland as a research area for WBC implementation. Although every country presents distinctive cultural, economic, and environmental conditions, research suggests that there are similar trends and attitudes towards WBC across the globe [33–36]. The Finnish research focus as a forerunner in the global forest industry provides valuable future insights and a better understanding of WBC, contributing to the growing body of knowledge which makes the application of these research findings to countries similar to Finland in the world.

Finland is a Northern European country with vast forest resources (approximately 75% of its land area) [37], a strong forestry industry, along with well-established forest management practices. Its strong background in traditional wood construction and ambitious sustainability goals make it an excellent study area for the development of multi-storey WBC. Despite the widespread support, research notes that the market share of multi-storey WBC has only increased from 1% in 2010 to approximately 5–7% in 2022 [33, 38, 39]. Compared to the state of WBC in countries like Sweden or the UK which share similar bioeconomy goals [40], Finland's progress has been limited.

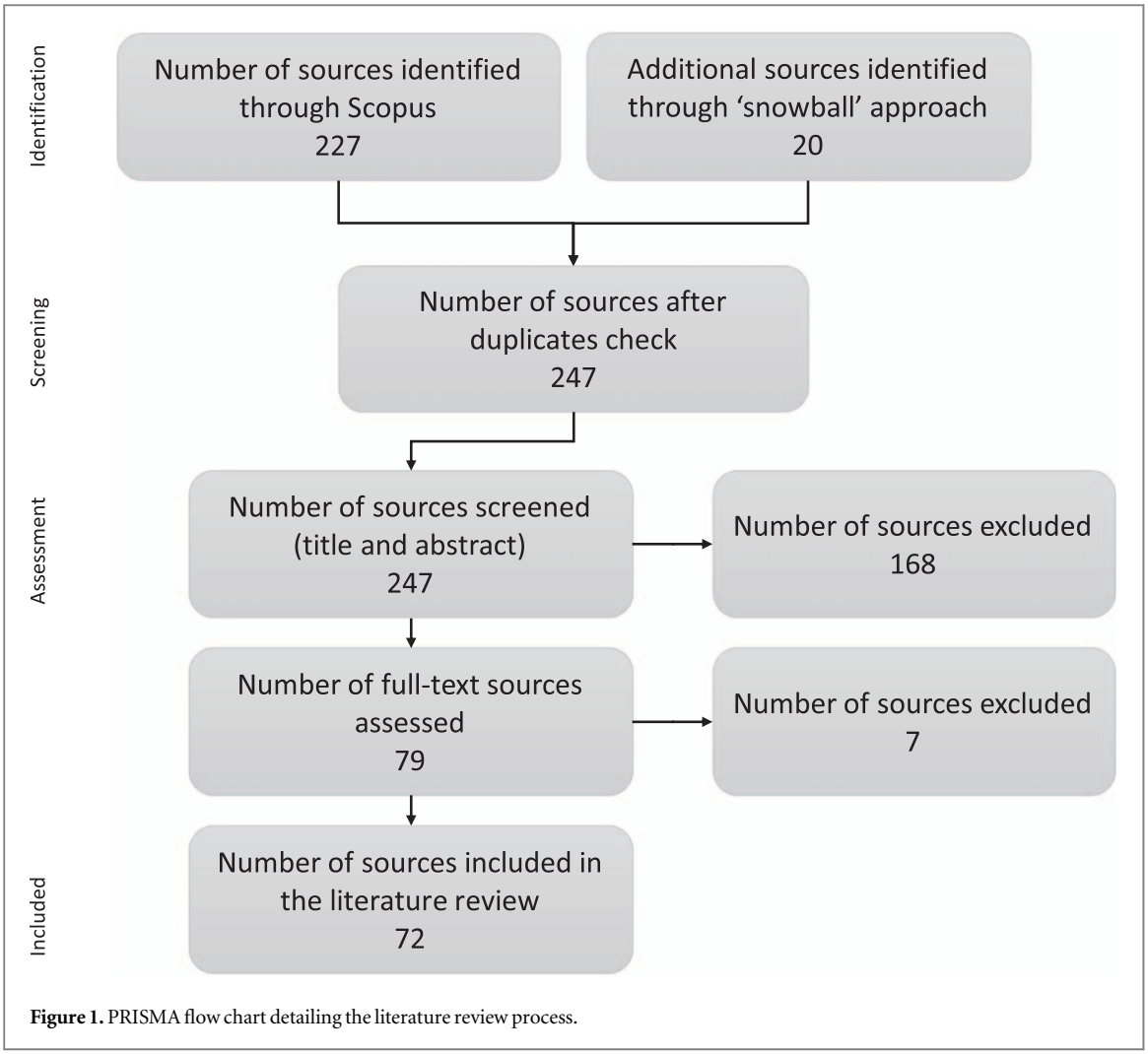

Figure 1. PRISMA flow chart detailing the literature review process.

2. Methodology

Two main methods were utilized to achieve the aims of this article, a literature review, and a set of semi-structured interviews targeted to the WBC sector. In this context, the WBC sector is composed of stakeholders in the following industries and domains: construction, engineered wood products (EWPs) manufacturers, investors, policymakers, and academia. The purpose of the literature review was twofold: to provide i) a theoretical foundation for developing the interview questions ii) and a research-based overview of the drivers and challenges of WBC. We present the literature review process and its findings in section 2.1. Following that, we use the results from literature to design the interview questions.

2.1. Theoretical background

The literature review was conducted in August 2023 and repeated in August 2024 to ensure that the latest research is included in this article. The search was performed with Scopus, and it used the keyword strings: (*wood* AND *construction**) to be found in the article title AND (*challenges* OR *barriers* OR *limitations* OR *drivers* OR *benefits* OR *advantages*) set to appear in the article title, abstract, keywords. The search criteria included all types of peer-reviewed academic publications (journal articles, reviews, conference papers, book chapters, etc) with results limited to English language availability. Additionally, after this initial search, the 'snowball' approach was used to complement the existing sources [41]. The approach consisted of checking the references list of key publications, consulting the publication lists of notable authors, and relying on previous expertise from the authors. The next step in the literature review was a preliminary examination of the publications which consisted of reading the title and abstract of each document. This was followed by a full-text assessment of the remaining sources (figure 1). Their relevance to the current article was determined by the authors based on the research questions and aims.

Going through the literature, we found that it is organized under different factors, i.e. environmental, technical, economic, and subjective perception, as separate categories for exploring drivers and challenges. They

are interdependent factors that influence the WBC sector. Firstly, environmental factors, such as the use of low-carbon, renewable building materials, are significant drivers in the promotion of wood. While concerns about deforestation and resource depletion act as barriers. Secondly, technical factors are crucial since structural properties, durability, and fire resistance are essential considerations in building standards and safety regulations. Thirdly, economic factors also play a vital role, with costs, market competitiveness, and lifecycle benefits influencing decision-making in construction. While wood can offer cost advantages in certain contexts, market price volatility and the need for specialized labour can create economic barriers. Lastly, the subjective perception impacts stakeholder acceptance, as public and professional perceptions about the safety, durability, and aesthetic value of wood can either drive or hinder its use.

Together, these four factors comprehensively represent the multidimensional influences on WBC, providing a framework that allows for a well-rounded exploration of the field. This framework will guide the semi-structured interviews, offering a clear structure for investigating both drivers and challenges identified in the literature. The following (table 1) presents a summary of the key drivers and challenges of WBC identified during the literature review phase.

2.2. Interview design

The second method used in this article was a qualitative research method in the form of semi-structured interviews. Interviews are commonly used in research to gain in-depth knowledge and insights from the participants, allowing for their perceptions to be later analysed [75, 76]. For the current research, semi-structured interviews were deemed an appropriate research method for two reasons. In the first instance, interviews provide practical insights from stakeholders to be compared to the theoretical findings from literature. Secondly, the method offers the opportunity for a wide range of perspectives. The semi-structured format of the interview allowed for open-ended, participant-focused questions with the option to further explore a subject by asking non-leading follow-up questions. Research shows that the semi-structured format creates a rapport between the interviewer and the participant, leading to a dialogue and the chance for more detailed information to emerge [77–79].

2.2.1. Interview development

The first phase of developing the interviewing framework consisted of literature research on drivers and challenges for the WBC sector with different stakeholder perspectives. The goal of this process was to become familiar with the study area, understand the general issues of WBC examined in literature, and map the WBC sector according to industries and stakeholder groups. The format of the interview followed guidelines reported in literature [79], namely two levels of questions: the main questions covering the goals of this study and follow-up questions encouraging participants to expand on their points. The follow-up questions were not pre-determined but rather based on participants' previous answers to maintain the dialogue. The establishing questions focused on the participant's background and previous experience with WBC. The main questions were aimed at answering the research questions of this study and were designed to focus on larger themes (table 2).

2.2.2. Participants selection

The next step in the process focused on compiling a list of potential interview participants. The research targeted all key stakeholders required in the WBC sector. The key stakeholders i.e. interview participants, were tentatively identified based on the WBC value chain, and later supplemented with our findings from the literature review. Based on our research, the key stakeholders for the WBC sector were identified to be developers & investors, contractors & designers, EWP manufacturers & supplies, public authorities, and researchers. The criteria for selection were (i) has a relevant background in one of the industries representing the WBC sector (ii) has prior expertise having been directly involved in WBC projects. The process relied on a snowball sampling method, starting with relevant participants previously known to the authors and progressing with referrals from these participants. The interview respondents have different professional backgrounds from industry, public authority, and researcher categories in order to capture multidimensional and diverse points of view (table 3).

2.2.3. The interviewing process

The potential participants were initially contacted through an email containing background information on the author and the study. In case of an affirmative answer, the potential participants were sent a detailed privacy notice to ensure transparency and compliance with data protection laws, a consent form, and the questions if they so requested. The interviews took place in a six-month period online through Microsoft Teams or in person in the Helsinki Metropolitan Region (Finland), at the request of the participants. They were conducted in

Table 1. A summary of literature review findings of the drivers and challenges of wood-based construction.

Drivers for wood-based construction		References
Environmental	Wood as a renewable source	United Nations Environment Programme 2024 [1], Hammond and Jones 2008 [10]
	Lower embodied energy	Buchanan and Levine 1999 [42], Börjesson and Gustavsson 2000 [43], Bejo 2017 [44], Schenk and Amiri 2022 [45]
	Substitution effects	Hildebrandt *et al* 2017 [46], Johnston and Radeloff 2019 [47], Talvitie *et al* 2023 [48]
	Carbon storage	Sathre and O'Connor 2010 [15], Leskinen *et al* 2018 [49], Howard *et al* 2021 [50]
Technical	Material innovations (composite materials)	Fadai *et al* 2014 [51], Weinand 2020 [52], Hänsel *et al* 2022 [53], De Araujo *et al* 2023 [54], Vladimirova and Gong 2024 [55]
	Prefabrication and modular construction	Cheung *et al* 2016 [56], Švajlenka *et al* 2017 [57], Wong Chong *et al* 2022 [58]
Economic	Added value for local development	Hynynen 2016 [59], Wuni and Shen 2019 [60]
	Support for circular economy	Husgafvel and Sakaguchi 2023 [61]
Perception	Positive outlook based on wood benefits	Hemström *et al* 2011 [62], Wang *et al* 2014 [36]
	Institutional support	Hurmekoski *et al* 2018 [63], Toppinen *et al* 2018 [30]
Challenges for wood-based construction		**References**
Environmental	Risks for unsustainable forestry practices	Ioannidou *et al* 2019 [64], Seppälä *et al* 2019 [65], Soimakallio *et al* 2021 [66]
	Biodiversity loss	Mishra *et al* 2022 [67]
Technical	Design difficulties due to fire safety	Roos *et al* 2008 [68], Mohammadi and Ling 2017 [69], Churkina *et al* 2020 [18]
	Lack of expertise and training	Hemström *et al* 2011 [62], Mahapatra *et al* 2012 [40]
	Limited industry capacity	Brege *et al* 2014 [70], Gosselin *et al* 2016 [31], Toppinen *et al* 2018 [30]
	Limited progress in automation	Gharaibeh *et al* 2022 [71]
Economic	Cost-competitiveness	Riala and Ilola 2014 [72], Salmi *et al* 2022 [73]
	Lack of sustained innovation	Bossink 2018 [74]
Perception	Misconceptions	Wang *et al* 2014 [36], Leszczyszyn *et al* 2022 [34],
	Lack of widespread acceptance	Lehmann 2012 [22]

Table 2. Interview questions format for stakeholders in construction, EWPs manufacturing, policymaking, and academia.

Type	Interview questions
Professional background	1. Please tell me a bit about your background. Can you describe a notable project you were involved with?
	2. Please tell me more about your organization and the business model (e.g., product sales, integrated forest-to-finished product, custom manufacturing, consulting etc)
Industry analysis: drivers and challenges	3. Please describe the wood construction industry from your perspective, following the highlights and trends that you have noticed.
	4. What are in your opinion the drivers for wood construction?
	5. What are in your opinion the biggest challenges faced by wood construction and its ability to grow in Finland?
	6. What is your opinion on the growth/development of the industry in Finland in the coming years (short/long term)?
	7. What is your impression of collaboration efforts among wood construction stakeholders? And the role you/your organisation has played?
Environmental factors of WBC	8. How important do you consider the forestry sector as a limiting factor in the growth of wood construction and engineered wood products?
	9. How important do you consider the carbon storage of wood-based materials in construction?
	10. How do you approach circular economy principles and what are the strategies in your organisation?

English, lasting from 30 minutes to one hour, and they were recorded for later analysis with the permission of the participants.

In total, 20 interviews were conducted during the study period. Thereafter, based on the author's observations during the interviews and by reading previous transcripts, there were no new themes emerging from the interviews. This was considered the point of saturation for this study [80, 81]. Some researchers consider it an 'ongoing, cumulative judgment' rather than a well-defined point [82]. This perspective is worth acknowledging because it indicates the balance to be achieved in data gathering between a robust data set and continued resource allocation.

2.2.4. Data analysis

The interviews were transcribed using the in-built function of Microsoft Teams. In the first step of the data analysis process, as a privacy measure, all personal information relating to respondents was censored, and the interviewees were given numeric identifiers. Secondly, the interview data was uploaded to the qualitative data management and analysis software Atlas.ti (v24). Given the goals of the current research, a thematic content analysis was deemed suitable. The study utilized thematic content analysis to identify and analyse patterns (themes) within data. It proved to be useful for examining the perspectives of different respondents, highlighting similarities and differences, and generating insights into stakeholder perception of drivers and challenges in WBC implementation in Finland [83]. Our analysis focused on identifying and coding themes, patterns, and concepts that emerge holistically across all interviews (representing the WBC sector); thus, we did not analyse each interviewee separately as a unit of analysis. The process progressed in the following steps: 1) familiarization with data, which included reading and re-reading the data and noting down initial i.e. draft codes, 2) coding, i.e. systematically identifying interesting features of the data across the entire dataset, which involved labelling segments of data with codes that capture their essence, 3) collating codes into potential themes driven from literature under the two categories of drivers and challenges in WBC, 4) reviewing the themes, i.e. checking if the themes work in relation to the coded extracts, pre-determined categories, and the entire dataset, 5) generating clear names for each theme. Finally, the findings were analysed for the whole dataset.

Table 3. Overview of interview respondents' industry/domain, primary position, duration of the interviews (average 43 minutes), and the date when they took place.

Industry & respondent numeric identifier	Position in organisation	Duration (minutes)	Date (m/y)
R5: Construction	Wood Technology Manager	33	Feb 2024
R6: Construction	Managing Director	47	Feb 2024
R7: Construction	Consultant	43	Apr 2024
R8: Construction	Construction Specialist	53	Feb 2024
R12: EWPs manufacturing	Sustainability Manager	38	Feb 2024
R13: EWPs manufacturing	Business Manager	40	Feb 2024
R14: EWPs manufacturing	Sales Director	46	Mar 2024
R15: EWPs manufacturing	Plant Manager	30	May 2024
R9: Investment & Development	Chief Architect	64	Feb 2024
R10: Investment & Development	Fund Manager	56	Apr 2024
R11: Investment & Development	Real Estate Director	32	Apr 2024
R16: Policy-making	Architect	44	Feb 2024
R17: Policy-making	Construction Specialist	55	Feb 2024
R18: Policy-making	Project Manager	59	Mar 2024
R19: Policy-making	Chief Specialist	50	Jan 2024
R20: Policy-making	Development Manager	45	Feb 2024
R1: Academia	Material science researcher	52	Jan 2024
R2: Academia	Construction & LCA researcher	21	Jan 2024
R3: Academia	Senior Project Manager	33	May 2024
R4: Academia	Architecture researcher	32	Jan 2024

[a]Policy-making as an industry category refers to public authorities as well as specialists involved in any capacity in shaping or influencing policy, legislation, etc

3. Results

3.1. Thematic content analysis results

Throughout the interview analysis process, all codes have been recorded and collated into themes (i.e., environmental, technical, economic, perception), with the results presented in figures 2 and 3. The total number for each code refers to the number of mentions, not the number of interview respondents who mentioned it. Respondents may have discussed the same topic in different contexts or added additional insights, in which case the code was applied again. It is relevant to apply codes in each instance in order to capture the prevalence of a topic and/or its richness.

3.1.1. Drivers for wood-based construction

Figure 2 displays the frequency of 17 different codes identified in the respondents' answers, providing a clear overview of the themes driving the development of WBC.

3.1.1.1. Environmental drivers

The environmental drivers were at the forefront of respondents' answers (figure 2). There are five codes grouped under this theme. Codes 7 and 8 indicated that Finland's strong forestry sector should be an encouraging factor for WBC development, as an opportunity: *'We need those materials [concrete and steel] too, but the materials don't grow back and that's one of the things that if we have a sustainable forest management, we can keep those forest blooming, which then again stores that carbon from the air and as long as we can make the building lifecycle longer, it's better for the environment too.'* (Respondent (R)12). Respectively, code 8 focused on the availability and material share allocation of forest resources between paper, pulp, bioenergy, construction, etc. When asked about the effects of WBC on forest resources, six respondents indicated that the share of resources diverted to construction is not nearly as significant as to affect the forest. *'If we had half concrete buildings to wood buildings, we still wouldn't be using that much wood. Most of it is simply exported. So the argument against wood construction based on that fact just doesn't stand up.'* (R1). Another respondent pointed out that the Finnish WBC sector uses an insignificant amount of the total wood resources *'I don't think it's a bottleneck in a way because it's only a very minor, minor part which is used in construction in Finland.'* (R3).

The other three environmental theme codes contained the mentions of circular economy practices (code 14), carbon storage (code 5), and climate considerations (code 1) as the main drivers for WBC. Three respondents mentioned the mutual benefits for WBC and circular economy principles, such as material reuse either from the EWPs production process or at the end-of-life of a building. Carbon storage was mentioned by 9 different respondents as a driver for WBC. Respondents mentioned that it is a beneficial factor, but its relative

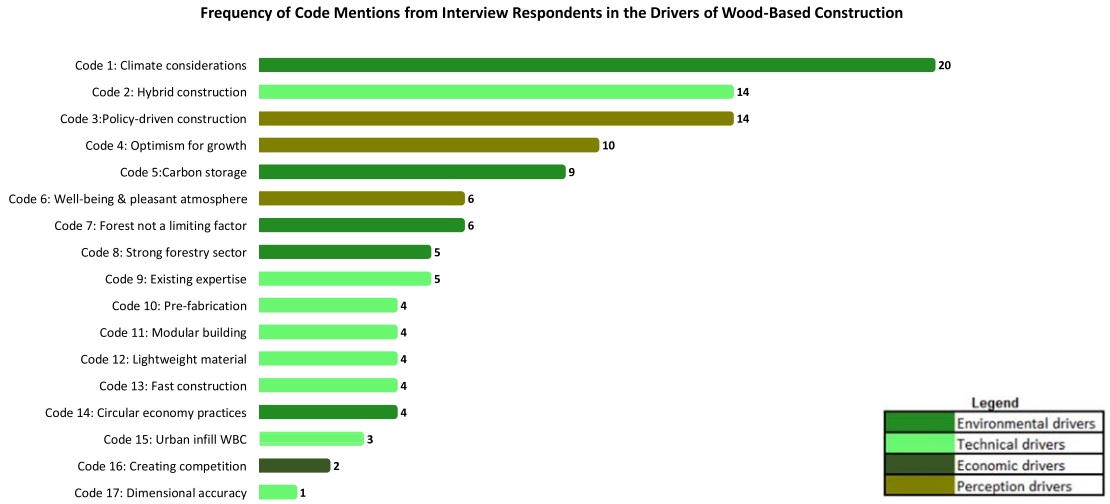

Figure 2. Identified codes grouped in themes for drivers of WBC using Atlas.ti (v24) and obtained from interview responses.

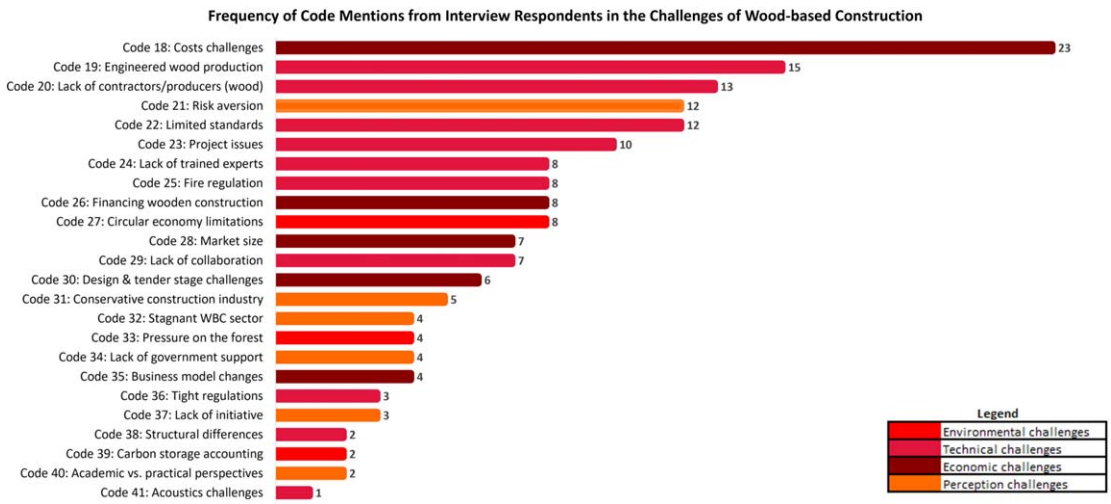

Figure 3. Identified codes grouped in themes for challenges of WBC using Atlas.ti (v24) and obtained from interview responses.

importance compared to other environmental benefits of WBC is much lower: '*Unless we reduce our total emissions, it's going to make no difference. It's going to be a drop in the ocean. But, of course, it makes more sense to store carbon in long-term wood products than not to.*' (R1). However, one respondent underlined that carbon storage capacity may bring advantages to WBC from a business standpoint: '*They are doing this quality-based competition for the different projects and one component is carbon footprint and innovation with the carbon footprint. So, this is how carbon sinks play a role in that.*' (R6).

The climate considerations code was based on the expressed motivation for developing WBC from the respondents. Among the interviewees, 13 highlighted the move towards wood as a construction material because it has lower environmental impacts compared to other materials. Respondents from academia based their remarks on project results and calculations '*we have been doing a lot of LCA calculations for the buildings […] and based on those, we know that the wood in those wooden buildings has lot lower emissions even though you are not calculating the carbon storage.*' (R3). While the other industry respondents commented on the demand for more sustainable construction stemming from broader changes toward environmental awareness and the need to align with those changes. They commented on the environmental drivers for WBC as a matter of corporate responsibility: '*But if we think about sustainability, we need to start to think about the whole life cycle and also the construction phase. If we want to be a responsible investor or developer, it's not only the energy efficiency, it's also what happens before the building exists.*' (R10); brand awareness for the client: '*It's a brand choice. Also concrete, anybody can we have a concrete office.*' (R8); or even consumer demand: '*I have also made many interviews from the*

inhabitants of multi-storey timber frame houses and all inhabitants say that these environmental aspects nowadays are the biggest issue in promoting construction.' (R4).

3.1.1.2. Technical drivers

When asked about the drivers for WBC, participants with a construction or manufacturing background focused on the technical theme. Prefabrication (code 10) and modular construction (code 11) were mentioned by seven different respondents, with one noting that '*I think in the highlights, is the prefabrication. That's where the biggest potential is.'* (R12). They mentioned that modern construction methods bring an increase in efficiency on and off the construction site due to ease of assembly (R14). Also, another respondent highlighted quality '*And then the other competitive edge for timber is quality. If you can produce as much as possible in a factory, you control the quality very well.'* (R8).

Fast construction (code 13) was mentioned four times by two respondents in connection to prefabrication techniques. An interviewee from the construction industry described the improved timeline of construction in wood projects when asked about the main drivers for WBC: '*Well definitely the first one is that the actual construction process is very fast. So on site it's a matter of weeks. The whole building is built or assembled and even if you count the time that the factory takes, it is still maybe eight months overall compared to 14 to 15 months in a traditional way.'* (R7). Likewise, two policy-makers emphasized that WBC is particularly suited in urban areas, where there is a need for infill construction projects (code 15) which can be modular and not disturb the surrounding areas (R 16,20).

Another driver mentioned in particular by construction and EWPs industries respondents is that wood is a lightweight material (code 12). All these technical drivers are connected and their implications are summarised by one respondent as such: '*[Wood] is also five times lighter than concrete, which means way less transportation and it's also making the timeline faster and the whole process has to be under control. So, in that sense, I see the biggest benefits with the wood construction, especially in the urban areas because of the transportation and the prefabrication.'* (R12).

In response to the question regarding drivers of WBC, 4 respondents addressed the existing expertise (code 9). Throughout their professional activities, they had noticed an increase in designers, architects, engineers who are trained to work with wood (R 9,3). Moreover, some indicated this expertise in a wider context: '*[…] construction companies, those biggest construction companies in Finland, they very much had plenty work to get to know CLT and those wooden structures.'* (R18).

Lastly, the most frequent code in the technical perspectives was hybrid construction (code 2). Twelve participants made a total of 14 mentions of hybrid construction techniques. They discussed the need for hybrid structures from a 'best-outcome possible' viewpoint, emphasizing materials serving different purposes in various proportions. '*But I think one thing that does strike me still though, is that we have this very polarised view. It's either a wooden building or not a wooden building. Whereas, in fact, they're both hybrid buildings. They both contain the same sets of materials. Just one has a bit more wood and one has a bit less concrete.'* (R1). Also, another interviewee echoed the sentiment from an industry perspective: '*I'd say the hybrid structure is the key. The dialogue with other material providers is the key. We don't need to battle between concrete sector and steel sector, they should be shaking hands because we all know that timber can be good in some places, but then again, concrete and steel, they have their own places. It's a material combination that works.'* (R12).

3.1.1.3. Economic drivers

Only two respondents focused on WBC as a business opportunity to improve overall price competition (code 16) in the industry. They remarked on the growth of WBC as a driver for more diverse options which, in turn, would lower prices for new developments: '*From the business point of view it's a good thing that we have other options for the concrete buildings. The competition between different kinds of construction solutions is good for the prices.*' (R9).

3.1.1.4. Subjective perception drivers

This larger theme incorporates more subjective views expressed by the participants and how they perceive and integrate WBC within the broader socio-political context. Generally, the codes in this section emerged from answers to questions on the perceived future of WBC and the main drivers behind it (table 2). Regarding their expectations for the future, nine respondents expressed their view as being relatively optimistic (code 4), especially compared to the present state: '*If we just talk about the multi-storey buildings, now the market share is around 5% and I think with relatively small changes, it could rise to 20%. […] And, when the market is as bad as it is now, then companies are more willing to discuss.*' (R19). Meanwhile, a respondent from the investors group was more reserved: '*Well, I do see increase in volumes and in the number of buildings being constructed. So, it is becoming more popular, but it is very regional.'* (R10).

Six respondents representing different industries reported on the feelings of well-being and health (code 6) associated with wood use in buildings. They discussed their own perception as well as general beliefs and feedback from users: '*I think the users usually like them, they like the wood, the feel, and the air quality. […] even though it's measured that the air quality is not automatically better in wooden buildings, but the people think that.*' (R17) and '*The atmosphere inside and the feedback we get from the tenants, they're really positive.*' (R11). While others focused on the well-being aspect as an opportunity to increase the usage of wood in such projects as kindergartens and schools (R 16,20).

The policy-driven construction (code 3) refers to the motivation behind selecting wood as a construction material, largely driven by climate policies and legislation regarding reductions in CO_2 emissions. This code is strongly related to the environmental code of climate considerations (code 1) and undoubtedly, they are both considered drivers for WBC. However, there is a clear difference in the reasoning expressed by 11 respondents. They referenced city planning and plot allotments, housing programmes, and climate legislation as drivers behind the choice for WBC. A policy-making industry respondent noted that '*the programme for housing policy has stated that we have to promote wood construction. So, we do it because it's a policy and also it has been for a long time. […] there were many options to cut carbon emissions and wooden housing was seen as being the only real solution.*' (R20). From the construction industry, one respondent remarked: '*One thing is, if you want to have projects, there's a heavy steering towards wood and wood construction from city level.*' (R6).

3.1.2. Challenges for wood-based construction

The WBC sector presents a complex set of challenges, as revealed through the responses of the interview participants. Figure 3 provides an overview of the 24 identified codes. They are accordingly categorised in the larger themes of environment, technical, economic, as well as subjective perceptions.

3.1.2.1. Environmental challenges

The environmental challenges emerged from the questions related to the importance placed on carbon storage of long-lasting HWPs, forestry, and circular economy perceptions (table 2). Thus, there are only three codes in this theme. One respondent from the construction industry signalled confusion related to carbon storage (code 39) benefits. While a respondent from the investment industry related that carbon storage is often disregarded in their activity due to misgivings about possible double counting when offsetting GHG emissions.

Regarding the forest resources (code 33), there were four respondents who raised concerns. A respondent from the EWPs manufacturing sector indicated uncertainty over differing accounts of resource availability. Meanwhile, three respondents from academia deliberated on resource distribution between industries and the efficiency of their processes: '*it very quickly comes to the debate between how do we value the forest? So, I think there needs to be a longer-term discussion about how we utilise forest resources. I would hope and wish to see a more balanced viewpoint and approach.*' (R1).

Lastly, when discussing the circular use of wood resources (code 27), there was a distinction between academics, industry, and policymaking respondents. The former focused on the need to increase the share of long-lasting wood products and the reuse of waste or by-products from the manufacturing process. The latter respondents discussed the missed opportunities to recycle materials at the end-of-life stage of a building or project: '*we should start to check how to recycle wooden structure parts, how to recycle concrete parts. We should connect those recycled parts more effectively. We are not active enough.*' (R18).

3.1.2.2. Technical challenges

The technical theme was at the forefront of the respondents' answers, with a share of approximately 38% of all codes in the challenges analysis. Interview participants highlighted issues related to acoustics (code 41), structural differences between WBC and traditional construction (code 38), tight regulations (code 36) regarding exposed wood in multi-storey wood buildings (over 8 storeys), and stringent fire regulations (code 25). Five respondents reflected on the impact that restrictive fire regulation in Finland has on the desirability of wood buildings. One respondent from the policy-making industry noted that '*most of the investors were thinking if the structure is all wood, some of it should be also visible. It's a problem in Finland because of the fire regulations.*' (R18).

Another significant code is the limited standards (code 22). Respondents had views on standardization on different scales, specific to their industry or domain. Policy-making respondents observed that there is no standardised construction method or preferred structural system for projects within the city's plan. In their opinion, this created a large number of unique projects, without continuity or the opportunity for knowledge transfer. From the construction sector, participants identified as challenges the lack of standard documentation and standard joint connectors. Respondents from academia provided an overview of the efforts to introduce standard elements and practices in WBC over the years: '*All major players have had their own systems and own details and own joint geometries. And a decade ago there was such a major effort in Finland to harmonise this […]. It*

really didn't take off. And that's why we are still in the same situation that different wood construction systems are pretty unique.' (R2).

The lack of collaboration (code 29) and the lack of trained experts (code 24) have seven and eight mentions, respectively (figure 3). Regarding collaboration, respondents from the manufacturing and construction sectors emphasized the large number of stakeholders involved in a project and the need for more widespread communication to avoid repetition and delays. Some specifically mentioned the dialogue between designers and contractors as lacking. A respondent from academia summarised the *'connections between different actors involved in the construction process. I think there's a lack of coordination, lack of joint understanding. I think the fragmentation within the process is actually often a hindrance.'* (R1). Six respondents from industries except academia also commented on the need for more expertise and training in architects, civil and structural engineers, etc One commented that *'there's not too many people in this country who actually know how to build, how to design with wood. And, of course, they're providing that continuous training. But there could be more.'* (R12).

Lastly, the two most mentioned codes from the technical theme are the challenges in EWPs manufacturing (code 19) and the lack of contractors and EWPs manufacturers (code 20). The first code was mentioned by 4 participants in several instances, and it is a two-dimensional challenge. It refers to both a lack of production capacity for large volumes of EWPs in Finland as well as a related challenge of producing elements with diverse dimensions/specifications. Respondents commented on the lack of capacity in the industrial production of EWPs: *'We manufacture wooden frame elements for our own needs and also sell […] if there is capacity available. Every project is customer-based. We don't manufacture anything unless there is a deal made with customers beforehand.'* (R15). The lack of contractors and manufacturers (code 20) was mentioned 13 times by 11 interview participants, predominantly from the construction, EWPs manufacturing, and policymaking. The developers have particularly remarked that the number of contractors able to handle a large project is severely limited in Finland.

3.1.2.3. Economic challenges

The economic theme gathered the most mentions when participants were asked about the challenges they see in the WBC sector. The business model changes (code 35) has four mentions, early-stage project challenges (code 30) has six mentions, and market size (code 28) has seven mentions. The first two codes relate to changes needed in WBC, specifically to address differences from traditional design, tender, and construction methods. They reflect some respondents' views on companies needing to adjust their business strategies in order to account for these differences and provide integrated solutions. A policy-making respondent commented on the procedure changes: *'Builders are also responsible for the design in our projects. Usually, we design them ourselves and then we get the contractor to build it, but with wood construction […] they're also responsible for the design because the contractors have one way of building wooden buildings, which is unique for them.'* (R20).

The market size code is interlinked with codes from the technical and economic themes. Respondents referenced the relatively small market in Finland as a challenge for WBC development and its stability as a sector, as well as for standardisation, contractor numbers, and investments in manufacturing capacity. A policy-making respondent noted that it is *'not easy to develop the systems or develop standardisation if we don't have so many customers, if we don't have big projects from abroad and we are only working inside Finnish borders.'* (R18).

The two most frequent codes in the economic theme are financing wood construction (code 26) and cost challenges (code 18). The former relates rather to the ability and readiness of construction companies to finance their projects rather than specific financing tools for WBC. One construction respondent described that challenges emerge in WBC due to faster construction times, leading to the company needing more working capital to cover upfront costs at the outset of a project. Also, they emphasised the balance of profit and risk in a project when the majority of wood elements are produced and installed by a subcontractor. *'In previous projects, less than 10% of the investment value was from wood products. Over 90% was something else. So, if you don't handle the 90%, then you lose a lot of money.'* (R19).

The latter code of cost challenges (code 18) has 23 mentions made by 13 respondents. The majority of respondents commented on the higher cost of WBC from their industry's perspective, trying to identify reasons for it. They have pointed out various other challenges such as a lack of contractors, limited competition, or variations in wood prices as causes for higher costs associated with wood buildings. They all indicated that, despite other benefits, the economic bottom line is essential, and without a decrease in prices, significant growth remains unlikely.

3.1.2.4. Subjective perception challenges

This theme is represented through 6 codes. Three respondents mentioned a lack of initiative (code 37) amongst industry stakeholders, referencing the discrepancies between their expressed goals and the effort to accomplish them. Furthermore, four respondents from the policymaking and construction industries commented on the

importance of continued government support for WBC (code 34), noting that the challenges faced by the sector in a supportive environment are likely to be exacerbated in the absence of such support.

The codes stagnant WBC sector (code 32) and conservative construction industry (code 31) stemmed from the respondents' perceptions of their experiences within the industry. An academia respondent pointed out WBC's lack of sustained development: *'those [construction] companies, they might have one wood project every five or 10 years. So, there is no systematic development going on. It's more like project-based approach and, even though you will work with them with some project, so there is no reputation after that.'* (R3). They continued by reasoning that WBC operates within a conservative construction environment: *'the sector is very conservative, and those changes are very slow. […] in the end when the project ends, we are going back to how we used to do things.'* (R3).

3.1.3. Key findings

Table 4 summarises the results for drivers and challenges in the WBC sector, including supporting quotes from interview respondents. Codes with similar meanings or related concepts were grouped in clusters under the larger themes of environment, technical, economic, and perception. As such, clusters provide clarity and coherence. This table, mirroring the format of the literature review findings in table 1, provides a straightforward basis for comparison that will be elaborated in the following Discussion section.

4. Discussion

The present research aimed to explore the drivers and challenges influencing wood-based construction (WBC) in Finland, a country with extensive forestry resources and a significant bioeconomy focus. Recognizing the potential of wood as a sustainable material for mitigating greenhouse gas emissions and promoting low-carbon building solutions, this study aimed to identify the factors that encourage or hinder the adoption of wood in construction. Given the global momentum for sustainable development, this research addresses an important gap by presenting the perspectives of multiple stakeholders within the WBC value chain, thus providing insights into the drivers and challenges for WBC development in a Finnish context.

Our research was conducted in two main stages: first, a comprehensive literature review to establish the theoretical foundation for WBC drivers and challenges, and second, a qualitative study involving semi-structured interviews with key stakeholders in Finland's WBC sector. The literature review allowed us to categorize the main drivers and barriers into four thematic areas—environmental, technical, economic, and perception factors. These themes then informed our interview questions, facilitating a structured approach to data collection. The interviews were conducted with professionals across academia, EWPs manufacturing, construction, investment and development sectors, and public administration. A thematic analysis was performed on the results of the interviews using the qualitative analysis tool Atlas.ti (v24). The data was coded and categorised according to themes, mirroring those identified in the literature review.

Wood-based construction has reemerged in the modern construction context due to its established environmental benefits, based on renewable materials, carbon storage, and substitution abilities. Thus, the potential to reduce the environmental impacts of the construction sector is at the forefront of WBC drivers. This perspective is emphasised by both literature and the results of the thematic analysis. Certainly, the focus in literature appears to have shifted towards questions of renewable resource management, future use scenarios, comparative LCAs, etc. The discussion is centred on more complex and detailed aspects of WBC, often exploring policy implications, regulatory frameworks, and incentives that promote the adoption of WBC to achieve broader environmental and economic objectives [63, 84].

The insights from interview participants demonstrate that environmental considerations are recognized by practitioners as a main driver for WBC. Their remarks pointed out similar themes of environmental awareness and the prominent role of wood as a renewable construction material. However, this appears to be more externally motivated. They acknowledge that climate considerations are desirable from societal and policy standpoints, rather than a core value which drives business decisions. By contrasting the drivers and challenges expressed by participants, it appears that economic factors such as the cost efficiency of WBC influence their decisions to a greater extent.

Economically, wood construction presents both drivers and challenges. Our findings reveal that WBC has economic advantages through reduced on-site construction times and lower transportation costs due to the lightweight nature of wood, which supports efficiency and affordability in some contexts. This aligns with findings by (57), who observed significant cost and time savings when comparing prefabricated wood elements to traditional masonry structures. However, stakeholders also pointed to economic barriers such as high upfront costs, market limitations, and EWPs production and construction constraints, which can make WBC less competitive in larger projects.) (72) note similar concerns, highlighting that high initial investment costs, limited supplier networks, and price volatility can deter construction companies from choosing wood. Thus, while there

Table 4. A summary of results of the drivers and challenges of wood-based construction.

Results of drivers for wood-based construction		Examples of respondent quotes
Environmental theme	Strong forestry sector (codes 7, 8)	**R12**: '… if we have a sustainable forest management, we can keep those forest blooming, which then again stores that carbon from the air and as long as we can make the building lifecycle longer, it's better for the environment too.'
		R1: 'If we had half concrete buildings to wood buildings, we still wouldn't be using that much wood. Most of it is simply exported. So the argument against wood construction based on that fact just doesn't stand up.'
	Carbon storage (code 5)	**R6**: 'They are doing this quality-based competition for the different projects and one component is carbon footprint and innovation with the carbon footprint. So, this is how carbon sinks play a role in that.'
	Lower embodied energy (code 1)	**R3**: 'We have been doing a lot of LCA calculations for the buildings […] and based on those, we know that the wood in those wooden buildings has lot lower emissions even though you are not calculating the carbon storage.'
	Environmental and brand awareness (codes 1, 14)	**R4**: 'I have also made many interviews from the inhabitants of multi-storey timber frame houses and all inhabitants say that these environmental aspects nowadays are the biggest issue in promoting construction.'
		R8: 'It's a brand choice. Also concrete, anybody can we have a concrete office.'
Technical theme	Prefabrication and modular construction (codes 10, 11, 13, 17)	**R12**: 'I think in the highlights, is the prefabrication. That's where the biggest potential is.'
		R7: '[…] the actual construction process is very fast. So on site it's a matter of weeks. The whole building is built or assembled and even if you count the time that the factory takes, it is still maybe eight months overall compared to 14 to 15 months in a traditional way.'
	Lightweight material (code 12)	**R12**: '[Wood] is also five times lighter than concrete, which means way less transportation and it's also making the timeline faster […] especially in the urban areas because of the transportation and the prefabrication.'
	Existing expertise (code 9)	**R18**: 'construction companies, […] they very much had plenty work to get to know CLT and those wooden structures.'
	Hybrid construction (codes 2, 15)	**R12**: 'I'd say the hybrid structure is the key. The dialogue with other material providers is the key. […] timber can be good in some places, concrete and steel, they have their own places. It's a material combination that works.'
Economic theme	Competition-driven prices (code 16)	**R9**: 'From the business point of view it's a good thing that we have other options for the concrete buildings. The competition between different kinds of construction solutions is good for the prices.'
Perception theme	Positive outlook (code 4)	**R19**: 'If we just talk about the multi-storey buildings, now the market share is around 5% and I think with relatively small changes, it could rise to 20%.'
	Well-being and health benefits (code 6)	**R17**: 'I think the users usually like […] the wood, the feel, and the air quality. […] even though it's measured that the air quality is not automatically better in wooden buildings, but the people think that.'
	Policy support (code 3)	**R6**: 'One thing is, if you want to have projects, there's a heavy steering towards wood and wood construction from city level.'
Results of challenges for wood-based construction		**Examples of respondent quotes**
Environmental theme	Pressure on the forest (code 33)	**R1**: 'it very quickly comes to the debate between how do we value the forest? So, I think there needs to be a longer-term discussion about how we utilise forest resources.'
	Limited circular practices (codes 27, 39)	**R18**: 'we should start to check how to recycle wooden structure parts, how to recycle concrete parts. We should connect those recycled parts more effectively. We are not active enough.'

Table 4. (Continued.)

Results of challenges for wood-based construction		Examples of respondent quotes
Technical theme	Design difficulties (codes 23, 25, 30, 36, 38, 41)	**R18**: 'most of the investors were thinking if the structure is all wood, some of it should be also visible. It's a problem in Finland because of the fire regulations.'
	Lack of standardisation (code 22)	**R2**: 'All major players have had their own systems and own details and own joint geometries. And a decade ago there was such a major effort in Finland to harmonise this […]. It really didn't take off.'
	Lack of collaboration (code 29)	**R1**: 'connections between different actors involved in the construction process. I think there's a lack of coordination, lack of joint understanding. I think the fragmentation within the process is actually often a hindrance.'
	Lack of expertise and training (code 24)	**R12**: 'there's not too many people in this country who actually know how to build, how to design with wood. And, of course, they're providing that continuous training. But there could be more.'
	Limited industry capacity (codes 19, 20)	**R15**: 'We manufacture wooden frame elements for our own needs and also sell […]. We don't manufacture anything unless there is a deal made with customers beforehand.'
Economic theme	Business model changes (code 35)	**R20**: 'Usually, we design them ourselves and then we get the contractor to build it, but with wood construction […] they're also responsible for the design because the contractors have one way of building wooden buildings, which is unique for them.'
	Costs (codes 18, 26)	**R19**: 'In previous projects, less than 10% of the investment value was from wood products. Over 90% was something else. So, if you don't handle the 90%, then you lose a lot of money.'
	Market size (code 28)	**R18**: 'not easy to develop the systems or develop standardisation if we don't have so many customers, if we don't have big projects from abroad and we are only working inside Finnish borders.'
Perception theme	Lack of sustained development (codes 32, 34, 37)	**R3**: 'those [construction] companies, they might have one wood project every five or 10 years. So, there is no systematic development going on. It's more like project-based approach.'
	Conservative mindset (codes 21, 31)	**R3**: 'the sector is very conservative, and those changes are very slow. […] in the end when the project ends, we are going back to how we used to do things.'

is economic potential, sustained support and market expansion are essential to make WBC more viable at a larger scale.

Technically, advancements in EWPs, prefabrication, and modular construction were frequently cited as key drivers for WBC, with participants noting that these technologies allow wood to compete with traditional materials in terms of structural integrity and building height. This supports the literature on the use of EWPs like cross-laminated timber (CLT) and laminated veneer lumber (LVL), which offer strong, durable options for multi-storey construction (21). However, technical challenges, particularly related to fire safety and durability, remain significant barriers. Stakeholders expressed concern over stringent fire regulations and the lack of standardized design practices, challenges that are mentioned by (18), (69), who point out that additional fireproofing requirements for wood construction add complexity and costs. This indicates that while technical innovation is a major solution, overcoming regulatory and safety barriers remains a priority for wider adoption.

The perception of wood's environmental benefits emerged as an important driver, with stakeholders noting that wood's natural appearance and perceived health benefits enhance its appeal, especially in residential and public buildings. Studies support this view, finding that wood interiors can contribute to improved well-being, air quality, and a comforting environment, which are particularly valued in schools and healthcare settings (24, 28). However, perception challenges also emerged, with stakeholders indicating that misconceptions about wood's durability, maintenance, and fire safety persist among both consumers and professionals. Research by (30, 36) similarly points out that while there is a positive shift in attitudes toward sustainable materials, lasting uncertainties about wood's long-term performance can prevent its acceptance. Addressing these perceptions through education and transparent communication about wood's capabilities is essential to build trust and wider acceptance within the construction industry and among end-users.

Our findings are valuable for academia, industry, and policymakers, providing a holistic view of the current state and future prospects of WBC. For academic researchers, these insights offer a basis for exploring solutions to technical and economic challenges, particularly in areas such as cost reduction and regulatory adjustments. Industry stakeholders may use these findings to understand market demands and consumer perceptions, thereby helping them to tailor their strategies to increase WBC adoption. For policymakers, this study provides evidence to support the development of incentives, such as subsidies for sustainable building materials, and to adjust building regulations to better accommodate WBC.

This study is subject to certain limitations, primarily due to its qualitative design and focus on a single country, which may affect the generalizability of the findings. Additionally, while we captured a diverse set of stakeholder perspectives, the sample size was constrained by logistical factors, and the findings may not fully represent all viewpoints within the WBC industry. Further research could expand on this study by conducting quantitative analyses to validate and measure the identified drivers and challenges. Additionally, cross-country comparisons would offer insights into how different regulatory environments and market conditions impact WBC adoption, potentially leading to globally applicable recommendations.

5. Conclusion

This study examined the primary drivers and challenges affecting WBC in Finland, integrating insights from both literature and practitioner interviews. The findings reveal that environmental benefits, such as carbon sequestration and lower embodied energy, make wood a promising sustainable building material, aligning with global carbon reduction goals. Yet, challenges, including sustainable forestry management and biodiversity impacts, highlight the need for responsible sourcing practices. Economically, WBC offers efficiency benefits like reduced construction times and transportation costs, while high initial costs and capacity constraints present significant barriers. Technologically, advancements in engineered wood products and prefabrication are enabling WBC to compete with conventional materials, but fire safety concerns and durability issues remain major obstacles. In terms of perception, wood's visual and health benefits enhance its appeal, but concerns of durability and safety inhibit it.

The practical implications of these insights are relevant for academia, industry, and policymakers. Academics can explore solutions to address the technical and economic challenges identified, while industry professionals may find these insights useful for understanding market demands and aligning strategies with consumer perceptions. For policymakers, the findings underscore the importance of regulatory adjustments, public awareness campaigns, and incentive structures to support WBC adoption. While this research provides valuable insights, its qualitative, Finland-specific approach may limit the generalizability of findings. Future research could benefit from quantitative studies and cross-country comparisons to understand how different regulatory and economic contexts impact WBC adoption.

Ethical considerations

Prior to participation, all individuals received detailed information about the study and provided written informed consent in accordance with institutional guidelines. Participants were assured of the confidentiality of their responses and their right to withdraw from the study at any time without penalty.

Acknowledgments

This work was supported by The Research Council of Finland under project numbers 13352450 and 13353847. We are grateful for their financial support, which made this research possible.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

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References

[1] United Nations Environment Programme 2024 *2023 Global Status Report for Buildings and Construction: Beyond foundations - Mainstreaming Sustainable Solutions to Cut Emissions from the Buildings Sector* (United Nations Environment Programme) Available from: https://wedocs.unep.org/20.500.11822/45095
[2] Intergovernmental Panel on Climate Change (IPCC) 2023 *Buildings. In: Climate Change 2022 - Mitigation of Climate Change: Working Group III Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge University Press) 953–1048 Available from: https://cambridge.org/core/books/climate-change-2022-mitigation-of-climate-change/buildings/458CA0414DBB715BF532153CB9872CA3
[3] United Nations (UN) 2019 *Department of Economic and Social Affairs, Population Division. World Urbanization Prospects: The 2018 Revision Report No.: (ST/ESA/SER.A/420)* Available from: https://population.un.org/wup/assets/WUP2018-Report.pdf
[4] Cabeza L F, Rincón L, Vilariño V, Pérez G and Castell A 2014 Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: a review *Renew. Sustain. Energy Rev.* **29** 394–416
[5] Deng S, Wang R Z and Dai Y J 2014 How to evaluate performance of net zero energy building—a literature research *Energy* **71** 1–16
[6] Sartori I and Hestnes A G 2007 Energy use in the life cycle of conventional and low-energy buildings: a review article *Energy Build.* **39** 249–57
[7] Passer A, Kreiner H and Maydl P 2012 Assessment of the environmental performance of buildings: a critical evaluation of the influence of technical building equipment on residential buildings *Int. J. Life Cycle Assess.* **17** 1116–30
[8] Röck M, Sørensen A, Tozan B, Steinmann J, Le Den X, Horup L H and Birgisdottir H 2022 *Towards embodied carbon benchmarks for buildings in Europe - Setting the baseline: A bottom-up approach* Available from (https://doi.org/10.5281/zenodo.5895051)
[9] Röck M *et al* 2020 Embodied GHG emissions of buildings—the hidden challenge for effective climate change mitigation *Appl. Energy* **258** 114107
[10] Hammond G P and Jones C I 2008 Embodied energy and carbon in construction materials *Proceedings of the Institution of Civil Engineers - Energy* **161** 87–98
[11] Hemmati M, Messadi T, Gu H and Hemmati M 2024 LCA operational carbon reduction based on energy strategies analysis in a mass timber building *Sustainability* **16** 6579
[12] Hemmati M, Messadi T, Gu H, Seddelmeyer J and Hemmati M 2024 Comparison of embodied carbon footprint of a mass timber building structure with a steel equivalent *Buildings* **14** 1276
[13] Ritter M A, Skog K and Bergman R 2024 *Science supporting the economic and environmental benefits of using wood and wood products in green building construction* FPL-GTR-206 U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. Available from: (https://doi.org/10.2737/FPL-GTR-206)
[14] Sathre R and Gustavsson L 2009 *A state-of-the-art review of energy and climate effects of wood product substitution* Mid Sweden University. Available from: https://rogersathre.com/Sathre&Gustavsson_2009_wood_product_substitution_review.pdf
[15] Sathre R and O'Connor J 2010 Meta-analysis of greenhouse gas displacement factors of wood product substitution *Environ. Sci. Policy* **13** 104–14
[16] Duan Z, Huang Q and Zhang Q 2022 Life cycle assessment of mass timber construction: a review *Build. Environ.* **221** 109320
[17] Amiri A, Ottelin J, Sorvari J and Junnila S 2020 Cities as carbon sinks—classification of wooden buildings *Environ. Res. Lett.* **15** 094076
[18] Churkina G *et al* 2020 Buildings as a global carbon sink *Nat Sustain* **3** 269–76
[19] Karjalainen M and Ilgın H E 2023 Wood industry - past, present and future outlook *Wood Industry - Past, Present and Future Outlook* ed G Du and X Zhou (IntechOpen) Available from: https://intechopen.com/chapters//chapters/81864
[20] Gustavsson L *et al* 2006 The role of wood material for greenhouse gas mitigation *Mitig. Adapt. Strat. Glob. Change* **11** 1097–127
[21] Hurmekoski E 2017 *How can wood construction reduce environmental degradation?* European Forest Institute Available from: https://efi.int/publications-bank/how-can-wood-construction-reduce-environmental-degradation
[22] Lehmann S 2012 Sustainable construction for urban infill development using engineered massive wood panel systems *Sustainability* **4** 2707–42

[23] Wimmers G 2017 Wood: a construction material for tall buildings *Nat. Rev. Mater.* **2** 1–2
[24] Burnard M D and Kutnar A 2015 Wood and human stress in the built indoor environment: a review *Wood Sci. Technol.* **49** 969–86
[25] Cho H M, Lee J, Wi S and Kim S 2019 Field study on indoor air quality of wood remodeled welfare facilities for physical and psychological benefits *J. Clean. Prod.* **233** 197–208
[26] Häyrinen L, Toppinen A and Toivonen R 2020 Finnish young adults' perceptions of the health, well-being and sustainability of wooden interior materials *Scand. J. For. Res.* **35** 394–402
[27] Kotradyova V *et al* 2019 Wood and its impact on humans and environment quality in health care facilities *International Journal of Environmental Research and Public Health* **16** 3496
[28] Strobel K, Nyrud A Q and Bysheim K 2017 Interior wood use: linking user perceptions to physical properties *Scand. J. For. Res.* **32** 798–806
[29] Brannen P 2024 *Timber! How Wood Can Help Save the World from Climate Breakdown [Internet]* 1 (Agenda Publishing) 256 Available from: https://agendapub.com/page/detail/timber/?k=9781788217354/
[30] Toppinen A, Röhr A, Pätäri S, Lähtinen K and Toivonen R 2018 The future of wooden multistory construction in the forest bioeconomy—a Delphi study from Finland and Sweden *Journal of Forest Economics* **31** 3–10
[31] Gosselin A, Blanchet P, Lehoux N and Cimon Y 2016 Main motivations and barriers for using wood in multi-story and non-residential construction projects *Bioresources* **12** 546–70
[32] Ramage M H *et al* 2017 The wood from the trees: the use of timber in construction *Renew. Sustain. Energy Rev.* **68** 333–59
[33] Hurmekoski E, Jonsson R and Nord T 2015 Context, drivers, and future potential for wood-frame multi-story construction in Europe *Technol. Forecast. Soc. Change* **99** 181–96
[34] Leszczyszyn E *et al* 2022 The future of wood construction: opportunities and barriers based on surveys in Europe and chile *Sustainability* **14** 4358
[35] Vihemäki H, Ludvig A, Toivonen R, Toppinen A and Weiss G 2019 Institutional and policy frameworks shaping the wooden multi-storey construction markets: a comparative case study on Austria and Finland *Wood Mater. Sci. Eng.* **14** 312–24
[36] Wang L, Toppinen A and Juslin H 2014 Use of wood in green building: a study of expert perspectives from the UK *J. Clean. Prod.* **65** 350–61
[37] Maa- ja metsätalousministeriö 2023 Forest resources in Finland. Available from: https://mmm.fi/en/forests/forestry/forest-resources
[38] Karjalainen M and Ilgin H 2021 *A Statistical Study on Multi-Story Timber Residential Buildings (1995-2020)* (In Finland)
[39] Westerholm N 2024 Assessing the carbon impacts of five apartment buildings with different timber frames: a finnish study *Architectural Research in Finland* **8** 420–44
[40] Mahapatra K, Gustavsson L and Hemström K 2012 Multi-storey wood-frame buildings in Germany, Sweden and the UK *Construction Innovation* **12** 62–85
[41] Wohlin C 2014 Guidelines for snowballing in systematic literature studies and a replication in software engineering *In: Proc. of the 18th Int. Conf. on Evaluation and Assessment in Software Engineering* (ACM) [cited 2024 Sep 21]. pp 1–10
[42] Buchanan A H and Levine S B 1999 Wood-based building materials and atmospheric carbon emissions *Environ. Sci. Policy* **2** 427–37
[43] Börjesson P and Gustavsson L 2000 Greenhouse gas balances in building construction: wood versus concrete from life-cycle and forest land-use perspectives *Energy Policy* **28** 575–88
[44] Bejo L 2017 Operational vs. embodied energy: a case for wood construction *Drvna ind.* **68** 163–72
[45] Schenk D and Amiri A 2022 Life cycle energy analysis of residential wooden buildings versus concrete and steel buildings: a review *Front Built Environ.* [cited 2024 Oct 9]; 8. Available from: https://frontiersin.org/journals/built-environment/articles/10.3389/fbuil.2022.975071/full (https://doi.org/10.3389/fbuil.2022.975071)
[46] Hildebrandt J, Hagemann N and Thrän D 2017 The contribution of wood-based construction materials for leveraging a low carbon building sector in europe *Sustainable Cities and Society* **34** 405–18
[47] Johnston C M T and Radeloff V C 2019 Global mitigation potential of carbon stored in harvested wood products *Proc. Natl Acad. Sci.* **116** 14526–31
[48] Talvitie I, Kinnunen A, Amiri A and Junnila S 2023 Can future cities grow a carbon storage equal to forests? *Environ. Res. Lett.* **18** 044029
[49] Leskinen P *et al* 2018 Substitution effects of wood-based products in climate change mitigation(European Forest Institute) [cited 2024 Oct 9]. (From Science to Policy). Available from: https://efi.int/publications-bank/substitution-effects-wood-based-products-climate-change-mitigation
[50] Howard C, Dymond C C, Griess V C, Tolkien-Spurr D and van Kooten G C 2021 Wood product carbon substitution benefits: a critical review of assumptions *Carbon Balance Manage.* **16** 9
[51] Fadai A, Fuchs M and Winter W 2014 Wood-based construction for multi-story buildings: application of cement bonded wood composites as structural element ed S Aicher, H W Reinhardt and H Garrecht *Materials and Joints in Timber Structures* (Springer Netherlands) 471–84
[52] Weinand Y 2020 *Towards Sustainable Timber Construction Through the Application of Wood-Wood Connections. In* 177–96
[53] Hänsel A, Sandak J, Sandak A, Mai J and Niemz P 2022 Selected previous findings on the factors influencing the gluing quality of solid wood products in timber construction and possible developments: a review *Wood Mater. Sci. Eng.* **17** 230–41
[54] De Araujo V *et al* 2023 Is cross-laminated timber (CLT) a wood panel, a building, or a construction system? a systematic review on its functions, characteristics, performances, and applications *Forests* **14** 264
[55] Vladimirova E and Gong M 2024 Advancements and applications of wood-based sandwich panels in modern construction *Buildings* **14** 2359
[56] Cheung K, Koo K, Al-Hussein M and Kok R 2016 Prefabrication - the future of north american wood frame construction *In: WCTE 2016 - World Conf. on Timber Engineering*
[57] Švajlenka J, Kozlovská M and Spišáková M 2017 The benefits of modern method of construction based on wood in the context of sustainability *Int. J. Environ. Sci. Technol.* **14** 1591–602
[58] Wong Chong O, Zhang J, Voyles R M and Min B C 2022 BIM-based simulation of construction robotics in the assembly process of wood frames *Autom. Constr.* **137** 104194
[59] Hynynen A 2016 Future in wood? timber construction in boosting local development *European Spatial Research and Policy* **23** 127–39
[60] Wuni I Y and Shen G Q P 2019 Holistic review and conceptual framework for the drivers of offsite construction: a total interpretive structural modelling approach *Buildings* **9** 117
[61] Husgafvel R and Sakaguchi D 2023 Circular economy development in the wood construction sector in Finland *Sustainability* **15** 7871

[62] Hemström K, Mahapatra K and Gustavsson L 2011 Perceptions, attitudes and interest of Swedish architects towards the use of wood frames in multi-storey buildings *Resour. Conserv. Recycl.* **55** 1013–21
[63] Hurmekoski E, Pykäläinen J and Hetemäki L 2018 Long-term targets for green building: explorative delphi backcasting study on wood-frame multi-story construction in Finland *J. Clean. Prod.* **172** 3644–54
[64] Ioannidou D, Pommier R, Habert G and Sonnemann G 2019 Evaluating the risks in the construction wood product system through a criticality assessment framework *Resour. Conserv. Recycl.* **146** 68–76
[65] Seppälä J *et al* 2019 Effect of increased wood harvesting and utilization on required greenhouse gas displacement factors of wood-based products and fuels *J. Environ. Manage.* **247** 580–7
[66] Soimakallio S, Kalliokoski T, Lehtonen A and Salminen O 2021 On the trade-offs and synergies between forest carbon sequestration and substitution *Mitig. Adapt. Strateg. Glob. Change* **26** 4
[67] Mishra A *et al* 2022 Land use change and carbon emissions of a transformation to timber cities *Nat. Commun.* **13** 4889
[68] Roos A, Woxblom L and McCluskey D 2008 Architects', building engineers', and stakeholders' perceptions to wood in construction-results from a qualitative study *Scandinavian Forest Economics* **42** 184–94
[69] Mohammadi J and Ling L 2017 Can wood become an alternative material for tall building construction? *Practice Periodical on Structural Design and Construction* **22** 04017014
[70] Brege S, Stehn L and Nord T 2014 Business models in industrialized building of multi-storey houses *Construction Management and Economics* **32** 208–26
[71] Gharaibeh L, Matarneh S T, Eriksson K and Lantz B 2022 An empirical analysis of barriers to building information modelling (BIM) implementation in wood construction projects: evidence from the swedish context *Buildings* **12** 1067
[72] Riala M and Ilola L 2014 Multi-storey timber construction and bioeconomy—barriers and opportunities *Scand. J. For. Res.* **29** 367–77
[73] Salmi A, Jussila J and Hämäläinen M 2022 The role of municipalities in transformation towards more sustainable construction: the case of wood construction in Finland *Construction Management and Economics* **40** 934–54
[74] Bossink B 2018 The influence of knowledge flow on sustainable innovation in a project-based industry: from demonstration to limited adoption of eco-innovations *J. Clean. Prod.* **193** 249–62
[75] DiCicco-Bloom B and Crabtree B F 2006 The qualitative research interview *Medical Education* **40** 314–21
[76] Gill P, Stewart K, Treasure E and Chadwick B 2008 Methods of data collection in qualitative research: interviews and focus groups *Br Dent. J.* **204** 291–5
[77] Dearnley C 2005 A reflection on the use of semi-structured interviews *Nurse Researcher* **13** 19–28
[78] Galletta A 2013 *Mastering the Semi-Structured Interview and Beyond* (NYU Press) Available from https://nyupress.org/9780814732946/mastering-the-semi-structured-interview-and-beyond/
[79] Kallio H, Pietilä A, Johnson M and Kangasniemi M 2016 Systematic methodological review: developing a framework for a qualitative semi-structured interview guide *Journal of Advanced Nursing* **72** 2954–65
[80] Given L M 2015 *100 Questions (and Answers) About Qualitative Research* (SAGE Publications;) 209
[81] Saunders B *et al* 2018 Saturation in qualitative research: exploring its conceptualization and operationalization *Qual Quant.* **52** 1893–907
[82] Strauss A L and Corbin J M 2003 Basics of qualitative research: techniques and procedures for developing grounded theory 2nd. ed. [Nachdr.](Sage Publ) 312
[83] Hecker J and Kalpokas N 2024 Atlas.ti Available from: https://atlasti.com/guides/thematic-analysis/inductive-thematic-analysis
[84] Sergent A and Smith A 2024 When decarbonization rhymes with industrialization. The political dilemmas of increasing wood usage within the French construction industry *J. Environ. Plann. Policy Manage.* **26** 473–86