Using Prefabricated Wood Light-Frame in Multi-Storey and Non-Residential Construction Projects: Motivations and Barriers of Professionals in Quebec

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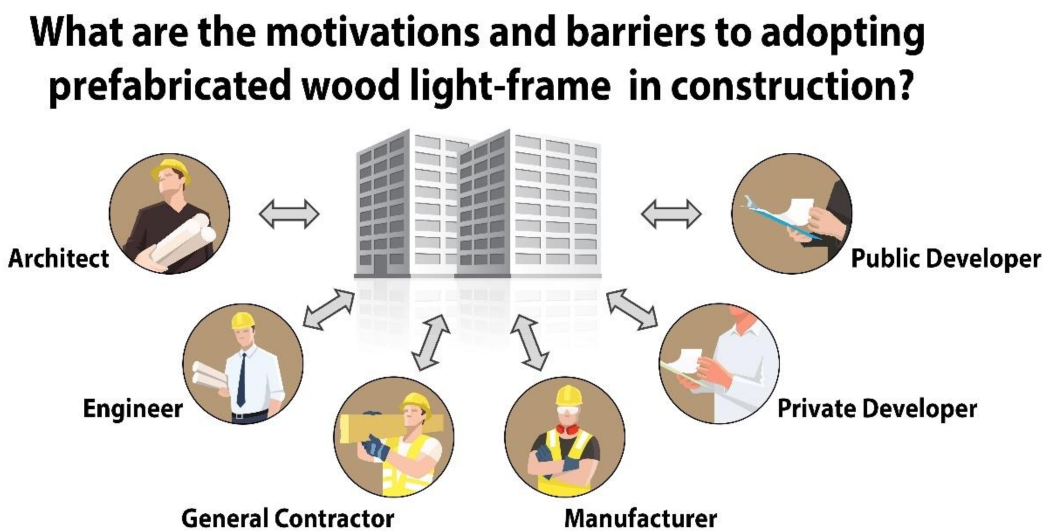
GRAPHICAL ABSTRACT



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Despite prefabricated wood light-frame construction's technical viability and ability to address labor shortages and industry productivity issues, its adoption remains limited. As an alternative to steel and concrete in non-residential buildings of four storeys or less and dwellings of five and six storeys, they represent only 23% and 6% of market shares, respectively. Based on a purposive sample of 40 interviews with diverse construction industry professionals in Quebec (Canada), the representations of prefabricated wood light-frame construction was highlighted. A thematic analysis identified the motivations and barriers to prefabrication adoption and the reasons for these positions more precisely. This work examined whether these perceptions differ significantly according to main professional activity. The findings confirm existing literature while providing deeper insights into motivations and barriers, revealing new viewpoints. Respondents primarily cited expertise as the most critical barriers. Availability of labor, cost, productivity, and construction quality were identified as key motivators, while manufacturing capacity and coordination were perceived with mixed opinions. Analyzing response profiles suggests that different stakeholders generally have similar perceptions. This research will aid in refining policies and strategies to encourage the widespread adoption of prefabricated wood light-frame in construction practices.

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Keywords: Decision making; Modular construction; Off-site construction adoption; Stakeholder perceptions; Timber building

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INTRODUCTION

In the current context of heightened demand for building construction in Canada (SCHL, 2024), the construction industry is confronted with several significant challenges, including a lack of productivity (Barbosa *et al.* 2017; Aaltonen *et al.* 2021), the labor shortage (Steinhardt and Manley 2020; Aaltonen *et al.* 2021; Zhang *et al.* 2022), and the imperative to reduce the environmental impact of buildings (Climate Chance, 2019). Over the last few decades, global productivity growth in the construction sector has been significantly lower than any other manufacturing sectors and in the overall economy (Barbosa *et al.* 2017). For instance, Koskenvesa *et al.* (2010) reported that productivity improvements in the construction industry were approximately 1% per year between 1975 and 2008, well below the average for other economic sectors. Key factors contributing to these low productivity values include the increasing complexity of projects, extensive regulatory requirements, high industry fragmentation, suboptimal design and project management processes, and insufficient investment in digitization and innovation (Barbosa *et al.* 2017).

The transition from on-site construction to factory prefabrication of a substantial proportion of factories' buildings is perceived as a promising solution to the above challenges. This approach notably reduces fragmentation in the value chain and addresses labor shortages (Steinhardt and Manley 2020; Zhang *et al.* 2022; Khan *et al.* 2023). Labor shortages have emerged as a main driver for adopting prefabrication, given its potential to utilize unskilled labor and revitalize employment in regions that have experienced industrial decline or economic recession (Blismas and Wakefield 2009; Steinhardt and Manley 2020).

In recent years, the construction industry has increasingly recognized the potential benefits of prefabricated construction, leading to its expansion, beyond single-family homes and low-rise multi-storey buildings, with markets such as schools, hospitals, healthcare facilities, and commercial buildings (Julien *et al.* 2015; Koronaki *et al.* 2021). Prefabrication includes various forms and materials to meet diverse needs, resulting in a wide range of terminology based on the degree of product completion and volumetric characteristics (Ginigaddara *et al.* 2022). According to Ginigaddara *et al.* (2022), prefabrication can be classified into two main categories: non-volumetric (*e.g.*, components, panels, foldable structures) and volumetric (*e.g.*, pods, modules, complete buildings). This study focused mainly on the types of prefabricated elements most commonly used within each category identified by Ginigaddara *et al.* (2022), namely panels and modules.

In the province of Quebec (Canada), the manufacturing industry focuses mainly on wood light-frame construction due to its cost-effectiveness and advantageous strength-to-weight ratio, which is well-suited for transportation (Julien *et al.* 2015). Even though 86% of the housing stock of four storeys or less is constructed with this material (Robichaud 2020), the prefabrication industry accounts for only 2.5% of the construction market in Canada in 2023 (Canadian Construction Association, s. d.; IbisWorld 2024). This market share reflects international trends (Zhang *et al.* 2022). Since 2015, an amendment to Quebec's National Building Code has permitted the construction of five and six storeys multi-family dwellings and light-frame wood business establishments (Chaurette *et al.* 2016). However, despite this regulatory support and policies promoting wood integration, only 23% of non-residential buildings of four storeys or less are built using wood light-frames, and just 6% of multi-storey housing buildings of five and six storeys are constructed with wood light-frames in Quebec (Robichaud 2020). This indicates substantial growth potential for prefabrication and engineered wood product industries. Furthermore, expanding the use of wood light-frame in non-residential and mid-rise construction could significantly contribute to the environmental transition of the building sector, by replacing structures currently made of steel or concrete (Sathre and O'Connor 2010; United Nations 2016; Myllyviita *et al.* 2021).

Despite political and legislative support, the widespread adoption of prefabricated wood light-frame construction for multi-storey or non-residential buildings remains slow. This situation can be attributed to deep-rooted dependencies on established materials such as concrete or steel (Mahapatra and Gustavsson 2008; Engström and Hedgren 2012; Hemström *et al.* 2017). Path dependency suggests that current decision-making is influenced by a sociotechnical regime that encourages stakeholders to make choices aligning with established practices, thereby hindering the widespread adoption of alternatives (Hemström *et al.* 2017). For instance, many stakeholders consider concrete structures superior to wooden structures for multi-storey buildings (Roos *et al.* 2010; Engström and Hedgren 2012). Stakeholders' perceptions and expectations are key factors underlying the slow diffusion of wooden construction (Roos *et al.* 2010). These perceptions must be modified or overcome for alternatives to achieve critical mass among influential actors and facilitate broader adoption (Roos *et al.* 2010; Hemström *et al.* 2017).

LITERATURE REVIEW ON PERCEPTIONS OF CONSTRUCTION INDUSTRY STAKEHOLDERS

Many studies have investigated the motivations and barriers associated with prefabrication as a construction method. Several authors have compiled the results of these studies in reviews (Kamali and Hewage 2016; Akmam Syed Zakaria *et al.* 2018; Wuni and Shen 2020; Zhang *et al.* 2022). Although each study presents a unique perspective and subjective classification, leading to overlapping topic groupings, the main motivations and barriers tend to converge significantly.

Main Motivations in the Literature

Zhang *et al.* (2022) categorized the main benefits of prefabrication in the literature into six main topics: schedule, environmental impact, quality, cost, local issues, and construction safety.

Schedule

Reduction in on-site construction time compared to traditional construction is one of the most frequently cited advantages and a significant driver for the adoption of prefabrication (Blismas *et al.* 2006; Blismas and Wakefield 2009; Kamali and Hewage 2016; Li *et al.* 2016; Wong *et al.* 2017; Razkenari *et al.* 2020; Steinhardt and Manley 2020; Koronaki *et al.* 2021; Zhang *et al.* 2022). This advantage can be attributed to several factors. Namely, the substantial advancements of in-factory construction and improved ergonomics due to a controlled work environment contribute significantly to increased productivity (Kamali and Hewage 2016; Zhang *et al.* 2022). The ability to conduct on-site and off-site construction activities concurrently further accelerates the process (Kamali and Hewage 2016; Li *et al.* 2016). In addition, prefabricated elements can be installed more quickly, reducing construction time on site (Wong *et al.* 2017). Lastly, prefabrication minimizes the impact of weather conditions and other inconveniences (*e.g.* theft and vandalism) (Kamali and Hewage 2016; Wong *et al.* 2017).

Environmental impact

Many studies identified prefabrication as beneficial for the environmental impact of buildings (Zhang *et al.* 2022). This advantage is mainly attributed to a reduction in construction waste (Blismas and Wakefield 2009; Kamali and Hewage 2016; Wong *et al.* 2017; Steinhardt and Manley 2020), supported by : 1) a reduction in material consumption (Jaillon and Poon 2010; Kamali and Hewage 2016); 2) an improved recyclability of waste (Evison *et al.* 2018); and 3) a lower defect rate achieved through improved manufacturing quality (Jaillon and Poon 2014). Prefabrication is also associated with lower greenhouse gas emissions (*e.g.* less movement of workers and materials) (Benson and Rankin 2016; Kamali and Hewage 2016), energy savings during construction and operation (Blismas and Wakefield 2009; Evison *et al.* 2018; Steinhardt and Manley 2020; Piggot-Navarrete *et al.* 2023). However, the environmental performance of prefabricated construction remains a topic of debate. Kamali and Hewage (2016) note that many studies focused on isolated cases, and the imprecision of the selected assumptions makes it difficult to justify these results on an industry-wide scale. Achenbach *et al.* (2018) highlighted that greenhouse gas emissions from the prefabrication process, particularly those related to building component transport, should not be overlooked. The distance between the production factory and the construction site can significantly influence the overall emissions.

Quality

Quality improvement is widely recognized in the literature as an important motivation for the industry's adoption of prefabrication (Blismas and Wakefield 2009; Jaillon and Poon 2010, 2014; Wong *et al.* 2017; Steinhardt and Manley 2020; Koronaki *et al.* 2021; Zhang *et al.* 2022). This improvement is largely due to a controlled environment that offers an ergonomic working environment and protection from the weather (Johnsson and Meiling 2009; Kamali and Hewage 2016; Wong *et al.* 2017). As well as quality control methods that are rigorously applied throughout the production process (Jaillon and Poon 2014; Wong *et al.* 2017). In addition, the use of computer-aided design applied to prefabrication have the potential to further reduce defects and rework (Jaillon and Poon 2014).

Cost

The use of prefabrication offers substantial cost-reduction opportunities for both customers and general contractors (Tam *et al.* 2007; Jaillon and Poon 2010; Benson and Rankin 2016; Wong *et al.* 2017; Steinhardt and Manley 2020; Wuni and Shen 2020; Koronaki *et al.* 2021; Zhang *et al.* 2022). The financial benefits stem from several key factors, such as the reduced need for skilled labor requirements on-site (Blismas and Wakefield 2009; Jaillon and Poon 2010; Benson and Rankin 2016; Jones *et al.* 2016; Wong *et al.* 2017; Ahmed and Arocho 2021). The labor required to operate the factory is also less costly (Blismas and Wakefield 2009; Hemström *et al.* 2017; Wong *et al.* 2017). The ability to relocate production to less costly regions, including overseas facilities, enables further cost optimization (Lu *et al.* 2018). Prefabrication also increases construction cost certainty thanks to its controlled environment and standardized processes (Sutrisna *et al.* 2019). Finally, the acceleration of projects through prefabrication significantly reduces fixed costs associated with construction sites, such as labor for site management, site development, lifting equipment, and scaffolding (Zhang *et al.* 2022). Moreover, faster project completion also implies the ability to handle a greater number of projects in a given timeframe for contractors (Jones *et al.* 2016; Hemström *et al.* 2017) and quicker returns on investment for customers (Blismas and Wakefield 2009; Hemström *et al.* 2017).

Local issues

Another advantage is the reduction of community disturbances near construction sites (Blismas *et al.* 2006; Wong *et al.* 2017; Zhang *et al.* 2022). The literature highlights several key benefits such as 1) the possibility of building in regions with labor shortages (Wong *et al.* 2017); 2) reduced noise and dust pollution (Blismas *et al.* 2006); 3) reduced number of deliveries, especially when high value-added products are used (Zhang *et al.*

2022); 4) reduced duration of street congestion (Zhang *et al.* 2022); and 5) reduced on-site storage space for materials by delivering ready-to-assemble prefabricated elements (Hemström *et al.* 2017; Zhang *et al.* 2022).

Construction safety

Prefabrication can also enhance worker safety both in the factory and on-site (Blismas and Wakefield 2009; Jaillon and Poon 2010; Wong *et al.* 2017; Steinhardt and Manley 2020; Koronaki *et al.* 2021; Zhang *et al.* 2022), although this aspect is considered to have little impact on the adoption of this construction method (Blismas and Wakefield 2009). Shifting a substantial portion of the work, which is typically carried out on-site and presents high safety risks, to a controlled factory environment significantly reduces these risks (*e.g.* weather conditions, working at height, work ergonomics, specialized tooling, automation, air quality) (Blismas and Wakefield 2009; Kamali and Hewage 2016; Wong *et al.* 2017). In addition, the on-site portion of the work also benefits from these improvements by reducing the duration of on-site activities and minimizing the number of workers required on-site (Blismas and Wakefield 2009; Hemström *et al.* 2017; Wong *et al.* 2017; Zhang *et al.* 2022). However, handling larger and heavier prefabricated components increases the potential consequences of any incidents, creating specific safety risks associated with lifting and transporting large loads that must be managed carefully (Blismas and Wakefield 2009).

Main Barriers in the Literature

According to the study by Zhang *et al.* (2022), the most frequently cited barriers can be categorized into seven topics: finance and market, skills and knowledge, standardization, design, manufacturing, transport and logistics, and on-site construction.

Finance and market

There are many financial and market-related challenges in the prefabrication sector, which constitute one of the main barriers to its widespread adoption, according to the literature (Blismas and Wakefield 2009; Zhang *et al.* 2022; Wang *et al.* 2023). Several studies have identified higher costs and a disability to reduce costs when using prefabrication compared to traditional construction methods (Blismas and Wakefield 2009; Jaillon and Poon 2010; Sutrisna *et al.* 2019; Steinhardt and Manley 2020). This perception is explained by several factors. First, high initial investment and fixed costs are required for setting up and operating prefabrication factories (Tam *et al.* 2007; Blismas and Wakefield 2009; Kamali and Hewage 2016; Wuni and Shen 2020; Wang *et al.* 2023). Second, the sector suffers from a restricted market and limited competition among manufacturers (Zhang *et al.* 2022; Rankohi *et al.* 2023). Third, establishing mass production is difficult due to the restricted, fragmented, and heterogeneous market that requires substantial product customization (Wuni and Shen 2020; Zhang *et al.* 2022; Wang *et al.* 2023). Fourth, additional organizational investments are required for specialized labor and skills (Rankohi *et al.* 2023). Fifth, costs associated with performance evaluation during the design phase and first-run prototyping (Rankohi *et al.* 2023). Sixth, uncertainties contribute to higher design and tendering costs (Blismas and Wakefield 2009; Wuni and Shen 2020). Seventh, low-bidder-oriented contract awarding process can involve many hidden costs (Wuni and Shen 2020). Eighth, complex financing and payment arrangements adds another layer of difficulty (Wuni and Shen 2020). Lastly, higher logistics and implementation costs (*e.g.* craning, transport) add to the overall expense compared to traditional construction methods (Blismas and Wakefield 2009; Wuni and Shen 2020; Zhang *et al.* 2022)

However, Blismas *et al.* (2006) highlighted that most costing exercises mainly consider direct costs such as materials, labor, and transport. This approach often neglects other indirect costs such as site overheads (*e.g.*, site facilities, hoisting equipment downtime), worker health and safety considerations, and late modifications that generate additional expenses. Consequently, prefabrication appears more expensive than traditional methods when only direct costs are considered. According to Blismas and Wakefield (2009), greater emphasis should be placed on total cost, acknowledging that increased volume makes production efficiencies possible. This comprehensive cost analysis can provide a more accurate comparison of prefabrication and traditional construction methods, potentially revealing the actual economic advantages of prefabrication.

In addition, the low adoption of prefabrication in the construction market can be attributed to a poor image from the technical failures of post-war prefabricated buildings and its association with low-quality, inexpensive social housing (Blismas and Wakefield 2009; Steinhardt and Manley 2020; Wuni and Shen 2020; Rankohi *et al.* 2023). This negative perception is compounded by the belief that significant changes to existing processes are required for prefabrication to succeed (Wuni and Shen 2020). However, Giorgio *et al.* (2022) noted an improvement in the perceived image of prefabrication in recent years, indicating a potential shift in attitudes towards this construction method.

Skills and knowledge

Many studies considered stakeholder expertise to be a significant barrier to the use of prefabrication (Tam *et al.* 2007; Blismas and Wakefield 2009; Wuni and Shen 2020; Zhang *et al.* 2022; Rankohi *et al.* 2023). This challenge arises primarily from negative perception regarding the performance and quality of prefabricated elements (Wuni and Shen 2020; Zhang *et al.* 2022). Additionally, there is a low level of knowledge among stakeholders, which compounds the issue (Blismas and Wakefield 2009; Wuni and Shen 2020; Wang *et al.* 2023). The lack of educational programs focused on prefabrication techniques for design professionals further exacerbates this problem (Wuni and Shen 2020; Zhang *et al.* 2022). Moreover, there is a shortage of skilled labor needed to produce and assemble prefabricated elements on-site (Wuni and Shen 2020; Rankohi *et al.* 2023). This lack of expertise may have historically contributed to the challenges in implementing prefabrication effectively (Rankohi *et al.* 2023).

Standardization

Lack of standardization is another significant challenge to the progress and widespread application of prefabricated construction (Evison *et al.* 2018; Razkenari *et al.* 2020; Wuni and Shen 2020; Khan *et al.* 2023; Wang *et al.* 2023). The absence of specific legislative frameworks, guidelines, and industry standards tailored for prefabrication contributes to this challenge (Wuni and Shen 2020; Khan *et al.* 2023; Rankohi *et al.* 2023; Wang *et al.* 2023). Prefabrication design practices often adhere to traditional building design standards, despite the differing structural loads and on-site construction processes, especially in modular construction (Khan *et al.* 2023). The result is a low degree of standardization for prefabricated components (Wang *et al.* 2023), which limits repeatability and restricts the reuse of these elements within the same project or between different projects (Wuni and Shen 2020). This lack of standardization also hampers the potential for mass production, making it difficult to achieve economies of scale (Wuni and

Shen 2020). Furthermore, this lack of normalization may lead stakeholders to perceive prefabricated components as failing to meet minimum standards and performing inadequately (Zhang *et al.* 2022). Such perceptions can hinder the development and adoption of more efficient prefabrication practices (Rankohi *et al.* 2023).

Design

Design challenges are main barriers to adopting prefabrication (Zhang *et al.* 2022; Khan *et al.* 2023). The design phase is crucial for successfully implementing prefabrication, as it has cascading effects on subsequent stages of the project (Sutrisna *et al.* 2019; Wuni and Shen 2020; Khan *et al.* 2023). Several studies note the need to freeze the design early in the process due to the high difficulty and cost associated with subsequent modifications (Tam *et al.* 2007; Jaillon and Poon 2010; Hemström *et al.* 2017; Wuni and Shen 2020; Khan *et al.* 2023). Design for Manufacture and Assembly (DfMA) principles are also required to replace traditional design approaches (Steinhardt and Manley 2020; Rankohi *et al.* 2023). Concerns about monotonous and repetitive architectural aesthetics have been raised in the literature due to the standardization of prefabricated elements (Tam *et al.* 2007; Blismas and Wakefield 2009; Steinhardt and Manley 2020; Wuni and Shen 2020). The non-existence of high-performance inter-module connections, which do not require internal access to prefabricated modules, is a limitation identified regarding the potential for adding value to prefabricated products (Wuni and Shen 2020). Another barrier is that prefabrication allows minimal tolerance for other trades (Wuni and Shen 2020). Compliance with fire resistance requirements varies depending on the constructive system, presenting additional challenges (Zhang *et al.* 2022). Lastly, the lack of collaborative working environments in the construction sector, exacerbated by traditional contracts (*i.e.* design-offer-build) leads to fragmentations, operational issues, and complex responsibility sharing (Wuni and Shen 2020; Zhang *et al.* 2022; Rankohi *et al.* 2023; Wang *et al.* 2023). These design-related issues increase the difficulties and workload for designers, lengthening the design phase (Jaillon and Poon 2010; Hemström *et al.* 2017; Steinhardt and Manley 2020; Wuni and Shen 2020; Zhang *et al.* 2022).

Manufacturing

The main barriers reported for off-site manufacturing include conflicts in module geometry due to dimensional errors in the design phase, which can lead to production errors, inaccuracies, and ultimately significant on-site inconsistencies (Tsz Wai *et al.* 2023). There is also a wide disparity in factory production capacity, which strongly affects the types of prefabricated elements and the size of projects they can complete (Zhang *et al.* 2022). In addition, sub-optimal production planning is a challenge, as it hinders the ability to maximize factory profitability (Fernandez-Viagas and Framinan 2015; Lin and Ying 2016). Lastly, the lack of adoption of automated production systems remains a significant barrier, notably due to the high initial investment required, low available investment budget and current work culture in the industry (Lachance *et al.* 2023).

Transport and logistics

The transport stage of prefabrication faces several significant barriers that obstruct its efficiency. One of these barriers is related to transport restrictions due to dimensional and weight constraints, traffic control in urban areas, and distance limit between the site and factory (Schoenborn 2012; Kamali and Hewage 2016; Steinhardt and Manley 2020; Wuni and Shen 2020; Rankohi *et al.* 2023). Traceability is deemed inefficient due to reliance on traditional communication methods rather than the adoption of digital real-time communication methods (Zhang *et al.* 2022; Wang *et al.* 2023). Lastly, damage to prefabricated components during transport can occur due to vehicle vibration, handling issues, or exposure to adverse weather conditions (Zhang *et al.* 2022; Khan *et al.* 2023).

On-site construction

The main barriers associated with on-site assembly include several challenges. The dimensional variability and errors are frequent due to the low tolerances of this construction method (Wuni and Shen 2020; Khan *et al.* 2023). The complexity of planification and logistics for lifting prefabricated elements adds to the difficulty of on-site assembly (Kamali and Hewage 2016; Khan *et al.* 2023). The availability of lifting equipment can also be a limiting factor (Wuni and Shen 2020; Zhang *et al.* 2022). Lifting delays can occur due to severe weather conditions, due to defective components that must be repaired or returned to the factory, or due to transport delays (Zhang *et al.* 2022). Lifting and installation safety is another major concern, as handling large and heavy components introduces a significant additional risk (Sutrisna *et al.* 2019). Lastly, slow quality inspection procedures are an issue, given the large number of connections that need to be checked (Wang *et al.* 2023).

Generally speaking, the fragmented nature of the construction industry, as reflected in its organizational, contractual, and operational structures, seems unsuited to the large-scale application of prefabrication (Blismas and Wakefield 2009; Wuni and Shen 2020). To overcome these challenges, many studies indicated that prefabrication must rely heavily on value chain integration (*e.g.* with integrated design processes) to generate competitive advantages (Blismas and Wakefield 2009; Wong *et al.* 2017; Wuni and Shen 2020; Koronaki *et al.* 2021; Rankohi *et al.* 2023).

Despite extensive research on the development of prefabricated construction, most studies have focused on concrete, steel and, to a lesser extent, mass timber construction systems, using small, isolated samples representing only a few stakeholder types (such as manufacturers and general contractors) among the wide panel of stakeholders that influence the adoption of a constructive method (Zhang *et al.* 2022). In addition, these studies have mainly been concentrated in Asia (*e.g.* China, Hong Kong), Europe (*e.g.* UK), and Oceania (*e.g.* Australia), where socio-technical and economic contexts significantly influence outcomes (Wuni and Shen 2020; Zhang *et al.* 2022; Khan *et al.* 2023). Consequently, the literature may not reflect the recent economic and industrial conditions of other regions, such as Canada, with its specific construction culture.

To provide robust insights into increasing prefabricated wood light-frame construction use in multi-storey and non-residential projects, this study gathered information from various construction professionals. The professionals interviewed include architects, engineers, general contractors, manufacturers, and private and public developers. The province of Quebec, Canada, served as a case study due to its regulatory openness to larger-scale buildings and the government's commitment to wood construction, of which prefabrication is a crucial component (Ministère des Forêts, Faune et Parcs 2013; Gouvernement du Québec 2020). This study addressed a research gap, as no similar investigation had been conducted in Quebec, contrasting with other countries with comparable construction economies (Zhang *et al.* 2022).

The main objective of this article was to understand the factors that favor the adoption of prefabricated wood light-frame construction by stakeholders in the multi-storey and non-residential construction sectors. Specifically, it aimed to identify perceived motivations and barriers in Quebec and assess whether these align with findings from other regions. Although some perceptions are linked to the use of wood light-frame, this article focused on the difference between on-site and off-site construction, seeking to characterize the perceptions associated with prefabrication. In addition, the study explored the underlying reasons for these positions and determine if perceptions significantly differ based on the respondents' professional activities.

DATA AND RESEARCH METHODOLOGY

Semi-structured Interviews

This study was based on the material and methodology employed in the work of Giorgio *et al.* (2024). Like the cited study, this research opted for a semi-structured interview approach as the most suitable methodology to gather insights from key professionals in the construction sector regarding mass timber. The main goal was to investigate their viewpoints and uncover the motivations and obstacles related to prefabricated wood-light-frame adoption. Semi-structured interviews were selected due to their flexibility and facilitation of two-way communication between the interviewer and respondents. This approach enables the exploration of a broad spectrum of topics while offering a nuanced understanding of the diverse motivations and perceived barriers. Notably, it allows for the emergence of new viewpoints and the representation of various perceptions (Ghiglione and Matalon, 1978; Barbour 2001; Edwards and Holland 2013; Cleary *et al.* 2014). Alternatively, a questionnaire could have produced more generalized data from a larger respondent pool but with less depth and precision (Ghiglione and Matalon, 1978; Barbour 2001; Edwards and Holland 2013). Given the nature of the study, as well as the limitations identified in previous research and the unexplored context of Quebec, the probability of new topics emerging during the interviews was high (Franzini *et al.* 2018; Aaltonen *et al.* 2021; Cleary *et al.* 2014).

Sample Composition and Characteristics

Based on the interviews conducted in the study by Giorgio *et al.* (2024), 40 of the 42 respondents were questioned about their perceptions regarding wood-light-frame prefabrication in multi-storey and non-residential building construction. Interviews considered in this article were conducted in French by videoconference between July and October 2021. With an average of 65±16 min, these interviews were digitally recorded and meticulously transcribed to facilitate a thorough analysis of the responses.

Table 1 presents the characteristics of the sample. Among the 40 respondents, nine individuals were engaged in dual professional roles simultaneously. The various combinations are general contractor and private developer, general contractor and engineer, general contractor and manufacturer, manufacturer and private developer, and engineer and manufacturer. However, only the primary professional activity was considered to simplify the profile analysis. Moreover, to assess the respondents' experience with prefabricated wood light-frame construction, this study defined and utilized three levels of expertise. An "Expert" is a respondent who has extensive experience with numerous projects involving prefabricated wood light-frame construction. "User" refers to respondent who has occasionally utilized prefabricated wood light-frame construction without attaining expert status. Lastly, "Non-user" represents respondent who lacks personal experience in prefabricated wood light-frame construction.

Table 1. Sample Characteristics

Characterization variable	Category	Frequency N=40
Gender	Male	35
	Female	5
Age	Less than 30 years old	6
	Between 30 and 40 years old	9
	Between 40 and 50 years	12
	Over 50 years old	13
Main professional activity	Architect	8
	Engineer	8
	General contractor	6
	Manufacturer	9
	Private developer	3
	Public developer	6
Number of types of professional activity	One type of professional activity	31
	Two types of professional activity	9
Level of responsibility	President or senior partner	21
	Senior manager	8
	Project manager	11
Level of expertise	Expert	16
	User	15
	Non-user	9
Company location	Quebec City and surrounding areas	22
	Montreal and surrounding areas	9
	Quebec City and Montreal area	7
	Estrie	1
	Saguenay – Lac-Saint-Jean	1
Number of company employees	1 to 99 employees	21
	100 to 499 employees	15
	500 or more employees	4

Interview Guide Content

The interview guide was designed based on the main motivations and barriers associated with prefabricated wood light-frame construction observed in the literature to assess whether Quebec professionals have similar or different perceptions (Blismas and Wakefield 2009; Kamali and Hewage 2016; Hemström *et al.* 2017; Akmam Syed Zakaria *et al.* 2018).

During interviews, participants were initially encouraged to talk about their professional practices and provide their overall perceptions on the advantages and disadvantages of prefabricated wood light-frame construction methods compared to on-site construction. Open-ended questions were used for this purpose, and additional inquiries for clarification were asked as needed. To achieve the study objectives, specific questions based on the primary topics identified in the literature and/or not covered in the initial phase were introduced in the last phase of the interview. These questions were designed to allow interviewees to go deeper into their viewpoints on the subject. While most respondents addressed all the initial topics of the interview guide, particular interviews focused on specific perceptions in more detail, depending on the interviewee's interests. The interviews ended with questions about the personal characteristics of the interviewees.

Before starting the study, the interview guide underwent a review process, and two pilot interviews were conducted as preliminary steps to refine both the guide and the interview methods. The Appendix B of this article includes the English version of the interview guide.

Data Analysis

The methodology employed for data interpretation follows the framework developed by Giorgio *et al.* (2024). A qualitative analysis approach was employed to capture the nuanced motivations and barriers perceived by Quebec professionals concerning the adoption of light-frame wood prefabrication in multi-storey and non-residential construction projects. A thematic analysis was used to extract data to elucidate the main reasons for these perceptions. Additionally, quantifying the occurrences of identified perceptions was conducted to evaluate the prevalence of perceived motivations or barriers. This research methodology is outlined in Fig. 1.

The thematic content analysis was performed with support from N'Vivo software (QSR International 2020). Thematic analysis offers a flexible approach for identifying, analyzing, and reporting recurring patterns of meaning within a dataset that lacks numerical data and formal structure. This qualitative method is not tied to a predetermined theoretical framework and can capture the complexity of reality through a set of research questions. In this study, the thematic analysis methodology proposed by L'Écuyer (1987), Braun and Clarke (2006), and Schreier (2012) was employed. This method aims to select and report interview findings deemed significant in understanding the adoption or non-adoption of prefabricated wood light-frame as a construction system in multi-storey and non-residential projects. The process involved reading interview transcripts to understand the results and then categorizing the data using a coding system to define topics. Specifically, this step focused on analyzing statements to uncover underlying meanings and identify connections, structures, similarities, and differences among responses. Instead of focusing on exact wordings (*e.g.*, through lexical analysis), the analysis prioritized the meaning behind responses to extract topics that could elucidate the motivations and barriers associated with prefabricated wood light-frame construction. The key topics contained in the interview guide served as the starting point for the data analysis.

The final analytical framework is based on professionals' motivations and barriers to adopt prefabricated wood light-frame construction (Fig. 2). These data were categorized into four categories: 1) feasibility in the design phase, 2) regulatory limits and performance achievement, 3) operational and financial factors, and 4) socio-environmental values. These categories have been divided into topics to represent more accurately the observations. Feasibility in the design phase was divided into three topics: 1) architectural liberty, 2) expertise, and 3) project delivery methods. Regulatory limits and performance achievement were divided into four topics: 1) regulations, 2) fire safety performance, 3) structural performance, and 4) construction height. Operational and financial factors were divided into nine topics: 1) availability of labor, 2) manufacturing capacity, 3) cost, 4) insurance, 5) productivity, 6) nuisance, 7) coordination, 8) construction quality, and 9) risk. Finally, socio-environmental values were divided into three topics: 1) worker safety, 2) lifespan, and 3) environmental impact. These topics and their scopes are detailed in the Professionals' Perceptions of the Most Concerning Barriers and Motivations by Topic section and in Appendix A.

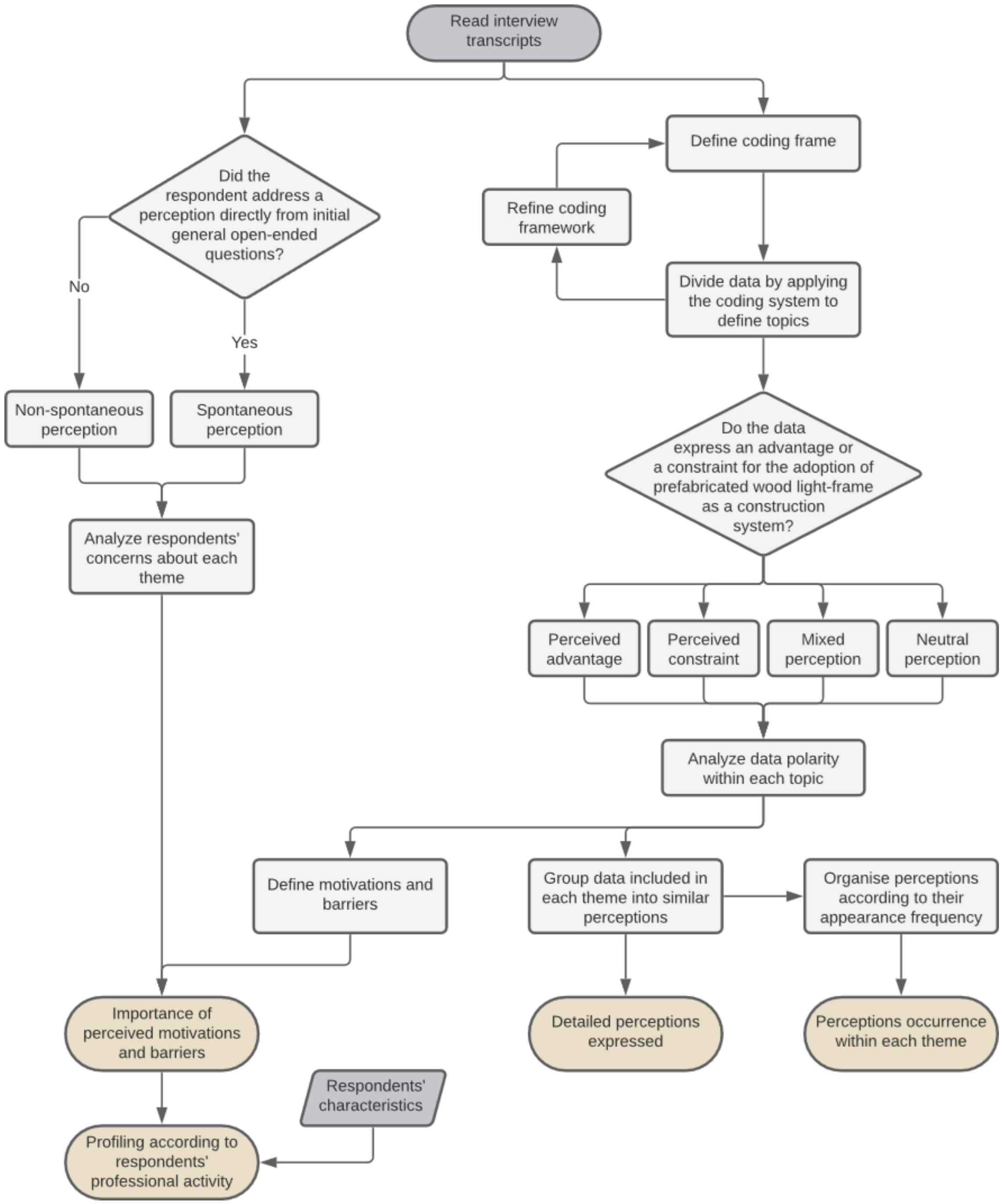

Fig. 1. Research methodology workflow based on Giorgio *et al.* (2024)

Following the methodology of Giorgio *et al.* (2024), the data were categorized based on their polarity (*i.e.* whether they express an advantage or a disadvantage for the use of light-frame prefabrication) in order to identify stakeholders' perceived motivations and barriers to its use.

Simultaneously, respondents' spontaneity was noted to serve as a subjective indicator capable of reflecting their concerns regarding these topics and their respective importance in choosing prefabrication. Spontaneity is defined in this study as the immediate answers elicited during the initial open-ended questions on the advantages and disadvantages of using wood light-frame prefabrication in contrast to on-site construction (see interview guide in Appendix B). The concept of spontaneity used here is derived from the concept of brand awareness used in marketing. In this discipline, brand awareness can be defined as the unconsciously and spontaneously associating a product with a brand without external influence (Rossiter 2014). Spontaneity is defined notably as behavior that is not thought through, the straightforward expression of what an individual thinks (Larousse n. d.). Thus, an individual's spontaneous response to an open-ended question corresponds to the element he or she perceives as most salient. So, by inference, spontaneous responses to an open-ended question can be interpreted as the priority topics for respondents.

Next, polarity analyses of each topic and spontaneity were cross-tabulated to define the motivations and barriers of most concern to respondents. These findings were cross-referenced with the respondents' professional activities to determine potential response profiles. Profile analysis is based on the disparity between the average trend observed in the sample and the more distinct viewpoints.

Lastly, the topics identified as the most concerning motivations and barriers were detailed. Similar perceptions were clustered into subjects within each topic and classified based on their frequency of appearance (indicated by a number in brackets) to ascertain their prevalence within the sample. Low-frequency perceptions were incorporated if they provided novel insights into the topic. The quotations in this article were translated into English. They were adjusted slightly to maintain anonymity and enhance clarity while ensuring the content remained unchanged. Topics considered to be of low concern for respondents are presented in Appendix A.

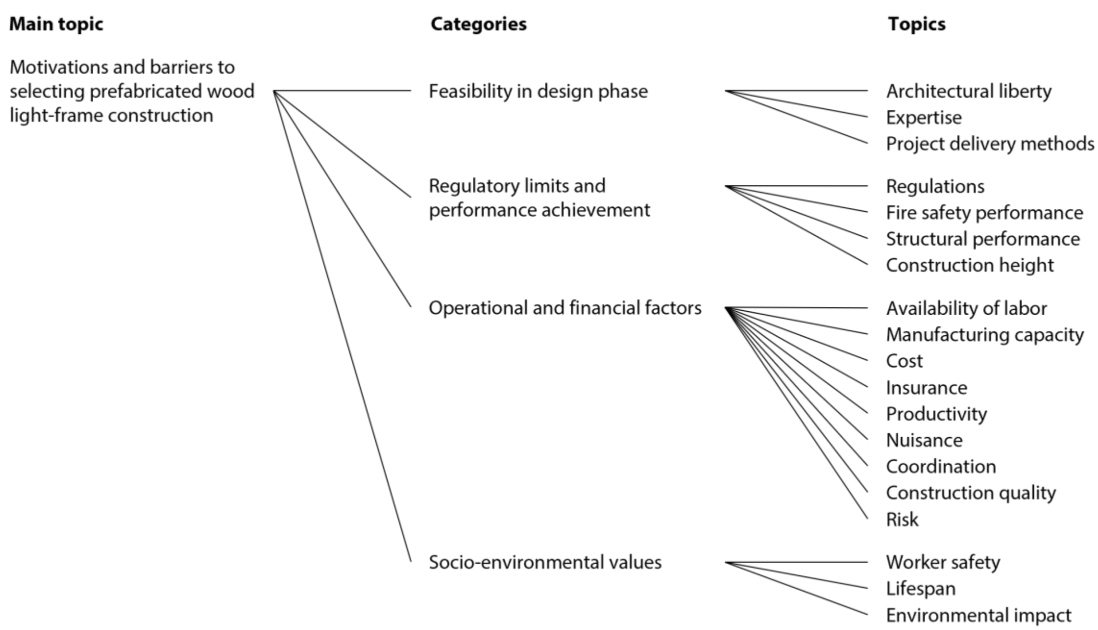

Fig. 2. Topic-based analytical framework derived from thematic analysis of interview data

RESULTS AND DISCUSSION

The results are presented in three sections. Initially, topics perceived as motivations or barriers for respondents, along with their respective significance in the adoption of prefabricated wood light-frame construction, will be identified. Next, the impact of professional activity will be studied, enabling specific profiles to be identified. Finally, a thorough analysis of the main barriers and motivations perceived by professionals will be conducted.

Identification of Perceived Motivations and Barriers

Perception analysis has allowed for identifying the most significant motivations and barriers. The findings presented in Table 2 indicate that the use of prefabricated wood light-frame is perceived as unfavorable only in terms of expertise and project delivery methods topics. Prefabricated wood light-frame use is widely perceived as positive in topics related to operational and financial factors and socio-environmental values (*i.e.*, availability of labor, cost, productivity, nuisance, construction quality, worker safety, and environmental impact).

Regarding more mixed perceptions, two trends can be distinguished. On the one hand, certain topics were perceived divergently, illustrated by an opposition between respondents with positive and others with negative points of view (*i.e.* architectural liberty, regulations, construction height, manufacturing capacity, coordination, and risk). On the other hand, professionals perceived some other topics as neutral (*i.e.*, fire safety performance, structural performance, insurance, and lifespan).

The results displayed in Table 2 indicate that some topics influence the decision among professionals to adopt prefabricated wood light-frame construction. These topics are consequently perceived as significant motivations or barriers and have been expressed spontaneously (high concerns).

Table 2. Identification of Perceived Motivations and Barriers Among Respondents

	High Concerns	**Low Concerns**
Mainly A Barrier	Expertise (38)	Project delivery methods (32)
Mixed Perception	Manufacturing capacity (37) Coordination (37)	Architectural liberty (38) Regulations (28) Fire safety performance (28) Structural performance (34) Construction height (35) Insurance (30) Risk (35) Lifespan (37)
Mainly A Motivation	Availability of labor (25) Cost (39) Productivity (38) Construction quality (40)	Nuisance (19) Worker safety (33) Environmental impact (36)

* The number in brackets expresses the quantity of respondents having addressed this topic.

Cross-referencing polarity with the spontaneity of perceptions expressed by respondents indicates that:

- The expertise barrier is considered the most concerning by professionals.
- Manufacturing capacity and coordination are concerning issues for respondents. However, there is a divergence of perceptions regarding them, with a significant proportion of professionals seeing both positive and negative aspects, another seeing it as an obstacle, while a minority see it as a motivating factor.
- The main motivations perceived by professionals are labor availability, cost, productivity, and construction quality.

The other topics, though less frequently mentioned spontaneously by respondents, can still be viewed as potential motivations or barriers. These perceptions are elaborated in Appendix A. Nevertheless, they are likely to hold less influence than the previously discussed motivations and barriers in the decision-making process of the professionals interviewed.

Response Profiles According to Professional Activities

Following previous results, response profiles were examined to assess whether perceptions varied based on the respondents' primary professional activity. While a comprehensive analysis was conducted, this section focuses on the critical trends that facilitate the emergence of response profiles.

A degree of consensus appears among various stakeholders within the construction industry on several of the topics examined. However, respondents' interests or professional practices may influence the spontaneity with which topics were discussed and their polarity. Thus, as shown in Table 3, distinct response profiles seem to emerge.

- Architects are more optimistic about architectural liberty, fire safety performance, construction height, and manufacturing capacity. They are more negative about project delivery methods. They are also more spontaneous about expertise, project delivery methods, construction height, and environmental impact.
- Engineers are more positive or optimistic about construction height, manufacturing capacity, insurance, and environmental impact. They do not express a more negative view of the topics than the general sample trend. They are concerned about project delivery methods, structural performance, and worker safety.
- General contractors stand out for their positive perception of current practices regarding project delivery methods, while the other groups are mainly negative. Like the architects, they are also positive about the architectural liberty afforded by prefabrication. General contractors are distinguished by their predominantly neutral perceptions of fire safety performance and structural performance. They are more negative about insurance and lifespan. Finally, general contractors (like manufacturers and private developers) are also highly concerned about the availability of labor.
- Manufacturers are more positive about nuisance and lifespan. They have mixed perceptions, with positive and negative views on fire safety performance, structural performance, construction height, and insurance. They also negatively affect architectural liberty, expertise, project delivery methods, regulation, and risk. Finally, manufacturers are more spontaneous with many topics, such as architectural liberty, expertise, structural performance, availability of labor, coordination, worker safety, lifespan, and environmental impact.
- Private developers express more mixed perceptions on productivity and

construction quality than the sample trend. They are more negative about project delivery methods, structural performance, construction height, insurance, and nuisance. Private developers are particularly concerned about the availability of labor, construction quality, and lifespan.

- Public developers are more negative about expertise, project delivery methods, regulation, and construction height. They are more spontaneous about expertise, coordination, and construction quality.

Table 3. Identification of Response Profiles Based on Professional Activities

	Architects	Engineers	General contractors	Manufacturers	Private developers	Public developers
Architectural liberty	Positive		Positive	Negative, X		
Expertise	X			Negative, X		Negative, X
Project delivery methods	Negative, X	X	Positive	Negative	Negative	Negative
Regulations				Negative		Negative
Fire safety performance	Positive		Neutral	Mixed		
Structural performance		X	Neutral	Mixed, X	Negative	
Construction height	Positive, X	Positive		Mixed	Negative	Negative
Availability of labor			X	X	X	
Manufacturing capacity	Positive	Positive				
Cost						
Insurance		Positive	Negative	Mixed	Negative	
Productivity					Mixed	
Nuisance				Positive	Negative	
Coordination				X		X
Construction quality					Mixed, X	X
Risk				Negative		
Worker safety		X		X		
Lifespan			Negative	Positive, X	X	
Environmental impact	X	Positive		X		

- Positive: More positive than the sample trend
- Neutral: More neutral than the sample trend
- Mixed: More mixed than the sample trend
- (blank): Identical to average sample trend
- Negative: More negative than the sample trend
- X: More spontaneous than the sample trend

Professionals' Perceptions of the Most Concerning Barriers and Motivations by Topic

Highest concern barriers

Expertise. For many respondents, expertise in light-frame construction is prevalent in Quebec, whether site-built (19 respondents) or prefabricated (13). However, several respondents felt that prefabrication expertise remains disparate among the stakeholders (5). Some are concerned that expertise is poorly established throughout the value chain (5). According to an expert, the lack of expertise needs to be considered regarding the different types of prefabricated products; for example, the use of panels allows a design that is very close to on-site construction (1). Nonetheless, multiple respondents highlight the insufficient development of expertise in manufacturing methods associated with five or six storeys buildings, whether panelized (8) or modular (8), as these markets are still underdeveloped. Construction of five or six storeys buildings requires additional expertise not required for buildings of four storeys or less (5).

> *"Building walls for five or six storeys is still very new. So it is true that in the beginning, it was more complicated. There were more uncertainties. [All] the professionals [involved in this project] (...) were a little more nervous, asking for a little more."* (Manufacturer, expert in prefabricated wood light-frame construction)

The scarcity of significant prefabricated wood light-frame non-residential projects also indicates a lack of expertise in this sector (1).

> *"There must be few major prefabricated [non-residential wood] projects in Quebec (...) To my knowledge, it is not an industry deployed and being used. We are referring to it more and more due to the multiplicity of construction methods due to the issues we are experiencing with the availability of labor for x, y, z reasons, but it is still in development in Quebec."* (Public developer, non-user of prefabricated wood light-frame construction)

The primary perceived factors contributing to this deficiency in expertise include the industry's predominant focus on single-family homes and structures of four storeys or less (8), insufficient knowledge transfer between manufacturers and designers (4), and the circumstance wherein the selection of construction method is determined by the contractor rather than the designer (2).

> *"I think it's an immature industry, which has specialized in the residential sector because that is where most of their customers are, (...) which has developed in silos without having standardized. (...) This industry is competent in what they do, but they have many paradigms exclusive to the residential sector, so it's very difficult for them to move on to commercial, industrial, institutional and multi-residential buildings."* (Engineer, expert in prefabricated wood light-frame construction)

> *"I would say that architects and engineers, most of the time, will design their projects without prefabrication, and the contractor decides to do*

> *prefabrication. That is why the details have not been adjusted."* (General contractor, user of prefabricated wood light-frame construction)

Regarding modular construction, additional reasons for the expertise gap include insufficient knowledge of mechanical force transfer between modules (1), limited sharing of manufacturing techniques to enhance product optimization (1), and added challenges arising from the fragmentation of building mechanics systems and constrained dimensions of technical spaces due to transportation limitations (1).

The consequences attributed to this expertise deficit include a deficiency in rigor and adaptability among general contractors in adhering to manufacturers' and engineers' specifications, who prefer to apply familiar and proven methods for structures of four storeys or fewer (4), a lack of standardization in construction processes within the industry (1) and an association of prefabrication with high technical and financial risks (1).

> *"I attended a project [anonymization], done in modules by a company that already does much prefabrication. It was a disaster. It was appalling. (...) Water problems, sound problems. There were multi-million lawsuits filed against the project. (...) It's a technology that was not mastered before it was put on the market."* (Private developer, user of prefabricated wood light-frame construction)

To address the expertise gap, some manufacturers commonly provide support to designers in utilizing their construction systems, as indicated by some respondents (2). However, relying on manufacturer assistance can also introduce market concerns and conflicts of interest during bidding (2).

> *"If, as an architect, I'm talking to a manufacturer and have a public tender project, I can't say "It's this manufacturer". There has to be competition between several manufacturers. So, how do I get the expertise I need to document the drawings to go out to tender if I do not have help from a manufacturer or an outside expert? On the other hand, if I use a manufacturer too much, it is favoritism. Because he is going to give me details that favor his product. (...) There's a lack of access to information to have the confidence to propose a project that will be put out to public tender [with a sufficient number of bidders]."* (Architect, user of prefabricated wood light-frame construction)

Ultimately, according to a private developer, continued research and product development are essential to validate these construction systems and ensure their performance in all aspects (1).

Highest concern topics with mixed perceptions

Manufacturing capacity. Many respondents perceive the number of wood light-frame structure manufacturers, production capacity, and product offerings as adequate to fulfill demand (13). On the other hand, some argue that there are insufficient manufacturers and advocate increasing the number to meet current and anticipated demand (6). This issue of product availability has become a significant concern in recent years, exacerbated by the surge in demand and the challenges posed by the Covid-19 pandemic (13). Specifically, this situation has compelled many general contractors to undertake on-site construction of their projects due to their inability to secure production schedules from manufacturers (13) and the potential loss of prefabrication benefits in terms of construction speed (1).

> *"We are a bit of a victim of our success at the moment because prefab companies in Quebec, and even in the northeastern U.S., cannot keep up with demand. As a result, our lead times for obtaining a production schedule are now [next year]."* (Manufacturer, expert in prefabricated wood light-frame construction)

As per one manufacturer interviewed, the limitation in production capacity is attributed to a productivity deficiency in Quebec factories (1).

> *"It's important that we improve because we are in one of the world's lowest-performing wood structure manufacturing industries today. There are countries [such as Australia, Germany and Switzerland which] that have already reached this level of performance ten years ago."* (Manufacturer, expert in prefabricated wood light-frame construction)

While the majority of manufacturers have focused on catering to the single-family and small multi-storey markets (7), several expressed a desire to tap into larger markets (five or six storeys or non-residential) that necessitate expanded production capacity (9). Despite the potentially higher financial returns associated with these larger projects (2), manufacturers face two risks inherent in their business model. Firstly, the production of a project may overly strain their production line to the detriment of their traditional markets (*e.g.* single-family homes) (2). Secondly, increasing complexity and uncertainties arise from these products' new requirements (1). According to some respondents, only a handful of manufacturers seem capable of undertaking such projects (2).

> *"In the summer period, between May and early September, (...) we do not do big projects because we cannot afford to take on a major project and then say no to 150 people who need our products for single-family homes, extensions, agricultural projects, commercial projects, etc., which will come out much more quickly. This means that major projects are carried out when these construction sectors are weaker, in the fall and winter."* (Manufacturer, expert in prefabricated wood light-frame construction)

> *"Of course, when you come to them with a project outside their core business, it's complicated. I called a couple of manufacturers about modular hospitals. Only one of them was able to adapt and wanted to come on board with us. The others said, "No, I am not doing that, I am doing housing, that is it". I think [their fear was] getting into something they had never done before."* (General contractor, user of prefabricated wood light-frame construction)

One solution identified by the industry to address this challenge is to achieve collaboration among multiple manufacturers for the production of a single building (5).

> *"By being a consortium, if one has less work than the other, it allows us*

> *not to affect the customer. We are able to take on any customer who comes along and share our projects so that they don't break our schedule as much as they would if we were on our own. Because when you have a factory and you do a big project that lasts too long, [other] residential projects are affected. (...) By being a consortium, we spread our risk of delays with other manufacturers."* (Manufacturer, expert in prefabricated wood light-frame construction)

In addition, the corporate culture and operational practices of many manufacturers, who are accustomed to private contracts with their customers, may not align with public procurement processes, particularly where high levels of prefabrication are involved (4).

> *"[Manufacturers usually] deal directly with the customer and act like contractors. Building a public building (...) where construction rules are not the same, where you have to deal with professionals, calls for tender, and so on, requires a lot of adaptation. (...) So it is a tall order, not only in terms of building methods, which can be different, but also in terms of construction culture, which is very different, and the project development relationship is not at all the same."* (Public developer, expert in prefabricated wood light-frame construction)

In the modular sector, there appears to be a limited number of companies experienced in manufacturing five and six storeys housing (5). Some professionals suggest that this segment of the industry may not be financially lucrative, which could account for the limited availability of companies offering these products (3). The challenge of finding a contractor proficient in modular solutions and equipped with the necessary technical resources for on-site assembly adds to the complexity of their utilization (1). Additionally, according to one professional, modular products are not yet fully developed and still offer significant potential for research and development (1).

> *"I think it's a market that's still very young in the modular sense, so I don't think there are many companies in Quebec that could say they have expertise."* (Manufacturer, expert in prefabricated wood light-frame construction)

Coordination. In general, prefabrication necessitates enhanced coordination among involved parties (6) and requires more effort in the design phase to reap benefits during on-site installation (5). More specifically, coordination between the factory and the construction site presents challenges according to many respondents (18). The primary issues identified include errors in foundation dimensions (9) and specialized labor-specific dimensional tolerances (7), which lead to occasional incompatibilities between prefabricated elements and other building components. Several professionals identified on-site adjustments as a significant challenge when the case arises (7). Hence, several respondents felt that the adjustments typically made on-site to address these issues must be foreseen during the design stage in prefabricated construction (7).

Some respondents point out that if the project design includes too many non-standard elements requiring customized solutions, recourse to prefabrication can impose a significant coordination burden on the project, making it less competitive than on-site construction (4). Furthermore, the greater the degree of prefabrication (*e.g.* modular construction), the higher the level of coordination and planning required, as the associated risks increase accordingly (3).

Engaging multiple manufacturers to address projects with greater production demands also introduces additional coordination requirements between manufacturers and those with other stakeholders (3). Nevertheless, according to one expert, there is no real coordination between designers (architects and engineers) and manufacturers, as the general contractor can choose the construction method that suits him best to meet the specifications (1). Finally, the division of professional responsibilities emerged as a concern raised by a less experienced respondent (1).

> *"There is a kind of shared responsibility, but I have the feeling (...) that [the responsibility] for dividing up the project would fall more on the general contractor (...) and less on the architect. (...) Who has the final say? Is it the architect who tells the contractor how to divide it up, or is it the contractor who chooses for himself, controls his resources, and decides how he is going to divide it up?"* (Architect, user of prefabricated wood light-frame construction)

Other professionals do not perceive coordination between the factory and the construction site as challenging, as most manufacturers respect dimensions meticulously (9). They believe that adjustments to prefabricated components can be addressed on-site if needed (9). Building Information Modeling (BIM) technology, currently being adopted by the industry, is seen by many stakeholders as a tool for improving coordination and planning by identifying conflicts in a preventive way (6).

On the other hand, many respondents emphasize that meticulous planning from the factory to delivery is essential for prefabrication utilization (12). Consequently, many believe that prefabrication enhances planning due to the inherent methodology of this construction approach (10). Moreover, adherence to planning is perceived as more probable, as factory work ensures consistent productivity by minimizing exposure to external disruptions and unforeseen events such as weather conditions, temperature fluctuations, and delays in material or labor delivery (7). However, some respondents suggest that prefabrication demands attention similar to on-site construction, as it does not always guarantee effective planning and adherence to schedules (3). Conversely, the need for foresight associated with prefabrication renders this construction method less flexible. For example, altering delivery dates poses challenges, as it necessitates storage of all produced components (*e.g.* in case of on-site delays) (4), and prefabrication is also intricate to implement in projects where not all parameters are known, such as renovation projects (2). Nonetheless, according to certain general contractors, prefabrication does not significantly impact schedules, as other trades must still intervene after the structural phase (2).

Highest concern motivations

Availability of labor. Many respondents express concerns at the current shortage of labor in the construction sector, which is evident in both major urban centers and rural areas (13). Prefabrication is viewed as reducing labor requirements on construction sites (12). Consequently, for many respondents, this construction method solves the labor shortage on construction sites (10) and makes it possible to build in remote areas where local labor is limited (6). Therefore, using prefabrication allows general contractors to undertake more projects with the same workforce compared to on-site construction (2).

While manufacturers encounter similar challenges with labor availability as general contractors (6), they are perceived to be in a more advantageous position. Many respondents believe that manufacturing jobs are accessible to a more diverse range of employees, as working conditions are less demanding than those on a construction site (*e.g.* reduced physical labor, less travel, protection from adverse weather conditions, and availability of ergonomic equipment), and require fewer professional qualifications (skills card of Construction Commission of Québec (CCQ)) (7).

> *"In Quebec, to work on a construction site [you need] skills cards, whereas in the factory, the labor force does not need qualifications. (...) Working in the factory gives us access to workers who do not necessarily have the knowledge initially but who will develop it over the long term by working in the factory."* (Manufacturer, expert in prefabricated wood light-frame construction)

> *"I think factory [working] conditions are accessible to a wider range of employees. We hear that some more women or people are not attracted to building sites where it is more physical to work (...) with the [climatic] conditions we have all year round. So having a fixed place to go and work might be interesting for these employees."* (Public developer, expert in prefabricated wood light-frame construction)

Consequently, labor employed by manufacturers is also less expensive than that on construction sites, and they are not bound by collective bargaining agreements specific to the construction sector (13).

> *"For factory workers, the cost might be thirty-five dollars an hour, while on construction sites, it might be eighty dollars an hour. There is a big margin."* (Manufacturer, expert in prefabricated wood light-frame construction)

According to specific stakeholders, factory prefabrication enables adaptation to the declining expertise of the labor force by simplifying their tasks (3). It facilitates centralized and simplified labor management compared to several construction sites' simultaneous supervision (1). In addition, factories have the capacity for robotization and automation, which cannot be achieved on construction sites, offering promising prospects for meeting these labor challenges in the future (4).

Cost. According to most respondents, prefabricated construction generally incurs lower costs or is comparable to on-site construction (24). The competitive rates offered by factories are primarily attributable to several factors: lower hourly wages for employees compared to on-site workers (17), economies of scale and production volume (10), factory working conditions that enhance worker productivity (8), and optimization of material consumption (3).

> *"Working in ideal conditions, with jigs and a system where RandD and industrial engineering have been applied, enables optimized manufacturing processes, which are capable of reducing costs, increasing quality and speeding up worksites." (Architect, non-user of prefabricated wood light-frame construction)*

Savings are also achieved through accelerated execution on-site, resulting in decreased fixed costs and a faster return on investment (12). Some respondents believed that the entirety of the savings came from this aspect alone (4).

> *"You almost triple the speed of a project. (...) And time is money. (...) [Then] for our kind of project, the monthly operating costs are just about three hundred thousand USD. So if you can save a month, you are saving three hundred thousand dollars."* (Manufacturer, expert in prefabricated wood light-frame construction)

Furthermore, according to some manufacturers, using prefabrication ensures precise costs (without adding unforeseen costs), thanks to the anticipation inherent in their construction methods (4).

> *"If we sign a contract worth 2 million, it will be exactly 2 million dollars. We never charge extras; there is no such thing as that. Whereas with traditional on-site construction, they'll say it costs 1.5 million, and then as the job progresses... Ah! you have to add another $100,000 Ah! you have to add another $200,000. (...) In fact, we reduce uncertainty enormously."* (Manufacturer, expert in prefabricated wood light-frame construction)

Some respondents adopt a more moderate point of view, suggesting that these financial advantages depend on several conditions, including an initial design that integrates prefabrication concepts, effective coordination, and a balance between the distance from the factory to the construction site and the quantity of transported elements, and the added value to offset transportation costs (6). In addition, some factors are recognized for their potential to increase prefabrication prices, such as: the lack of expertise in the process for five and six storeys construction, leading to increased risks and consequently higher financial guarantees demanded by stakeholders (5); the duplication of structures in modular construction (*e.g.*, walls, floors, ceilings) (4); the structural reinforcement necessary for transporting prefabricated elements (2); and the public tendering process (1).

> *"We are trying to push prefabrication a little further, but there are a few unknowns concerning this industry, the risk it represents. [For example], the division of responsibilities between the main manufacturer and other subcontractors are elements that artificially inflate costs. (...) Because prices can't be precise between the various suppliers and the general contractor, [since] everyone takes a share of the risk on that, the cost can be slightly higher than with an on-site contractor." (Public developer, expert in prefabricated wood light-frame construction)*

Productivity. For the majority of respondents, prefabrication means faster execution on-site (35). Factory manufacturing also speeds up production by controlling manufacturing conditions (12).

> *"That is the promise of prefabrication. It is the principle of added value: better, faster, less expensive."* (Architect, non-user of prefabricated wood light-frame construction)

Productivity gains in the overall schedule are also associated with the ability to progress site work (*e.g.*, foundations) at the same time as factory production (13). However, one expert qualifies this theoretical advantage by noting that the manufacturers' production schedules need to be considered, as they can sometimes hinder this advantage to the overall schedule (1).

For some, prefabrication has not yet reached a level that substantially improves productivity, and the industry could incorporate more value-added features into its products (5). Although speed construction allows rapid protection from the elements (2), it is mainly the assembly of the structure that is accelerated prefabrication of panels, leaving many tasks to be carried out conventionally on site (2).

Construction quality. The majority of respondents believe that factory work provides superior construction quality due to several factors, including protection from the elements and humidity (26), improved quality control measures (23), and optimal working conditions with ergonomic workstations and streamlined processes that ensure consistent production quality (20).

> *"Of course, we tend to have a bit more quality. We receive well-dimensioned workshop drawings, ensuring that the joists line up with the studs, and that the load transmission is vertical, (...) whereas on site, (...) we leave the workers free, and then there can be important problems."* (Engineer, user of prefabricated wood light-frame construction)

Factory-based quality control also facilitates the implementation of more rigorous procedures required for the construction of five or six storeys buildings (*e.g.* monitoring wood moisture content to mitigate dimensional shrinkage), which would be challenging to achieve on-site (1).

Nevertheless, while prefabrication makes it easier to achieve superior quality, the construction quality itself is not determined solely by the construction method. Instead, it varies according to the quality of the manufacturers and contractors involved (8).

> *"The industry varies in quality; there are defects in the prefabrication industry (...). Then the same goes for the building site, so it is all relative. You cannot generalize that on-site construction is better. However, with off-site construction, if the concept is optimized for the system on which there has been research and development, experience, and performance demonstration, and if the product is manufactured as it should be by qualified resources, delivered to the site in ideal conditions and installed in ideal conditions (...), prefabrication has the potential to be more efficient... But ideal conditions are never found. There are always labor issues at some point, such as staff turnover." (Architect, non-user of prefabricated wood light-frame construction)*

For quality to be truly effective, it must also manifest on-site through the assembly of elements, especially concerning sealing (5). Some professionals believe that current prefabrication practices do not allow high-performance building envelopes due to insufficient sealing at the interfaces between prefabricated parts (3).

> *"It is really the opposite of a high-performance envelope. (...) And then when you get to the building site, you assemble it. All the joints have to*

> *be dismantled to make a watertight seal. So we undo what has been done in the factory, and then we put tape on top of all that. (...) And as we know, after four or five years, the moisture gets the better of it, and it peels off anyway, and then there are problems of water infiltration..."* (Private developer, user of prefabricated wood light-frame construction)

Others assert that the quality achieved through prefabrication is comparable to on-site production (1), and may be compromised if modifications are made to prefabricated elements on-site (1).

Regarding the quality perceived by users, most respondents indicate that any difference in quality is not discernible to the end user once the building has been completed (22). Conversely, some believe that prefabrication is associated with good perceived quality because industrialized processes are often equated with improved quality practices and rigorous control methods (7). The quality perceived by users depends mainly on their perceptions and experiences (or those around them), rather than a rational assessment of construction quality (4). In addition, users' perceptions may vary according to age, with younger people favoring prefabrication, while older generations may remember previous experiences associated with poor-quality construction, typically intended for temporary or affordable buildings (4).

> *"It may depend on people's age. Today, young people may prefer prefabs."* (General contractor, user of prefabricated wood light-frame construction)

> *"There is also a perception of the poor quality of modular buildings. (...) In the construction industry, when you talk about modular buildings, most people will say "trailers, trailers". It is not a good perception of a permanent building when you talk about trailers."* (Manufacturer, expert in prefabricated wood light-frame construction)

Discussion

The results of this study presented the motivations and barriers perceived by Quebec construction professionals regarding the adoption of wood-light-frame prefabrication in multi-story and non-residential construction. Key motivations identified include labor availability, cost efficiency, productivity, and construction quality. Mixed perceptions concerned manufacturing capacity and coordination. Expertise emerged as the most significant barrier. These findings correspond to the prevalent motivations and barriers identified in the literature despite a different classification of topics (Kamali and Hewage 2016; Akmam Syed Zakaria *et al.* 2018; Wuni and Shen 2020; Zhang *et al.* 2022). The reasons provided by respondents are very similar to those discussed in the literature review, though some complementary or contradictory points were not addressed in the literature.

- The advantage associated with labor availability is justified in this study, as in the literature, by the reduction in labor required for the production and assembly of buildings (Blismas and Wakefield 2009; Jaillon and Poon 2010; Benson and Rankin 2016; Wong *et al.* 2017; Zhang *et al.* 2022). In addition, this study determined that prefabrication facilitates the use of unskilled labor, creates jobs accessible to a broader diversity of profiles due to improved working conditions, and enables automation of specific tasks. Contrary to these results, the literature has identified a need for a more specialized workforce with skills specific to prefabrication (Wuni and Shen 2020; Rankohi *et al.* 2023).

- Cost improvement is justified in this study, as in the literature, by several factors: lower labor costs (Jones *et al.* 2016; Wong *et al.* 2017; Ahmed and Arocho 2021), improved productivity due to optimal production conditions (Wong *et al.* 2017; Zhang *et al.* 2022), improved cost certainty (Sutrisna *et al.* 2019), and acceleration of on-site work, which reduces site costs and leads to a faster return on investment (Blismas and Wakefield 2009; Jones *et al.* 2016; Hemström *et al.* 2017; Zhang *et al.* 2022). However, the literature also highlights contradictory perceptions or aspects not mentioned by respondents, such as the disability to reduce costs (Sutrisna *et al.* 2019; Steinhardt and Manley 2020; Wuni and Shen 2020; Zhang *et al.* 2022; Wang *et al.* 2023) and challenges associated with financing prefabricated projects (Wuni and Shen 2020).
- The increase in productivity is justified in this study, as in the literature, by controlled production conditions (Zhang *et al.* 2022), the ability to conduct on-site and factory work simultaneously (Kamali and Hewage 2016; Li *et al.* 2016), and speed of on-site assembly (Wong *et al.* 2017). However, the literature also mentions aspects not highlighted in this study, such as the need to design high-performance inter-module connections that preserve interior finishes to maximize added value in the factory (Wuni and Shen 2020).
- The increase in construction quality is justified in this study, as in the literature, by optimal and ergonomic working conditions, protection from weather and moisture (Johnsson and Meiling 2009; Kamali and Hewage 2016; Wong *et al.* 2017), and factory quality control measures (Jaillon and Poon 2014; Wong *et al.* 2017). However, this study did not address issues related to time-consuming on-site connection inspection procedures, which are highlighted in the literature (Wang *et al.* 2023).
- Finally, the lack of expertise is justified in this study, as in the literature, by the disparate level of knowledge of prefabrication among various stakeholders in the value chain (Blismas and Wakefield 2009; Wuni and Shen 2020; Wang *et al.* 2023), insufficient understanding of load transfer in inter-module connections (Khan *et al.* 2023), and a lack of interest due to previous technical and financial failures in projects (Wuni and Shen 2020; Zhang *et al.* 2022; Rankohi *et al.* 2023). This study additionally identified the lack of expertise from inadequate knowledge transfer between manufacturers and designers, the decision-making dominance of general contractors over designers in choosing construction methods, and the industry's focus on the house and small building market, which has not exposed it to more complex projects. However, the literature mentions other perceptions not present in this study, such as the lack of training for design professionals (Wuni and Shen 2020; Zhang *et al.* 2022) and the shortage of skilled labor for assembling prefabricated elements on-site (Wuni and Shen 2020; Rankohi *et al.* 2023).

Studies to date demonstrate a consistency of perceptions over time and across different regions studied. Thus, these topics significantly influence professionals' perceptions and decisions. However, differences can be observed between this study and the literature. For instance, topics that lead to mixed perceptions are approached differently in the literature.

- Manufacturing capacity in this study is associated with both positive perceptions (*i.e.* sufficient capacity to meet current demand and innovative multi-manufacturer business models to address production challenges swiftly) and negative perceptions (*i.e.* lack of production capacity for new markets and difficulties in obtaining production slots quickly, which can negate the benefit of construction speed). In contrast, the literature mainly highlights disadvantages, such as wide disparity in factory production capacities (Zhang *et al.* 2022), sub-optimal planning to maximize factory profitability (Fernandez-Viagas and Framinan 2015; Lin and Ying 2016), and lack of adoption of automated systems due to high initial investments (Lachance *et al.* 2023).
- Both the study and the literature highlight coordination challenges associated with prefabrication, including the need to freeze the design early in the project process (Wuni and Shen 2020; Khan *et al.* 2023), anticipating tolerances for each trade (Wuni and Shen 2020), and the risk of dimensional incompatibility between prefabricated elements and on-site construction (Wuni and Shen 2020; Khan *et al.* 2023; Tsz Wai *et al.* 2023). In addition, the difficulty and high cost of adjustments after manufacture are identified both in the literature and in this research (Wuni and Shen 2020; Khan *et al.* 2023), while also recognizing the potential for improved coordination with the adoption of Building Information Modeling (BIM) (Wang *et al.* 2020; Ben Mahmoud *et al.* 2022; Zhang *et al.* 2022). This study also determined that, for some respondents, coordination was not seen as a challenge. Rather, it enabled better planning, reduced the risk of unforeseen events, and it allowed that adjustments could be made as required on-site. The results of this research also reflect the increasing complexity of coordination as the complexity of products evolves (*e.g.* modules) and the need for this coordination to benefit from the advantages of prefabrication. However, certain aspects highlighted in the literature, such as prolonged design phases due to extensive coordination (Jaillon and Poon 2010; Hemström *et al.* 2017; Steinhardt and Manley 2020; Wuni and Shen 2020; Zhang *et al.* 2022), and logistical and planning complexities of lifting prefabricated elements on site (Kamali and Hewage 2016; Khan *et al.* 2023), were not explicitly mentioned by respondents in this study.

While the literature highlights specific barriers, such as standardization, manufacturing, transport, and on-site construction, as major concerns, the present sample indicated less concern regarding these issues, although the underlying reasons are consistent with literature findings (Zhang *et al.* 2022). However, a significant disparity is noted regarding project delivery methods, which the literature considers to be fundamental prior to prefabrication adoption (Blismas and Wakefield 2009; Wong *et al.* 2017; Wuni and Shen 2020; Koronaki *et al.* 2021; Rankohi *et al.* 2023). In contrast, this study did not rank the transition of design processes toward more integrated management modes among the barriers of greatest concern.

These differences can be attributed to several factors. First, variations in the definition and scope of topics across studies result in different overlaps and classifications (Zhang *et al.* 2022). Second, differences in analytical methodology play a role. While this study categorized topics solely as barriers or motivations, other studies may simultaneously classify them in both categories (Blismas and Wakefield 2009; Zhang *et al.* 2022). In addition, this study ranked topics of highest concern based on the spontaneity with which respondents addressed them, whereas the literature often relies on frequency (Wuni and

Shen 2020; Zhang *et al.* 2022). However, Giorgio *et al.* (2024) have suggested that this approach may introduce significant bias, limiting a holistic view of stakeholders' perceived motivations and barriers. Third, some studies lack a clear distinction between materials (*i.e.* steel, concrete, wood light-frame, mass timber, and plastic) and the techniques used (Zhang *et al.* 2022). Many studies focusing only on modular construction further complicate comparisons, potentially leading to divergent perceptions on topics such as costs (Benson and Rankin 2016; Kamali and Hewage 2016; Wuni and Shen 2020; Khan *et al.* 2023; Tsz Wai *et al.* 2023). Fourth, most studies deal primarily with technical and operational constraints, neglecting broader factors influencing adoption. Lastly, variations in the supply chain, socio-technical, and economic contexts across studies and samples could also contribute to these differences (Wuni and Shen 2020; Zhang *et al.* 2022; Khan *et al.* 2023). For instance, Hemström *et al.* (2017) note instances where precast elements were deemed more expensive, often referring to imported concrete structures, incurring additional costs.

This research has underscored that perceptions regarding prefabricated wood-light-frame construction for multi-storey and non-residential buildings are widely shared among construction professionals in Quebec. However, there are divergent interests among these professionals. While previous research has focused mainly on manufacturers and contractors (Hemström *et al.* 2017; Wong *et al.* 2017; Wuni and Shen 2020; Zhang *et al.* 2022; Rankohi *et al.* 2023), few studies have simultaneously examined the key stakeholders involved in building construction (Blismas and Wakefield 2009; Khan *et al.* 2023; Wang *et al.* 2023). This limits understanding on potential motivations and barriers to adopting prefabricated wood light-frame construction across the entire value chain.

Although different perceptions between various stakeholders emerge in the results, these differences are not marked. Several topics were generally perceived similarly across the sample, including labor availability, manufacturing capacity, cost, productivity, coordination, construction quality, worker safety, and environmental impact. The minor discrepancies observed are probably due to the different experiences of the respondents and their exposure to prefabrication issues (Riala and Ilola 2014). This homogeneity of perceptions can be partly attributed to the study's focus on comparing construction processes (*i.e.*, prefabrication versus traditional methods) using the same material, thus orienting interviews towards operational questions. Consequently, respondents with limited prefabrication experience often express neutral or widespread perceptions (Riala and Ilola 2014). Despite this, a few major trends can still be discerned.

First, architects and engineers tend to express generally more positive positions than the overall sample trend. In contrast, general contractors and manufacturers exhibit more polarized perceptions, while private and public developers show more negative perceptions than the sample trend. These results closely align with those of Giorgio *et al.* (2024) regarding adopting mass timber as a construction system, potentially indicating a broader pattern of optimism or reluctance towards new practices across different stakeholder groups.

Second, profiling across each topic reveals that specific issues are more frequently reported by stakeholders who are most exposed to them in their professional activities. For example, the availability of labor is a topic of strong spontaneity among general contractors, manufacturers, and private developers. It also appears that certain topics, such as project delivery methods, are highly polarized among various stakeholders. General contractors notably express a more positive stance towards current project management practices than the rest of the sample. This could reflect an inertia to change in the face of implementing new, more integrated project management practices, as shown in other studies (Roos *et al.* 2010; Hemström *et al.* 2017; Giorgio *et al.* 2024). The literature has consistently highlighted the necessity of a more collaborative approach, integrating manufacturers from the design stage and adapting the awarding of contracts due to the lack of standardization and normalization of manufactured products (Blismas and Wakefield 2009; Wong *et al.* 2017; Wuni and Shen 2020; Koronaki *et al.* 2021; Toppinen *et al.* 2022; Rankohi *et al.* 2023). This example demonstrates that although this topic is not among the most concerning, its polarization can significantly obstruct the adoption of prefabrication.

Furthermore, not all stakeholders possess the same decision-making influence. General contractors and developers are considered to have the most significant influence over the choice of building materials and methods. However, these stakeholders contribute most to maintaining reliance on established practices (Roos *et al.* 2010; Hemström *et al.* 2017). Consequently, their negative perceptions can significantly impact adopting new construction methods. In contrast, architects and engineers, often perceived as central to design and structural decisions, have limited authority over material choices (Roos *et al.* 2010). In addition, the end user typically remains unaware of the building material or construction method, exerting almost no influence on decision-making (Roos *et al.* 2010).

Moreover, several studies have identified additional stakeholders influencing the adoption of prefabrication beyond the construction practitioners interviewed in this study. These include governments, industry associations, financial organizations, and educational and research institutions (Zhang *et al.* 2022; Rankohi *et al.* 2023). This broader array of influences highlights the multifaceted nature of decision-making in the construction industry and underscores the importance of involving a wide range of stakeholders to facilitate the adoption of prefabricated construction methods.

Generally, the results indicate that the motivations and barriers identified in Quebec are consistent with those found in the literature, although some differences are evident due to the unique socio-technical and economic context of the region (Wuni and Shen 2020; Zhang *et al.* 2022; Wang *et al.* 2023). For instance, the wood-light-frame prefabricated construction sector is well-established in Quebec’s house and small multi-storey dwelling market, which enables manufacturers to support initial factory investments and collaborate with many professionals familiar with these construction methods (Julien *et al.* 2015). In addition, the reduced technical constraints mentioned in the literature are probably due to using a wood-light frame, a material that offers greater flexibility than prefabricated steel or concrete elements (Julien *et al.* 2015). Unlike Blismas and Wakefield (2009), who identified more barriers than motivations, this study revealed more motivations than constraints to adopting prefabrication, suggesting better acceptance in Quebec. Specifically, the results demonstrate advanced adoption of prefabricated wood light-frame panels but highlight challenges in adopting modular prefabricated elements in multi-storey and non-residential construction. The difficulties associated with using modular products are attributed to various issues such as limited access to information, absence of monetary advantage, unique properties of the elements, inflexibility, low competition, and contractual challenges. These findings suggest that while significant progress exists, further efforts are needed to standardize this construction practice.

The literature suggests several strategies to address these challenges and improve the adoption of modular construction. The transition to more integrated project management methods to promote DFMA and the increased use of information technologies, such as BIM, to support collaboration and logistics, appear to be promising prospects in the short term (Wang *et al.* 2020; Ben Mahmoud *et al.* 2022; Penfield *et al.*

2022; Rankohi *et al.* 2023). In the long term, the move from flexibility-oriented artisanal production to standardized and automated production is necessary (Lachance *et al.* 2023; Wang *et al.* 2023). Automation and standardization could optimize productivity, align manufacturing capacity with market demand for multi-storey and non-residential construction, and reduce costs, contractual issues, and reliance on increasingly scarce labor (Lachance *et al.* 2023). However, this shift towards more standardized production might alter the role of manufacturers, as prefabrication impacts the activities of other stakeholders (Wuni and Shen 2020). Unlike the single-family home and small multi-storey markets, where manufacturers often have an integrated role as designers, manufacturers, and builders, they could assume the role of component suppliers in the traditional multi-storey and non-residential construction value chain without intervening in other project phases.

Limitations

Like most qualitative studies in the literature, the present research also presents limitations related to validity. Despite the interpretive method associated with coding framework development, different interpretations of the same material can be equally valid, as Schreier (2012) stated. This research method involves several biases related to the researcher, including the selection of the sample, which depends on the researcher's subjective judgment; interactions with participants, which may unintentionally influence results through the researcher's own beliefs and expectations; and distribution of data within the coding process, as this requires a subjective understanding of the language used in responses (Schreier 2012; Aaltonen *et al.* 2021; Viholainen *et al.* 2021).

The construction techniques associated with prefabrication were not defined for respondents to minimize any influence on their perceptions. Consequently, some respondents referred exclusively to prefabricated panel elements, others only to modules, and some discussed both methods. This lack of uniformity in the definition limits comparisons across the interviewed stakeholders on specific topics.

Most respondents who participated in this research were interested in the subject or the scientific contribution. Therefore, the concerns raised by a minority of the panel, who are not advocates of prefabricated construction, should not be disregarded due to their lower frequency, these points of view warrant further investigation.

Finally, although the respondents' selection aimed to represent the diversity of key stakeholders in Quebec's construction industry and despite conducting many interviews, the data may not fully represent the entire industry. As with many studies using similar methods, this research alone cannot generalize the results beyond the studied sample (Riala and Ilola 2014; Aaltonen *et al.* 2021; Rankohi *et al.* 2023). Nonetheless, given the similarity of the present findings with the existing literature, it is highly likely that the observed perceptions accurately capture the various points of view within the industry.

CONCLUSIONS

1. Based on interviews with diverse stakeholders in the Quebec construction industry, this study examined the advantages and challenges associated with implementing prefabricated wood light-frame construction for multi-storey and non-residential buildings.
2. The findings indicate that a lack of expertise is perceived as the most concerning

barrier. Conversely, the availability of labor, cost, productivity, and construction quality are key motivating factors for adopting this construction method. Production capacity and the required coordination for prefabrication received mixed views, with perceptions ranging from positive to neutral to negative. Overall, the results indicate good adoption of prefabricated panelized components but a more challenging adoption of modular construction.

3. While different viewpoints were illustrated, the underlying reasons for these perceptions largely correspond with the existing literature. These different points of view also provide a deeper understanding of the issues involved in adopting prefabricated wood light-frame in Quebec's socio-technical and economic context.
4. Analysis of the response profiles suggests that various stakeholders generally share similar perceptions, although some may be more conservative depending on the specific issues at stake that affect their professional interests.
5. This study can serve as a valuable reference for all stakeholders in the construction value chain. With the anticipated industry-wide adoption of prefabrication to address various structural challenges, the findings of this study will assist professional associations and government bodies in refining policies, educational programs, and strategies to promote the widespread adoption of prefabricated wood light-frame construction practices. Practitioners can also use these insights to understand better the issues faced by other stakeholders, adapt their business and communication strategies to meet the expectations and concerns of their counterparts, and thus capitalize on the emerging competitive advantages of prefabrication.

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Disclosure Statement

The authors report there are no competing interests to declare. The funders had no role in the study's design; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Ethics of Research Involving Human Participants

This study has been performed in accordance with the ethical rules of Laval University. The agreement of the multi-faculty committee on ethics of research involving humans of Laval University has been obtained. The approval number of the project is 2020-367 R-1 / 04-01-2022. Informed consent was obtained from all subjects involved in the study.

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APPENDIX A

Barriers of Lesser Concern

Project delivery methods. For many respondents, while traditional project delivery methods may be suitable for prefabricated construction, an integrated approach such as design-build is considered preferable, particularly for complex projects (14). As a result, according to many, integrated design-build processes are the preferred method for prefabricated projects (16).

> *"I think it's important for all the stakeholders to be at the same table when it involves prefabrication. It alleviates some of the stress, puts everyone on the same level in terms of technical understanding for implementation, and also enables a certain amount of dialogue on "Well, here's what we can do to break the prefabrication mold a little in terms of aesthetics". So I think this kind of dialogue is welcome, to facilitate the overall design of a project."* (Architect, user of prefabricated wood light-frame construction)

The modular prefabrication process faces challenges due to the tendering and contracting system established in Quebec (8). Indeed, it is often not feasible to involve a manufacturer in the design phase before the tendering stage (6), which sometimes results in the abandonment of the modular prefabrication approach (5). As a result, design-build arrangements become particularly binding for prefabricated modular projects (9), as they require the early involvement of the manufacturer in the design process (6).

> *"It's true that in traditional public tenders, it's a little more difficult (...) If we use modular construction, the construction method is completely different from if we did it on site or with manufacturers of different structural components. We could, for example, duplicate floors, ceilings, etc. Then, we could integrate mechanical elements or even gypsum. Here, what becomes difficult is the separation between what is done by the manufacturer and what is done on site by the general contractor and subcontractors, and all the connections that have to be made on site, on the foundations, on the mechanics, etc., these are grey areas if the call for tenders is not specific." (Public developer, expert in prefabricated wood light-frame construction)*

On the other hand, in cases where the manufacturer operates as a subcontractor under the general contractor, the conventional tendering and construction process is not a disadvantage to prefabrication. Indeed, the contractor retains autonomy to determine construction methods and award contracts accordingly (2).

In order to make it easier to prescribe modular prefabrication in calls for tender, it is necessary to improve the expertise and standardization of the products offered by the industry. This would reduce conflicts of interest and minimize risks (4). Particularly when dealing with highly specialized products, an integrated design process or design-build approach becomes essential to help designers to incorporate them effectively (2). In private projects or turnkey contracts, where contracts are usaully awarded by mutual agreement and based on performance rather than strict prescription, the adoption of prefabrication is facilitated (8).

Finally, some stakeholders do not perceive any issues with the construction methods (3). However, for others, the traditional method is preferres because it allows greater control of the duration of the construction site and leaves more time for completion the overall design (1).

Less concerns topics with mixed perceptions

Regulations. For many respondents, regulations are neither a barrier nor an advantage to prefabrication, as the building code mandates compliance primarily with materials rather than construction processes (17). However, some experts highlight limitations modular prefabrication regulations, as they were designed for standard construction and not for splitting into parts (*e.g.* lateral loads, electromechanical) (4). Local regulations can also be obstacles to prefabrication, particularly modular methods, due to height restrictions that can prove challenging to adhere to, especially with double floors (2).

Conversely, transportation regulations may be an obstacle due to restrictions on maximum dimensions, requiring adjustments to the project's design and segmentation (8).

> *"One of the disadvantages is that we have to transport our modules. We're governed by transport regulations, so we're limited in what we can do in terms of module width, height and, to a lesser extent, length, but length isn't so much an issue as width and height. So, for example, 9-foot ceilings are very difficult for us to do."* (Manufacturer, expert in prefabricated wood light-frame construction)

Architectural liberty. For most of the respondents, integrating prefabrication into building design is perceived as a constraint that can restrict architectural possibilities (21). While prefabrication is perfectly suited to standardised spaces, such as residential construction, it is perceived as limiting and repetitive, which is not necessary desirable for all types of project (6).

> *"We see prefabrication more for residential projects, because it's always more or less the same recipe. (...) In other types of project, for example a commercial project, the company's needs take priority over respecting a prefabricated system, so it's often not something we use. We prefer to meet the customer's needs in the best possible way, without getting bogged down in prefabrication."* (Architect, non-user of prefabricated wood light-frame construction)

Another group of respondents estimates that prefabrication does not impact design possibilities (13), particularly in the case of panel prefabrication (8). Some respondents even believe that prefabrication expands architectural options by allowing complex shapes (*e.g.* roof trusses), to be creating using manufacturers' modeling and construction tools, which can be difficult to achieve on site (3).

A large proportion of professionals perceive modular construction as a method that requires a tailored design, exerting considerable influence on building design (16). Nevertheless, several respondents expresse that the modular system could be used to design a project adapted to construction methods (8).

> *"I think there's a lot of potential, I'm not one of those people who thinks*

> *it's ugly or redundant or looks the same. I think, in modularity or "prefab", you can create a whole variety of looks and designs, so it doesn't bother me there."* (Architect, user of prefabricated wood light-frame construction)

Fire safety performance. The majority of respondents consider that the regulatory requirements are the same whether the building is prefabricated or not, which ensure equivalent safety standards (22). However, it is recognised that fire safety during the construction phase poses a challenge, particularly because wood light-frame is susceptible to catch fire until fireproofing elements are installed. Prefabrication, particularly at the more advanced stages, can mitigate this risk by accelerating the achievement of a fire-safe condition through compartmentalisation, thus reducing the time of exposure to the risk of widespread fire (8).

> *"As soon as the building is compartmentalized and the sprinkler system is in operation, the risk drops considerably, because if there's a fire, it's very easy to locate and extinguish quickly."* (Architect, user of prefabricated wood light-frame construction)

> *"For fire safety in construction, prefabrication is far superior. Because when we deliver the product, the gypsum has already been installed. So fire barriers are already in place. So there's a fire potential, but it's never as high as if we were building from scratch."* (Manufacturer, expert in prefabricated wood light-frame construction)

In addition, the controlled environmental conditions in factories reduce the risk of fire (1). Furthermore, quality control processes ensure the presence of all required fire-retardant sealants (2).

Structural performance. Many professionals surveyed believe that mechanical strength is equivalent whether construction is carried out on site or prefabricated. They argue that compliance with the building code, the engineer's prescriptions, and the physical properties of the material are the most important factors in achieving good resistance, not the constructive method (19). However, some respondents suggest that prefabrication offers greater structural resistance due to factors such as: better construction quality and compliance with specifications (14), as well as the oversizing of structures to take into account lifting and transport constraints (11).

> *"The volumetric module has to stand up to be transported. So, often, it's a little stronger than it should be. This isn't true in all cases, but for me it's like a guarantee of greater robustness. But we don't need it. It's just too strong for anything, it's reassuring, but it's not necessary."* (Architect, expert in prefabricated wood light-frame construction)

However, doubts have been raised as to whether this increased structural resistance actually exists. Concerns stem from factors such as the resistance of anchors at the interfaces of prefabricated elements (7) and the potential impact on structural integrity due to handling during installation (1).

> *"What's important when they're assembling the panels [is] that they manipulate them properly so as not to soften them. Because when it's*

> *nails that hold it together, once you've maybe stirred it too much, I'd be tempted to think that the nails would come loose in the holes."* (Engineer, user of prefabricated wood light-frame construction)

Construction height. Some professionals express that despite the opening up of the National Building Code to five and six storeys wood light-frame construction (NBC 2010 - amended, effective in 2015), expected increase in the number of projects has not materialized as expected, unlike in British Columbia (5). Despite a few experiments, there haven't been enough projects or demonstration buildings of five or six storeys to demonstrate their relevance to the market (6). In addition, despite its incorporation into the national building code since 2015, certain interviewed professionals maintain that the height limit is still capped at four storeys (2).

Many respondents believe that wood light-frame construction is most suitable for buildings between one to four storeys (19), citing significant constraints at five storeys and above, such as supporting brick cladding at each storey, anchoring to resist lateral forces, managing dimensional shrinkage of timber, ensuring fire safety, and addressing envelope performance due to the large number of studs (13). However, another group believes that it's possible to build up to six storeys without encountering significant issues (11).

Moreover, many respondents believe that prefabrication of buildings is relevant regardless of the number of storeys (11). Another group suggests that prefabrication becomes interesting from 3 storeys upwards, in order to achieve a sufficient volume of repeatability to make it worthwhile in terms of cost (13). In the same way, some professionals note that repeatability can also be achieved horizontally or by repeating the elements that compose the building (3).

> *"[At six storeys] there may be safety and ease of installation issues that make it a bit more advantageous in terms of height to use prefabrication. You know, we're going to need less scaffolding and systems for working at height. So I think there can be some advantages to prefabrication in terms of height."* (Architect, user of prefabricated wood light-frame construction)

Insurance. For a large portion of respondents, the construction method does not significantly affect insurance premiums (17). However, insuring wood projects is reported to be considerably more expensive than those made of other materials (7).

> *"It's obvious that when it comes to insurance, when you're in the construction phase, it costs three times as much to insure a wood light-frame structure as a concrete or steel one. (...) The difference is enormous."* (General contractor, user of prefabricated wood light-frame construction)

Some professionals believe that prefabrication could potentially lower insurance premiums due to shorter on-site construction times, which also could reduce fire risks (7), as well as the overall quality of construction (2). However, they note that the construction method does not typically affect insurance premiums during the building operation phase (11).

> *"On the site, (...) we'll be less expensive because we're on the site for less time, because site insurance is based on the number of days we*

> *spend. That means we're on site for less time (...) So naturally, the risk is lower for us."* (Manufacturer, expert in prefabricated wood light-frame construction)

> *"There is a surcharge as long as the sprinkler system is not operational, and as long as the wood elements are not protected if they need to be."* (Architect, user of prefabricated wood light-frame construction)

Risk. A significant portion of respondents perceive equivalent risks, whether financial or supply-related, between prefabrication and on-site construction (17). Some even believe that prefabrication could mitigate risks associated with the construction phase, notably by shortening worksite times, thereby reducing exposure to potential issues as vandalism, theft, construction quality concerns, and risk of bankruptcy (since manufacturers are generally well-established players) (7). Prefabrication also aids in better controlling supply and financial risks upstream of the construction phase due to the management of resources and materials in larger volumes compared to on-site construction (4).

Another group of professionals perceives several risks associated with using prefabrication for various stakeholders, including the general contractor, manufacturer, and customer. For the general contractor, the primary identified risks include the potential need for rework if coordination is suboptimal (7), the challenge of timely delivery by the manufacturer (which is also exists with other suppliers during on-site construction) (6), and the dependency on a primary supplier that may be difficult to replace in case of issues (3).

> *"That's a big risk, because you can't replace a prefabricator in the middle of a project. So if he doesn't make it to completion, that's a big risk. That's why we asked for surety bonds. We asked for bonds from specialized contractors, manufacturers. (...) [If we'd had to finish it without the manufacturer] it would have been difficult. You know, I think we would have finished it in build stick at the job site. We would have finished it in traditional mode if that had ever happened. Because, transferring that, I had made approaches to other manufacturers and they weren't that interested. I don't think anyone would have taken it back in the end."* (General contractor, user of prefabricated wood light-frame construction)

The main risks highlighted for manufacturers include the significant fixed costs of operating the factory, which require consistent production and a high volume of projects to maintain profitability (3), the potential for production line congestion caused by larger and more complex projects (2), the need for strong financial capacity to support large projects until components are shipped and paid for (as opposed to managing many smaller customers) (2), and the need to source substantial quantities of materials to support factory operations without guaranteed construction contracts (although this practice also mitigates material prices fluctuations compared to on-site construction) (1).

> *"Of course, prefabrication requires a certain volume. There are significant fixed costs when you don't reach that volume. It's not always easy to smooth out production. What we find extremely hard is that projects move around. It's extremely hard, and seems to be the general rule everywhere (...) When you move a small project, it's no big deal.*

> *But when you move a larger project by a week, you've just created a very big production gap."* (Manufacturer, expert in prefabricated wood light-frame construction)

Investing in factory automation also presents a significant financial risk, as manufacturers' business models may not always align with this strategy (3).

> *"They have to put cash up front to hope to make a profit later. But this industry isn't used to doing that. This industry is used to [the person] who wants a house yesterday (...) So wasting cash that lowers your results at the quarters, your investors aren't interested in having that, even if it's a long-term vision."* (Engineer, expert in prefabricated wood light-frame construction)

For the customer, the main risk lies in the uncertainty surrounding the remaining on-site work (2). Finally, delegating the production of working drawings to the manufacturer entails no financial loss for architects or engineers, as they remain responsible for checking them in accordance with their professional obligations (4).

Lifespan. The majority of respondents believe that the lifespan of a building is comparable whether it is constructed through prefabrication or on-site methods (25). However, they acknowledge that construction quality significantly affects the longevity of both factory-built and site-built structures (7). Therefore, prefabrication is perceived to potentially extend a building's lifespan due to enhanced construction quality (7) and reduced exposure to weather elements (5). Conversely, one respondent express concerns that prefabrication might compromise a building's durability compared to on-site construction, citing potential challenges related to sealing between components (1). In the same spirit, one manufacturer suggests that developers exhibit apprehension regarding the lifespan of five and six storeys wood light-frame buildings, which contributes to their scepticism about these projects (1).

Less concerns motivations

Nuisance. A large proportion of respondents assert that prefabrication minimises nuisance on the construction site, mainly by reducing the volume of work required on-site (12). This results in shorter construction periods (11), reduced noise levels (6), and less waste and dust generation (2).

> *"Most of our customers tell us that the shorter construction time means less stress for the people around them. Of course, for us, the phase when we bring the modules in and install them is quite intense. So it's annoying for a few days or a few weeks, depending on the project. On the other hand, on a conventional site, the trucks don't stop for a year."* (Manufacturer, expert in prefabricated wood light-frame construction)

Nonetheless, the use of prefabrication may introduce challenges, such as the storage of trailers, walls, or modules in urban settings (9), as well as the deployment of larger transport and lifting equipment which may require street closures (8). In essence, some stakeholders summarise that while prefabrication may cause more pronounced nuisances, these occur over much shorter times (6).

> *"The nuisance is the space it takes up. You know, we parked on the street and the police kept coming to see us. We occupied the street for two months. We always had 5 trailers on the walls. We had 35 trailers to unload. We had applied for a permit, we had a protection zone, but the citizens were complaining."* (Private developer, expert in prefabricated wood light-frame construction)

Worker safety. The majority of respondents perceive controlled factory working conditions as providing a safer environment for employees compared to on-site conditions (20). In addition, some manufacturers believe that their employees receive more comprehensive safety and health training in the factory than on-site (2). According to an expert, working in a factory also reduces the necessity for workers to commute to the job site, thereby mitigating certain risk factors such as fatigue and road accidents (1).

> *"They have tables, everything is done within their reach, which makes it much safer to do it prefabricated here than built on site. Because on the building site, they're not within their reach, they're up in the air, especially when you go upstairs. It's okay on the first level, but if you go up to the second, they'll have to use guardrails all the way around. In the factory, the temperature doesn't affect you, there's no wind, there's no rain, there's no ice."* (Manufacturer, expert in prefabricated wood light-frame construction)

In the on-site phase of the project, the adoption of prefabrication likewise reduces workers' exposure to risks (22), as well as the length of time they are subject to the most significant risks (7). While some argue that using prefabrication on-site initially presents greater risks due to the handling of voluminous elements using a crane, it enhances safety in the second instance as workers no longer work without safety guards (4). Moreover, the use of prefabrication reduces the number of contractors required on-site, which is associated with a reduction in risk, as noted by one respondent (1).

> *"I think that "prefab" systems offer the possibility of greater safety. Because in the factory, conditions are controlled, and on the site, these are large pieces delivered by crane. Instead of having workers walking on the joists, which are open, without bridging, and walking at height on a structure being erected, I find that it's probably safer with cranes, where the large pieces are fixed together, and where people are less exposed to holes and site hazards."* (Architect, user of prefabricated wood light-frame construction)

Finally, several respondents indicate that erecting prefabricated elements or conducting on-site construction posed comparable risks for workers (5).

Environmental impact. The majority of respondents note that factory prefabrication allows better optimisation of materials, resulting in reduced waste production (31), which is considered the main environmental benefit of prefabrication (8). Furthermore, many respondents believe that factories manage their residual materials and recycle construction waste more efficiently than construction sites (*e.g.* reusing small pieces, energy recovery) (10).

> *"The more prefabrication there is, I have the impression that materials*

> *will be better optimized, because on the building site, having already, in a recent case where light-frame walls were assembled on site, they didn't bother too much. They'd fill all the doors and windows with OSB panels, and then say to themselves : "Look, this is costing me so much labor on the site that the loss I'm going to have in my holes for my OSB isn't worth it, so I'm going to throw away all the OSB holes". Whereas in the factory, maybe the pieces are better used because there's better control."* (Engineer, user of prefabricated wood light-frame construction)

Other professionals express that no difference exists in environmental impact between factory-built and on-site construction (4), including in terms of the amount of waste generated (3).

> *"There will be a little more waste, but normally, wood waste is recycled. So now, when we're doing LEED projects, or even if we're not, when we have significant accumulations of a specific material, it goes to recycling. So no, I don't think it makes any difference to the environmental footprint to build in a factory or on site."* (General contractor, user of prefabricated wood light-frame construction)

A common perception among some respondents is that the environmental impact of a building is mainly influenced by the materials used and the performance targets, rather than the construction method itself (7). However, some note that certain construction methods, like modular construction, may have a higher environmental impact due to the duplication of structures (1).

In terms of environmental impact of transport, many respondents posit that prefabrication reduces overall transportation needs, substituting numerous deliveries and labor movements necessary for on-site construction, thereby resulting in fewer greenhouse gas emissions (11). However, they note that these benefits are contingent on the project context, particularly the distance between the factory and the construction site (6).

> *"Of course, in our case, there's an element of module transport that doesn't exist in traditional construction. On the other hand, traditional construction means having all materials delivered to the site in small volumes, whereas we have full trucks delivered to our factory, for example 2x4s and 2x6s. All our employees come to our factory and often carpool. Whereas on a worksite, each employee typically comes in his own vehicle morning and evening. We don't have any studies to back this up, but we estimate that modular construction has a smaller environmental footprint than traditional construction."* (Manufacturer, expert in prefabricated wood light-frame construction)

APPENDIX B - INTERVIEW GUIDE

Presentation of the project and obtaining consent.

Professional practices and general opinion on motivations and barriers to using prefabricated wood light-frame construction

(1) What do you think of prefabrication, and do you use it?
- What types of components do you use?
- With what degree of finish?
- What do you think of wood light-frame prefabrication?

(2) What are the advantages and disadvantages of using wood light-frame prefabrication compared with on-site construction?
- Can't you see any others? (Relaunch at least once)

Specific questions to address topics not covered in the first part of the interview

(3) What effect do you think prefabricated construction has on quality?

(4) Between on-site and prefabricated construction, do you think one solution offers better perceived quality for the end user?

(5) In your opinion, does prefabrication influence architectural possibilities?

(6) Do you think prefabrication has any effect on the building's environmental footprint?

(7) In your opinion, does factory prefabrication influence the amount of construction waste?

(8) In your opinion, does prefabrication have an effect on scheduling accuracy (*e.g.* delivery delays, interference between contractors)?

(9) In your opinion, does prefabrication influence productivity in building construction?

(10) Do you see coordination between factory and construction site as an issue for prefabricated buildings?

(11) In your opinion, does the use of prefabrication have an effect on on-site construction time and site nuisance?

(12) What do you think about worker safety when using a prefabricated construction system?

(13) In your opinion, are regulations a barrier or an advantage for prefabricated construction?

(14) For which building heights do you think this technique is particularly suitable?
- Is it compatible with 5- and 6-storey multi-storey buildings?

(15) What do you think of the structural resistance of prefabricated wood light-frame construction?

(16) Do you believe that the lifespan of a building constructed using prefabricated

systems is equivalent to that of a site-built structure?

(17) What's your opinion on the fire safety of prefabricated buildings?
- Does it perform as well as on-site construction in terms of fire resistance?

(18) Do you feel that expertise in this type of constructive method is well established in Quebec?

(19) Do you think the manufacturing capacity and product offering in Quebec are sufficient for this type of construction method?

(20) In your opinion, does the use of a prefabricated construction system cost less or more than on-site construction for 5-6 storey buildings?

(21) Do you think insurance is an issue for prefabricated buildings?

(22) Does the use of prefabricated building systems entail any risks in your practice?
- Does the use of a prefabricated wood light-frame construction system represent a financial risk?
- Does the use of a prefabricated wood light-frame construction system represent a supply risk?

(23) For you, can project delivery methods be facilitators (advantages) or barriers to the use of this constructive method?

Questions about respondents' characteristics

(24) How old are you?

(25) What is your level of responsibility in your organization?

(26) How long have you held this or a similar position?

(27) In which region is your organization located?

(28) How many employees does your organization have?

(29) For which types of building are you most often called upon in your activities?
- Commercial
- Industrial
- Institutional
- Multi-storey housing
- Single-family housing

(30) How many construction projects does your company handle on average per year?
- Less than 5
- Between 5 and 20
- More than 20

(31) What is the average monetary value of your company's projects?
- Less than $2M CAD
- Between $2M and $10M CAD
- More than $10M CAD

(32) What is the tallest building among your projects?
- 4 floors or less

- Between 5 and 6 storeys
- More than 6 storeys

(33) Overall, what is the average height of your projects?
- 4 storeys or less
- Between 5 and 6 storeys
- Over 6 storeys

Note: The questionnaire presented here is a translation. The original questionnaire, distributed in French, is available upon request from the authors.