

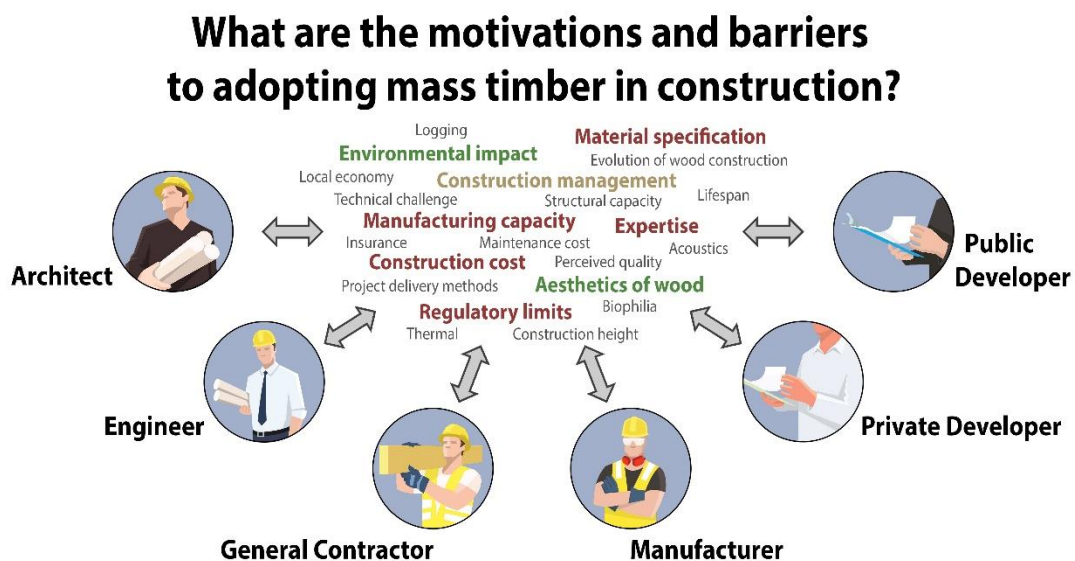
Using Mass Timber in Multi-Storey and Non-Residential Construction Projects: Motivations and Barriers for Professionals in Quebec

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GRAPHICAL ABSTRACT



Using Mass Timber in Multi-Storey and Non-Residential Construction Projects: Motivations and Barriers for Professionals in Quebec

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Despite their environmental benefits and technical viability, mass timber structures adoption remains limited. As an alternative to steel and concrete in non-residential and multi-storey construction, they represent only 10.2% of buildings four or fewer storeys high, 1% of those five or six storeys high and 4% of those seven to twelve storeys high in Quebec. Based on a purposive sample of 42 interviews with various construction industry professionals in Quebec (Canada), the representation of mass timber construction was highlighted. A thematic analysis approach enabled a study of the motivations and barriers to adopting mass timber and the specific reasons behind them, and to determine whether respondents' perceptions differ significantly depending on their main professional activity. The results corroborate existing literature while offering deeper insights into motivations and barriers, revealing new viewpoints. Respondents cited construction costs, expertise, manufacturing capacity, regulatory limits, and material specifications as the most critical barriers, while environmental impact and aesthetics of wood as key motivators. The response profile analysis suggests that private developers and general contractors should be the primary targets of measures promoting mass timber adoption. This research will aid in refining policies and strategies to encourage the widespread adoption of mass timber in construction practices.

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Keywords: Decision-making; Mass timber adoption; Stakeholder perceptions; Structural material; Sustainable building; Wood building

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INTRODUCTION

The construction sector continues to be associated with practices that result in excessive carbon emissions, the consumption of primarily non-renewable materials, and environmental degradation (Climate Chance 2019). Therefore, it is necessary to transition towards more sustainable construction practices (Climate Chance 2019).

One aspect of this change focuses on building materials (Stephan *et al.* 2011; Ruuska and Häkkinen 2014). Lately, attention has been focused on timber and the fact that it is a renewable construction material that can contribute to sustainable development goals by reducing carbon emissions (Sathre and O'Connor 2010; Myllyviita *et al.* 2021) and

supporting the transition to a more sustainable bioeconomy through the use of long-lasting products (Näyhä 2019). However, timber use cannot be considered the only avenue to sustainably developing low-carbon built environments. Timber resources would not be sufficient to meet demand, and increasing production would probably lead to overexploitation, which would be environmentally harmful to forests (Göswein *et al.* 2022). Despite this, timber use remains judicious when timber can replace fossil materials with high embodied emissions, or when other bio-sourced options are not suitable, as in the case of multi-storey and non-residential building structures (Göswein *et al.* 2022).

Countries such as the European Union (EU) member states, the United States, and Canada have key policies in place related to increasing wood multi-storey and non-residential construction (United Nations 2016; Franzini *et al.* 2018; Toppinen *et al.* 2018; Maniak-Huesser *et al.* 2021). In most cases, these policies favor the widespread use of wood in construction (Hurmekoski *et al.* 2015; Toppinen *et al.* 2018; Vihemäki *et al.* 2019). In the province of Quebec (Canada), a wood integration and regulatory relief policy (Ministère des Forêts, Faune et Parcs 2013) has increased the use of mass timber in non-residential and multi-storey construction. However, mass timber construction accounts for only 10.2% of non-residential buildings four or less storeys high, 1% of multi-storey buildings five or six-storeys high, and 4% of those seven to twelve storeys high (Robichaud 2020).

Despite political and legislative support, the widespread adoption of timber for multi-storey and non-residential building structures remains slow due to what has been described as heavy path dependence on established materials such as concrete and steel (Mahapatra and Gustavsson 2008; Hemström *et al.* 2017; Toppinen *et al.* 2019; Marfella and Winson-Geideman 2021).

Path dependence indicates that decision-making is influenced by a sociotechnical regime that encourages stakeholders to make choices in line with established practices and hinders the widespread adoption of alternatives (Geels 2004; Engström and Hedgren 2012; Hemström *et al.* 2017). For example, many stakeholders consider concrete to be better than wood for multi-storey building structures (Engström and Hedgren 2012; Roos *et al.* 2010). Thus, stakeholders' perceptions and expectations have been identified as a key underlying factor for the slow adoption of wood in construction (Roos *et al.* 2010). Stakeholders' perceptions must change or be overcome so that alternatives can achieve a critical mass of interest from influential actors and become more widely used (Roos *et al.* 2010; Mahapatra *et al.* 2012; Hemström *et al.* 2017).

LITERATURE REVIEW OF CONSTRUCTION INDUSTRY PROFESSIONALS' PERCEPTIONS

Main Barriers Identified in the Literature

Several studies have focused on perceived barriers and uncertainty significantly hindering the development of mass timber construction market. Gosselin *et al.* (2017) identified seven commonly cited barriers to wood multi-storey construction: the regulatory limits of building codes, a lack of expertise in the construction industry, higher construction and operating costs, skepticism about wood materials' lifespan and technical challenges, the construction industry's traditional culture, and insufficient availability of engineered wood products. It's important to note that some topics are considered both motivations and barriers.

Regulations

Regulations are undoubtedly the main perceived barrier to mass timber adoption according to several studies, which specify that they are closely linked to costs due in particular to overly restrictive fire safety legislation pertaining to, for example, height restrictions, sprinkler requirements, and cumulative safety measures, and to differing municipal interpretations of fire safety creating additional uncertainty for developers and construction companies (O'Connor *et al.* 2004; Roos *et al.* 2010; Mahapatra *et al.* 2012; Hurmekoski *et al.* 2015; Laguarda Mallo and Espinoza 2015; Gosselin *et al.* 2017; Franzini *et al.* 2018; Maniak-Huesser *et al.* 2021).

The literature also indicates that the professionals surveyed found a) the regulations reflect a poor understanding of the fire resistance of mass timber (O'Connor *et al.* 2004; Roos *et al.* 2010; Hurmekoski *et al.* 2015; Gosselin *et al.* 2017); b) there is a lack of knowledge about these regulations, including how to calculate lateral loads and connections (O'Connor *et al.* 2004; Mahapatra *et al.* 2012; Gosselin *et al.* 2017); and c) that building code interpretation and compliance are complex for mass timber construction (Gosselin *et al.* 2017). However, some recent studies have also highlighted that some professionals do not perceive building codes to be a major barrier (Marfella and Winson-Geideman 2021; Penfield *et al.* 2022). These findings are attributable to the gradual adjustment of regulations in the territories studied, which has paved the way for wood to be used more in multi-storey construction (Marfella and Winson-Geideman 2021).

Expertise

Numerous studies indicate that the professionals they surveyed perceived expertise to be a significant barrier to using mass timber (Gosselin *et al.* 2017). This is mainly due to a lack of product and construction process knowledge, a lack of experience, and gaps in the range of training that is available for both designers and builders (Roos *et al.* 2010; Franzini *et al.* 2018; Toppinen *et al.* 2019; Penfield *et al.* 2022).

According to the literature, the main consequence of a lack of expertise is continued dependence on established practices creating a shortage of skilled labor for mass timber construction (Hemström *et al.* 2017). This leads to a heightened perception of risk and to skepticism about related aspects of interest, such as long-term performance and lifespan (Hemström *et al.* 2017; Franzini *et al.* 2018).

The literature indicates that all professionals, but particularly general contractors, lack knowledge and experience (Laguarda Mallo and Espinoza 2015; Penfield *et al.* 2022). These results are consistent with the study by Penfield *et al.* (2022) that focused on architects and engineers and whose respondents identified a lack of experience among general contractors, not themselves, as having the most significant impact on mass timber construction adoption.

Construction costs

Existing studies have found that the professionals they interviewed perceived construction costs to be one of the most important barriers to mass timber use (Gosselin *et al.* 2017). A limited number of studies have investigated the actual costs associated with mass timber buildings. Some of them have found that mass timber buildings cost more to construct than equivalent concrete or steel buildings (Jones *et al.* 2016; Ahmed and Arocho 2021a), while others have found they cost less or equivalent costs (WoodWorks 2012). These inconsistent outcomes therefore make it difficult to clearly report the construction costs associated with different solutions.

The economic benefits associated with timber construction are mainly related to the speed of building erection and a reduction in fixed site costs (Jones *et al.* 2016; Vlosky *et al.* 2019; Ahmed and Arocho 2021b; Marfella and Winson-Geideman 2021; Penfield *et al.* 2022). Faster construction also means developers see their return on investment sooner (Jones *et al.* 2016; Penfield *et al.* 2022).

Timber construction costs are perceived to be higher due to increased procurement costs, design costs due to the extra workload involved in complying with complex regulations, and construction costs; a lack of stakeholder expertise; reduced profitability; and potential additional costs arising from uncertainty and unforeseen events (O'Connor *et al.* 2004; Roos *et al.* 2010; Riala and Ilola 2014; Xia *et al.* 2014; Hurmekoski *et al.* 2015; Laguarda Mallo and Espinoza 2015; Hemström *et al.* 2017; Aaltonen *et al.* 2021).

Although some stakeholders, such as architects and users, prefer building with mass timber, they are not prone to pay extra for it (Lindblad and Gustavsson 2021). Hemström *et al.* (2017) reported that not only would their general contractor respondents not build with wood even if it were cost-effective due to the associated uncertainty and risks, but some have even already accepted higher construction costs to obtain the perceived benefits of concrete.

Finally, concerns about resale value have also been raised as a minor consideration (Gosselin *et al.* 2017). The lower residual value of mass timber buildings would be due to higher operating costs, such as insurance and maintenance (Riala and Ilola 2014; Gosselin *et al.* 2017; Maniak-Huesser *et al.* 2021).

Lifespan and technical aspects

Concerns about the lifespan and technical aspects of mass timber have been identified as a major barrier to mass timber adoption. The perceptions evoked pertain to a wide variety of characteristics, such as poor acoustic performance (Roos *et al.* 2010; Riala and Ilola 2014; Laguarda Mallo and Espinoza 2015; Hemström *et al.* 2017; Ahmed and Arocho 2021b); resistance to water, insects, and mold (Roos *et al.* 2010; Riala and Ilola 2014; Hemström *et al.* 2017; Ahmed and Arocho 2021b); the dimensional stability of wood (Roos *et al.* 2010; Gosselin *et al.* 2017); and lateral load resistance (Gosselin *et al.* 2017; Larasatie *et al.* 2018).

On the other hand, some of mass timber's technical aspects, such as its ease of assembly (Mahapatra *et al.* 2012; Hurmekoski *et al.* 2015), mechanical properties, and light weight, are considered advantages and make it an appropriate material for building on soil with low load-bearing capacity (Riala and Ilola 2014; Hurmekoski *et al.* 2015; Laguarda Mallo and Espinoza 2015).

The construction industry's traditional culture

The construction industry's traditional (conservative) culture has also been identified as a barrier that frequently leads to a marked preference for established practices (Mahapatra and Gustavsson 2008; Roos *et al.* 2010; Hemström *et al.* 2017). The industry is perceived as fragmented because construction stakeholders do not interact with each other enough (Roos *et al.* 2010) and therefore lacking standardization, particularly when it comes to mass timber construction (O'Connor *et al.* 2004; Gosselin *et al.* 2017).

Manufacturing capacity

Finally, a number of studies in the literature indicate that a lack of suppliers and production capacity is a major barrier to mass timber construction adoption (Laguarda

Mallo and Espinoza 2015; Franzini *et al.* 2018; Ahmed and Arocho 2021b; Marfella and Winson-Geideman 2021; Penfield *et al.* 2022). Several major consequences have been observed, one of which is increased costs due to a lack of local competition and availability, which lead many project teams to turn to foreign suppliers (Laguarda Mallo and Espinoza 2015; Marfella and Winson-Geideman 2021; Penfield *et al.* 2022). Another is the prioritization by manufacturers of structural elements. Export markets reduce the availability of products locally, which creates a need to turn to international manufacturers (Roos *et al.* 2010) and results in increased cost or supply risk (Gosselin *et al.* 2017; Franzini *et al.* 2018).

Main Motivations Identified in the Literature

According to a study by Gosselin *et al.* (2017), the most commonly cited motivations for choosing mass timber construction include environmental impact, technical aspects, costs, construction speed, and aesthetics of wood. The perceived advantages associated with technical aspects, costs and construction speed have already been explained in the Main Barriers subsection above.

Environmental impact

Mass timber's environmental impact has been cited as the most important motivation for adopting mass timber in the construction industry. The main reasons cited were its low carbon emissions, the fact that it is a renewable material, its carbon sequestration capacity, and its energy efficiency (O'Connor *et al.* 2004; Roos *et al.* 2010; Riala and Ilola 2014; Hurmekoski *et al.* 2015; Laguarda Mallo and Espinoza 2015; Hemström *et al.* 2017; Marfella and Winson-Geideman 2021). However, it appears that interest in mass timber as a construction material remains closely linked to a desire to obtain environmental certifications and that the rest of the construction market sees it only as a secondary benefit for which they are not willing to pay more (Riala and Ilola 2014; Hemström *et al.* 2017; Toppinen *et al.* 2018).

Aesthetics of wood

The aesthetics of wood has been qualified by stakeholders as an important motivation for using mass timber due to the attractive atmosphere it lends to an environment, although multiple notions are used to describe this, including warm character, inviting, comfortable, attractive and aesthetic, enjoyable for occupants, user health and well-being, and biophilia (O'Connor *et al.* 2004; Riala and Ilola 2014; Hurmekoski *et al.* 2015; Laguarda Mallo and Espinoza 2015; Larasatie *et al.* 2018; Ahmed and Arocho 2021b; Marfella and Winson-Geideman 2021).

However, though the literature does provide data on wood multi-storey construction development, most studies focus on a few types of actors in isolation, with particular attention being given to architects and engineers since they are considered key stakeholders in design and construction material selection (Franzini *et al.* 2018; Gosselin *et al.* 2017). This limits the scope of the discussion on potential motivations and barriers in the interest of increasing wood multi-storey construction because other essential stakeholder groups, such as promoters, general contractors, regulatory authorities, suppliers, and end-users, also influence decision-making (Roos *et al.* 2010; Hemström *et al.* 2017; Aaltonen *et al.* 2021).

Furthermore, study conclusions tend to be primarily based on the perceptions of those who have experience working on or promoting wood structures (Riala and Ilola 2014;

Wang *et al.* 2014; Xia *et al.* 2014; Aaltonen *et al.* 2021) rather than those who advocate continuing to follow existing practices (Hemström *et al.* 2017).

Finally, several studies have focused on specific topics (such as technical innovation and environmental impact) rather than providing an overview of stakeholders' general attitudes, perceptions, or preferences with regard to wood multi-storey construction (Franzini *et al.* 2018; Toppinen *et al.* 2018, 2019).

To provide solid insights in the interest of increasing mass timber use, this study gathers information from a wide variety of professionals involved in construction projects (architects, engineers, general contractors, manufacturers, private developers and public developers). It also focuses on multi-storey and non-residential construction projects, given that mass timber currently has limited presence in this market, but its use is growing and represents strong growth potential for the sector (Robichaud 2020). The province of Quebec (Canada) was chosen as a case study because the provincial government has long been committed to wood construction through promotional campaigns and development initiatives aimed at embracing wood construction (Ministère des Forêts, Faune et Parcs 2013; Gouvernement du Québec 2020). Moreover, this study contributes to filling a gap in the literature since no similar research has yet been conducted in Quebec, whereas it has for other territories that support wood construction (Maniak-Huesser *et al.* 2021).

The main objective of this article is to contribute to understanding what factors influence stakeholders in the multi-storey and non-residential construction sector to choose to use mass timber. This investigation aims to identify the perceived motivations and barriers of stakeholders in Quebec and determine whether the evolution in the number of mass timber construction projects observed in recent years corresponds to a change in professionals' perceptions in relation to the literature findings. It also seeks to investigate the main reasons behind these positions and determine whether respondents' perceptions differ significantly depending on their main professional activity. This study is, therefore, part of a series of similar contributions over time and worldwide. The interest is to track the evolution of mass timber adoption issues in construction.

EXPERIMENTAL

Semi-structured Interviews

A semi-structured interview approach was determined to be the most appropriate method for this study to obtain the perceptions of key construction professionals regarding mass timber and to obtain a deeper understanding of the motivations for and barriers to using it in construction. Semi-structured interviews allow for flexibility and two-way communication between the interviewer and respondent. They also make it possible to address a wide range of topics while obtaining an in-depth contextual understanding of the breadth of perceived motivations and barriers, identify new points of view, and capture and represent a wide variety of perceptions (Ghiglione and Matalon 1978; Barbour 2001; Edwards and Holland 2013; Cleary *et al.* 2014).

A questionnaire would have provided more general data from a large group of respondents but with less detail and fewer subtleties (Ghiglione and Matalon 1978; Barbour 2001; Edwards and Holland 2013). Furthermore, given the nature of this study, the limitations that have been identified in previous studies, and the fact that the Quebec context has yet to be studied, it was highly likely that new topics would emerge during interviews (Cleary *et al.* 2014; Franzini *et al.* 2018; Aaltonen *et al.* 2021).

Sample Selection and Characterization

Purposive sampling was used to select respondents (Barbour 2001; Cleary *et al.* 2014), in accordance with previous studies (Roos *et al.* 2010; Holopainen *et al.* 2015; Hemström *et al.* 2017; Duesberg and Ní Dhubbáin 2019). It is considered an effective and reliable means of ensuring a reasoned representation of stakeholder types based on various characteristics (such as their primary professional activity(ies) and level of expertise with wood construction) when the number of respondents is small (Barbour 2001; Cleary *et al.* 2014).

Potential respondents' contact information was obtained by contacting some industry experts and inviting them to provide a list of construction professionals. In addition, a list of companies or organizations that offer each type of activity considered was compiled using Google databases, and potential respondents' personal information was collected from their respective company's website. In all, a list of 2,039 companies or organizations was compiled. Potential interview respondents were selected from this list to create a sample representative of the wide variety of stakeholder profiles found in the Quebec construction sector. To be selected, individuals had to:

- Be an architect, engineer, general contractor, mass timber or wood light-frame manufacturer, private developer, or public developer).
- Be active in the multi-storey or non-residential construction sector.
- Work for a company that is located in the greater Quebec City or Montreal area, or have commercial activities there. These large agglomerations were targeted because they are home to a large proportion of multi-storey and non-residential construction projects in the province of Quebec.
- Hold a position of responsibility and have experience managing several projects. Thus, the target respondents were presidents, senior partners, senior managers, and project managers.

A total of 89 potential respondents were selected. They were then contacted by email in multiple stages. Despite how difficult it was to find respondents that fit certain groups of professionals, the aim was to arrive at a sample of professionals that was as balanced as possible, with all the different types of professional activities and a sufficient number of experts, users and non-users to ensure a wide variety of viewpoints are represented.

Interviews were conducted in successive phases, in French, and *via* videoconference between July 2021 and October 2021 until data saturation was reached. Saturation was reached with 42 respondents (Cleary *et al.* 2014; Toppinen *et al.* 2019). Despite new marginal information continuing to be gathered, many perceptions began to repeat in the responses obtained, so the data collection process was deemed to be complete. The interviews lasted on average 64 ± 17 minutes, were digitally recorded, and were fully transcribed for response analysis.

The final sample's characteristics are presented in Table 1. Notably, 11 of the 42 respondents worked in two types of professional activities simultaneously (*i.e.*, general contractor and private developer, general contractor and engineer, general contractor and manufacturer, manufacturer and private developer, and engineer and manufacturer). When quotes are provided, the respondent's main activity is always indicated before their level of expertise to better reflect their point of view. However, only respondents' main professional activity was considered to simplify profile analysis. Furthermore, three levels of expertise were defined and considered in this study to qualify respondents' experience

with mass timber construction. The “expert” level describes respondents who have completed at least one major project using mass timber. The “user” level applies to respondents who have used mass timber on occasion or on portions of a building but are not experts. The “non-user” level represents respondents who have no personal experience with mass timber construction. Lastly, it should be noted that there are few private developers in the sample compared to the other professionals interviewed, but this is the sample to which we were limited despite considerable recruitment efforts.

Table 1. Sample Characterization

Characterization Variable	Category	Frequency
		N=42
Gender	Male	37
	Female	5
Age	Less than 30 years old	7
	Between 30 and 40 years old	10
	Between 40 and 50 years old	12
	Over 50 years old	13
Main professional activity	Architect	8
	Engineer	9
	General contractor	6
	Manufacturer	9
	Private developer	4
	Public developer	6
Number of types of professional activities	One type of professional activity	31
	Two types of professional activities	11
Level of responsibility	President or senior partner	22
	Senior manager	8
	Project manager	12
Level of expertise	Expert	13
	User	13
	Non-user	16
Company location	Quebec City and surrounding area	23
	Montreal and surrounding area	10
	Quebec City and Montreal areas	7
	Estrie	1
	Saguenay–Lac-Saint-Jean	1
Number of employees in the company	1 to 99 employees	22
	100 to 499 employees	15
	500 or more employees	5

Interview Guide Content

The interview guide was designed cover the main motivations and barriers that are associated with mass timber construction in the literature in order to assess whether professionals in Quebec have similar or different perceptions than professionals outside Quebec who were surveyed in other studies (Riala and Ilola 2014; Gosselin *et al.* 2017; Hemström *et al.* 2017; Franzini *et al.* 2018; Toppinen *et al.* 2019; Ahmed and Arocho 2021b; Marfella and Winson-Geideman 2021; Penfield *et al.* 2022).

The interview guide was reviewed, and two pilot interviews were conducted in the preliminary stages of the study to refine the guide and interview methods. An English version of the guide is available in Appendix B of this article. Note, however, that interviews were conducted only in French.

During the interviews, respondents were first invited to discuss their professional practices and express their overall view of the advantages and disadvantages of building with mass timber *versus* other construction materials through open-ended questions. Clarification questions were asked when necessary. To ensure the study objectives were met, topics that respondents did not cover in this initial phase were addressed in a second phase by asking more specific questions that built on the main topics observed in the literature. All these questions were asked to encourage the interviewees to delve deeper into their perceptions of the subjects in question. Although most respondents addressed all the topics in the interview guide, some interviews focused on deepening the perceptions initially discussed depending on each respondent's interests. Questions regarding respondents' characterization were asked at the end of the interviews in order to reduce bias associated with respondents' profiles. Indeed, the information gathered could have affected the approach to the questions and made it difficult to compare answers between different professionals.

Data Analysis

Qualitative analysis was used to capture the complexity of the perceived motivations and barriers that were expressed by the professionals interviewed regarding mass timber use in multi-storey and non-residential construction projects in Quebec. A thematic analysis was performed to extract information about the main reasons behind the perceptions shared. A quantitative analysis was also conducted to characterize the frequency of occurrence of the perceptions that interviewees identified. This made it possible to assess how widespread the perceived motivations or barriers were. This research approach is summarized in Fig. 1.

Analytical framework

The data were analyzed by means of thematic content analysis using the software NVivo (QSR International 2020). Thematic analysis is a flexible approach that makes it possible to identify, analyze, and report recurring patterns in meaning (topics) within a non-numerical and less structured dataset. This qualitative method is not linked to any pre-established theoretical framework and can be used to capture and reveal the complexity of reality through a set of research questions. The thematic analysis methodology proposed by L'Écuyer (1987), Braun and Clarke (2006), and Schreier (2012) was used in this study to analyze the data collected.

This methodology aims to deductively select and report the interview results that emerged as important for the adoption or non-adoption of mass timber as a building material in multi-storey and non-residential construction projects. It involved reading the interview transcripts to obtain a general impression of the responses and applying a coding system to the data to categorize respondents' perceptions and define topics. More specifically, respondents' statements were analyzed to grasp meanings and find links, structures, similarities, and differences between the responses. Rather than examining exact formulations (*e.g.*, by means of a lexical analysis), this type of analysis focused on the meaning of responses to extract topics that might explain existing motivations and barriers associated with mass timber use in multi-storey and non-residential building

construction. A coding structure was created for this in line with the work of Gosselin *et al.* (2017). The major topics considered in the interview guide served as the foundation for data analysis.

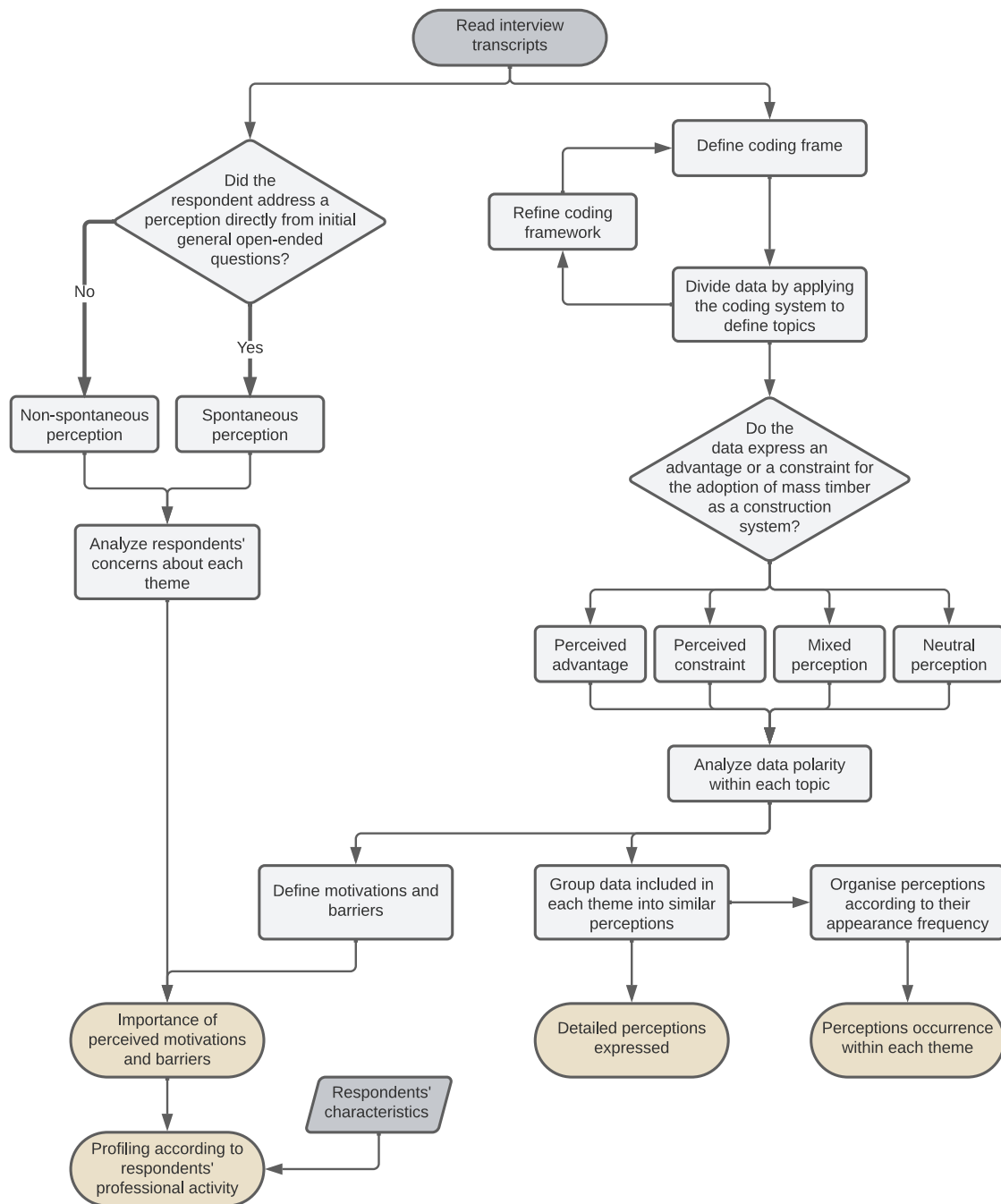


Fig. 1. Flowchart illustrating the research methodology workflow

The final analytical framework included professionals' perceived motivations and barriers to choosing to use mass timber in construction (Fig. 2). The data were divided into five categories: 1) feasibility in design phase, 2) regulatory limits, 3) operational and financial factors, 4) user experience, and 5) socio-environmental values. Four of those

categories were further divided into topics to more clearly report the observations. Feasibility in design phase was divided into eight topics: 1) evolution of wood construction, 2) expertise, 3) technical challenges, 4) structural capacity, 5) construction height, 6) material specifications, 7) project delivery methods, and 8) construction management. Operational and financial factors were divided into four topics: 1) manufacturing capacity, 2) construction costs, 3) insurance, and 4) maintenance costs. User experience was divided into five topics: 1) acoustics, 2) thermal, 3) biophilia, 4) aesthetics of wood, and 5) perceived quality. The socio-environmental values were divided into four topics: 1) lifespan, 2) local economy, 3) environmental impact, and 4) logging.

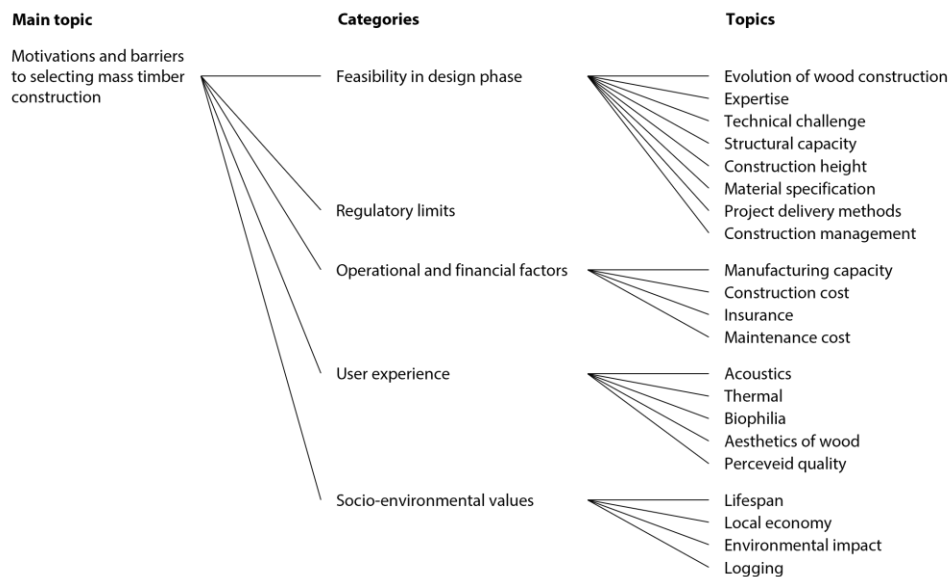


Fig. 2. Topics arising from the thematic analysis of the interview data

Data processing

The data were coded and then classified by polarity in the final analytical framework. Each perception evoked by the interviewees was classified as either a perceived advantage or a perceived constraint for the adoption of mass timber as a construction system. A polarity analysis was then performed for each topic to identify the dominant perception (*i.e.*, advantage or constraint). This made it possible to determine which topics construction professionals in Quebec predominantly perceive as motivations or barriers.

The spontaneity of respondents' responses was also noted. In this study, spontaneity is defined as the direct expression of a perception in response to an initial open-ended question regarding the advantages and disadvantages of using mass timber *versus* other building materials in general for multi-storey and non-residential building construction (see the interview guide in Appendix B). This notion of spontaneity was used as a subjective indicator of respondents' level of concern about the topics considered and how important they perceive each one to be when selecting mass timber for multi-storey and non-residential building construction. The use of spontaneity as an indicator of level of concern is an original qualitative interpretation of the data extracted from the interviews.

The polarity analysis results for each topic and the spontaneity results were cross-referenced to determine respondents' level of concern about the perceived motivations and barriers identified. When the number of respondents who expressed a spontaneous

perception regarding a certain topic was greater than or equal to the number who expressed a non-spontaneous perception or no perception for said topic, the topic was considered to be of high concern to respondents. Conversely, when the number of respondents who expressed a spontaneous perception regarding a given topic was less than the number who expressed a non-spontaneous perception or no perception, the topic was considered to be of low concern to respondents. These results were also cross-referenced with the types of professional activities considered to perhaps identify different response profiles and see whether any groups stood out from the general trend.

Finally, the topics that were determined to be the most concerning motivations and barriers were detailed. Similar perceptions were grouped into subjects under each topic, and ranked according to their frequency of appearance to identify their occurrence within the sample. Each topic was described using its main subjects in order of decreasing occurrence. Subjects that were raised infrequently were also included when they provided new insights into the topic in question. To identify occurrence, each statement's occurrence is reported as a number in parentheses indicating how many respondents who said it. The topics that were discussed less frequently by those who had any perception to express about them are discussed more briefly in the corresponding results section.

Quoted responses were translated into English for inclusion in this article. They were also modified slightly to ensure anonymity and improve clarity, for example, by removing colloquial expressions. However, precautions were taken to make sure the content and message remained unchanged. Other topics that were found to be of low concern to respondents are presented in Appendix A.

RESULTS AND DISCUSSION

The results are broken down into three parts as follows: (1) whether respondents perceived the topics studied as motivations for or barriers to adopting mass timber for multi-storey and non-residential construction, and the relative importance they gave each topic when it comes to choosing to use mass timber; (2) an analysis of the sample response profiles developed by type of professional activity; and (3) a detailed analysis of the barriers and motivations that the professionals interviewed perceived as being of highest concern.

Identification of Perceived Motivations and Barriers

Analyzing respondents' perceptions of the various topics studied enabled the authors to identify the motivations and barriers that respondents considered to be of highest concern. The results presented in Table 2 indicate that most of the topics related to feasibility in the design phase, regulatory limits, and operational and financial factors (*i.e.*, evolution of wood construction, expertise, technical challenges, construction height, material specifications, project delivery methods, regulatory limits, manufacturing capacity, construction costs, and insurance) are perceived as having a negative impact on mass timber adoption for multi-storey and non-residential building construction. The topic of acoustics is also perceived as a barrier. On the other hand, the topics related to user experience and socio-environmental values (*i.e.*, thermal, biophilia, aesthetics of wood, perceived quality, local economy, environmental impact, and logging) are widely perceived as having a positive influence on mass timber adoption.

Table 2. Identification of Respondents' Perceived Motivations and Barriers

	High Concern	Low Concern
Mainly a barrier	Expertise (42) Material specifications (40) Regulatory limits (40) Manufacturing capacity (37) Construction costs (41)	Evolution of wood construction (23) Technical challenges (35) Construction height (22) Project delivery methods (34) Insurance (38) Acoustics (32)
Mixed perceptions	Construction management (35)	Structural capacity (28) Maintenance costs (31) Lifespan (28)
Mainly a motivation	Aesthetics of wood (42) Environmental impact (40)	Thermal (13) Biophilia (29) Perceived quality (24) Local economy (19) Logging (36)

* The number of respondents that expressed at least one perception for the topic is shown in parentheses.

The results shown in Table 2 also suggest that specific topics (*i.e.*, expertise, material specifications, regulatory limits, manufacturing capacity, construction costs, construction management, aesthetics of wood, and environmental impact) weight more heavily on the professionals' decision to adopt mass timber for multi-storey and non-residential building construction and are therefore perceived as motivations/barriers of high concern based on the interviewees' spontaneous responses.

The results of cross-referencing the polarity and spontaneity of respondents' perceptions suggest that:

- The perceived barriers that were of the highest concern to professionals were construction costs, expertise, manufacturing capacity, regulatory limits, and material specifications.
- Despite the fact that the perceptions expressed regarding construction management were mostly spontaneous, they were nevertheless mixed, with a large proportion of professionals seeing it as a barrier, another viewing it as a motivation, and a minority considering it to have both positive and negative aspects.
- The professionals interviewed perceived environmental impact and aesthetics of wood to be motivations.
- Regarding the aesthetics of wood in particular, many respondents considered it to have both positive and negative aspects that can partially contribute to its perception as a motivation but also indicate it will be difficult to federate around this motivation.

The other topics that were less frequently spontaneously cited by respondents can also be considered motivations or barriers. The perceptions related to these topics are detailed in Appendix A. However, they are likely to carry less weight than the above-mentioned motivations and barriers when the professionals interviewed make decisions.

Response Profiles by Professional Activity

Response profiles were derived from the above results to determine whether perceptions differed by main professional activity. The findings are expressed in terms of the difference between the average trend of the sample and that of the individuals belonging to a specific professional activity. Although an exhaustive analysis was conducted, this section focuses on the major trends that made it possible to develop response profiles.

Table 3. Identification of Response Profiles Based on Professional Activities

	Architects	Engineers	General contractors	Manufacturers	Private developers	Public developers
Evolution of wood construction						
Expertise						
Technical challenge		X			X	
Structural capacity						
Construction height						
Material specification						
Project delivery methods						
Construction management						
Regulatory limits	X	X				
Manufacturing capacity						
Construction cost						
Insurance						
Maintenance cost						
Acoustics						
Thermal						
Biophilia						
Aesthetics of wood						
Perceived quality						
Lifespan					X	
Local economy						
Environmental impact						
Logging						

 More positive than the sample trend

 Identical to average sample trend

 More neutral than the sample trend

 More spontaneous than the sample trend

 More negative than the sample trend

The results suggest a certain level of viewpoint homogeneity among the various construction industry stakeholders considered for many of the topics studied. The respondents' interests or professional practices explain the spontaneity with which they

discussed topics. However, as shown in Table 3, some specific response profiles do seem to exist.

- Architects were more positive about expertise and construction costs. They (and engineers) expressed their perceptions about regulatory limits more spontaneously. They were also more negative about manufacturing capacity and logging.
- Engineers were more positive or optimistic about expertise, maintenance costs, aesthetics of wood, and logging. They were particularly concerned about the technical challenges and regulatory limits associated with mass timber construction. They were also more negative about manufacturing capacity.
- General contractors stood out for their mainly positive perception of current project delivery methods, whereas the other groups were mainly pessimistic about this topic. They were also more negative about acoustics and logging.
- Private developers were particularly concerned about the technical challenges associated with mass timber construction and the lifespan of mass timber buildings. They expressed themselves more spontaneously when it came to these topics and were very negative, which reflects the fact that they perceive these topics to be barriers of high importance. They were also more negative about regulatory limits, maintenance costs, acoustics, and lifespan.
- Public developers were more positive about the aesthetics of wood and acoustics, and more negative about regulatory limits. They stood out for having a predominantly neutral perception of insurance. This viewpoint may be attributable to the fact that government buildings are self-insured, such that public developers are not exposed to insurance-related issues within their practice.

Professionals' Perceptions of the Barriers and Motivations of Highest Concern by Topic

Barriers of highest concern

Expertise. A large group of respondents were of the opinion that mass timber construction expertise is increasing (15 respondents) but remains concentrated in a few specialized companies (10). Several respondents indicated that the wood construction market's small size does not permit all professionals to complete their training (9). This is particularly true for large-scale or high-rise projects, as very few of these types of projects have been completed (9). Many noted that it is essential to have a good network of partners who possess or develop the expertise needed to carry out these types of mass timber projects (6). Not only did some respondents indicate that a lack of expertise on the part of designers is a barrier (5), a similar number of respondents reported that a shortage of skilled labor to assemble mass timber buildings on-site is also a major barrier (6), as it can eventually lead to significant defects (6) or increase the labor costs associated with building assembly (4).

For a large group of professionals, this lack of expertise can be explained by the fact that the industry is still maturing and needs more product and process knowledge (17). Respondents identified two main reasons for this: a loss of know-how following the adoption of the National Building Code in 1941, which required that non-combustible materials be used for medium- and high-rise buildings (5), and a lack of education, particularly among engineers (7), though a number of respondents reported this latter reason is being resolved with the incorporation of mass timber construction in certain university courses (6).

According to some experts, a lack of expertise leads some professionals to make costly mistakes that can discourage customers (2). Some respondents highlighted that a lack of expertise also leads to other deviations, such as insurers overestimating risks mainly because of beliefs (5) or local project assessment departments (e.g., fire departments) putting the brakes on projects because of their beliefs about wood's combustibility (3). A large group of respondents indicated building with mass timber adds a layer of complexity (14).

“Doing a project in wood requires a lot of communication from the outset. Everyone has to understand, because (...) the industry isn't standardized enough to make it easy.” (Engineer, expert in mass timber construction)

Respondents stated that professionals who lack mass timber construction expertise tend to use pre-established practices and other materials (10), as doing so enables them to preserve their profitability by avoiding added complexity (8), meet their tight schedules (6), benefit from more complete software (4), and not assume additional professional responsibility to perform new processes (5), although it does not help to create economic opportunities for mass timber construction (7). However, some professionals stated they were willing to use mass timber in construction on account of its environmental or aesthetic benefits (8). A minority of respondents identified collaborative project management or an integrated design process as solutions to overcome a lack of expertise (4).

Material specifications. Respondents noted that the customer has to be the one to prescribe using wood; otherwise, it's difficult to get the choice accepted (7) and that customers' main motivations for using mass timber in construction were the aesthetic of wood (7) and a desire for their project to be environmentally-friendly (6). When it comes to the latter motivation in particular, some experts pointed out that environmental certification is a strategic mainstay for wood construction (2) and that imposing a carbon intensity criterion would help to promote the use of more environmentally-friendly alternatives to traditional construction processes (1).

“I don't understand why there isn't more pressure, financial incentives and so on to support this. Because in recent years, even the Société Québécoise des Infrastructure (Quebec Infrastructure Society) has questioned its policy of requiring LEED Silver certification for its major projects. It's a strategic move because if they drop this policy, we'll see a marked decline in environmental performance and the use of wood.” (Architect, expert in mass timber construction)

Professionals mentioned that they generally use a sales pitch that relies on the visual advantages of wood (13), the uniqueness it lends to a project (3), its environmental impact (6), the local economy (3), or health benefits associated with wood (1) to convince their customers to use mass timber. However, respondents indicated that customers often have prejudices about mass timber, such as it is too costly (6), it doesn't last very long and ages poorly (3), it performs poorly in fire situations (2), and it increases the complexity of construction (1). In short, many professionals stated it was necessary to explain the material to the customer (5). In addition, developers reported their lack of interest in mass timber construction was attributable to other financially motivated reasons: a lack of expertise (2), increased design costs and engineering fees (2), an unsuitable financing system that does not allow more money to be injected upstream of construction (2), lack of examples of

mass timber projects that have been financially successful (1), and the fact that it is difficult to sell mass timber projects (1).

“In Quebec, projects have not been very successful (...) as investments. (...) It’s been a few years ago, then they had soundproofing problems, they had all kinds of problems, and lots of condos haven’t sold yet. So, it’s a financial flop.” (General contractor and private developer, user of mass timber construction)

“We had a lot of trouble [selling our units]. The customers were less open, they didn’t see much-added value [in using cross laminated timber (CLT)]. In addition we had a competitor across the street (...) who convinced people by saying ‘mine is much more solid, it’s concrete, it’s better for acoustics, it’s better for that.’ These are all falsehoods, but that’s marketing, so it was more complicated.” (Private developer and general contractor, expert in mass timber construction)

According to some experts, bad experiences severely undermine customer confidence (1) and mass timber remains a demonstrator material, so some customers feel they are “test subjects” paying the price for the industry’s immaturity (3). Respondents noted that stakeholders need assurance there is sufficient expertise at their disposal in the industry (4) and product available at the right price (2) to be able to prescribe mass timber use. Even if using wood is generally still seen by some to increase the risk associated with a construction project (7).

Several interviewees indicated the limited number of mass timber construction projects that have been completed also stems in part from designers wanting to protect their habits or preserve their profitability (3), wanting to avoid having to comply with an overly restrictive regulatory framework (7), wanting to avoid having to request equivalent measures (5), wanting to meet tight deadlines (5), considering certain types of construction (e.g., multi-residential buildings) to be less suited to mass timber use (2), or wanting to stick to tight budgets (1).

Finally, some respondents indicated that Quebec’s “wood charter” policy that encourages using mass timber in public projects has had positive effects (3). Still, other professionals said they have found it is often rendered ineffective by regulatory criteria (4). A similar observation was made regarding existing public subsidies intended to encourage the use of wood in construction, with one expert pointing out that project deadlines are incompatible with the time frame it takes to obtain the subsidies (1).

Regulatory limits. Most respondents considered regulatory limits to be a major barrier to using mass timber in construction due to their restrictiveness (22) and the complexity they add for the professionals involved (8). For many respondents, the province of British Columbia (Canada) or countries that are similar to Canada, have building codes that permit more things (12).

Many interviewees indicated the main barriers in this category were related to fire safety regulations, which they consider to be too restrictive in terms of the fire resistance time of mass timber *versus* that of other materials (12). According to several respondents, the regulations discriminate based on structures’ combustible or non-combustible nature (3), which is determined from their potential to accelerate flame propagation and cause increased smoke emissions (5). Respondents mentioned that fire safety regulations significantly restrict the possibility of leaving wood exposed (11) and make it necessary to

apply for equivalent measures for most projects (10), which is seen as a major constraint in the industry (6) and an additional risk for projects (4).

“For each of the projects we’d like to do in wood, we have to apply to the Régie du bâtiment du Québec (Quebec building authority) for equivalent measures, which generally doesn’t fit into the timetable or is a risk that customers don’t want to take.” (Engineer, expert in mass timber construction)

A small number of respondents reproached the Quebec Construction Code for being too restrictive (2); not addressing certain subjects that are outside the scope of traditional forms and designs (e.g., lateral load), which makes professionals responsible for doing so and limits the possibilities for innovative projects (2); having to be educated by the bearers of innovative projects (2); creating conflicts between different construction options that are geared toward sustainable development, such as the fact it is not possible to build a green roof on a mass timber structure (2); and being less permissive than the National Building Code of Canada when it comes to certain aspects despite the fact that Quebec has a policy in place that is supposedly in favor of using wood (2). A number of interviewees said they consider this overly cautious approach on the part of the regulatory authorities to be a disadvantage for wood construction because of the costs involved in complying with such requirements (6). However, many professionals stated they find the regulation to be evolving gradually to permit more and more uses (9).

Meanwhile, a minority of respondents indicated that they do not consider regulations to be a barrier (4), as certain uses, such as low-rise commercial buildings and multi-storey dwellings up to 12 storeys, are permitted (5), and existing limitations are justified to ensure structures remain safe (3). Some experts reported that wood construction is less tolerant to fire due to potential construction errors or building compliance being compromised by subsequent interventions (2), and one respondent said it would be desirable to set up an inspection program to ensure construction quality (1).

Manufacturing capacity. The majority of respondents acknowledged there is a lack of suppliers and manufacturing capacity (27), and a few highlighted that the situation is particularly serious for CLT (4) and large-scale projects (1). Interviewees indicated the shortage of local competition makes it difficult to obtain several compliant bidders for calls for tender (26) and creates supply and availability problems for engineered mass timber products (16), which result in very long supply lead times (13) and increased costs (4).

“When we have to build with mass timber, we have a hard time finding two or three bidders.” (General contractor, user of mass timber construction)

“With a lack of competition— and not to say a monopoly, but not far off— there are very few products available, so obviously prices are higher. (...) For example, [this company] has no competition, so I imagine they don’t go out of their way to cut their prices. If you don’t have competition, you do what you have to do.” (Engineer, expert in mass timber construction)

“If it’s more expensive than concrete or its supply is less certain (...), it makes everyone insecure. And by default, people say, ‘I don’t have money or time to lose’ and they go for concrete [, it’s] as simple as that. Because concrete is available.” (Architect, user of mass timber construction)

Roughly a quarter of interviewees commented that all these factors generate supply risk for stakeholders (11), and one mentioned that an integrated design process that includes the manufacturer may be relevant in this respect to guarantee supply (1).

Several professionals also expressed fears for the future of Quebec's wood construction industry due to pressure from the American market, which seems more attractive to large manufacturers in terms of the volume and prestige of the projects on offer (6). According to some experts, more than two-thirds of a major Quebec manufacturer's current production is exported to the U.S. despite solid local demand (3). Meanwhile, several respondents also indicated that Quebec's engineered wood products industry seems to be having difficulty keeping up with the growth of its local market (7), which has prompted some professionals to source from other countries (2) despite the fact that doing so reduces their projects' compatibility with the socio-environmental values that wood construction promotes (1). In contrast, a few other professionals stated the number of suppliers is increasing (4) and manufacturing capacity is sufficient and adapted to demand (4).

Finally, with regard to the product offering, a number of respondents said that it is unfortunate that there is no standardization in effect for products from different manufacturers, as a great deal of resizing is needed if a product becomes unavailable since engineered wood products are most often proprietary products (4).

Construction costs. A large group of respondents perceived mass timber construction to be more expensive than equivalent steel or concrete construction (14), and many indicated this is the main barrier to its use (10). Added costs were mainly attributed to the amount of additional work and complexity that are involved in terms of, for example, coordination, acoustics, and fire protection when building with wood (7); manufacturing capacity issues and a lack of competition within the industry (6); low production volume making the industry uncompetitive (5); the need to apply for equivalent measures to exceed building code limits (4); additional fire protection costs (2), structures becoming oversized due to the sum of (fire/earthquake/other) safety coefficients in structural calculations (2); a lack of expertise (2); the need to involve several building trades, such as concrete contractors for floors or elevators (2); manufacturer remoteness (2); increased labor costs (1); and construction site fire risk insurance (1).

"If I take [one of my projects] as an example, I was able to have a mass timber structure at the same price as a steel structure (...) except that my guys were less familiar with it, (...) which meant that it took me a lot more hours to lift the building and, in the end, that drove up the cost of the building." (General contractor and private developer, user of mass timber construction)

However, some interviewees indicated using exposed mass timber also represents an opportunity to save money when it comes to finishings (5) or to generate related benefits that can add value in terms of brand image, uniqueness, a particular aesthetic, increased attractiveness, or marketing that highlights wood's advantages (7).

Professionals also mentioned that other aspects can be used to help make mass timber more competitive, such as hybridizing structures (2), reducing fixed costs by cutting construction times and making buildings available more quickly (1), using the most appropriate engineered wood product for the mechanical properties required, such as nailed laminated timber (NLT) instead of CLT (1), taking advantage of Quebec government funding programs to offset additional costs, even though they are sometimes incompatible

with project schedules (1), and developing expertise (1). Some respondents felt that mass timber construction can be competitive as it is not systematically more expensive, since costs depend on the project context (4). However, according to a couple of experts, incentives such as economic or regulatory relief (buildable height, *etc.*) would enable wood construction to turn a corner in terms of production capacity and expertise development (2).

Finally, some respondents reported that the long-term residual value of concrete buildings is more attractive than that of mass timber buildings (4), mainly due to investor perceptions (3) and associated operating costs (1).

“The extra costs at the outset are fine, but the extra operating costs are not to be overlooked. It’s ten times more expensive to insure a mass timber building than a concrete one (...) When there’s water damage in a wood building, after that, it’s very difficult just to find an insurer. Sometimes there are three or four insurers sharing the risk. It’s very complicated [because] for the value of a rental property, it’s important to keep expenses as low as possible. [So] when your insurance costs you \$100,000 more, well, you’re not able to have a good building value.” (Private developer and general contractor, expert in mass timber construction)

Motivations of highest concern

Aesthetics of wood. A large group of respondents stated that customers and users want exposed wood in their buildings (20), as it has highly sought-after aesthetic qualities (12). Professional also highlighted the fact that advantages that favor exposed wood use can be monetized or increase building value in terms of occupancy quality (7) through an enhanced user experience (*e.g.*, pleasant and warm living environments (21), occupant well-being (20)), differentiation from the market (12) by creating an identity and architectural signature that are specific to the building or brand (11), or a sense of consistency with environmental values in the case of a corporate or institutional structure (4).

“It’s always wood’s enhancement of the experiential dimension that is the best selling feature.” (Architect, expert in mass timber construction)

However, professionals said they often find themselves unable to keep mass timber exposed as much as they would like due to regulatory limitations (19). Many respondents stated that it is not worth building with mass timber if the wood is not visible (12), as it loses many of its advantages (12).

“People want mass timber construction to see the wood. But when you have to cover everything with gypsum, it’s no longer interesting for the developer, in terms of sales strategy. (...) [So for them] it’s more profitable to do the structure in steel or concrete, cover everything in gypsum, and install wood siding on top.” (General contractor and engineer, expert in mass timber construction)

Other respondents were of the opinion that it is still worthwhile to build with mass timber when it is not visible if the project considers other objectives, such as enhancing the local economy or environmental performance, though these other advantages are difficult to finance (16). Interviewees therefore concluded that having visible wood inside buildings is a strong motivation for mass timber construction (10). However, some professionals

acknowledged that customers' attraction to mass timber construction is based on its exclusivity, so if this construction method were to become more widely used, it would lose much of its appeal (6). A couple of respondents claimed that mass timber construction is therefore somewhat confined to being used in demonstrator projects (2).

Environmental impact. Most respondents agreed that mass timber has a lower environmental impact than other materials such as steel and concrete (33). The main reasons they cited for this included its renewable nature (26), its lower contribution to global warming by producing less greenhouse gas emissions (19), its ability to store carbon in building stock for a long time (15), its ability to stimulate carbon capture by forests (3), the fact that it leads to small timber sections being valorized for the manufacturing of engineered wood products (1), the carbon emission reduction that can be achieved by relying on the local economy and reducing material transportation (1), the reduction in construction waste that is generated (1) and the fact that it requires very few harmful inputs such as glues and other chemicals for use (1). One respondent did stress though that the toxicity of inputs, such as glues, should be given more consideration than their contribution to environmental indicators (1).

According to some respondents, mass timber construction can therefore meet high environmental performance targets (4). Demand for mass timber to meet environmental performance targets is mainly driven by government policy guidelines (4), the establishment of environmental performance criteria by regulations or certifications (4), a strong interest in eco-friendly buildings (3), and corporate environmental commitments (1). Unfortunately, some experts said that reducing environmental impact is of little value when the advantage cannot be capitalized on from a marketing point of view (2).

“The environmental aspect has value from an image point of view, from a corporate social and environmental responsibility point of view. From a life cycle or greenhouse gas emissions point of view, the environmental value is interesting but often doesn't carry much weight in the grand scheme of things.” (Architect, expert in mass timber construction)

Other professionals indicated that they also consider the fact that mass timber can be sourced locally to weight heavily on its perceived environmental benefits (4). One expert also expressed doubt about the environmental benefits of building with wood in terms of ecosystem damage (1). Additional perceptions about the environmental impacts of wood supply are detailed in the chapter on logging in Appendix A. Furthermore, one expert doubts the environmental relevance of building with mass timber when the building code does not permit exposed wood to be preserved given the materials needed to protect it from fire hazards (1).

“[When] you can't expose the wood, the only thing you're left with is the ecological value, but there's so much gypsum on top that it's not certain that there's any gain in terms of carbon (...) Personally, I think you have to ask yourself if this isn't just being relentless.” (Architect, expert in mass timber construction)

Finally, some professionals pointed out that Quebec regulations lag behind European regulations when it comes to environmental impact (3).

Discussion

The results of this study highlight the perceived motivations and barriers that were expressed by construction professionals in Quebec regarding the adoption of mass timber as a structural material in multi-storey and non-residential buildings. The motivations of highest concern (*i.e.*, environmental impact and aesthetics of wood) and the barriers of highest concern (*i.e.*, construction costs, expertise, manufacturing capacity, regulatory limits, and material specifications) that were identified are in the same spirit as the literature findings (Riala and Ilola 2014; Gosselin *et al.* 2017; Hemström *et al.* 2017; Franzini *et al.* 2018; Toppinen *et al.* 2019; Ahmed and Arocho 2021b; Marfella and Winson-Geideman 2021; Penfield *et al.* 2022). Thus, the topics that they found to be of highest concern in this study were also the motivations and barriers that were the most frequently identified in the literature (Gosselin *et al.* 2017). Moreover, the reasons the respondents gave for their choices were generally very similar to those that were raised in our literature review (see the Literature Review section). This demonstrates a consistency of perceptions over time and across territories studied. It is therefore clear that these topics significantly influence professionals' perceptions and decisions.

However, differences can be observed between the results of this study and those reported in the literature. For example, material lifespan and technical aspects are considered to be among the main barriers in the literature, whereas the professionals interviewed in this study perceived them to be barriers of low concern or even had mixed perceptions of them with low concern (Roos *et al.* 2010; Riala and Ilola 2014; Laguarda Mallo and Espinoza 2015; Gosselin *et al.* 2017; Ahmed and Arocho 2021b).

Conversely, manufacturing capacity was identified as a barrier of high concern in this study, whereas it is a main barrier in only 4% of studies in the literature (Gosselin *et al.* 2017). While the impact of a lack of suppliers and production capacity has already been established in previous works, the results of this study highlight the fact that professionals find it difficult to obtain several compliant bidders during tender processes for mass timber construction projects and have to deal with long lead times and a lack of product uniformity or standardization between manufacturers, the latter of which currently leads to numerous resizing operations in the event a product becomes unavailable. The data also illustrate that respondents lack knowledge about provincial and foreign manufacturers that are located close to the border, as they often mentioned European rather than North American manufacturers when discussing sourcing outside the province of Quebec. This last point is interesting because Ahmed and Arocho (2021b) reported there is a relationship between the number of suppliers that are available locally and the ease of project completion, with a greater number of suppliers meaning it is easier to adopt mass timber construction.

When it comes to a lack of expertise, our interview data supplement the literature findings by highlighting contextual reasons for the shortage. One reason identified is limited market size due to a loss of know-how as the result of a decline in mass timber use following the entry into force of the National Building Code in 1941. Respondents also suggested having partner networks and following integrated design processes as ways of overcoming a lack of expertise. Lack of support for technical aspects, which has been identified in previous works, was not raised in this study (O'Connor *et al.* 2004; Roos *et al.* 2010). This difference can probably be attributed to the 2008 establishment of the Center of expertise on commercial wood construction (CECOBOIS) with support from the Canadian and Quebec governments to provide free technical support to stakeholders involved in wood construction projects.

In terms of motivations, this study found that environmental impact and aesthetics

of wood were key perceived advantages, while Gosselin *et al.* (2017) also identified technical aspects and the cost and speed of construction as key motivations. However, it would appear that no study has nuanced the motivations for wood aesthetics, despite the contradiction that was observed between the desire for exposed wood and the difficulty of achieving it while complying with the technical regulations in effect in Quebec. Environmental benefits do not seem to have been nuanced previously either, whereas our study indicates that some professionals question the environmental benefits of using mass timber in construction due to ecosystem degradation and the fact that regulations require that additional quantities of materials be used to meet fire safety requirements.

Several factors can explain these differences. First, the analysis methodology used in this study classifies topics as either barriers or motivations, whereas other studies may permit them to be in both categories simultaneously (Gosselin *et al.* 2017). Second, the definitions and scopes of the topics considered may differ from one study to the next. For example, in this study, the speed of construction is a component of the construction management topic. Third, it would appear that some studies fail to make a clear distinction between mass timber and wood light-frame construction and group them together as wood construction (O'Connor *et al.* 2004; Roos *et al.* 2010; Riala and Ilola 2014; Wang *et al.* 2014; Xia *et al.* 2014; Gosselin *et al.* 2017; Franzini *et al.* 2018; Toppinen *et al.* 2019; Aaltonen *et al.* 2021; Maniak-Huesser *et al.* 2021). This complicates comparison and probably leads to divergent perceptions regarding costs (Gosselin *et al.* 2017). Fourth, variability in the socio-technical contexts of studies and sampling could also partly explain these differences. For example, Riala and Ilola (2014) observed that the respondents who had the most experience with mass timber construction projects were the most critical and referred to problems they had experienced, while the less experienced mentioned generalized subjects that were related to the most represented perceptions.

The results of this research also highlight that the perceptions that respondents associated with using mass timber as a structural material in multi-storey and non-residential buildings are shared by a large proportion of construction professionals in Quebec, but divergent interests do exist among professionals.

Few previous studies have simultaneously investigated a range of main stakeholders involved in building construction, though many have focused on architects and engineers (Roos *et al.* 2010; Hemström *et al.* 2017; Franzini *et al.* 2018; Aaltonen *et al.* 2021; Penfield *et al.* 2022). This limits the scope of discussions on potential motivations for and barriers to mass timber construction growth. However, some studies have surveyed other stakeholders, such as general contractors (Hemström *et al.* 2017), or survey architects and engineers about their capacity to influence different stakeholders (Roos *et al.* 2010).

Like the findings of Penfield *et al.* (2022), this study's results suggest that designers (architects and engineers) have comparable perceptions, though each group has its own specific topics of interest. This differs slightly from the results obtained by Roos *et al.* (2010), who characterized architects as having rather positive perceptions, while engineers were considered to view mass timber structures negatively. However, the authors noted that engineers who had wood construction knowledge and experience generally expressed positive perceptions. Therefore, the differences observed may stem from differences in professional expertise between the samples.

General contractors stood out from the rest of the sample for their positive view of current project management practices, which could reflect inertia to change in response to the implementation of new project management practices, as other studies have shown (Roos *et al.* 2010; Hemström *et al.* 2017). The results also suggested that project owners

(private and public developers) have similar perceptions of regulatory limits and different perceptions of a building's operating phase. Private developers were much more concerned than the other respondents about the topics that pertain to a building's operating phase, such as lifespan, maintenance costs, and acoustics. This makes them particularly reluctant to adopt mass timber as a building material, since the potential disadvantages remain for them even after construction is complete.

By limiting their research to select stakeholders, the studies in the literature induce bias because they do not represent the motivations and barriers perceived by all members of the value chain and therefore limit their understanding of which factors are decisive when it comes to choosing to adopt mass timber as a construction material. Furthermore, it would appear that not all stakeholders have the same influence over building material selection.

When it comes to stakeholders' ability to influence decisions, general contractors and developers are considered to have the greatest influence over structural material selection (Roos *et al.* 2010; Hemström *et al.* 2017). These stakeholders also contribute the most to maintaining a dependence on pre-established practices (Roos *et al.* 2010; Hemström *et al.* 2017). Although architects and engineers have been considered in previous studies to occupy a central role in design and structural aspects (Gosselin *et al.* 2017), in reality, they possess limited authority over material selection (Roos *et al.* 2010). Manufacturers were also found to have limited influence over material selection due to their minor involvement in project design (Roos *et al.* 2010). Still, according to Roos *et al.* (2010), end users are often unaware of a building's structural material and therefore have very little control over decision-making. Developers, on the other hand, consider that users perceive sound transmission as a construction-related issue. However, this statement needs to be put into perspective in the context of mass timber construction, where the marketing focuses on wood and even exposed wood. In addition, Giorgio *et al.* (2022) show that end users like private developers are particularly concerned about acoustics, durability, and construction and maintenance costs.

These results therefore illustrate that professional activities influence perceptions in accordance with the interests and issues that are associated with their respective practices. Some points of view would not have been raised without this wide variety of respondents (*e.g.*, private developers' perceptions of the operational phase). In a future survey, it will be essential to obtain as broad of a sample as possible to establish a comprehensive view of the motivations and barriers that are associated with an industry.

In short, the fact that the main perceived motivations and barriers emerge in most studies suggests that these barriers to the adoption of mass timber as a construction material are systemic. Even political commitments to the timber industry do not seem to affect these perceptions, as they are constant over time. However, it is reasonable to think that these policies help to reduce constraints little by little, as the results for the topic of expertise have shown. Furthermore, even if the barriers and motivations that are perceived to be of high concern are consistent with the main barriers and motivations that have been identified in the literature, other topics that are more present in the practices of some stakeholders and minorities in terms of frequency need to be addressed. The adoption of mass timber as a construction material can be severely limited if actors who have a strong influence over the value chain (such as contractors and developers) perceive barriers that are not targeted by policies aiming to encourage the adoption of wood as a construction material. Given the fact that limited resources are available to promote the adoption of mass timber construction, it makes sense to work on the barriers that are perceived by the most

influential players while simultaneously working toward removing traditional barriers. An analysis of which would estimate stakeholders' respective level of influence over the choice to use mass timber would be a key addition to the literature.

The results of this study also call into question the use of the frequency of appearance of motivations or barriers in the literature as a criterion for determining which topics influence the adoption of mass timber. Given that most studies investigate a limited number of topics that often recur, this contributes to artificially increasing the importance of those topics by gradually erasing other ones. It is therefore possible that previous studies have provided an incomplete understanding of the real constraints to adopting mass timber as a construction material. In this context, the use of spontaneity through general open-ended questions in interview surveys limits the biases that are introduced by the researcher when designing the questionnaire and interview guide, and gives the respondent the freedom to discuss what is most important to him or her. It also has the potential to reveal perceptions that would not otherwise have been identified.

Limitations

Like most of the qualitative studies in the literature, the present study also has limitations when it comes to validity, which is a common concern in qualitative research. Despite the interpretive method that is associated with coding framework development, different interpretations of the same material can be equally valid, as Schreier (2012) has stated. Indeed, this research method involves several researcher-related biases, such as sampling unit selection being dependent on the researcher's subjective judgment, interactions with participants potentially unintentionally influencing the results through the researcher's own beliefs and expectations, and the grouping of data for coding requiring a subjective understanding of the language used in responses (Schreier 2012; Aaltonen *et al.* 2021; Viholainen *et al.* 2021).

Moreover, most respondents who agreed to participate in this research had an interest in its subject or scientific contribution. Consequently, the topics that are mentioned by a minority of the panel, who are not wood construction advocates, should not be discarded for their low frequency of occurrence. They could be subject to further study.

Regarding analysis of response profiles, some respondents had more than one professional activity, but they were only compared according to their main role.

Finally, although the respondents selected were representative of the wide variety of key stakeholders that are involved in Quebec's construction industry, and despite the large number of interviews that were conducted, the data collected may not be proportionally representative of Quebec's construction industry. Like several studies employing similar methods, this study alone does not permit generalizing the results to a scale larger than the sample studied (Riala and Ilola 2014; Franzini *et al.* 2018; Aaltonen *et al.* 2021; Maniak-Huesser *et al.* 2021). However, considering the results obtained converged with those of the literature works studied, it is highly probable that the perceptions observed represent the different viewpoints in the industry. Regarding private developers, who are under-represented in this study and have not been studied in the literature, the authors consider that the conclusions about them are viable, as their perceptions are polarized. However, the authors also acknowledge a limitation in interpreting these results relating to their low numbers within the sample compared to the other professionals interviewed.

In future work, it would be interesting to carry out a quantitative study with a representative sample of the construction sector value chain to give statistical robustness

to the results. Future surveys should also look at stakeholders' respective impact on mass timber adoption.

CONCLUSIONS

1. This qualitative interview study broadened the scope of research on the adoption of mass timber in construction by exploring the perceptions of the wide variety of key professional stakeholders involved in multi-storey and non-residential building construction in Quebec. In addition, this study covered a more comprehensive range of topics than previous research to provide a more complete picture of construction stakeholders' perceptions and a much finer understanding of the different perceptions that apply to each topic. Perceptions on topics of less concern are detailed in Appendix A. Thus, though many of the subjects identified had already been mentioned in the literature, new reasons for these perceptions have been discovered.
2. Generally speaking, the results of this study were similar to the main findings observed in the literature. The results indicate that the barriers that are of highest concern to respondents are: construction costs, expertise, manufacturing capacity, regulatory limits, and material specifications. At the same time, wood's environmental impact and aesthetics were the respondents' perceived motivations of highest concern.
3. The literature has already identified that motivations and barriers have remained constant over time and across the various territories studied. This study confirms that the province of Quebec (Canada) is no exception to this rule despite having a policy in place that promotes integrating wood in construction and the increase in the number of mass timber constructions, as the perceived barriers that respondents mentioned are similar to those indicated in the literature. This study is in line with the literature's findings, except for professionals who had never been interviewed before, and who may express divergent interests (*e.g.* private developers) because their concerns extend beyond a project's design and construction phase. This research shows that overcoming barriers still requires a great amount of work, but will offer significant growth prospects for the mass timber construction industry. These results could help refine local policies to encourage wood use.
4. The study of the response profiles revealed several findings. First, all the stakeholders interviewed broadly share the same motivations and barriers. Second, some professional profiles appeared more marked for some topics, probably due to their interests or professional practices. Given the strong influence that private developers and general contractors have over structural material selection and the fact that their perceptions were more negative than the overall sample trend, these key stakeholders should be prime targets for measures to promote mass timber adoption.
5. From a methodological perspective, this study confirms that it is necessary to interview a diversified sample of stakeholders about a wide range of topics to establish a comprehensive view of the motivations and barriers associated with an industry. This latter observation helps to reduce sampling biases and the biases introduced by the researcher during study design that have been observed in similar studies.
6. Finally, the method that was developed for this study, that considers the spontaneity with which respondents discuss a topic to measure their level of concern about said

topic, was deemed interesting by the authors. It makes it possible to precisely qualify one subject's level of importance in relation to another within the sample. This method allows researchers to better evaluate, in an exploratory way, the different factors influencing the adoption of a product or process.

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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 Low Concern

Evolution of wood construction. A minority of respondents claimed that mass timber is a niche market and is used much less than concrete or steel, though wood has made great inroads in the commercial and institutional sectors, mainly in projects where an architectural signature is desired (3). Several professionals pointed out that mass timber construction is a practice they are trying to develop (4). Still, respondents raised some reservations, including about stakeholders' and end-users' beliefs (4), and promoters' reservations about cost and complexity (3). A couple of professionals indicated the expansion of the National Building Code to five- and six- storey light-frame wood construction has led to an increase in the use of wood but not widespread adoption by the Quebec market (2). Therefore, a small number of respondents concluded that some progress has been made in recent years (2), and that these advances will only be felt in a few years (2).

In contrast, another group of respondents reported that wood construction has grown significantly in recent years (7), mainly due to regulatory changes (2) and the experience that has been gained from the first projects (2), but also because it is a highly subsidized sector (1).

Technical challenge. A significant proportion of respondents—those less experienced—said they consider mass timber construction of five storeys or more to represent a challenge (16) because it is impossible to transpose a steel or concrete design to mass timber (6). The main challenges they mentioned were: the need for more coordination with stakeholders from design through execution (11), construction details concerning dimensional changes of wood (8), details concerning the passage of mechanical systems (6), technical and economic solutions for hanging the masonry cladding that several Quebec municipalities require (4), assembly tolerance when hybridizing several materials in a structure (4), details about structural connections (3), the compliance of onsite implementation with prescriptions (3), a lack of complete software for designing wood structures and making the calculations necessary (3), a lack of framework for seismic regulations (2), and managing moisture in materials during high-rise building construction (2). Some experts also mentioned it is difficult to convert the use of a mass timber building (2) and achieve the vibration performance levels necessary for projects such as hospitals and research laboratories (1).

Standardization and prefabrication have been identified in previous works as two ways of resolving some of these issues. Professionals stated that currently available engineered wood products are not standardized and offer slightly differing characteristics (dimensions and strengths), which results in market issues (non-interchangeable suppliers), design issues, and higher costs (4). Moreover, they acknowledged that standardized connection systems for mass timber structures are almost non-existent, so custom fabrication at high cost is often necessary (1). According to some experts, the added value of prefabrication level is lower for mass timber than for concrete or light-frame wood, which could increase the performance of this construction method and renew developer interest (2).

Finally, it's important to note that some experts who have solved some challenges by carrying out innovative and demonstrative projects seemed to want other players to take over so that they can share the burden of efforts to develop the sector (3).

“I’m not saying I’ll never do CLT again, but we were pioneers (...). It’s been a great experience, but it’s been extremely difficult.” (Private developer and general contractor, expert in mass timber construction)

Construction height. Some respondents explained that high-rise projects (those seven or more storeys high) built with mass timber are seen as experimental (5), because though the building code allows for it, very few have been built (3). In addition, interviewees raised several height-related issues pertaining to high-rise mass timber projects: the height restrictions that are imposed by fire safety regulations and their associated costs (2), the performance of mass timber in terms of deformation, humidity, *etc.* compared with steel or concrete (1), the complexity of managing humidity on site (1), and higher floor heights due to the thickness of floor systems, which affect a building’s profitability due to the height limitations municipalities impose (1).

Project delivery methods. According to several respondents, projects should be carried out using integrated construction methods, as they are beneficial regardless of the material used (6); however, they are even more advantageous for mass timber projects, since they help reduce complexity through transdisciplinary problem-solving (5). In particular, interviewees noted they support further project optimization (7) by making use of the manufacturer’s strong expertise (5), overcoming the immaturity of expertise and reducing errors (6), addressing product selection early in the process to speed up design because products are not standardized (3), improving coordination (3), improving planning and reducing execution costs (1), and reducing market risk for the customer by transferring it to a design-build contractor (1).

However, respondents highlighted that the integrated design model has some limitations, such as contractual issues related to public procurement (*e.g.*, the need to have multiple bidders) (3), the need to align stakeholder interests (3), often higher professional fees (2), the fact that shortening deadlines restricts innovation (2), and fact that the unsuitable financial system does not allow money to be released upstream to improve design and reduce on-site costs (1).

On the other hand, a small number of respondents were of the opinion that the process used has no influence on the finished product (4) and that it is possible to make a mass timber project using a traditional process (2). In addition, some stated they see integrated design as unnecessary if projects are standard (2) or if the stakeholders involved are sufficiently qualified (1). A couple interviewees acknowledged the traditional management method also has limitations, such as negative reciprocity of the benefits afforded by integrated design, and difficulty defining a specific project while remaining broad enough to proceed with a public tender process (2).

“It’s difficult at the call-for-tender stage to get the specifications detailed enough to avoid vagueness. But if they’re too specific, you’re targeting a supplier and you can’t do that. So, in traditional public tenders, it’s a bit more difficult (...) for mass timber [because it] has specifications or particularities. If you’re in wood light-frame construction, where there are several manufacturers, there’s no problem and they can adapt to any public tender. But (...) I think design-build projects are more appropriate [for mass timber].” (Public developer, user of mass timber construction)

Insurance. Respondents’ perceptions for this topic pertained to two main subjects: insurance covering building construction, and insurance covering building operation.

Over a third of respondents claimed that construction insurance is perceived to be more expensive for mass timber buildings than for an equivalent concrete or steel building (16).

“Just due to the insurance premium I had to pay, I abandoned it and went with a standard steel structure. As a result, we gave up because of insurance.” (General contractor, user of mass timber construction)

“They charged us double the premium of the concrete [building]. Double!” (Private developer, expert in mass timber construction)

Respondents cited a variety of reasons for this: insurers find it difficult to assess their risks due to the low volume of insureds (11), they lack knowledge about engineered wood products (7), they are concerned about fire safety (6), they discriminate based on the combustible or non-combustible nature of structures rather than their performance in a fire situation (3), they include light-frame wood construction claims in their assessment of the risks associated with mass timber construction (2), they consider the risk of fire to be greater when fire protection systems are not functional (1). In addition, some respondents indicated insurers impose specific requirements, such as maintaining a fire channeling system throughout the building as construction progresses (2), and strict control over activities carried out on site that could cause aesthetic damage to mass timber as a result of flames, smoke, humidity, stains, etc. (2). Despite these constraints, some respondents reported they found it difficult or impossible to insure their projects in Canada (4) and that for larger projects, project owners must either have multiple insurers to spread the risk (3) or turn to international insurers (2), which entails higher costs. Finally, it's important to note that some respondents didn't have any concerns about this subject (5).

As for operating insurance, interviewees perceived it to be more expensive for mass timber buildings than for equivalent concrete or steel buildings (9). A number of the professionals interviewed reported that although fire safety remains a major concern for insurers (4), water damage is the main reason for high insurance premiums (5), because this type of damage is more complicated and costly to resolve in buildings made of wood than in those made using other construction methods (5).

“It's safe to say that concrete in multi-residential (...) if there's water damage, you don't have to rip out all the layers of soundproofing we'd have put in [a wood building]. There are fewer layers of soundproofing, fire protection, etc.” (Engineer, non-user of mass timber construction)

Some respondents also reported that it was difficult to obtain insurance after making a claim (2). Finally, it's important to note that a number of respondents had no opinion (9) or perceived no issues (6) for this subject.

Acoustics. Several professionals acknowledged that soundproofing is very important in many markets, including multi-residential construction (6), and that achieving good acoustic performance with mass timber requires more work on construction details (9), remains complex (7) and is costly (3), particularly when exposed wood is used (9).

“Rightly or wrongly, it doesn't matter if your construction system has better soundproofing than a concrete slab; a concrete slab, to the average person who knows nothing about construction, seems more soundproof.” (General contractor and private developer, user of mass timber construction)

Interviewees mainly identified problems pertaining to the soundproofing of floors (4). Many respondents admitted there are few functional and cost-effective technical solutions available for acoustic problems when exposed wood is used (8). Some acknowledged the fact that several design guides have been created by organizations to support construction professionals (3) but deplored the lack of training and documentation that is available on this subject (3).

Other respondents indicated that wood can achieve good soundproofing performance (6) but requires using multiple materials, such as a concrete screed (3), and that there is no high-performance dry-process solution available (3). On the other hand, several respondents noted that wood remains easier to soundproof than steel (5), and others expressed no issues with the acoustics of mass timber buildings (4).

Topics with Mixed Perceptions

Construction management. This topic covered construction time and the benefits and disadvantages of using mass timber on building sites. When it comes to construction time, several respondents noted that mass timber buildings can be erected more quickly (12), especially more quickly than an equivalent concrete building (7), but less so than an equivalent steel building due to the added protection that must be applied to mass timber (3). A few respondents noted, however, that this doesn't necessarily reduce the overall schedule, but shifts the work upstream and then accelerates the erection phase, where most of the costs are still concentrated (4). A couple of professionals also pointed out that increased speed is conditional upon assembly teams' experience (2), and that although the amount of time spent on the structure can be reduced, the gain is more limited than a gain resulting from a more advanced prefabrication process with finishing work (2).

Respondents recognized that when mass timber use enables construction to be accelerated, several corollary benefits emerge, such as cleaner construction sites (4), reduced noise pollution (3), less time spent using cranes and blocking roads (2), safer construction sites (2), fewer workers needed (2), less space needed for storage and handling (1), and a few months' extra operating income (1). However, a number of professionals noted that mass timber construction also brings disadvantages to the worksite, such as the need to protect it from the weather (9) and protect it from workers to preserve finishes (3), the need to store large engineered wood components close to the worksite in an urban environment (5), the need to store elements while awaiting assembly due to the aging of building components (2), and low adjustment tolerance (1). According to one expert, bad weather on the building site is a significant fear for customers (1). Despite this, a number of other respondents indicated mass timber construction sites have no more constraints than sites where other building methods are used (8).

Structural capacity. Many respondents commented that mass timber permits considerable structural design flexibility but has greater mechanical property limitations in terms of its strength-to-volume ratio (7). Some pointed out that it is possible to achieve large spans with wood as with, for example, steel (3) due to the fact that engineered wood products improve wood's structural performance (1). In addition, several respondents highlighted the fact that mass timber can be used to build to a greater height than concrete can for a given soil-bearing capacity because it is lighter, which is particularly advantageous when building on poor-quality soils (7).

On the other hand, a number of respondents raised issues that were specific to mass timber construction, such as the attachment of masonry cladding, which calls into question

the load-bearing capacity of joists, which is difficult from an economic viewpoint (5). One expert mentioned that wood exhibits good seismic performance (1), but analyzing its seismic performance can become very complex when there is an atypical distribution of bracing (1) because the lateral load calculation rules that are set out in the building code are not advanced enough, particularly when it comes to CLT construction (1). Finally, some respondents noted that customers can have confidence in engineers' ability to propose a structural design in mass timber that is as safe as an equivalent one designed using other construction methods (6), though it often entails over-design and therefore higher costs (1).

"When you're not sure about certain behaviors, what do you do? You oversize. (...) On top of that, the National Building Code has other impacts too (...), so you have other oversizing caused by fire protection and so on that can add up. Put end to end, it can easily add up to 150, 200% of the required structure, and therefore 150, 200% of the structure's costs."
(Engineer, expert in mass timber construction)

Maintenance costs. Many professionals were of the opinion that mass timber requires no more maintenance than other structural materials do if it is adequately protected (19) and, therefore, a mass timber building costs no more to maintain than an equivalent steel or concrete one does (7). Furthermore, some respondents commented that when exposed wood is used as an indoor finishing material it has a longer lifespan than other alternative indoor finishing materials (2) and improves the lifespan of structures by making it possible to perform maintenance more quickly and inexpensively than if the wood structure were encapsulated (1).

Respondents also had mixed perceptions as to whether a mass timber structure would require more maintenance in the long term (3), which were fueled by the fact that limited data are available to compare engineered wood products' durability performance with that of other long-term construction products (3).

Finally, some respondents noted that although mass timber can have higher maintenance costs due to outdoor exposure (5), poor technical detail design (3) and deformation over time (3), water damage is the main problem (6) as it can lead to severe structural problems (6), and that mass timber structures require regular maintenance and early water damage detection to maintain a reasonable lifespan (5). A few interviewees pointed out that mass timber buildings can thus represent a challenge for developer-managers who keep their buildings in their real estate portfolios over the long term (3), especially since many managers have no experience with the long-term maintenance of this type of structure (4).

Lifespan. A number of respondents acknowledged that structural mass timber is highly durable—at least as durable as other building materials—if it is adequately protected (13), but it is considered problematic from a longevity and maintenance standpoint if it has been exposed to the outdoors (4). On the other hand, one interviewee pointed out that exposed mass timber that is used as an indoor finishing material can outlast the finishing materials it replaces (1) provided that its use is compatible with building's use (1). Many professionals also noted that it is generally necessary to watch out for water infiltration and humidity problems and to perform regular maintenance on wood structures to not deteriorate their lifespan (9).

“Water damage needs to be identified, contained, and repaired quickly. If there’s water damage to concrete, it’s a concrete slab, so it doesn’t have much long-term impact. (...) [when] mass timber building maintenance is poorly done, or not done at all, it can cause huge problems for [the building’s] lifespan.” (Private developer, expert in mass timber construction)

Some respondents also pointed out that it’s not possible to generalize that mass timber has a long lifespan in all use conditions as engineered wood products have not been around long enough to know how they age after many decades (4). Finally, other professionals said they found concrete (3) or steel (2) structures to be more durable than mass timber ones.

Motivations of low concern

Thermal. Many interviewees mentioned that mass timber’s main advantage specific to this topic is its low thermal conductivity, which enables it to enhance an envelope’s thermal performance by reducing thermal bridging (7), though special attention must be paid to connectors to benefit from this effect (2). In addition, a few indicated that exposed wood interiors also contribute to water-buffering capacity (2) and radiant thermal comfort (2). Finally, some respondents reported that certain engineered wood products such as CLT offer a certain degree of thermal inertia (2), although they have much less thermal capacity, and therefore thermal efficiency, than concrete (1).

Biophilia. A majority of respondents said the use of exposed mass timber inside buildings creates living environments that are more pleasant and warm (21), promote occupant well-being (20), are more attractive (7), and smell good (1). A few noted these benefits are critical to the argument for prescribing mass timber use (2). However, several respondents pointed out that exposed wood must be preserved to benefit from these effects (4).

Perceived quality. Many respondents indicated that users’ perception of mass timber is very positive (17) as they find it beautiful (12) and consider it to be synonymous with high-quality construction (6). A couple of interviewees explained one of the reasons for this perception is no doubt the care that is taken when designing these buildings (2).

Local economy. A large number of respondents said they view mass timber construction as a strong supporter of local economy as it draws on local resources and an economic fabric that stretches across the province (14) and perceive the industry to be efficient, innovative, and socially and environmentally responsible (7). Some said they were proud to use a material that’s part of Quebec’s identity (2).

“There’s wood everywhere in Quebec. It’s not like we’re in the desert and it’s an imported material. (...) To have it in our buildings, I really see it as an added value and a source of pride.” (Public developer, non-user of mass timber construction)

On the other hand, a few experts admitted the lack of local manufacturers sometimes means they have to turn to foreign suppliers and thereby sacrifice the notion of supporting the local economy and its associated socio-environmental values (3).

Logging. A large group of respondents were of the opinion the forest is managed responsibly as a whole (15), particularly when it comes to the macro-management of forest stocks (8). In contrast, a number of interviewees (7) said that attention needs to be paid to

how much wood stock is being left for others, as the resource is not always renewed and to land management and the various ecological issues this entails, such as the preservation of flora and fauna (5).

“Cutting wood has quite a wide impact, but wood is renewable. Which of the two is better? I don’t know.” (Engineer, expert in mass timber construction)

One interviewee also made the criticism that forest management favors monocultures, which increases the forest’s fragility to pests and forest fires, and reduces the variety of ecosystem services a mixed forest can provide (1). In addition, others reported issues pertaining to local-scale logging management and communication with citizens living close to logging areas (4) even though organizations exist to foster relations between the various stakeholders involved (1).

Some professionals reported that bad practices still exist in the industry and receive more media attention, which does not help to create a positive perception of logging (4). Some of them provided the example that practices such as clear-cutting are still perceived as being common (2), particularly among large forestry contractors (3), even though they have not been allowed on government-owned land in Quebec for decades.

“There are good forestry contractors, just as there are not-so-good ones. Some clearcut and then replant a tiny tree. Whereas others cut much more selectively, letting species regenerate or [grow when] they’re just 10 years old (...) instead of ramming them. (...) [It’s] the big contractors [with their big machinery] who generate the largest volumes, and who have the least respectful practices in most cases.” (General contractor, user of mass timber construction)

One interviewee stressed that the fact it is difficult to establish precise indicators to quantify environmental impacts is another issue that is slowing down practice improvement (1). Many respondents stated that although clear-cutting has been forbidden for decades (8), there is still room for improvement when it comes to logging practices to reduce environmental impacts (8). Some indicated that the use of forest certifications (*e.g.*, Forest Stewardship Council (FSC)) is helping to improve practices (5), although Quebec already has one of the highest ratios of certified sustainably managed forests (2) and, despite this, the general public still associates logging with deforestation (2) due to a lack of communication (1). One interviewee mentioned that improving the image of the forestry sector and its environmental impact would therefore help to promote wood construction industry (1).

On the other hand, many professionals admitted that the growth of the wood construction market worries them because of the negative pressure it could put on the forest environment (4). One called for reserving more harvested resources for local consumption (1), this, despite the fact that logging is an important part of the Quebec economy due to exports and the significant economic benefits it generates for the regions (1). However, a few respondents insisted that while logging does negatively impact the environment, its impact is far less than that of other materials (4).

Some interviewees acknowledged that the forest industry’s environmental impact is a political subject that generates mistrust among the general public (4) and that the industry seems to have a strong influence over Quebec’s Ministry of Natural Resources and Forests (4) as it is a significant economic sector for the province (3).

“We hear reports that the ministry responsible for forests (...) seems to listen more to industry and less to the environment and the common good.”
(Architect, user of mass timber construction)

Moreover, professionals pointed out that logging currently seems to be managed for the benefit of sawyers and exports at the expense of supplying local markets (3) this, despite the fact that the industry receives a considerable amount of public subsidies (2).

“[Forests] are managed for the benefit of sawyers, [and not] for the benefit of consumers or manufacturers. [Because] more than 50% of their market is based on exports. (...) So it will take a government commitment if [we want to build with our wood]. (...) What do we want to continue doing, exporting or building with our own wood? For now, the government’s intention is very clear: export.” (Manufacturer, non-user of mass timber construction)

Lastly, this topic was the one that was most non-spontaneously approached. Unlike for the other topics, 15 respondents used distancing terms such as “I’m not an expert, but...” or an externalizing phrase such as “What stands out in the media is that...” when talking about this topic. Two respondents refused to answer any questions on the topic. This suggests that the subject is a particularly delicate one to broach.

APPENDIX B – INTERVIEW GUIDE

Presentation of the project and obtaining of consent.

Professional practices and general opinion on motivations and barriers to using mass timber in construction

- (1) Tell me about your practice and the building materials you use?
 - What do you think of using these materials for structural elements?
 - Have you ever completed a mass timber construction project?
- (2) What are your thoughts about the evolution of mass timber construction in Quebec in recent years?
- (3) What are the advantages and disadvantages of building with mass timber *versus* other building materials?
 - Can't think of any others? (Ask again at least once)

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

- (4) In your opinion, can this material be used to create a particular architectural aesthetic?
- (5) How do you think end users perceive the quality of mass timber construction?
- (6) In your opinion, do end users wish to have a home with an exposed mass timber structure?
- (7) In your opinion, does mass timber offer advantages or disadvantages in terms of comfort (*e.g.*, thermal comfort, acoustic comfort) compared to other building materials?
- (8) What is your opinion of the environmental impact of wood construction?
 - What do you think of logging in Quebec?
- (9) Do you consider regulations to be a barrier to mass timber use?
- (10) In your opinion, is mass timber construction more of a challenge when buildings are 5 or more storeys tall?
 - Do you see other challenges?
 - How about in terms of the structural capacity of mass timber?
- (11) In your opinion, is fire safety an obstacle to mass timber construction today?
- (12) Would you say that expertise in mass timber construction is well established in Quebec?
- (13) In your opinion, does Quebec have sufficient manufacturing capacity and product supply to support mass timber construction?
- (14) What is your opinion of the cost of mass timber construction compared with that of other construction methods for buildings 5 or more storeys tall?
- (15) Do mass timber buildings require more maintenance than buildings made of other materials to maintain a reasonable lifespan?

- (16) Do mass timber structures age faster than buildings made of other materials?
- (17) In your opinion, is insurance an issue when it comes to mass timber buildings?
- (18) In your opinion, does the use of mass timber influence construction site constraints in urban environments (*e.g.*, noise pollution, construction time, delivery)?
- (19) Do you think mass timber construction requires that integrated design processes be used?
- (20) Have you encountered issues prescribing mass timber construction or obtaining customer acceptance on a mass timber building project?

Questions about respondents' characteristics

- (21) How old are you?
- (22) What is your level of responsibility in your organization?
- (23) How long have you held this or a similar position?
- (24) In which region is your organization located?
- (25) How many employees does your organization have?
- (26) Which types of building do you work on most often?
 - Commercial
 - Industrial
 - Institutional
 - Multi-storey housing
 - Single-family housing
- (27) How many construction projects does your company handle per year, on average?
 - Less than 5
 - Between 5 and 20
 - More than 20
- (28) What is the average monetary value of your company's projects?
 - Less than CAD 2 million
 - Between CAD 2 million and CAD 10 million
 - More than CAD 10 million
- (29) How tall is the tallest building you have worked on?
 - 4 storeys or less
 - 5 or 6 storeys
 - More than 6 storeys
- (30) Overall, what is the average height of your projects?
 - 4 storeys or less
 - 5 or 6 storeys
 - More than 6 storeys

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