Main Motivations and Barriers for Using Wood in Multi-Story and Non-Residential Construction Projects

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Steel and concrete are traditionally used as structural materials for non-residential and multi-housing buildings. However, wood can meet the same structural property requirements, and a variety of multi-story buildings have recently been built all over the world using this key material. In this study, the main motivations and barriers to wood adoption for structural uses in non-residential buildings are highlighted, based on an analysis of grey literature concerning some well-known buildings and on scientific literature. The motivations found were linked to sustainability, lack of expertise, costs, rapidity of erection, and aesthetic of wooden structures. In contrast, the barriers preventing its use encompass building code implementation, technology transfer, costs, material durability and other technical aspects, culture of the industry, and material availability. Furthermore, an analysis of non-residential timber building meeting minutes for nine projects is also presented to support the identification of problems and concerns related to site assembly issues, the conception of the building, the scheduling, and stakeholders' relationships. With a better understanding of the expectations and challenges concerning wood usage in non-residential construction projects, companies will be able to adapt their business models and use the resource even more in the future to develop innovative structures.

Keywords: Non-residential buildings; Timber buildings; Structural material; Motivations; Barriers

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INTRODUCTION

The construction industry in Canada employs more than 1.3 million workers, making it the fifth-largest employer of the country and accounting for 7.3% of jobs among all industries (StatisticsCanada 2016). In the Province of Quebec, it also accounts for investments worth approximately $45.4 billion in 2014, representing 12% of Quebec's Gross Domestic Product (GDP). It creates 257,800 direct jobs on average every month, accounting for one out of 20 jobs in the province, without counting the thousands in related sectors (CCQ 2016). Indeed, the construction industry is closely linked to the forest products industry, which is a $58 billion dollar a year industry that represents 2% of Canada's GDP. The industry is one of Canada's largest employers, operating in 200 forest-dependent communities from coast to coast, and directly employing 230,000 Canadians across the country (FPAC 2016).

A more intensive use of wood in non-residential buildings would create a stronger demand for engineered wood products, resulting in a positive impact for job creation in the forest industry across Canada. While in recent years there has been an inclination toward the construction of non-residential buildings using wood structures, there are still some perceptions and barriers that slow down the development of this market. In this study, motivations and barriers were identified based on information related to some well-known wood multi-story apartments and work offices construction projects over the world from a combination of systematic surveys of both grey and scientific literature. Meeting minutes from nine non-residential wooden building projects built in the Province of Quebec, Canada, were also used to identify problems and concerns met on the project sites using wood as a structural material. Meeting minutes are documents integrating written and summarized discussions occurring in every meeting related to a specific construction project. The idea of using meeting minutes was to identify the problems and concerns related to wood uses within the context of construction projects rather than only focusing on the ones linked to wood material itself. Those problems and concerns were then compared with barriers previously found, showing a significant match. The results confirmed the promising avenue of using three different information sources, which were the grey literature, the scientific literature, and meeting minutes, to conduct relevant content analyses and generate useful categories of explanatory factors for the adoption of wood. Moreover, to the best of the researchers' knowledge, it was the first time that meeting minutes were used for the wealth and depth of information they convey. This study was structured as follows. In the next section, wood's market shares are presented. The samples and methodology used to conduct this research are detailed. The results, discussion, and conclusion complete the paper.

Current Market Shares of Wood Structures in Non-Residential Constructions

The use of wood in non-residential construction projects has increased in the last decades, but it is still not a common practice. As a result, a variety of studies have been aimed at estimating the market shares of wood for non-residential constructions. Because architects and structural engineers involved in a construction project tend to have a stronger influence over structural material choices, this probably explains why these studies have tried to capture their perceptions and habits, instead of the opinion of other professionals also playing roles in non-residential construction projects.

According to a survey conducted on a small sample of 50 structural engineers, 4 architects, and 14 other building professionals, all working in the Province of Quebec, market shares of wood use as structural material have increased from 18% to 22% between 2006 and 2009 (FPInnovations 2010, on behalf of Cecobois). Another study conducted on 72 architects and 27 engineers also showed that, between 2009 and 2012, the specification of wood for structural systems remained relatively stable. This survey, furthermore, demonstrated that structural engineers tended to pick wood for building structures slightly more frequently than architects did (20% *versus* 17.8%) (FPInnovations 2013, on behalf of Cecobois). A recent study conducted in 2015 on a bigger sample has indicated that, on average, 24.1% of the non-residential buildings of 4 stories and less built in 2014 by 118 architects and 54 engineers had a wooden structure (Drouin 2015).

Wood use as a structural material in non-residential buildings has increased over the years, but could it grow more? In fact, only in Canada, a study on 47 non-residential buildings in Ontario has shown that while 81% of these buildings could have been constructed using wood, only 19% had finally selected wood as the main material (O'Connor 2006a). Another investigation based on the non-residential building construction permit emitted for the entire year of 2004 in Red Deer, Calgary, and Edmonton, three cities in the Province of Alberta (Canada), showed that 10% of all areas are currently being framed in wood, and another 23% of all areas are still available for wood usage. As reported by O'Connor (2006b), wood consumption in non-residential buildings could be increased by a factor of three because the constructed area could be over three times more in wood.

While many well-known and most frequently cited non-residential buildings all around the world have used wood as the key structural material, many studies have shown the economic potential is still unexplored. In the next section, some motivations and barriers were identified that could explain the role played by wood in non-residential constructions.

EXPERIMENTAL

This paper relied on three different data sources and used a three-step research design. Extensive content analysis was carried out using the software package N'Vivo (QSR International Pty. Ltd. Doncaster, Australia). The various sources of the data and the three-pronged research design are discussed, followed by the content analysis.

Data Sources

To find motivations and barriers related to using wood as a structural material for non-residential buildings, three data sources and samples were used. The first sample included 13 extensively studied and remarkable global timber building projects. They all have been flagship buildings at some point. The second encompassed 53 scientific articles related to motivations and barriers of using wood in buildings. Finally, the third consisted of the complete meeting minutes of nine non-residential wood building projects in Quebec, Canada. These three samples are detailed in the following paragraphs.

Major timber building projects in the world

Thirteen wooden multi-story buildings were analyzed. This sample included many of the most popular non-residential multi-stories wood building cases over the world used as apartments or work offices and multiple documents, news articles, technical reports, and grey literature (unpublished, non-commercial, hard-to-find information that organizations produce) related to them that were available. These 6 to 14 story constructions were built between 2000 and 2015 (Table 1).

In Berlin, Germany, the *Esmarchstrasse 3* project is a renowned wooden non-residential project. This seven-floor multi-story building has an outdoor concrete emergency staircase that made the building different from an architectural point of view (CECOBOIS 2013). H8 Bad Aibling, another German project, is an eight-floor building that was built in 2011. The builder used Cross-Laminated Timber (CLT) panel and a prefab-concrete stairway to provide lateral stability (Schreyer 2012).

In London, England, the nine-story building, named Stadthaus Murray Groove, was erected in 2009. It is considered as the pioneer of timber residential tower buildings in the world. It was made of CLT provided by the building company KLH and was shaped as a cellular structure of timber load bearing walls, in which all components were made of wood, including stair and lift cores (KLH 2015). The Bridport House is another example of building entirely constructed in CLT in 2010. As an eight-floor multi-story residential building, it was designed to provide 41 residential units (Birch 2011).

In Austria, Lifecycle Tower One, erected in 2012, was the world's first hybrid wood passive eight-floor building. Its first floor was made of concrete, while the seven other floors were built using wood (Buildup 2013).

The *Forté* Building, a ten-story building, was built in Melbourne, Australia, in 2013. It was, at the time, the tallest building made of wood in the world and Australia's first residential timber tall building (WoodSolution 2013). It is made of 759 CLT panels (485 tons) of European spruce (*Picea abies* L.) from Austria. Its sustainable attributes were brought forward in the marketing strategy used to promote the project (LendLease 2015).

In Växjö, Sweden, the *Limnologen*, 134 co-op apartments divided in 4 towers of 8 floors each, was built between 2006 and 2009. Floors and walls were constructed of solid wood (CLT), except for the first floor, which was made from concrete (Serrano 2009).

The *Via Cenni* in Milan, Italy, was built in 2013. It is another nine-floor residential tower, and it is a showcase for social housing using multi-story timber construction. The CLT was selected as structural material (Storaenso 2015).

In Auckland, New Zealand, the Scotia Apartment Tower is a 12-story apartment building standing on a single story basement. It has wood floor diaphragms and lateral load-resisting systems (Moore 2000). This hybrid structure built in 2000 was the most cost-effective structural system that could also meet the building code.

The highest wood building in the world, the *Treet* (meaning "the tree"), is located in Bergen, Norway. This 14-story project was finished in 2016. All main load-bearing structures are made of wood, and glulam was used for the trusses. CLT was also used for the elevator shafts, staircases, and internal walls (Abrahamsen and Malo 2014).

In the Province of Quebec, Canada, a series of buildings have been constructed in wood in the last ten years. The *Fondaction* building and District 03 are both examples of six-story buildings erected using wood in 2008 and 2013, respectively (CECOBOIS 2013; Beaucher 2015). The *Fondaction* building was constructed using glulam, and *District 03* with CLT. Stadiums, hotels, and commercial buildings are other examples of non-residential buildings constructed entirely from wood in the past years in the Province. Furthermore, *Origine*, a 13-floor building, will become the highest timber building in North America (Origine 2015). It should be completed by the end of 2016. The projects mentioned above are summarized in Table 1.

Table 1. Major Timber Building Projects in the World

Number of Stories	Building Year	Country	Building Name
6	2013 - 2014	Canada	*District 03*
6	2006	Canada	*Fondaction*
7	2008	Germany	*Esmarchstrasse 3*
8	2011	Germany	H8 Bad Aibling
8	2012	Austria	Lifecycle Tower One
8	2009	England	Stadthaus Murray Groove
8	2010	England	Bridport House
8	2006 - 2009	Sweden	*Limnologen*
9	2013	Italy	*Via Cenni*
10	2013	Australia	*Forté* Building
12	2000	New Zealand	Scotia Apartment Tower
13	2016 (to be built)	Canada	*Origine*
14	2015	Norway	*Treet*

Scientific literature

Information from 53 scientific articles was gathered to confirm the motivations and barriers found through the analysis of the major projects. Major databases in wood sciences (CAB Abstracts, Compendex, Web of Science) were searched using targeted keywords (motivations, barriers, opportunities, perceptions, timber buildings, and multi-story buildings), and eight major articles were found. The sample was snowballed to 45 more papers among the cited references. When data saturation was reached (*i.e.*, the repetition of the articles found in the reference section of these 53 articles), the sample was considered complete. These articles were written between 1999 and 2015. Important facts worth a mention are that written sources found in the literature mainly concerned multi-story timber buildings, and the literature mostly contained insights from architects and structural engineers.

Meeting minutes of nine wood building projects in Québec, Canada

Surprisingly, construction meeting minutes did not seem to have been widely used for research purposes, although they may have added great value. These practical documents were filled with all the discussions that took place in all meetings related to a given construction project. So when teams working on a specific project sit around the table, their discussions are written and summarized in such meeting minutes document. People attending these meetings are professionals, technicians, or representatives of all enterprises involved in the construction of the project. The meeting minutes are, therefore, the best and most complete first-hand record of what happened during the course of the work, as they summarized all conversations and decisions taken in these meetings. They were also really helpful to keep the players of the process updated while the project was being conducted. According to the Ontario Association of Architects, meeting minutes help to prevent costly schedule changes since they allow interested parties to provide valuable input before it impacts the projects (Stechyshyn 2015). However, because the confidential data they contained belongs solely to the firms involved, their use has implied the signature of confidentiality agreements between the researcher and the company that has shared them. Even if this measure was agreed upon, one company was not comfortable to share this information source for a specific building since this case is currently in court. Nevertheless, all the others companies accepted to share the entirety of the meeting minutes of the construction project we had selected. They were easier to get when a trust relationship existed between the companies and the research team, as was the case in this research.

Depending on the property owner and the mode of construction chosen for a given project, the meeting minutes' format varied. When the building was privately owned, there were no fixed rules for upkeep, and meeting minutes records could be kept or not. It depended on the owner's interests. In the case of public building construction projects, they had to be written down. If using the traditional mode of construction, the architect was the one responsible for writing down all discussions and decisions taken. Architect associations typically provide templates online, so their format was formal (Word or Adobe). When the construction project was managed following a stewardship mode, meeting minutes were under the responsibility of the project manager who was part of the builder's team. If the design-build mode was used, the records could simply be the whole set of emails having been sent all along the project between all stakeholders. The sample used included 8 projects conducted following the traditional mode and one based on the design-build mode. All of these construction projects were conducted in the Province of Quebec.

The biases when working with construction meeting minutes were mostly related to content depth variations. Depending on the company vision, culture, and habits, as well as on the person who was writing them, the amount of details varied enormously. In some cases, it was possible to find many details about a situation, while in others only the main issues were written down. It then became difficult to understand what really happened. When construction problems and concerns were analyzed, there was some disequilibrium in the information available between projects and the aspects recorded. Problems and concerns could be extracted from this type of data when they were written down, but they might not include every single specific issue that really took place during the project.

The oldest building being part of the sample is an educational building built in 2004 and 2005, standing on glulam structure. The interior was also made of wood. Half of its area was devoted to teaching and the other half was housing laboratories. The main objective of the design strategy was to provide users with the most comfortable environment possible, while minimizing energy consumption. Most important in this regard was to rely on solar heating and passive cooling, as well as natural ventilation and light. Due to certification costs, it has not been certified LEED, but some professionals are saying that it could have deserved the silver label.

The second project analyzed is a multi-sport stadium built with glulam structure in 2009. The structure was made of 13 massive laminated arches using a total volume of 617 m^3 of wood for the whole stadium. This wood mass represented 1,234 tons of sequestered CO_2. The arches were connected to a concrete base. The amount of wood cost 10% of the entire building cost.

The third building of the sample is a city park building made of a traditional light frame built in 2009. It was constructed through a revitalization program.

The fourth building was the only private building included in the sample. It was a mill owned by a large company that bet early on green products and environmental issues to develop a competitive advantage and its brand image. This industrial plant was built in 2008 and 2009.

The fifth building studied is a provincial government construction that houses a regional team of civil servants. This building was erected in 2010 and was made out of a glulam structure. A large garage was also included in the other section of the building.

The sixth construction project is the second multi-sport stadium of the sample. It was built in 2010 and 2011. It is a covered sports field that serves a dual purpose for both soccer and football. There are 13 massive laminated arches weighing about 50 tons altogether that compose the structure.

The seventh building is a river station owned by the government of Quebec, completed in 2014 and 2015. It offers a panoramic view, and its structure includes steel and wood. About 50 beams measuring up to 18 meters in length and 40 CLT panels were used. The erection of the structure was planned to take about two weeks, if mounted by a team of four men. This building is set to achieve LEED certification.

The eighth building is a 4-story timber building built in 2014 and 2015 for social housing. It includes 40 living units and has two sections. The first section is a traditional light frame structure, and the second section is a CLT structure. The building was designed to meet an energy efficiency of 25.1 kWh/m^2 per year.

The last building analyzed houses a pool in an eco-neighbourhood and was built in 2014 and 2015. It stands on a laminated structure storing 67 tons of CO_2.

Methodology

The study was carried out following three main steps. Step one consisted of collecting and analyzing a series of documents and technical reports related to the 13 major national and international multi-story construction projects previously described. The motivations and barriers found were then corroborated with the aforementioned 53 scientific articles related to the subject. The second step involved the analysis of meetings minutes from the nine non-residential wood buildings, also introduced in a previous section. The third step involved a comparison of the results from the first step with those found in the second step.

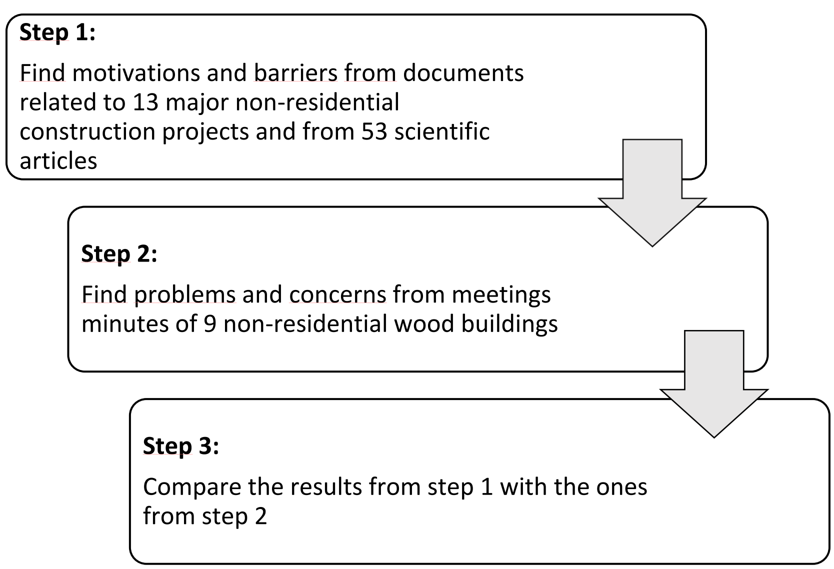

Fig. 1. The three steps of the research design

The principle of triangulation was used to reinforce the reliability and validity of research results because employing a variety of information sources allowed a better contrast between their similarities and/or differences. More differences were generally obtained when different methods of analysis or information sources were exploited, but they allowed the researcher to report a holistic and comprehensive view of a given reality (Mathison 1988).

Content analysis

In order to gather key information concerning motivations and barriers but also on problems and concerns that could emerge when building non-residential wood buildings, the different sources of information used were explored using a qualitative approach. According to L'Écuyer (1990), this type of method describes specific particularities of different elements (words, sentences, ideas) contained in different categories. The essential signification of the phenomena studied came from the nature and the specificity of the contents studied, rather than from its quantitative distribution. To analyze the content, the 6-step methodology proposed by L'Écuyer (1987) was followed. It involved: 1) performing several readings of the collected material for; 2) breaking its content into smaller data sets that will be used for; 3) categorization. This third step consisted of gathering statements, which had similar meaning. A category is a kind of common denominator in which a set of statements can be naturally incorporated without forcing a meaning. It was then possible to 4) quantify the categories in terms of frequencies, percentages, or various other indexes. Only then did 5) the scientific description emerge, based on quantitative analysis and qualitative analysis, which was often used to explain the findings of the quantitative analysis. The content analysis ended with 6) an interpretation of the results.

Content analysis could, therefore, be considered a scientific method, used to process diversified data by applying a coding system that led to the definition of categories. These categories allowed data to be analyzed in quantitative and qualitative ways. Qualitative analysis included analysis of manifest—or actual—contents, revealing the ultimate exact meaning of the phenomenon studied, and latent content to access the hidden meaning potentially conveyed by the same set of data. For the documents, technical reports, and scientific literature, the content analysis was conducted manually, and the N'Vivo software suite was used to analyze the meeting minutes.

Using N'Vivo

The content analysis conducted following the steps suggested by L'Écuyer (1987).

1) After having inserted the nine sets of construction meeting minutes in N'Vivo, their contents were read multiple times. 2) The data were broken into smaller data sets prior to 3) categorization. A code was allocated to text segments, following some rules preliminarily defined while achieving in-depth reading. These rules were adjusted through successive analyses, and coded segments became part of the categories. Because some data sets were fairly big, queries were also conducted to find parts of the construction meeting minutes related to the categories created. Different words were used to browse the data: structure, wood, and problems. At a certain point, no new elements were revealed by subsequent queries, *i.e.*, data saturation, which indicated the end of the analysis (Mucchielli 1996; Poupart *et al.* 1997). With N'Vivo, it was possible to mark and allocate labels to data sets so these sets could then be integrated into main categories when desired.

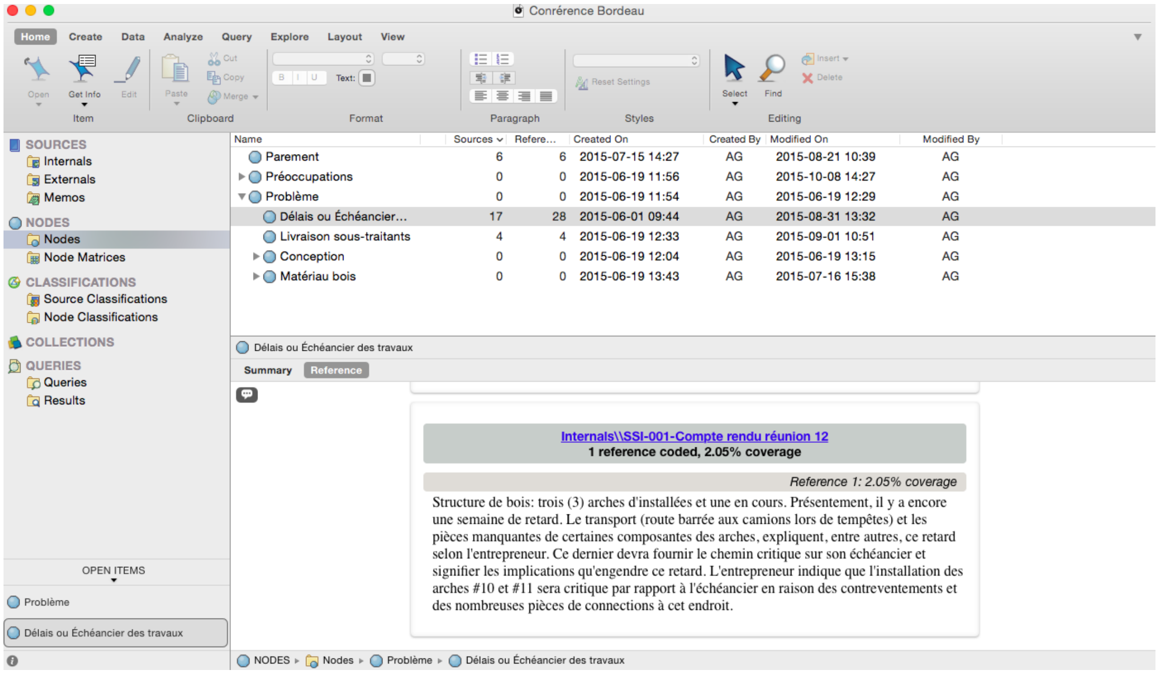

Fig. 2. Screenshot of the N'Vivo software used to build the categories and to conduct the analysis

The key rule finally used contained two main categories: problems and concerns. They represented two levels of issues. A problem was a concern that had to be solved either during the conception or at the construction phase. A concern was rather an issue having been discussed. These two main categories contained a variety of sub-categories that were presented in the following section (results).

To continue with l'Écuyer's methodology, 4) the problems and concerns were presented by order of importance, which, in fact, was directly linked to the number of mentions related to categories and sub-categories; 5) they were also explained; and 6) put into context, as well as interpreted, in the next section.

RESULTS AND DISCUSSION

Motivations and Barriers Linked to Using Wood in Construction

In this section, the motivations underpinning the interest of architects, structural engineers, promoters, and clients for wood as a structural component are described. The obstacles that seemed to have an impact on wood promotion in construction projects are also highlighted. It is true that every stakeholder opinion will surely be guided according to their role and responsibilities when taking part in a given project. All stakeholders also use vocabulary that is directly related to their work area. In this research, we considered the wood construction industry as a whole and we collected information from technical documents and scientific literature according to a mix of professionals. That is why it was possible to give a broad representative view of the industry. This research shed new evidence on the relevance of wood use for structural applications, while it unveiled new information related to wood uses as a structural component in construction projects. Figure 3 prioritizes and summarizes the motivations found.

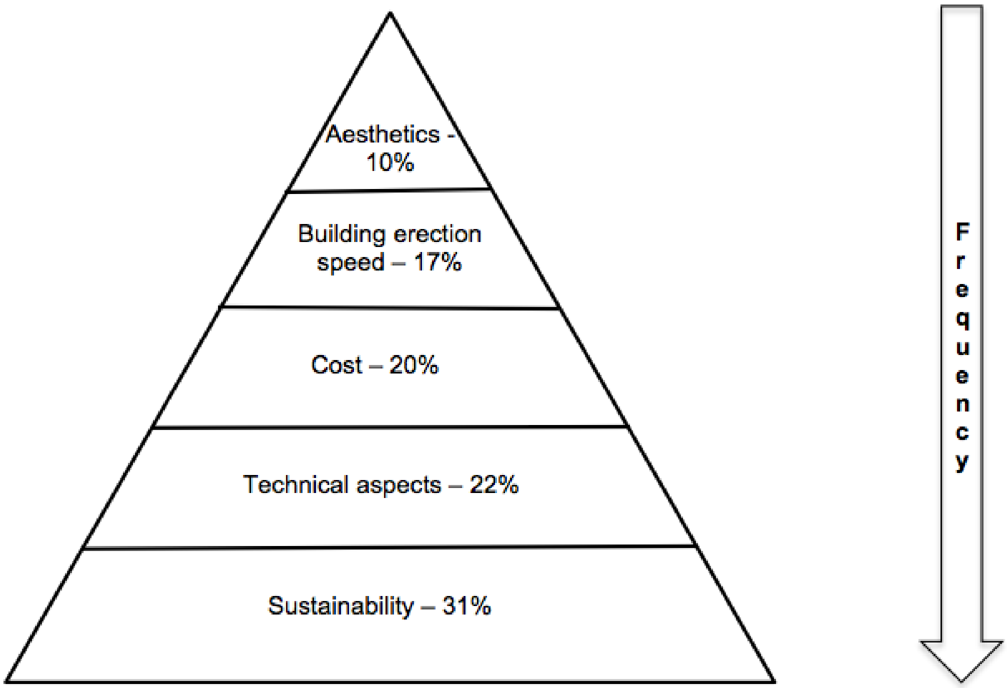

Fig. 3. Motivations and their respective relative weight for the adoption of wood as structural material for non-residential buildings

The contribution to sustainable development was the most cited reason for choosing wood as a structural material in non-residential buildings. For its construction only, the *Fondaction* building in Quebec totaled a net carbon benefit of 1,350 tons of CO_2, this being equivalent to saving the emissions of 270 automobiles in a given year (FondactionCSN 2013). The literature also confirmed: 1) the positive environmental performance of wood (Kozak 1995; O'Connor *et al.* 2004b; Roos *et al.* 2008; Shmuelly-Kagami 2008; Gold and Rubik 2009; Robichaud *et al.* 2009; Roos *et al.* 2010; Hemström *et al.* 2011a; Kuzman and Groselj 2011; Nolan 2011; Mahapatra *et al.* 2012; Schmidt and Griffin 2013; Thomas *et al.* 2013; Manninen 2014; Hurmekoski *et al.* 2015; Laguarda and Espinoza 2015), 2) its carbon sequestration capacity (Schmidt and Griffin 2013), 3) its energy efficiency (Bayne and Taylor 2006; Bysheim and Nyrud 2008; Bysheim and Nyrud 2009; Hemström *et al.* 2010; Hemström *et al.* 2011a; Kuzman and Groselj 2011; Van De Kuilen *et al.* 2011; Lehmann *et al.* 2012; Schmidt and Griffin 2013; Robichaud 2014). In this regard, a study showed that wooden structures can prevent the emission of the equivalent of 1.10 tons of CO_2 per m^3 compared with non-timber systems (Frühwald 2007). Roos *et al.* (2008) also discussed the limited demand for energy in the construction process. Indeed, Shmuelly-Kagami (2008) mentioned the low amount of energy consumed when manufacturing engineered wood products. The sustainable development category also included the good thermal insulation properties of wood (Roos *et al.* 2008) as well as the lower heating costs involved in wooden structures (Oliveira *et al.* 2013).

Technical and performance properties of wood accounted for the second motivation for using wood in non-residential constructions. Literature can be found on: 1) the performance of wood related to fire (Bayne and Taylor 2006; Bysheim and Nyrud

2008; Roos *et al.* 2008; Hemström *et al.* 2010; Schmidt and Griffin 2013; Manninen 2014; Hurmekoski *et al.* 2015), 2) its acoustics and insulation performances (Hemström *et al.* 2010; Kuzman and Groselj 2011; Oliveira *et al.* 2013 Robichaud 2014), 3) its good mechanical and physical properties (Bysheim and Nyrud 2008; Bysheim and Nyrud 2009; Kuzman and Groselj 2011; Hurmekoski *et al.* 2015; Laguarda and Espinoza 2015), 4) the ease of working with the material (Kozak and Cohen 1999; Nolan and Truskett 2000; Nolan 2011; Mahapatra *et al.* 2012; Hurmekoski *et al.* 2015), 5) its hygrothermal performance (Oliveira *et al.* 2013), 6) its durability (O'Connor *et al.* 2004; FPInnovations 2013, on behalf of Cecobois; Hurmekoski *et al.* 2015), 7) its stability (Hemström *et al.* 2010, and 8) its lightness (Roos *et al.* 2008; Birch 2011 Beaucher 2015). When the soil's bearing capacity was low, this factor may have been the main reason for wood selection. In the case of the District 03, building plans foresaw a concrete structure. A soil analysis led to the realization that the ground could not carry the load. This was what convinced the promoter to use wood rather than other materials. For the same capacity and structural volume, the weight of timber represented only 20% of the weight of concrete (Beaucher 2015). In the case of the Bridport House project, the lightness was also a key factor because using wood has allowed for doubling the height of the high-rise while adding only 10% of the weight (Birch 2011).

The third most important motivation was related to cost reductions. It encompassed: 1) material, construction, and maintenance costs (Kozak 1995; Kozak and Cohen 1999; Nolan and Truskett 2000; O'Connor and Gaston 2004; Walford 2006; Bysheim and Nyrud 2008; Roos *et al.* 2008; Shmuelly-Kagami 2008; Williamson *et al.* 2009; Eliasson and Thörnqvist 2010; Nolan 2011; Van De Kuilen *et al.* 2011; Thomas *et al.* 2013; Manninen 2014; Robichaud 2014; Hurmekoski *et al.* 2015) and 2) building erection speed (which constituted the fourth motivation of this study, as discussed in the following paragraph). For example, for the *Via Cenni* project in Italy, "The high degree of prefabrication of CLT elements allows faster assembly times and offers cost advantages (Storaenso 2015)."

The building erection speed was the fourth most valued criteria. Wooden buildings of several floors could apparently be built in very short periods of time (Schmidt and Griffin 2013). For example, the Lifecycle Tower One tower was erected in eight days after the foundation was completed (Buildup 2013). According to Birch (2011), in the case of the Bridport House in London, "The structure was built in 10 weeks, while it is estimated that a concrete structure would have taken 21 weeks to build." This became an important advantage, especially in high density areas, as a possibility to reduce the duration of traffic disruptions. Frequently mentioned terms in the literature are: 1) ease of installation, 2) construction speed, 3) simplicity, 4) flexibility, and 5) lightness (Kozak 1995; O'Connor and Gaston 2004; Bayne and Taylor 2006; Walford 2006; Roos *et al.* 2008; Hemström *et al.* 2010; Van De Kuilen *et al.* 2011; Mahapatra *et al.* 2012; FPInnovations 2013, on behalf of Cecobois; Thomas *et al.* 2013; Robichaud 2014; Hurmekoski *et al.* 2015). Based on surveys conducted by mail and on a series of focus groups about the perception of architects and engineers on wooden structures, O'Connor *et al.* (2004) found that "ease of use" was ranked as the greatest attribute of wood. During their talks and discussion groups, Roos *et al.* (2010) also came to the conclusion that wood is "easy to handle," according to architects and engineers.

The fifth motivation concerned the aesthetics and/or the pleasant atmosphere rendered by the use of wood as a structural material. All of the following terms were used by many authors: 1) warm character, 2) inviting, 3) comfortable, 4) attractive, 5) aesthetic, 6) interesting, 7) enjoyable by occupants, 8) welfare, 9) health effects, 10) natural design, 11) visual beauty, and 12) friendly feeling (Kozak 1995; Goetzl and McKeever 1999; Nolan and Truskett 2000; O'Connor and Gaston 2004; O'Connor *et al.* 2004; Bayne and Taylor 2006; Walford 2006; Bysheim and Nyrud 2008; Roos *et al.* 2008; Bysheim and Nyrud 2009; Gold and Rubik 2009; Kuzman and Groselj 2011; Nolan 2011; Oliveira *et al.* 2013; Manninen 2014; Hurmekoski *et al.* 2015; Laguarda and Espinoza 2015).

Some barriers could also be found in the literature and in post-project evaluations, which could explain why many opportunities related to wood building constructions have remained unexplored. They are prioritized and summarized in Fig. 4.

Difficulties related to the building codes were unquestionably the main obstacle to the adoption of wood as a structural material. National building codes included a variety of rules and limitations that seemed to constrain the use of wood as a structural material. Interestingly, some of the well-known non-residential buildings studied have allowed some code modifications. 1) The fire safety rules and 2) the incorrect perception of wood fire resistance, presented in the building codes, were the most frequently cited elements (Enjily and Bregulla ; Kozak 1995; Goetzl and McKeever 1999; Kozak and Cohen 1999; Gaston *et al.* 2001; O'Connor *et al.* 2003; Bregulla *et al.* 2004; O'Connor and Gaston 2004; Östman 2004; Walford 2006; GeskinConseil 2008; Mahapatra and Gustavsson 2008; Roos *et al.* 2008; Gold and Rubik 2009; Robichaud *et al.* 2009; Williamson *et al.* 2009; FPInnovations 2010, on behalf of Cecobois; Griffin *et al.* 2010; Lehmann *et al.* 2012; Mahapatra *et al.* 2012; Robichaud 2014; Drouin 2015; Hurmekoski *et al.* 2015; Roth 2015). Some authors also pointed out 3) the lack of knowledge related to those codes and to the calculation of wooden beam sizes and ties (O'Connor *et al.* 2003; Bregulla *et al.* 2004; O'Connor and Gaston 2004; GeskinConseil 2008; Mahapatra and Gustavsson 2008; FPInnovations 2010, on behalf of Cecobois; Griffin *et al.* 2010; Mahapatra *et al.* 2012; Robichaud 2014). For example, in many countries, the maximum height authorized by their respective code concerning wooden buildings was six floors. Obviously, many of the studied buildings include several alternatives that were designed, developed, and defended before getting the authorization for construction. For instance, the *Esmarchstrasse 3* in Germany was built while the building code of the city normally authorized constructions in wood up to five stories. To achieve seven floors, some measures had to be taken, the most spectacular of which is probably the concrete cage staircase open to the outside (ReThinkWood 2014).

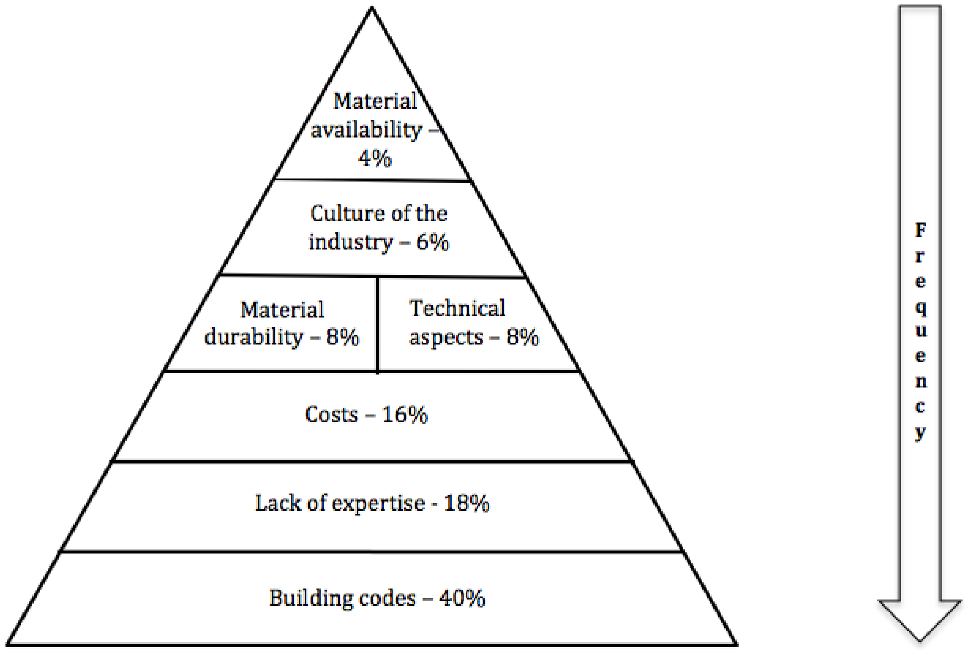

Fig. 4. Barriers and their respective relative weight to the adoption of wood as structural material for non-residential buildings

The second main barrier referred to the lack of expertise and was explained by the following items: 1) lack of research findings transferred to the industry, lack of academic, or continuing training (Enjily and Bregulla; Kozak and Cohen 1997; Gaston *et al.* 2001; Bregulla *et al.* 2004; Mahapatra and Gustavsson 2008; Williamson *et al.* 2009; Manninen 2014; Robichaud 2014), 2) lack of information (Nolan and Truskett 2000; O'Connor *et al.* 2003; Bayne and Taylor 2006; Robichaud *et al.* 2009; Griffin *et al.* 2010), 3) lack of support for technical aspects (Nolan and Truskett 2000; Gaston *et al.* 2001; O'Connor *et al.* 2003; Bayne and Taylor 2006; Roos *et al.* 2010; Nolan 2011), and 4) lack of experience/knowledge/skills towards wood (Enjily and Bregulla; Nolan and Truskett 2000; O'Connor *et al.* 2003; O'Connor and Gaston 2004; GeskinConseil 2008; Mahapatra and Gustavsson 2008; Roos *et al.* 2008; Tykkä *et al.* 2010; Nolan 2011; Manninen 2014; Robichaud 2014; Hurmekoski *et al.* 2015; Roth 2015). Indeed, O'Connor *et al.* (2004) indicated that technology transfer was an obvious obstacle to the adoption of wood, referring directly to the ability of architects and engineers to handle the concepts of timber construction. Roos *et al.* (2010) identified "lack of knowledge" as a criterion reducing wood use by architects and structural engineers. Xia *et al.* (2014) highlighted how knowledge on emerging technologies related to wood is limited. Knowles *et al.* (2011) spoke of knowledge of options and willingness of the design team to compromise. Moreover, wood also faces an image issue, both within the industry and by the general public, because wood is often seen as an out-dated and low range material (Gaston *et al.* 2001; O'Connor *et al.* 2003; Gold and Rubik 2009; Williamson *et al.* 2009).

Paradoxically, cost, which was previously introduced as a motivation for wood use, also seemed to be considered as a barrier. 1) Capital, 2) material, 3) construction, and 4) long-term maintenance costs are often mentioned (Enjily and Bregulla; Kozak 1995; Kozak and Cohen 1999; Gaston *et al.* 2001; O'Connor *et al.* 2003; O'Connor and Gaston 2004; O'Connor *et al.* 2004; Bayne and Taylor 2006; Wei *et al.* 2007; Bysheim and Nyrud 2009; Bysheim and Nyrud 2010; Eliasson and Thörnqvist 2010; Griffin *et al.*

2010; Roos *et al.* 2010; Hemström *et al.* 2011b; Knowles *et al.* 2011; Lehmann *et al.* 2012; Mahapatra *et al.* 2012; FPInnovations 2013, on behalf of Cecobois; Riala and Ilola 2014; Drouin 2015; Hurmekoski *et al.* 2015; Laguarda and Espinoza 2015; Roth 2015), 5) Risk aversion of the construction industry (Emmitt 2001; Bayne and Taylor 2006; Bysheim and Nyrud 2008; GeskinConseil 2008; Mahapatra and Gustavsson 2008; Roos *et al.* 2008; Bysheim and Nyrud 2010; Mahapatra *et al.* 2012; Hurmekoski *et al.* 2015; Roth 2015), 6) fears related to the resale value (Oliveira *et al.* 2013; Robichaud 2014), and 7) lack of experience and of a skilled workforce could also affect construction costs (O'Connor *et al.* 2004; GeskinConseil 2008; Mahapatra and Gustavsson 2008; Roos *et al.* 2008). 8) Insurance issues and increased costs for fire protection *via* the addition of sprinklers were all raised (O'Connor *et al.* 2003; O'Connor *et al.* 2004; Mahapatra and Gustavsson 2008; Robichaud 2014). As stated by Knowles *et al.* (2011), cost is an important factor in the choice of a structural material. Laguarda and Espinoza (2015) have indeed identified the initial cost as part of the main obstacles to the adoption of CLT for tall buildings. The same authors and Xia *et al.* (2014) also mentioned concerns about the high costs related to maintenance of the wood.

The durability of the material and technical aspects were positioned as the fourth constraint to the adoption of wood for non-residential buildings. Both arrived *ex aequo*. Durability encompassed the concerns and perceptions related to the technical lifespan of wood (Enjily and Bregulla; Kozak 1995; Kozak and Cohen 1999; Gaston *et al.* 2001; O'Connor *et al.* 2003; O'Connor *et al.* 2004; Mahapatra and Gustavsson 2008; Gold and Rubik 2009; Robichaud *et al.* 2009; Roos *et al.* 2010; Lehmann *et al.* 2012; Mahapatra *et al.* 2012; Robichaud 2014; Xia *et al.* 2014; Hurmekoski *et al.* 2015; Laguarda and Espinoza 2015). Although durability was integrated into the category of technical aspects in the motivations categories, wood durability appeared so often as a barrier that the choice of creating two categories was made.

Technical aspects concerned several characteristics of wood material: 1) the acoustic performance, 2) security feeling, 3) stability and wood shrinkage, 4) humidity, 5) stiffness and strength, 6) quality, 7) technical defects, and 8) the protection against vermin, insects, rot, water, wind, and earthquakes (Enjily and Bregulla; Kozak 1995; Kozak and Cohen 1997; Kozak and Cohen 1999; O'Connor *et al.* 2003; O'Connor and Gaston 2004; O'Connor *et al.* 2004; Bayne and Taylor 2006; Walford 2006; Roos *et al.* 2008; Gold and Rubik 2009; Mahapatra and Gustavsson 2009; Williamson *et al.* 2009; Eliasson and Thörnqvist 2010; Lehmann *et al.* 2012; Mahapatra *et al.* 2012; Oliveira *et al.* 2013; Robichaud 2014; Hurmekoski *et al.* 2015). Roos *et al.* (2010) mentioned that architects and engineers have negative perceptions concerning wood rot.

The fifth barrier came from the culture of the construction industry. This category also encompassed several elements. 1) The conservative attitude of the sector, 2) the lack of openness, 3) a high preference for established practices (GeskinConseil 2008; Tykkä *et al.* 2010; Hemström *et al.* 2011b; Robichaud 2014; Hurmekoski *et al.* 2015), and 4) the lack of standardization and organization of the industry have been mentioned several times (Enjily and Bregulla; Gaston *et al.* 2001; O'Connor and Gaston 2004; Bysheim and Nyrud 2008; Roos *et al.* 2008; Nolan 2011; Lehmann *et al.* 2012). Comments on 5) the fragmentation of the industry and 6) the idea that stakeholders in non-residential construction did not interact enough with each others are also present in this document sample (Enjily and Bregulla ; Williamson *et al.* 2009; Roos *et al.* 2010; Nolan 2011). Nolan (2011) mentioned a 7) lack of construction-oriented solutions from wood manufacturers, while Oliveira *et al.* (2013) pointed out 8) the stigmatization of wood as a material dedicated to social housing. Lehmann *et al.* (2012) brought 9) the need of cultural, behaviors, organizational and policy changes.

Material availability was the last obstacle found to a greater use of wood in construction (Enjily and Bregulla; Kozak and Cohen 1999; Gaston *et al.* 2001; Bayne and Taylor 2006; Mahapatra and Gustavsson 2008; Roos *et al.* 2008; Robichaud *et al.* 2009; Knowles *et al.* 2011; Nolan 2011; Laguarda and Espinoza 2015). It was mentioned by the four focus groups conducted by Knowles *et al.* (2011). Laguarda and Espinoza (2015), for example, mentioned the poor availability of CLT in the US market.

Following this detailed analysis, an interesting observation can be made: some key elements, including those related to technical aspects, appeared in both the motivations and barriers. This could be explained by the fact that most of the motivations and barriers were perceptions that could change and evolve gradually as the players gained experience. Hurmekoski *et al.* (2015) summarize the idea in an interesting way. They mention that perceptions on costs, fire safety, and stability of wood depend on the experience level and the less experienced, and the majority tends to be more skeptical. Perceptions influence the markets and this explains why they should be known and studied.

Problems and Concerns for Wood Use Based on Minutes Meetings

In this section, the problems and concerns extracted from the building meeting minutes analysis are highlighted. Those problems and concerns are related to the wood material itself and its use on construction sites and/or in the construction industry. The difference between problems and concerns was that, for a problem, an action had to be taken to correct the situation. A comparison with the barriers previously found is then presented.

Problems category

Problems included three sub-categories: on-site assembly, conception, and scheduling. These problems often came with extra costs associated to problem resolutions.

On site assembly problems were noted in 5 of the 9 building projects analyzed. For example, a column was broken, others were too short, and some trusses were damaged, so they had to be repaired. Some roof trusses were also deflected. A piece of wood was dropped and damaged, something not mentioned by the contractor. The dimensions of some structural pieces were incorrect. Some structural elements had to be strengthened and some beams had to be moved. Problems also included the deformation of a joist caused by gravity forces between strengthening beams. Some grooves were too deep. Some bracings were placed inappropriately both on plans and on sites, so their locations in the structure had to be changed. Others were missing or had to be strengthened. Some could not be used in their initial delivered form and had to be modified since delivery time of new pieces was not acceptable. Pieces of wood, but also steel plates, were improperly pierced and some pieces of wood were not manufactured according to specifications. Some glue overflow and dirt on wood arches were visible and had to be cleaned since for glulam aesthetic properties are important. Other problems related to the use of wood came from humidity levels and sites assembly issues. Some CLT panels got too humid and it became necessary to remove humidity as quickly as possible from the structure. Fans and heating systems were used in a way to prevent a thermal shock and the problem was solved.

Some steel washers were furthermore conflicting with some vertical bar reinforcements and had to be cut to allow the installation of a bracing. Some bolts had to be tightened. Some holes for anchorages were made at the wrong place so they had to be fixed. Some new screws had to be bought and some new plates had to be built. Others had to be repainted. In one of the buildings, there was confusion in the identification of the anchorages and some had to be galvanized, but were not once they arrived on construction site. Anchorage and connector deliveries were sometimes not on time, which caused delay in the work planning.

Hanging roofs have to be hanged at the right distance from the main roofs to allow all equipment to be installed. In some cases, they had to be lowered down due to lack of space for the equipment. The equipment must be attached to the right pieces of wood to be strong enough to support the weight. In these cases, the lighting system had to be moved after it had been affixed in the wrong place. More wires were then needed to reach its new location, increasing the total system cost.

The conception sub-category mainly included problems related to plans and it appeared in 3 of the 9 buildings for which data were obtained. In one of the projects, there was an issue related to the structure's supplier selection causing an important delay. Surprisingly, one of the structures was up while its official plans were missing. Material environmental information was also difficult to obtain.

According to a professional registered in the data set, working with wood was different from working with steel or concrete. When working with wood, once the structure was erected, modifications were less easy to make. That was why a lot of attention seemed to have been given at the conception phase, in order to make sure that a maximum of mistakes would be caught before potentially being introduced in the final structures.

The last sub-category for the problems is related to scheduling issues, and it was found in 3 of the 9 projects studied. Some delays were observed when building certain parts of the plan and the conception phase took longer than what was planned. Sometimes, arches' and, in some cases, beams' strengths had to be recalculated, which took longer. The installation of the structures also took longer than thought or planned. Some fabrication and delivery delays for manufactured structural components were also part of the problem. When this happened, the work sequence planned had to be reviewed, causing some delays in the erection of the structure. Some professionals being involved in many projects, their workloads were sometimes significant, which might also have explained some delays.

Concerns category

Of less importance, but also worthy of consideration, the concerns that came up through the construction of these nine buildings were related to the following sub-categories: stakeholders' relationships, conception, on-site assembly, and scheduling.

These projects involved many relationships between many stakeholders. These issues were found in 6 of the 9 datasets. Of course, the higher the number of professionals involved in a project, the more complex it might have become to manage the business relationships. Misperceptions, communication problems, delays, and accountability issues seemed common. In some of the projects, two different structural engineers were involved for the same project, including an "official" one hired to design the structure and another one from the structure's supplier, leading to complex communications and often ill-defined responsibilities. In fact, the engineered wood manufacturer played an important role in the conception since he owned the intellectual property related to the engineered product itself, so the “official” structural engineer had to interact frequently with him, but also to wait for his answers. The electrical engineer also had to be included in the work soon enough so the services needed could be harmonized with the structure. The data analyzed revealed lots of discussion related to this kind of harmonization. In construction, City Hall is responsible for delivering permits and making sure that the project will be conducted according to the Building Code and regulations in general. Professionals had to demonstrate how their proposed solutions met the Code requirements. In one of the projects analyzed, the city asked to be provided with the following details: the method used to install the arches, the documentation related to the environmental impact of the product applied on wood, and a confirmation from the structural engineer that the assembly method for the arches and for the end connectors used by the installer was compliant. The project team also had to explain why the work necessary for affixing the anchors to stabilize the arches had not begun yet. Similarly, a detailed schedule had to be provided before a given deadline. In addition, the builders asked confirmation of the structural engineer for certain elements that were already addressed and sealed in the conception phase, causing tensions. In another project, City Hall had to give a second approval after the modification of some design details. In another one, the government representative asked for information related to flame dispersion of the Oriented Strand Board (OSB) used in beams. In one of the cases, one insurer asked for signed documents by engineers. Builders having less experience with wooden structure might have wanted to protect themselves or limit the risks they were taking. In one of the cases studied, the builder asked to be discharged of tubing freezing risks located in the roof although the setting would have been the same if using concrete or steel. The architect and builder finally agreed to use expanding material to isolate the tubing without signing any discharge. The builder also agreed to pay for it.

The conception sub-category mostly includes connectors and structure issues. It was found in 6 of the 9 datasets. Among all types of connectors, the anchorages were widely discussed, the problems being pointed out concerning hole locations on the structure and on the plates. Plate and bolts sizes, as well as joints’ designs, also seemed challenging. Obviously, all the elements cited above had to be planned appropriately since they could have interfered with the structural properties of the buildings. The visual aspect of the anchorages also mattered. Their positions had to make sense structurally, while looking good. The electrical and mechanical holes and hangers were another example of connector discussed. Decisions linked to the choice of the location to attach them on the structure and where on them they could be attached were mentioned. In addition, the screw dimensions, types, and fixation techniques used to affix nozzles and lighting systems seemed an issue, while the space left between the hanging roofs and main roofs had to be planned so as to allow all mechanical and electrical services, including ventilation and plumbing, to be installed properly. The structural elements were also widely discussed in the meeting minutes of the wood building projects analyzed. In some projects, special meetings were organized to coordinate and work on the technical elements of the structure itself and to specify types of wood engineered products, pieces dimensions, and requirements. Concerns linked to the Building Code were sometimes examined. In one of the cases, the seismic charges of the arches were checked and some special materials prescribed to meet fire safety Code requirements. Arches and beams sizes have to be determined, especially in relation to snow loads and wind forces, necessitating the manufacturer’s insight. The holes position in the arches had to be checked as well as the number of columns needed. The joists, rim boards, and bracings locations also had to be determined to prevent interference with others components of the structure. Picking the right varnish for one of the building structure and applying it properly was also discussed.

On-site assembly concerns were found in 6 of the 9 studied projects. Discussions about work sequencing and scheduling were numerous. In some cases, delivery constraints for the wooden material slowed down off-site assembly for the structure. Concerns noted in this sub-section were also related to the protection of the structure against sun exposure, and against breaking and damaging, while being manipulated. Material storage had to be done in a proper way to avoid losing aesthetic properties. Roof truss deflection, openings in the floor, roof heights, and humidity were also issues discussed in the various projects reviewed.

Scheduling concerns were detected in 4 of the 9 projects analyzed. Ordering had to be done on time to make sure wooden pieces got on the field at the right moments and, of course, the structure manufacturers should have produced and delivered the orders on time. In one of the projects, a contractor could not determine the fabrication date of the wood elements, which impacted the projected schedule. Work delays also got to be part of the picture in some projects and for a particular project, possible winter construction site costs were also discussed.

Discussion

As presented in Table 2, this paper found overlapping evidence from the multiple settings and data sources examined. Motivations and barriers related to the use of wood in non-residential construction emerged from an analysis of multi-story buildings, while problems and concerns were derived from various categories of buildings (commercial, industrial, institutional, and governmental). By the same token, some problems and concerns found in the meeting minutes match the barriers that were found *via* technical documents, reports, and the literature. It was important to note that the motivations for using wood are less likely to be recorded in meeting minutes because they often involved a different decision level. This is why the choice to study the barriers to the use of wood was made.

The first common issue was related to the Building Code. In the meeting minutes, the Building Code was pointed out for several reasons: fire safety, seismic strengths, wind and snow loads impacts, and so on. The information found in the meeting minutes thus confirms that the Building Code was a real challenge for architects and engineers, particularly at the building design phase.

Lack of expertise appeared as the second common issue. The meeting minutes revealed many assembly issues possibly strongly related to the lack of experience of the staff working with wooden structures. As mentioned previously, university programs dedicated to the use of wood as structural material have remained very limited (Gaston *et al.* 2001; O'Connor *et al.* 2004; O'Connor 2006; FPInnovations 2013, on behalf of Cecobois). The fact that each professional uses different design tools that were often incompatible also provided some potential explanations for assembly issues.

Increased costs, the third most common issue, was associated in the meeting minutes with assembly issues, changes in schedules, and planning errors, confirming its importance when using wood.

Other technical aspects also constituted a common issue, confirmed by acoustics, wood shrinkage, humidity, stiffness, and strength calculation concerns (*e.g.*, wind and earthquakes), as well as manufacturing or installation mistakes.

The limited availability of engineered wood products on markets was pointed out in the meeting minutes, with the structural elements not being delivered on time on construction sites or some delivery dates being sometimes difficult to obtain. These uncertainties interfering with costs and project schedules may have fueled scepticism about the use of wood for non-residential buildings.

The durability of wooden material was not cited directly in the meeting minutes. It was observable only after a certain number of years following the construction of the building. However, the meeting minutes reported on many necessary precautions at the operational level when using wood: it had to be protected and handled with great care, while storage and protection precautions were considered to avoid negative effects on the appearance and durability of the wood. The culture of the industry was also not directly mentioned in the meeting minutes. It was quite easy to assume that the culture of the industry was probably not widely discussed on project sites. Nevertheless, multiple events occurring on construction sites were certainly affected by this "culture," such as conflicting relationships between stakeholders, unclear responsibility sharing, undesired delays in orders and deliveries, *etc.* Many of those decisions were specifically related to the strategic level of companies, but they also affected actions at the operational level, so it became very important to keep the influence of industrial culture in mind.

Table 2. Comparison between Barriers, Problems, and Concerns

Barriers (Documents, Technical Reports and Literature)	Problems and Concerns (Meeting Minutes)
National Building Codes	Fire and seismic safety
Lack of expertise	On-site assembly issues
Costs	Cost increases
Material durability – Other technical aspects	Storage and protection - Acoustics, wood shrinkage, humidity ranges
Culture of the industry	Stakeholders' relationships, delays, and workloads
Material Availability	Orders and deliveries

Taking a step back, it seemed that many of the on-site problems and concerns mentioned could have been avoided, if all the players involved in the projects had worked together, especially at the conception phase. If real-estate developers, architects, engineers, builders, and suppliers had shared their insights from the beginning, it was probable that many problems and concerns found in the meeting minutes would have been solved before starting on-site operations. Through collaborative work, individual experiences could, furthermore, be more efficiently shared than when individual stakeholders were working on their own for various project phases. Indeed, the design-build construction methodology implied seating all professionals together from the conception phase to the end of construction, precisely to avoid important main disagreements caused by the classical *modus operandi*. Wood building projects would probably have gained substantially if managed following a design-build construction methodology.

Another particularity was that using wooden structures is new for most of the stakeholders involved in these projects. Therefore, the following questions arose. What kind of attitude do these workers have towards innovation? Would their work tasks be revised or modified knowing that working with wood is novel to them? Would training help teams to develop the skills required for working with wooden structures? Maybe such reflections could help sustain the wooden structure market and constitute a lynchpin for companies to succeed in this niche.

CONCLUSIONS

1. Many tall wooden buildings have been built in recent years all around the world. Nevertheless, wood is still less popular than steel and concrete. The tallest wood construction project completed at the time of the study reached 14 stories (now 18 stories in BC, Canada). Some studies indicate that wood tends to be selected slightly more often than before, although it could technically be used in many other construction projects. An increase of wood as structural material in non-residential buildings would stimulate the forest products industry, while having a great impact for the Canadian economy.
2. An analysis of non-residential building case studies from around the world, as well as articles from the literature, found many motivations that could explain the market's interest for wood. Sustainability, technical aspects, costs, rapidity of erection, and aesthetics of wooden structures are perceived as positive aspects of wood for multi-story buildings. On the other hand, some barriers still prevent its use. Building Codes implementation, lack of expertise, costs, material durability and technical aspects, culture of the industry, and material availability appear to be the main ones.
3. An analysis of nine non-residential building projects completed between 2004 and 2015 in the province of Quebec, Canada, brought up a variety of problems and concerns related to the use of wood. They were mainly linked to the conception of the buildings, on-site assembly issues, scheduling, and stakeholder relationships.
4. The barriers and the problems and concerns found are consistent. The latest results validate what had been found in the cases studied and the literature. These findings should help—and be used by—companies or government authorities to better understand the current timber building context and to position themselves in this market because it could become a source of sustainability-driven economic growth.

ACKNOWLEDGMENTS

The authors are grateful to Natural Sciences and Engineering Research Council of Canada for the financial support through its ICP and CRD programs (IRCPJ 461745-12 and RDCPJ 445200-12) as well as the industrial partners of the NSERC industrial chair on eco-responsible wood construction (CIRCERB).

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Article submitted: June 28, 2016; Peer review completed: September 17, 2016; Revised version received and accepted: November 14, 2016; Published: November 23, 2016.
DOI: 10.15376/biores.12.1.546-570