Main Motivations and Barriers for Using Wood as a Structural Building Material – A Case Study

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Résumé – Depuis plusieurs années, l'acier et le béton se sont avérés les matériaux traditionnellement utilisés pour la structure des bâtiments non résidentiels et multi-logements. Le bois offre pourtant les mêmes propriétés structurales et ce n'est que récemment qu'une variété de bâtiments de plusieurs étages ont été construits à partir de ce matériau. Dans cet article, nous nous penchons sur les principales motivations et les principaux obstacles à l'adoption du bois, en nous appuyant sur une étude de cas et une analyse de projets réalisés en bois. Les motivations que nous mettons en relief sont liées à la durabilité du matériau bois, la rapidité d'érection des bâtiments, la réduction des coûts, la visibilité et la légèreté du matériau. Les obstacles sont quant à eux liés aux Codes de construction, au transfert de technologies, aux coûts de construction, à la durabilité perçue du matériau et à sa disponibilité. L'analyse du contenu de compte-rendu de réunions concernant la construction de deux bâtiments non résidentiels en bois a par ailleurs permise de souligner certains problèmes et préoccupations concernant leur conception, l'utilisation du matériau bois lui-même, des retards, le Code du bâtiment, les relations entre les intervenants et un certain manque d'information. Avec une meilleure compréhension des enjeux et des attentes des clients, les entreprises du milieu pourront ainsi mieux développer leur offre et contribuer à valoriser encore plus le bois dans la construction non-résidentielle.

Abstract – Steel and concrete are traditionally used as structural material for non-residential and multi-housing buildings. However, wood can meet the same structural properties and a variety of multi-storey buildings have recently been built all over the world using this key material. In this article, main motivations and barriers to wood adoption for structural uses have been highlighted, based on a case study and an analysis of construction projects using wood. The motivations found are linked to the following aspects of using wood: sustainability, rapidity of erection, cost reductions, visibility, and lightness of wooden structures. On the other hand, the barriers preventing its use are Building Codes implementation, technology transfer, construction cost, material durability, and material availability. An analysis of the non-residential timber building meeting minutes of two projects also helped in identifying problems and concerns related to the conception of the buildings, wood material use, scheduling the conception of the buildings, wood material issues, construction delay, Building Codes difficulties, stakeholders' relationships, and a certain lack of information. With a better understanding of the expectations as well as the challenges concerning wood usage in non-residential construction, companies will be able to adapt their business models and use even more the resource to develop innovative structures.

Mots clés – Bâtiments non résidentiels, bâtiments en bois, matériau de structure, motivations, freins
Keywords – Non-residential buildings, timber buildings, structural material, motivations, barriers

1 INTRODUCTION

The construction industry in Canada includes more than 1.3 million workers, representing the fifth-largest employer of the country and accounting for 7.3% of jobs among all industries [Forest Products Association of Canada, 2011]. In the Province of Quebec, it also involves around $48 billions investments in 2013, representing 13 % of Quebec's Gross Domestic Product (GDP). It creates 257 800 direct jobs in average every months, accounting for one out of 20 jobs in the province and this is without counting the thousands ones in related sectors [Commission de la Construction du Québec, 2015]. 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, 2015]. In 2013, the Quebec's Province forest industry offered 60 082 jobs which 23 969 of them were related to the forest product industry [Industrie Canada, 2015].

A more intensive use of wood in non-residential buildings could create a stronger demand for engineered wood products resulting in a positive impacts for job creation in the forest industry across Canada and nonetheless on the forest economy. While even more buildings have been constructed in recent years using wood structures, there are still some perceptions and barriers that contribute to slow down the development of this market. In this article, we will present those concerns and obstacles identified based on real wood construction projects. The goal of this paper is to help companies as well as the government to better understand the challenges related to using wood as a structural material in non-residential constructions so they could adapt their business models/legislation to facilitate the market expansion.

The article is structured as follows: In the second section, a presentation of major construction projects in different countries using wood as key material is made, as well as the current picture of wood market shares in non-residential constructions. The third section highlights the main motivations and barriers related to wood construction identified based on a real projects analysis and some articles of the literature. The fourth section presents the chosen methodology. The fifth section introduces concerns gathered using two non-residential timber building meeting minutes and a conclusion ends the article.

2 MAJOR TIMBER BUILDING PROJECTS IN THE WORLD

After World War II and the following industrialized era, steel and concrete quickly became the most commonly used building materials for non-residential constructions. For almost half a century, all kind of buildings, namely industrial, commercial, institutional, governmental, and multi-storey buildings, have been built with one – or both - of these two materials. However in the last 20 years, this trend has evolved. Wood has increasingly been considered as a structural building material for non-residential constructions and this recent trend is observed in many countries.

For example, in Berlin, Germany, many renowned wooden non-residential projects have been carried out such as the *Esmarchstrasse 3 project.* This seven-floor multi-storey building has an outdoor concrete emergency staircase that makes the building different from an architectural point of view [CECOBOIS, 2013]. *H8 Bad Aibling*, another German project, is an eight-floor building built in 2011. The builder used Cross-Laminated Timber (CLT) panel and a prefab-concrete stair to provide lateral stability [As, 2012].

In London, England, the nine-storey building named Stadthaus Murray Groove was erected in 2009. It is considered as the pioneer of timber residential tower buildings in the world. It is made of CLT provided by the building company KLH and is shaped as a cellular structure of timber load bearing walls where all components are 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-storey residential building, it was designed to provide 41residential units [Birch, 2011].

In Austria, the Lifecycle Tower One, erected in 2012, is the world's first hybrid wood passive eight-floor building. Its first floor is made of concrete while the seven other floors have been built using wood [Build up energy solutions for better buildings, 2013].

The *Forté Building*, a ten storey 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 [Wood Solutions design and build, 2013]. It is made of 759 CLT panels (485 tons) of European spruce (picea abies) coming from Austria. Its sustainable attributes were brought forward in the marketing strategy used to promote the project [Land Lease, 2015].

In *Växjö*, Sweden, the *Limnologen*, a 134 co-op apartments divided in 4 towers of 8 floors each, were being 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 floors residential tower and this one is presented as a showcase for social housing using multi-storey timber construction. The CLT was selected as structural material [Storaenso, 2015].

In Auckland, New Zealand, the Scotia Apartment Tower is a 12 storey apartment building standing on a single storey basement. It has wood floor diaphragms and lateral load resisting systems

[Moore, 2000]. The objective for this hybrid structure built in 2000 was to develop the most cost-effective structural system that could also meet the building code.

The highest wood building in the world, the *Treet* (meaning the three), is located in Bergen Norway. This 14-storey project started in 2014 and should be finished by the end of 2015. All main load-bearing structures are made of wood and glulam is used for the trusses. CLT is 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. *Fondaction Québec Building* and *District 03* are both examples of six storey buildings erected in wood in 2008 and 2013 respectively [CECOBOIS, 2013; Beaucher, 2015]. *Fondaction Québec Building* has been constructed using glulam and *District 03* with CLT. Stadiums, hotels, and commercial buildings are other examples of non-residential buildings constructed entirely in wood in the last years in theP. Furthermore *Origine*, a 13 floors, will be built in the fall of 2015 and will become the highest timber building in North America [Origine Écocondos de la Pointe-aux-Lièvres, 2015]. All these projects are summarized in table 1.

In the next sub-section, we will now look at the importance of wood from an economic point of view in the non-residential market.

Table 1: Major timber building projects in the world.

Storeys number	Building year	Country	Building name
6	2008	*Québec*	*Fondaction*
6	2013-2014	*Québec*	*District 03*
7		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	2015 (to be build)	*Québec*	*Origine*
14	2015	Norway	*Treet*

Current market shares of wood in non-residential constructions

The use of wood in construction projects has increased in the last decade, but it is still not a common practice. As a result, a variety of studies 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 explain 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 Province of Quebec, market shares of wood used as structural material have increased from 18 % to 22 % between 2006 and 2009 [FPInnovations on behalf of Cecobois, 2010]. Another study conducted on 72 architects and 27 engineers has also shown that between 2009 and 2012, the specification of wood for structural system had remained relatively the same. This survey has furthermore demonstrated that structural engineers tended to pick wood for building structures slightly more frequently than architects did (20 % versus 17,8 %) [FPInnovations on behalf of Cecobois, 2013]. A recent study conducted in 2015 on a bigger sample has indicated that in average, 24.1 % of the non-residential buildings of 4 storeys and less built in 2014 by 118 architects and 54 engineers had a wooden structure [FPInnovations on behalf of Cecobois, 2015].

Wood use has increased over the years, but could it grow more? In fact, only in Canada, a study on 47 buildings in Ontario has shown that while 81% of these buildings could have been constructed in wood, only 19% had finally selected wood as main material, leaving a 62% possibilities to be captured. Another investigation based on the 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 area are currently being framed in wood, and that another 23% is still available for wood usage. "This suggests that over three times more constructed area could be in wood and, subsequently, wood consumption in non-residential buildings could be increased by a factor of three" [O'Connor, 2006].

As aforementioned, many major construction projects all around the world have used wood as the key material. On the other hand, many studies have shown the economic potential still unexplored. In the next section, we will try to identify some motivations and barriers that could explain the role played by wood in non-residential constructions.

3 MOTIVATIONS AND BARRIERS LINKED TO USING WOOD

In this section, the motivations for which architects, structural engineers, promoters, and clients are interested by wood as structural component are described. The obstacles that seem to have an impact on wood promotion in construction projects are also highlighted. It could have been interesting to analyse the motivations and barriers linked to steel and concrete uses to be able to compare the three structural materials. Since this study is limited to buildings with wooden structure, the results do not offer a global picture of the reasons why a specific material is selected over another. Even if this study is partial, it still brings some new information related to wood uses as structural components in construction projects.

The motivations and barriers of this study were gathered from the different national and international renowned projects introduced in section 2 as well as from articles found in the literature. These articles were written between 1999 and 2015. They come from 3 Wood Sciences databases and mains keywords used to gather them were the following: motivations, barriers, opportunities, perceptions, timber buildings, and multi-storey buildings. It is important to mention that written sources found in the literature mainly concern multi-storey timber buildings and the literature mostly contains insight from architects and structural engineers. The following lists could vary if other building categories and actors' perceptions were analyzed. Figure 1 prioritises and summarises the motivations found.

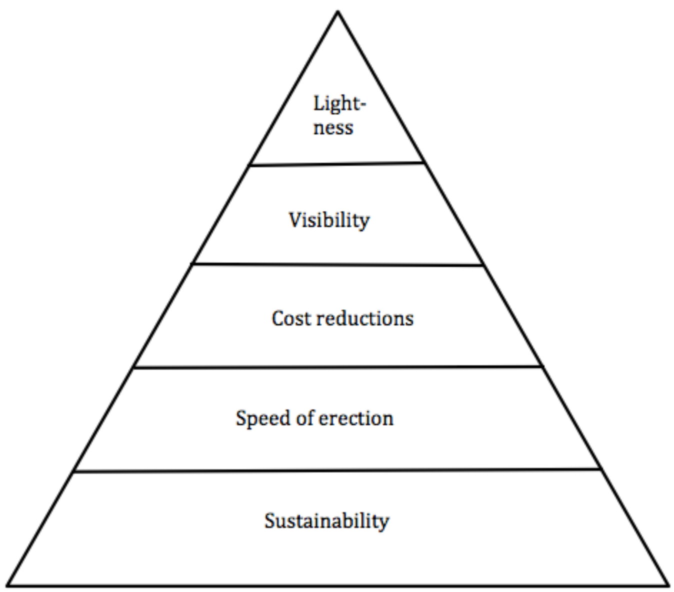

Figure 1 – Motivations to the adoption of wood as structural material for non-residential buildings.

When looking at many construction projects, the most cited motivation for choosing wood as structural material for multi-storeys buildings appears to be sustainability. For instance, the *Fondaction Building* built in Quebec City "contributed to an energy saving of 40% if compared to the Energy National Model Code for buildings, in addition to having reduced 1 350 tonnes of CO2 emissions in the atmosphere" [CECOBOIS, 2013]. The literature also confirms the environmental performance of wood [Schmidt & Griffin, 2013; O'Connor and *al*., 2004; Lagurda Mallo and Espinoza, 2015; Roos and *al*., 2010] and its energy related specificities [Schmidt and Griffin, 2013; Bysheim and Nyrud, 2009]. In this regard, a study has shown that wood systems may replace the equivalent of 1.10 t of CO2 emissions per m^3 in comparison to non-wood systems [Frühwald, 2007]. Sustainability also encompasses good thermal insulation properties, energy related specificities, and lower heating costs.

The speed of erection of the structure is the second most appreciated criteria. Timber multi-storey buildings can apparently be erected in very short periods of time. For example, the Lifecycle Tower One, the eight floors Austrian timber tower, was erected in eight days after the foundation was done [Build up energy solutions for better buildings, 2013]. Birch [2011] says on the technical aspects of the London Bridport House that "The structure was built in 10 weeks, while it is estimated that a concrete structure would have taken 21 weeks". This could be an important advantage in high-density districts to decrease circulation perturbations. "Ease of use" and "simple handling" again related to building erection were also mentioned frequently. Based on mail surveys and a series of focus group conducted on architects and engineers' perceptions of wood structure, O'Connor and *al.* [2004] revealed that "Ease of use" was rated as wood's greatest attribute. Roos and *al.* [2010] also came to the conclusion from their interviews and focus groups that wood is "simple to handle" for architects and structural engineers.

The third most important motivation concerns cost reductions. They encompass both wood material cost and construction costs while being closely related to the previous motivation mentioned (i.e., rapidity of erection). Based on the *Via Cenni* case in Italy "The high degree of prefabrication of CLT elements enables fast erection times and offers cost advantages" [Storaenso, 2015]. In the literature, many authors pointed out the economic benefits that could be generated when using wood as structural material [O'Connor and Gaston, 2004; Roos and al., 2010; Bysheim and Nyrud, 2009; Riala and Ilola, 2014; Schmidt and Griffin, 2013].

Visibility also comes up often around the tall wood building projects; it is the fourth more important motivation. This factor takes many forms or is expressed in many ways and is often supported by the construction project promotors. Constructing the highest building in the world seems to be honorific. The will of being the leader and the first country, city or promoter to build the highest building repeatedly appears in the project's related texts. This fact is obvious when reading on many of the studied projects and on their advertising. "Explore the world tallest timber apartments" can be red on the *Forté Building* promotion web page [Land Lease, 2015]. More technical documents also highlight this fact: "*District 03*, the highest wooden multi-residential on the east coast" [Beaucher, 2015]. This concern was not found in the scientific and technical literature, which is mostly prior to the construction of these two projects.

According to texts and data found in this research, the lightness of wood structures is also advantageous, especially when the bearing capacity is low. This is the fifth most frequent motivation in wood construction projects. In some cases, it is the main reason explaining why wood was selected instead of steel or concrete structures. In the case of *District 03*, the six storeys building plans called for an apparent concrete structure. But an analysis suggested that the soil could not bear the load without an important pile foundation. This is what convinced the promoter to use wood instead of another heavier material. For a same structural capacity and volume, weight of wood only represents 20% of the weight of concrete [Beaucher, 2015]. For the Bridport House project for example, the lightness was "an essential key factor since using wood as allowed to double the previewed height while adding only 10% weight" [Birch, 2011]. Curiously, this criterion was again not mentioned in the scientific and technical literature.

More criterions can be found in the literature although they are mentioned less frequently. The physical and mechanical properties of wood [Bysheim and Nyrud 2009; Laguarda Mallo and Espinoza, 2015] and its appearance are examples of particularities that seem being appreciated [O'Connor and *al.*, 2004; Bysheim and Nyrud 2009; Laguarda Mallo and Espinoza, 2015]. Schmidt and Griffin [2013] also pointed out the idea that some professionals adopt wood structure because of it is a fire resistant material while requiring less labour to build the structure.

Some barriers can also be found in the literature and in post-project evaluations that could explain why many opportunities concerning wood building constructions are still unexplored. . They have been prioritized and resumed in Figure 2.

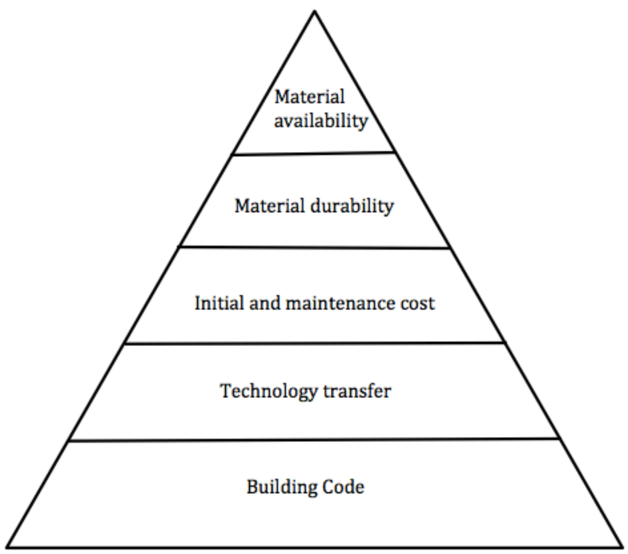

Figure 2 – Barriers to the adoption of wood as structural material for non-residential buildings.

Difficulties related to Building Codes stand out for the first major barrier. National Building Codes include a variety of rules and limitations often preventing the use of wood for building structures. For example, in many countries, the maximum height for wood buildings authorized by the Code is six storeys. Most of the buildings studied present several alternatives that have been thought, proposed, and defended, to meet the requirements of the Codes. For instance, the *Esmarchstrasse 3* was built in Germany while the City Building Code was normally authorizing the erection of maximum 5 storeys for wooden building. To be able to reach seven storeys, some measures were taken and the most spectacular one was probably the concrete cage staircase open to the outside. Fire and seismic safety rules also included in theses construction codes are often difficult to meet when using wood [ReThinkWood, 2014]. Knowles and *al.* [2011] showed that Building Codes regularly drives the structural material selection. The four groups of construction professionals interviewed identified the Code as part of the primary design constraints. This fact has also been identified in other studies [Schmidt and Griffin, 2013; O'Connor and *al.*, 2004; Bysheim and Nyrud, 2010; Laguarda Mallo and Espinoza 2015].

Technology transfer as well as information and knowledge gaps appear to be the second main barriers to more wooden structural material adaption. Architects and engineers have regularly not learnt how to use engineered wood products through their respective diplomas. When they accept to work on timber buildings, is it less easy if compared to steel or concrete structures. Working with wood is fairly new to many construction professionals and implies more risks and challenges. There is a need for knowledge extension to make wood structures as easy as to work with steel or concrete ones. For example, O'Connor and *al*., [2004] indicated that technology transfer is a clear barrier for wood adoption, referring to the ability of the architects and engineers to handle wood building concepts. Roos and *al*., [2010] identified “knowledge gaps” as criteria having reduce the use of wood among architects and structural engineers. Knowles and *al.* [2011] talked about “the impact of design team knowledge of options and trade-offs”. Xia and *al.,* [2014] used the terms “limited awareness of the emerging timber technologies”.

While less important but not negligible, the initial material cost is pointed out to explain a reduced use of wood in non-residential buildings. This aspect is mainly mentioned in the literature. As indicated by Knowles and *al.* [2011], cost is an important driver for structural material selection. Laguarda Mallo and Espinoza [2015] have identified the initial cost to be part of the main barriers to succesfull adoption of CLT for tall buildings. The same authors as well as Xia and *al*. [2014] also mentioned perceived concerns about “high maintenance cost of wood”.

Material durability (also linked to maintenace) often linked to material performance is another constraint for more wood adapotion [O'Connor and *al*., 2004]. Roos and *al*. [2010] mentioned that “architects, and even more so engineers, perceptions of negative aspects of wood focused on decay”.

Material availability finally appears to be a barrier. It was stated by the four focus groups interviewed by Knowles and *al.* [2011]. Laguarda Mallo and Espinoza [2015] on their side talked about “lack of CLT availabality on the US market”.

Motivations and barriers summary

As seen above, wood as structural material is used more commonly these years. Lots of buildings have been constructed all over the world and specialists think that they will gain even more popularity and importance in the future. Lots of motivations explain this attitude towards wood but barriers to its adoption also exist and should not be underestimated.

By analyzing major construction projects using wood as the main material as well as some articles from the literature, some elements that could certainly help companies to better adapt their offer and business models have been pointed out. Construction meetings minutes were also used to better identify and understand problems encountered in wood building construction projects and sites. It is probably the first time that such documents are used to gather information concerning wood building construction motivations and concerns. The next sections will explain the methodology followed and the results obtained.

4 METHODOLOGY FOR GATHERING INFORMATION FROM CONSTRUCTION MEETINGS MINUTES

In order to gather key information concerning problems and concerns that could emerge when building multi-storey wood constructions, construction meetings minutes have been explored based on a qualitative approach. According to Écuyer [1990], this type of method aims to describe specific particularities of different elements (words, sentences, ideas) contained in different categories. The essential signification of the phenomena studied comes from the nature and the specificity of the studied contents rather than from its quantitative distribution. To analyze the content, the 6 steps methodology proposed by *Écuyer* [1987] was followed. It involves: 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 consists in gathering statements whose meaning is similar. A category is a kind of common denominator in which a set of statements can be naturally incorporated without forcing the meaning. It is then possible to 4) quantifying the categories in terms of frequencies, percentages or various other indexes. Eventually comes 5) the scientific description, based on quantitative analysis and qualitative analysis, which is often used to explain the findings of the quantitative analysis. Content analysis ends with 6) an interpretation of the results which can take several forms.

Content analysis can therefore be considered as a scientific method, used to process diversified data by applying a coding system leading to the definition of categories. These categories allow data to be analyzed in quantitative and qualitative ways. Qualitative analysis includes analysis of manifest content, 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. While it is possible to make content analysis manually, without specific IT support system, N'Vivo software has been selected in this study to conduct the analysis.

4.1 Construction meeting minutes

Construction meeting minutes encompass all the discussions taking place in all meetings related to a given construction project. They are therefore the best record of what happened during the progress of the work resuming all conversations and decisions taken in these meetings. They are also really helpful to keep the players of the process updated while the project is being conducted. According to the Ontario Association of Architects [2015], they “may enable interested parties to provide valuable input before it impacts project cost or schedule”. Their format can vary. Word or Adobe documents are usual. E-mails can also be archived.

4.2 Projects analyzed

The construction meeting minutes analyzed concerned two non-residential wood construction projects conducted in the Province of Quebec. The first project analyzed is a multi-sport stadium built with glulam structure in 2009. The structure is a 13 massif laminated arches using a total volume of 617 m^3 of wood for the whole stadium. This wood mass represents 1,234 tons of CO_2 sequestered. The arches are connected to a concrete base. The amount of wood has cost 10% of the entire building cost. The second building is a 4-storey timber building developed for social housing including 40 living units. It has been built in 2015. The building has two sections. The first section is a traditional light frame structure where the second section is a CLT structure. The building was design to meet an energy efficiency of 25.1 kWh/m2 per year.

4.3 Analyzing construction meeting minutes with N’Vivo

The methodology is now presented following the steps suggested by l’Écuyer. 1) After having inserted the two sets of construction meeting minutes in N’Vivo, their content was read a couple of times each. 2) Once done, it became possible to start breaking data into smaller data sets and 3) categorization could begin. A code was allocated to text segments following some rules preliminary defined while achieving readings. These rules were adjusted through analyses and coded segments became part of the categories. Since data sets were fairly big, queries were also conducted in order to find parts of the construction meeting minutes related to the categories created. Different words were used to browse data: structure, wood, and problems. After having done many queries came a point where no more new elements would be revealed by subsequent queries. It is called data saturation and indicates the analyse end [Mucchielli, 1996; Poupart and *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.

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

To continue with l’Écuyer’s methodology, 4) the problems and concerns are presented by order of importance which in fact is directly linked to the number of data sets related to categories and sub-categories; 5) they will also be explained and detailed and 6) they will be put into context and interpreted.

5 RESULTS: PROBLEM AND CONCERN CATEGORIES

Analyses of the two buildings data through the qualitative methodology explained above has brought up a bunch of problems and concerns related to the use of wood in non-residential building structures. They are explained below.

5.1 Problems category

The problem category included 3 sub-categories: the conception of the buildings, wood material use, and scheduling.

Conception problems include the deformation of a joist caused by gravity forces between straightening beams. Some bracings

having also been placed inappropriately both on plans and on sites, their localisation had to be changed. Some steel washers were furthermore conflicting with some armature vertical bars and had to be cut to allow the installation of a bracing. Finally, some holes for anchorages had been made at the wrong place. They had to be fixed and some new plates had to be built.
Problems related to the use of wood came from humidity rates and sites assembly issues. Some CLT panels got too humid and it became necessary to remove some water 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. The technician in architecture while visiting the site observed some abnormalities in the wood structure. A column was broken and some struts were damaged, so they had to be repaired. Some glue overflow and dirt on wood arches were visible and had to be cleaned since the glulam were also aesthetic. A piece of wood was finally dropped and damaged while the contractor did not mention a thing.

Some delay where also observed when realizing certain parts of the plan. According to a professional, working with wood is different from working with steel or concrete. When working with wood, once the structure is erected, modifications are less easy to make. That it why lots of attention has to be given at the conception phase, to make sure that a maximum of mistakes are caught before being introduced in the final structures. Also, some professional being involved in many projects, their workloads can sometimes be really challenging which might also explain some delays.

5.2 Concerns category

Of less gravity but also being part of the picture, the second category includes the concerns that came up through the construction of these two buildings. They were related to the following sub-categories: the conception of the buildings, wood material issues, Building Code difficulties, stakeholder relationships, and lack of information.

In order of importance, the conception category includes connectors and structure issues. Among all types of connectors, the anchorages are the most discussed, the problems being pointed out concern holes localisations on the structure and on the plates. This relates to the accuracy of the machining at the manufacturing plan or simply of mistakes. The plate and bolts sizes as well as the joints design seemed challenging. Obviously all the elements cited above had to be planned in the right way since they could interfere with the structural properties of the buildings. The visual aspect of the anchorages also counted. Their positions had to make sense while looking good. The electric and mechanic holes and hangers were the second connector type discussed. Decisions linked to the choice of the location to attach them on the structure and where on them they can be attached were mentioned. In addition, the screw dimensions, types, and fixation techniques to use seemed an issue.

The structure elements were also widely discussed in the meeting minutes of the two wood building projects analyzed. A meeting was organized to work on the structure itself. Obviously, the wooden frame had to be redesigned and forced new calculations. Arches and beams sizes had to be determined especially in relation to snow loads, necessitating the manufacturer insight. The holes position in the arches had to be verified as well as the number of columns needed. The joists, rim boards, and bracings localisations where also to be determined to prevent interference with others components of the structure.
Concerns about the material itself were discussed. A laminated arch was cracked and the cause was not clear. Humidity was an hypothesis but not confirmed. Some questions on the structure erection schedule were asked. The responsibilities of the actors linked to the wood structure had to be clarified between a manufacturer and a structural engineer. At some point the contractors could not determine the fabrication date of the panels, which could have impacted the project schedule.

Some concerns linked to the Building Code were verified. The seismic charges of the arches were checked and some special materials were prescribed for the roof of the fourth floor to meet fire safety Code requirement. The anchorage tolerance level was not specified in the wood standard so steel was used instead.

These projects involved many relationships that had to be built with many stakeholders. And of course the higher the number of actors involved in a project, the more complex the business relationship management should be. Perceptions, communication, delay, and responsibilities issues are commons in teamwork. When some stakeholders are attributed more power even more difficulties can arise. In construction, the city administration is responsible for delivering permits and making sure the project to be realized will meet the Code and regulations in general. The professionals have to demonstrate how their proposed solutions meet the Code requirements. In one of the project analyzed, the city asked to provide the following details: the method used to install the arches, the attestation of equivalence for the product applied on wood, a confirmation from the structural engineer that the assembly method for the arches and for the end connectors used by the installer were conform. The project team also had to explain why the work necessary for fixing the anchors to stabilize the arches had not begun yet. A detailed schedule of work before a given date had similarly to be delivered. In addition, the builders asked confirmation for certain elements to the structural engineer that had been addressed and sealed in the conception phase causing tensions. On top of that, the engineered wood manufacturer plays an important role in the conception since he owns the knowledge related to the engineered products by itself, so the structural engineer had to interact frequently with him but also to wait for answers. When working with wood the structural engineer seems to be more dependent of the manufacturer knowledge and his decisions if compared to steel and concrete which can be uncomfortable for some of them.

6 CONCLUSION

In conclusion, many high wooden buildings have been built in recent years all around the wood. Nevertheless, wood compared to steel and concrete is still less popular and the highest wood construction ever built has reached 14 storeys. 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 increased of wood in non-residential buildings would stimulate the forest products industry while having a great impact in both Province of *Quebec* and Canada economies.

When analysing case studies built around the world as well as articles from the literature, we have noticed many motivations that could explain the market interest for wood. Sustainability, rapidity of erection, cost reductions, visibility and lightness of wooden structures are perceived as positive aspects of wood for multi-storeys buildings. On the other hand, some barriers still prevent its use. Building Codes implementation, technology transfer, cost, material durability, and material availability appear to be the main ones.

A content analysis conducted with the N'VIVO software on two non-residential building projetcts completed in 2009 and 2015 brought up a variety of problems and concerns related to the use of wood. The problems were linked to the conception of the buildings, wood material use, and scheduling, while the concerns included criterion related to the conception of the buildings, wood material uses, Building Code difficulties, stakeholder relationships, and lack of information. They somehow confirmed part of what had been found in the cases studied and the articles read. Some elements are also new and could be explored more deeply in future research. 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 since as already mentioned, it could become source of an impressive future economic growth for all instances implied.

This study included only two construction meeting minutes. In a close future, more of them will be analyzed in order to compare, strengthen and adjust the results. Further research could also include other categories of non-residential buildings.

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