Table des matières

Liste des tableaux

Liste des figures

Liste des abréviations et des sigles

CIRCERB - Chaire industrielle de recherche sur la construction éco-responsable en bois

CIRRELT - Centre interuniversitaire de recherche sur les réseaux d'entreprise, la logistique et le transport

ENSAS - École Nationale Supérieure d'Architecture de Strasbourg

FRQNT - Fonds de recherche du Québec – Nature et technologies

CRMR - Centre de recherche sur les matériaux renouvelables

BI - Bureau international

AELIÉS - Association des étudiantes et des étudiants de Laval inscrits aux études supérieures

CRSNG - Conseil de Recherche en Sciences Naturelles et de Génie du Canada

SQI - Société Québécoise des Infrastructures

CIGI - Congrès International de Génie Industriel

PIB - Produit intérieur brut

GIEC - Rapport du Groupe d'experts intergouvernemental sur l'évolution du climat

UNEP-SBCI - Sustainable Buildings and Climate Initiative du Programme de l'environnement des Nations Unies

CLT - Lamellé-croisé (*Cross Laminated Timber*)

LVL - Composantes de placage de bois lamellés (*Laminated Veneer Lumber*)

PSL - Parallam (*Parallel Strand Lumber*)

OSB - Panneaux de lamelles orientées (*Oriented Strand Board*)

GES - Gaz à effet de serre

SCM - Gestion de la chaîne d'approvisionnement – (*Supply Chain Management)*

GDP - *Gross Domestic Product*

LEED - Leadership in Energy and Environmental Design

CO_2 - Dioxide de carbone

À tous ceux qui croient que le chemin est plus important que la destination,

À tous ceux qui croient en la théorie de « connecting the dots » de Steve Jobs,

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Avant-propos

Ces travaux de doctorat ont été dirigés par le professeur agrégé Pierre Blanchet et financés par la Chaire industrielle de recherche sur la construction éco-responsable en bois (CIRCERB) dont il est le titulaire. Cette thèse a été co-dirigée par Nadia Lehoux, professeure agrégée au département de génie mécanique, et par Yan Cimon, professeur titulaire au département de management, tous membres de l'Université Laval.

La rédaction de deux des articles composant cette thèse a été rendue possible grâce à un séjour terrain de trois mois en Europe via la réalisation d'un stage à l'École Nationale Supérieure d'Architecture de Strasbourg (ENSAS). Vingt-trois entrevues conduites auprès de professionnels (architectes, ingénieurs en structure, constructeurs, fournisseurs de matériaux structuraux en bois) et de trois académiques dans neuf pays, soit : l'Autriche, l'Allemagne, la Suisse, l'Italie, l'Angleterre, l'Écosse, la Norvège, la Suède et le Danemark. Ce stage a été financé par le Fonds de recherche du Québec – Nature et technologies (FRQNT) via l'obtention d'une bourse à la mobilité. Le Bureau international et l'AELIÉS de l'Université Laval ont aussi participé au financement de ce séjour d'études.

L'étudiante Annie Gosselin a été la chercheure et rédactrice principale des trois articles scientifiques intégrés à cette thèse. Les co-auteurs de tous les articles sont les directeurs et co-directeurs de recherche. Chacun des directeurs et co-directeurs ont révisé les versions préliminaires des articles tout en suggérant des corrections et améliorations. L'article 1 a été publié le 23 novembre 2016, l'article 2 a été soumis le 15 novembre 2017 et l'article 3 est toujours sous révision et devrait être soumis au début de 2018.

Les trois articles en question sont les suivants :

1- Gosselin, A., Blanchet, P., Lehoux, N. and Cimon, Y. 2016 *Main Motivations and Barriers for Using Wood in Multi-Story and Non-Residential Construction Projects. BioResources Journal,* 12 (2), 546-570.

2- Gosselin, A., Lehoux, N., Cimon, Y. and Blanchet, P. soumis le 15 novembre 2017. *Characterizing supply chain relationships to enable the adoption of innovative wooden structures in construction*. Soumis.

3- Gosselin, A., Cimon, Y., Lehoux, N., and Blanchet, P. *Mapping Business Models for the Wood Structure Building Industry.* En préparation.

Les résultats de ces travaux de recherche ont été présentés à diverses occasions :

- À la 11e édition du Congrès International de Génie Industriel (CIGI 2015) qui a eu lieu du 26 au 28 octobre 2015 à Québec.

- À l'École Nationale Supérieure d'Architecture de Strasbourg (ENSAS) le 9 mai 2017.

- Lors de quelques bureaux de direction de la Chaire de recherche en construction éco-responsable en bois (CIRCERB), entre 2014 et 2017.

Chapitre 1 - Introduction

L'industrie de la construction au Québec et au Canada représente un secteur important de l'économie de la province et du pays. Ces territoires sont recouverts d'une ressource forestière abondante et l'industrie des produits forestiers y est également un secteur d'activité économique majeur. Le bois est typiquement utilisé dans le secteur résidentiel de la construction, mais plutôt de façon limitée dans ce qui est appelé le non-résidentiel en Amérique du Nord, ce qui englobe les bâtiments de grande taille et d'envergure, soit ceux de type multi-étages de quatre étages et plus, institutionnels, commerciaux et industriels (StatistiquesCanada 2017). En fait, depuis l'ère industrielle, le béton et l'acier sont devenus les principaux matériaux de construction pour ce type de bâtiments. En plus de représenter un bon potentiel de développement économique, l'utilisation accrue de bois dans les éléments structuraux des bâtiments non-résidentiels procure aussi l'avantage de contribuer à la lutte contre les changements climatiques. Non seulement la production d'éléments structuraux en bois émet moins de CO_2 que la production d'éléments de mêmes dimensions en béton et en acier, mais leur utilisation dans les structures des bâtiments permet également d'y séquestrer du carbone qui y restera tout au long de la durée de vie du bâtiment.

Les structures en bois dans les bâtiments non-résidentiels ont été peu utilisées avant la deuxième guerre mondiale, mais leur utilisation est en croissance depuis quelques décennies puisque des avancées significatives ont été réalisées dans le développement de produits d'ingénierie et structuraux en bois et ce, dans plusieurs pays. Les parts de marché de cette industrie sont effectivement en augmentation. Cette thèse vise à alimenter la réflexion sur cette industrie qui se développe rapidement. La première question a été posée afin de mieux comprendre le marché de cette industrie. La deuxième question vise la même préoccupation et plus précisément la compréhension des relations présentes au sein des acteurs composant la chaîne de valeur de projets de construction au sein de l'industrie. Pour sa part, la troisième question porte sur les entreprises des acteurs eux-mêmes, soit la composition de leurs modèles d'affaires respectifs de même que sur l'identification des éléments clés et prometteurs de cette industrie. Ces questions de recherche sont les suivantes : 1- Quelles sont les barrières et les motivations en liens avec l'utilisation du bois comme matériau structural? 2- Quels types de relations sont présentes entre les acteurs de l'industrie de la construction structurale en bois? 3- Comment une entreprise peut-elle organiser son modèle d'affaires afin de se positionner stratégiquement dans ce créneau en développement?

La méthodologie préconisée pour le premier article a été de conduire une analyse de contenu à partir de littérature grise liée à treize bâtiments non-résidentiels bien connus et d'articles scientifiques ayant été écrits jusqu'à date au sujet des motivations et des barrières reliées à l'utilisation des matériaux structuraux en bois. Ces résultats ont par la suite été confrontés à une deuxième analyse de contenu conduite cette fois sur neuf comptes-rendus de chantiers de projet de construction structurale en bois québécois. De leur côté, les deuxième et troisième articles ont été rédigés sur la base de données obtenues lors d'un travail de terrain d'une durée de trois mois réalisé dans dix pays européens, soit la France, l'Autriche, l'Allemagne, la Suisse, l'Italie, l'Angleterre, l'Écosse, la Norvège, la Suède et le Danemark. Vingt-trois professionnels : architectes, ingénieurs en structure, constructeurs, fournisseurs de matériaux ont été interrogés et trois académiques ont été rencontrés. Deux autres analyses de contenu basées cette fois sur les sujets respectifs des articles 2 et 3 ont ensuite été réalisées. Pour le deuxième article, le thème exploré était les relations présentes entre les acteurs qui composent la chaîne de valeur de l'industrie de la construction structurale en bois. Ces relations ont principalement été catégorisées en trois niveaux. Pour le troisième article, le thème était les modèles d'affaires des entreprises d'architectes, d'ingénieurs en structure, de constructeurs et de fournisseurs de matériaux. Ces modèles d'affaires ont été décomposés selon les neuf éléments qui les composent selon le modèle proposé par Osterwalder et Pigneur (2010): les segments de marché, la proposition de valeur, les canaux de distribution, les relations avec les clients, les flux de revenus, les ressources clés, les activités clés, les partenariats clés et la structure de coûts.

Des résultats porteurs ont ainsi été dégagés dans le cadre de ce projet de doctorat. Les principales motivations liées à l'utilisation du bois comme matériau structural ayant été identifiées sont : la volonté de contribution au développement durable, les aspects techniques du bois, les coûts réduits, la rapidité d'installation des structures et les aspects esthétiques du bois. Pour leur part, le code du bâtiment, le transfert de technologies, les coûts, la durabilité et les autres aspects techniques du matériel, la culture de l'industrie et la disponibilité du matériel sont les principales barrières à l'utilisation du bois comme matériau structural qui ont été trouvées. Lors de l'identification des relations présentes au sein de la chaîne de valeur de l'industrie de la construction non-résidentielle structurale en bois, un réseau complexe d'interrelations a été observé. Il s'agit d'un réseau comprenant trois types et niveaux de relations soit les contractuelles, celles liées à des projets de construction en bois et celles liées à l'industrie de la construction structurale en bois. Ces relations étant nombreuses et plus que de simples relations transactionnelles, il devient possible de parler de l'émergence d'un réseau de collaboration au sein de cette industrie. Suite à l'analyse des vingt-trois modèles d'affaires d'entreprises étudiées, certaines tendances parmi les modèles d'affaires de l'industrie ont pu être observées. Notamment, la proposition de valeur des ingénieurs structuraux fait parfois aussi partiellement partie de celles des constructeurs, des fournisseurs de matériaux et des fournisseurs-constructeurs. Aussi, la responsabilité de développement des produits structuraux incombe majoritairement aux fournisseurs et fournisseurs-constructeurs. Les partenariats avec les universités et les partages des connaissances au sein de l'industrie sont essentiels tout comme un virage vers les modes d'attribution de contrats collaboratifs de même que vers la préfabrication.

La réalisation de cette thèse permettra d'apporter des contributions de types méthodologiques, scientifiques et industrielles. Les contributions méthodologiques sont les suivantes :

- Pluridisciplinarité et interdisciplinarité: intégration des sciences du bois, du génie industriel et des sciences de l'administration au même projet ;

- Utilisation d'une source d'information jamais exploitée dans la littérature scientifique : compte-rendu de chantiers de construction ;

- Croisement entre trois sources d'information pour le 1er article ;

- Tournée internationale et entrevues réalisées auprès d'entreprises et d'académiques dans neuf pays européens.

Les contributions scientifiques sont:

- Proposition de catégories distinctes résumant les motivations et les barrières à la construction non-résidentielle structurale en bois ;

- Caractérisation des relations comprises au sein de la chaîne de valeur de l'industrie de la construction non-résidentielle structurale en bois ;

- Mise en relief de la composition des modèles d'affaires de l'industrie de même que des éléments de compétitivité clés à développer et à mettre en place afin de répondre aux motivations et barrières précédemment déterminées.

Tel que mentionné, ces travaux permettent également des contributions industrielles puisque les membres du CIRCERB et les industriels en général pourront profiter des résultats trouvés. Ces informations pourraient leur être utiles dans le développement de leurs marchés ainsi que des modèles d'affaires de leurs entreprises.

La prochaine section de ce document présente le chapitre 2 qui est la revue de littérature ayant été bâtie tout au long de ce projet de doctorat. Le chapitre 3 rappelle les trois objectifs poursuivis dans le cadre de cette étude. Le chapitre 4 constitue la rétrospective méthodologique établissant les liens entre les trois articles scientifiques qui composent cette thèse. Les chapitres 5, 6 et 7 présentent les articles en question. Suivra ensuite la conclusion de même que la bibliographie et les annexes.

Chapitre 2 – Revue de littérature

La section suivante contient la revue de littérature et les détails concernant la plupart des concepts utilisés dans cette thèse. Les industries canadiennes et québécoises de la construction et des produits forestiers sont premièrement brièvement présentées. L'industrie de la construction non-résidentielle structurale en bois, les produits d'ingénierie en bois de même que leurs marchés actuels et potentiels sont ensuite expliqués. Ensuite, le concept de chaîne de valeur est défini et sa composition est présentée. Le concept de gestion de la chaîne de valeur sera aussi abordé. La chaîne de valeur en construction non-résidentielle structurale, le déroulement typique d'un projet de construction et les problèmes et améliorations possibles seront ensuite décrits. Cette section se termine par une présentation du concept de modèles d'affaires qui sera défini et caractérisé, le concept des modèles d'affaires innovants sera explicité et finalement, certains travaux de recherche en lien avec les modèles d'affaires de l'industrie de la construction seront revus.

2.1 L'industrie de la construction

L'industrie de la construction au Canada inclut plus de 1,3 million de travailleurs et elle est le cinquième plus grand employeur du pays ; elle représente 7,3 % des emplois toutes industries confondues (StatistiquesCanada 2016). Au Québec, elle a conduit à plus de 45,4 milliards de dollars d'investissements en 2014, représentant 12 % du Produit intérieur brut (PIB). L'industrie de la construction représente un emploi sur 20 dans la province et ce, sans compter les milliers d'autres emplois créés dans les secteurs reliés (CCQ 2016).

2.2 L'industrie des produits forestiers

Pour sa part, l'industrie des produits forestiers est une industrie qui rapporte 58 milliards de dollars par année, représentant 2 % du PIB du Canada. Cette dernière est aussi l'un des plus grands employeurs du Canada, créant 230 000 emplois directs, localisés dans 200 communautés qui sont encore aujourd'hui dépendantes de la forêt (FPAC 2016). En 2012, l'industrie forestière de la province de Québec offrait 25 066 emplois reliés à l'industrie des produits forestiers (MFFP 2015).

2.3 L'industrie de la construction non-résidentielle structurale en bois

Tel que mentionné plus haut, la construction non-résidentielle inclut les bâtiments multi-étagés, les bâtiments institutionnels (et gouvernementaux) de même que ceux de nature commerciale et industrielle. Dans cette thèse, afin de se concentrer sur l'utilisation des produits d'ingénierie dans la construction non-résidentielle, les bâtiments multi-étagés de plus de quatre étages ont principalement été considérés. L'utilisation du bois comme matériau structural en construction non-résidentielle a connu une certaine popularité au début du siècle pour ensuite presque disparaître à l'ère industrielle. Cette pratique a connu un nouvel essor au début des années 1990 et depuis, l'utilisation du bois comme matériau structural est en expansion (Osterwalder*, et al.* 2005). Il existe de nombreux avantages qui puissent expliquer qu'aujourd'hui elle gagne du terrain et des parts de marchés et ce, un peu partout dans le monde.

L'utilisation du bois en construction non-résidentielle comporte des avantages économiques et environnementaux. En termes d'avantages économiques, elle représente une bonne opportunité d'augmenter le volume de transformation du bois produit au Québec et d'ainsi favoriser la vente de produits à valeur ajoutée permettant de récupérer une plus grande valeur monétaire pour de plus petites quantités de bois vendues. Le développement de la construction non-résidentielle structurale en bois offre également le potentiel de faire naître de nouvelles catégories de produits, par exemple des éléments préfabriqués. De nouvelles entreprises pourraient ainsi être créées tout en offrant des emplois à plus de travailleurs. En outre en considérant que plusieurs éléments de structure en acier sont fabriqués à l'extérieur des frontières canadiennes, un transfert des parts de marchés de l'acier au bois favoriserait un rapatriement des emplois au pays (Louis Poliquin, *communication personnelle*, 2016).

Tel que mentionné, l'utilisation du bois en construction non-résidentielle comporte également des avantages environnementaux. Selon le cinquième Rapport du Groupe d'experts intergouvernemental sur l'évolution du climat (GIEC), le climat a effectivement changé de façon significative. Le *Sustainable Buildings and Climate Initiative* du Programme de l'environnement des Nations Unies (UNEP-SBCI), estime que les bâtiments dans le monde consomment 40 % de l'énergie globale tout en émettant un tiers des gaz à effet de serre. Ainsi, le secteur de la construction serait le plus grand contributeur aux émissions mondiales de gaz à effet de serre (GES) (UNEP-SBCI 2016). Avantageusement, la production d'éléments structuraux en bois émet moins de GES que la production des mêmes éléments structuraux en acier et en béton (Reid*, et al.* 2004, Sathre et O'Connor 2010). Une étude réalisée récemment par une équipe de chercheurs de l'Université de Yale et de l'université de Washington a estimé que l'émission globale de CO_2 pourrait être réduite de 14 à 31 % si plus de bois était utilisé dans les bâtiments et infrastructures au lieu de l'acier et du béton (Oliver*, et al.* 2014). Bien entendu, une plus grande utilisation de produits d'ingénierie pourrait créer une plus grande pression sur la ressource forestière québécoise, canadienne et même mondiale. Tant que la matière première proviendra de forêts certifiées et que la récolte respectera les possibilités forestières déterminées, les forêts ne devraient pas souffrir de l'augmentation de la demande créée par une plus grande utilisation du bois en construction non-résidentielle.

2.4 Les produits d'ingénierie en bois

Les produits d'ingénierie sont des produits fabriqués à base de fragments, lamelles ou particules de bois qui combinent ses propriétés traditionnelles à l'ingénierie et aux technologies modernes. Les fragments, lamelles ou particules sont collés et le produit final possède des propriétés structurales qui peuvent être supérieures aux produits en bois massif (Bowyer*, et al.* 2007). Il existe plusieurs produits d'ingénierie en bois. En voici quelques exemples: le bois jointé, le lamellé-collé, le lamellé-croisé (*Cross Laminated Timber – CLT*), bois d'oeuvre de placage de bois laminé (*Laminated Veneer Lumber – LVL*), le parallam (*Parallel Strand Lumber – PSL*), les poutrelles en I et les panneaux de lamelles orientées (*Oriented Strand Board – OSB*).

2.4.1 Marchés actuels et potentiels des produits d'ingénierie en bois

Bien que l'utilisation des produits d'ingénierie en bois dans les projets de construction semble avoir augmenté au cours des dernières décennies, elle n'est toujours pas une pratique des plus populaires. Une série d'études a permis d'estimer les parts de marché du bois dans le secteur de la construction non-résidentielle structurale en bois ainsi que leurs augmentations potentielles (McKeever et Adair 1995 , Kozak et Cohen 1999, Gaston*, et al.* 2001, McKeever*, et al.* 2003, O'Connor*, et al.* 2003, JaakkoPöyryConsulting 2004, O'Connor et Gaston 2004, Vlosky et Gaston 2004, O'Connor 2006a, O'Connor 2006b, GeskinConseil 2008, Bayne et Page 2009, Jonsson 2009, Mahapatra et Gustavsson 2009, Robichaud*, et al.* 2009, Robichaud 2010, Chamberland et Robichaud 2013, Manninen 2014, Robichaud 2014, Drouin 2015). Les enquêtes menées afin de recueillir ces données ont le plus souvent été conduites auprès d'architectes et d'ingénieurs, mais certaines ont aussi permis de questionner des promoteurs et des entrepreneurs (O'Connor et Gaston 2004) ainsi que des fabricants de matériaux de construction en bois (Robichaud 2014).

De ces études réalisées entre 2004 et 2015, il ressort que la construction non-résidentielle utilisant des structures en bois totalise entre 18 et 25 % des parts de marchés mondiales de la construction non-résidentielle actuelle. Il y est aussi démontré qu'il serait techniquement possible de construire beaucoup plus de ces bâtiments que ce qui se fait actuellement. Une étude menée sur les permis de bâtir délivrés en 2004 en Alberta a montré que 25 % de tous les bâtiments non-résidentiels construits comportaient des éléments de structure en bois, même si 84 % d'entre eux auraient pu être supportés par des structure en bois (O'Connor 2006b). Une autre étude réalisée en 2005 sur 47 bâtiments de l'Ontario a montré que même si 81 % de ces bâtiments aurait pu être construits en bois, seulement 19 % l'ont finalement été, offrant 62 % de possibilités d'augmentation (O'Connor 2006a).

Selon une enquête menée par Robichaud (2010) sur un échantillon de 50 ingénieurs en structure, 4 architectes et 14 autres professionnels du bâtiment travaillant dans la province de Québec, il semble que les parts de marché du bois utilisé comme matériau de construction aient augmenté de 18 à 22 % entre 2006 et 2009. Une autre étude menée par Chamberland et Robichaud (2013) auprès de 72 architectes et 27 ingénieurs a également montré qu'entre 2009 et 2012, la spécification du bois comme système structural est restée relativement la même. Cette enquête a démontré que les ingénieurs en structure ont tendance à choisir le bois un peu plus fréquemment que les architectes (20 % contre 17,8 %). Une étude récente réalisée en 2015 sur un échantillon plus important indique qu'en moyenne, 24,1 % des bâtiments non-résidentiels de quatre étages et moins construits en 2014 par 118 architectes et 54 ingénieurs avaient une structure en bois (Drouin 2015).

L'enquête menée par Robichaud (2014) auprès des fabricants de bois d'ingénierie montre que ces derniers font face à un changement important en termes de popularité et d'utilisation de leurs produits en construction non-résidentielle. Effectivement, l'étude montre que l'utilisation des produits structuraux en bois est en augmentation et que les fabricants reçoivent un nombre grandissant de demandes. Par exemple, les ventes des producteurs de lamellé-collé auraient augmenté de 20 % entre 2010 et 2013.

2.5 La chaîne de valeur

2.5.1 Définition

Une chaîne de valeur suppose qu'un ensemble de membres intègrent plusieurs éléments en un tout, dans le but de produire et de livrer un produit ou un projet final. C'est l'ensemble des actions et des apports de chacun des membres qui créent cette valeur finale (Porter 1985). Les membres de la chaîne insèrent ainsi de la valeur ajoutée à chacune des étapes du processus. Les deux termes chaîne de valeur et chaîne d'approvisionnement peuvent être utilisés pour parler de ce type de chaîne. Afin de réaliser le produit ou le projet en question, les membres de la chaîne doivent notamment échanger des informations et partager des relations (Holti*, et al.* 2000). Le Conseil canadien sectoriel de la chaîne d'approvisionnement (2017) spécifie que la définition de chaîne d'approvisionnement inclut trois fonctions : 1- la fourniture d'un produit à un fabricant, 2- le processus de fabrication et 3- la distribution de produits finis au consommateur par un réseau de distributeurs et de détaillants. Il ajoute qu'il s'agit d'un flux de produits qui est supporté par un flux d'informations qui circulent entre les fournisseurs et les clients.

2.5.2 Composition

Une chaîne de valeur est donc composée de membres, de flux de produits ou de projets et de flux d'informations et de relations. Les membres sont en fait des entreprises qui contribuent à la réalisation d'un produit ou d'un projet. Chacune des entreprises impliquées doit s'organiser afin de pouvoir contribuer de la meilleure manière possible à cette chaîne, puisqu'au cours du processus, des informations et des relations doivent être partagées (Christopher 2001). Cette façon stratégique d'agir est normalement reflétée par les modèles d'affaires des entreprises. Ce concept sera exploré et défini un peu plus loin dans cette section.

2.5.3 La gestion de la chaine de valeur

Dans les années 1980, assez rapidement après l'apparition des concepts de chaîne d'approvisionnement et de chaîne de valeur, celui de gestion de la chaîne d'approvisionnement (*Supply Chain Management - SCM*) a pris de l'ampleur et a grandement intéressé de nombreux chercheurs. L'intérêt pour la gestion de la chaîne d'approvisionnement est devenu tellement grand que Carter*, et al.* (2015) affirment que la définition de la théorie de la chaîne d'approvisionnement elle-même, a peut-être été négligée au profit de celle de la gestion de la chaîne d'approvisionnement - *SCM*.

La gestion de la chaîne d'approvisionnement propose une amélioration des processus et des relations présentes au sein de cette chaîne afin d'en optimiser la performance et de créer de la valeur accrue par l'utilisation de l'innovation et de l'amélioration continue (Christopher, 2005, Peck, 2006, Blanchard, 2010, Fulford et Standing, 2014, Behera et al., 2015, Van Weele, 2010). Beaucoup d'auteurs ont d'ailleurs réalisé des travaux sur le partage d'informations au sein des chaînes d'approvisionnement. Une des contributions de la gestion de l'information au sein des chaînes de valeur est d'éviter le *Bullwhip Effect* ou Effet coup de fouet qui peut être traduit par une distorsion de la demande qui tend à augmenter au fur et à mesure que les commandes remontent dans la chaîne (Lee*, et al.* 1997, Lee*, et al.* 2000). Le fait de mettre en place des systèmes de gestion de l'information ouverts facilite la communication entre les entreprises composant la chaîne.

Plusieurs études traitent par ailleurs de la performance de la gestion des chaînes de valeur (Akyuz et Erkan 2010). Cette performance est mesurable et des modèles de maturité de ces chaînes sont proposés (Lockamy III et McCormack 2004, Netland et Alfnes 2011, MacCarthy*, et al.* 2016). Selon Meng et al. (2011), les études de maturité de chaines de valeurs auraient transité du secteur des achats et de l'approvisionnement vers celui de la construction.

2.5.4 La chaîne de valeur en construction

Le terme chaîne de valeur sera utilisé pour le reste de cette thèse. Un projet de construction inclut plusieurs phases. Le projet doit d'abord être conçu pour ensuite être construit. Chacune des phases est sous la responsabilité de différents acteurs. Ces acteurs sont des entreprises engagées afin de livrer un service. Elles incluent des architectes et des ingénieurs, des entrepreneurs principaux, des sous-traitants spécialisés et des fournisseurs de matériaux (Behera et *al.* 2015). Hui et Weishuang

(2017) ont mis en évidence les flux de partage d'informations présents au sein de la chaîne de valeur de la construction.

2.5.4.1 Déroulement d'un projet type

Lorsqu'un promoteur immobilier privé ou le gouvernement décide de construire un bâtiment non-résidentiel, plusieurs modes d'attribution de contrats s'offrent à lui. Le mode traditionnel est le plus souvent utilisé et il implique que chacun des acteurs nécessaires à la réalisation d'un projet de construction joue son rôle de façon séquentielle. Le mode traditionnel sous-entend que l'architecte produit des plans et devis pour l'enveloppe du bâtiment et que l'ingénieur doit par la suite concevoir la structure qui permettra de soutenir le bâtiment. Un entrepreneur général sera dès lors choisi et il engagera des sous-contractants formés dans chacune des spécialités de la construction de même que les fournisseurs de matériaux. Chaque entreprise est donc seulement responsable d'une petite partie du projet en y contribuant selon ses capacités (Segerstedt et Olofsson 2010).

Tel que mentionné, la réglementation liée aux contrats de construction dans le domaine public prévoit normalement un concours permettant la sélection de chacune des entreprises pour chacun des projets, mais aussi pour chacune de étapes de celui-ci. Les équipes sont donc différentes pour chacun des projets de constructions lancés par les gouvernements. Du côté du secteur privé, il est cependant possible de sélectionner les mêmes partenaires, projets après projets.

La plupart des chaînes de valeur en construction ont un caractère éphémère, particulièrement parce qu'elles sont basées sur des projets versus des processus, ce qui crée leur caractère ponctuel (Egan 1998, Behera*, et al.* 2015). Les chaînes de valeur en construction sont donc imprévisibles et instables puisqu'à chacun des projets, les gens doivent apprendre à travailler ensemble et que l'exercice est constamment à répéter (Behera*, et al.* 2015, Kim et Nguyen 2018).

2.5.4.2 Les problèmes et les améliorations possibles

Deux rapports rédigés dans les années 1990 ont largement critiqué l'industrie de la construction au Royaume-Uni (Egan, 1998, Latham, 1994). De nombreux travaux ont par la suite été entrepris afin de tenter de corriger les problèmes notés. L'implantation des principes de la gestion de la chaîne d’approvisionnement mentionnée plus haut ont permis bien des avancées, mais tout n’est pas encore réglé (Saada*, et al.* 2002).

Une partie des défis provient de la nature temporaire et de l’approche séquentielle des projets de construction puisque ces caractéristiques causent généralement un manque d'intégration au sein des chaînes de valeur (Holti et *al.,* 2000). L’absence de continuité est souvent liée au mode d’attribution des contrats réalisés la plupart du temps sous le mode traditionnel (Kantola et Saari 2016). La nature temporaire et fragmentée des projets de construction, des « chaines de valeur » elles-mêmes, conduit à la fragmentation de l’information qui se doit alors d’être partagée entre les entreprises de la chaîne. Certaines refusent toutefois de partager leurs informations sachant que les entreprises impliquées dans leurs futurs projets de construction risquent fortement de ne pas être les mêmes (Cheng*, et al.* 2010). Le manque d’intégration des chaînes de valeur peut mener à la détérioration des relations et engendrer de faibles performances de projets et des marges de profits limitées (Meng 2012). Plusieurs travaux ont été faits sur la collaboration, les partenariats et les alliances au sein des chaînes de valeur de l’industrie de la construction (Akintoye*, et al.* 2000, Holti*, et al.* 2000, Dainty*, et al.* 2001, Wood et Ellis 2005, Akintoye et Main 2007, Bygballe*, et al.* 2010, Kim et Nguyen 2018). Les principaux travaux touchant ces diverses formes de relations seront explicités dans l’article 2. La façon dont une entreprise choisit de gérer les relations qu’elle entretient avec ses clients et ses partenaires fait partie intégrante de son modèle d’affaires ce qui est l’objet de l’article 3.

2.6 Les modèles d’affaires

Les premières études sur les modèles d’affaires ont été réalisées dans les années 1990, époque où Internet est devenu populaire (Osterwalder*, et al.* 2005, Zott*, et al.* 2011). Une trentaine d’années plus tard, beaucoup de définitions de ces modèles cohabitent encore et le sens de ce terme reste encore sans consensus (Morris et al. 2005).

2.6.1 Définition

Plusieurs définitions de différents auteurs peuvent effectivement être retrouvées dans la littérature (Timmers 1998, Amit and Zott (2001), Chesbrough and Rosenbloom (2002), Magretta (2002), Johnson, M. W., Christensen, C. M., and Kagermann, H., 2008; Morris et al. (2005): Casadesus-Masanell et Ricart (2010), Osterwalder and Pigneur (2010), Teece (2010); Zott, C., Amit, R., and Massa, L., 2011

George and Bock (2011). Par rapport à la stratégie d'entreprise, les modèles d'affaires expliquent comment les pièces du modèle créent l'ensemble, alors que les stratégies d'entreprises incluent les liens avec la compétition et leurs positionnements en vue d'augmenter leur performance relative ou leurs avantages compétitifs (Magretta 2002, Osterwalder*, et al.* 2005).

En 1998, Timmers définissait les modèles d'affaires comme une architecture de flux de produits, de services et d'informations incluant une description des différents acteurs et de leurs rôles respectifs. Les bénéfices potentiels et les sources de revenus des acteurs y étant aussi décrits. Amit and Zott en 2001 écrivaient qu'un modèle d'affaires décrit le contenu, la structure et la gouvernance des transactions servant à créer de la valeur via l'exploitation d'opportunités d'affaires. Pour sa part, en 2002, Magretta affirmait qu'un modèle d'affaires permet de raconter l'histoire du fonctionnement d'une entreprise. Selon sa vision, un modèle d'affaires devrait permettre de répondre aux incontournables questions de Peter Drucker. Qui sont les clients? Quelle valeur viennent-ils chercher? Comment le gestionnaire fait-il du profit ? Finalement, quelle logique économique explique qu'une valeur puisse être livrée à un client à un coût approprié? Morris et al. (2005) avancent plutôt qu'un modèle d'affaires est une représentation concise d'une série d'éléments interreliés de décisions dans les domaines de la stratégie, de la modélisation et de l'économie visant à créer un avantage compétitif durable dans des marchés définis. De leur côté, Osterwalder et Pigneur (2010) avançaient l'idée qu'un modèle d'affaires puisse décrire comment une organisation crée, livre et saisit une valeur. Casadesus-Masanell & Ricart (2010) pensent qu'un modèle d'affaires reflète la stratégie mise en œuvre par une entreprise.

2.6.2 Principales caractéristiques

Les modèles d'affaires définissent comment une entreprise crée de la valeur, mais ils servent également à envoyer un message clair, tant à l'externe qu'à l'interne, sur ce qui est offert par l'entreprise, ils sont en fait des outils de communication (Magretta 2002). Lorsqu'une entreprise fait des affaires et qu'elle fait l'exercice de définir son modèle d'affaires, celle-ci doit premièrement choisir de vendre des produits de masse ou de niche (Juslin et Hansen 2002). En fait, son modèle d'affaires devrait lui permettre de se démarquer parmi un ensemble d'entreprises œuvrant dans le même secteur. Michael E. Porter (1985) a beaucoup écrit sur cette idée d'avantages compétitifs. Selon lui, une entreprise peut développer et adopter différentes stratégies de compétition: dominer par les coûts, se différencier ou focaliser sur les coûts réduits ou sur la différenciation. Gulati (2007) explique comment une entreprise doit s'organiser afin d'opérationnaliser la stratégie de focalisation et d'ainsi répondre à la demande des consommateurs; autrement dit il explique comment vendre des solutions qui répondent aux besoins des consommateurs plutôt que de simples produits. Afin d'y arriver, Gulati favorise l'implantation de quatre attitudes et types d'actions au sein des entreprises: la coordination, la coopération, le renforcement des compétences et la connexion.

2.6.4.1 Besoin constant de renouvellement

Porter (1985) ajoute que pour qu'une entreprise puisse être compétitive, elle doit se démarquer mais aussi pouvoir conserver ses avantages compétitifs au fil du temps. Les modèles d'affaires sont en fait une représentation à un moment donné de comment une entreprise se représente, mais les modèles d'affaires doivent constamment être adaptés et changés (Linder et Cantrell 2001). Demil et Lecocq (2010) parlent de « dynamique constante ». Porter conseille de maintenir les avantages compétitifs dans le temps alors que pour Demil et Lecoq c'est plutôt la gestion du changement via des outils et des concepts permettant de les mesurer qui favorisera la prise de décisions permettant d'assurer la performance de l'entreprise. Selon eux, afin d'être compétitive, une entreprise doit constamment réaliser des boucles de rétroaction en évaluant les changements internes et externes et s'y adapter lorsque détectés. Afin de pouvoir réagir rapidement aux changements, Osterwalder et Pigneur (2010) suggèrent aussi d'avoir en tête différents scénarios de modèles d'affaires.

2.6.3 Modélisation

Morris et al. (2005) ont identifié six composantes d'un modèle d'affaires: la proposition de valeur, le consommateur, les processus et compétences internes, le positionnement externe, le modèle économique et les facteurs personnels et d'investisseurs". Demil & Lecocq (2010), pour leur part, proposent aussi qu'un modèle d'affaires soit composé de six éléments. Il s'agit de ressources et de compétences, d'une proposition de valeur, d'une organisation interne et externe, d'un volume et d'une structure de revenus, d'un volume et d'une structure de coûts et d'une marge. Selon le modèle développé par Osterwalder et Pigneur (2010), un modèle d'affaires comporte neuf éléments essentiels: les segments de marché, la proposition de valeur, les canaux de distribution, les relations clients, les flux de revenus, les ressources clés, les activités clés, les partenariats clés et la structure de coûts. Voici comment ils le représentent :

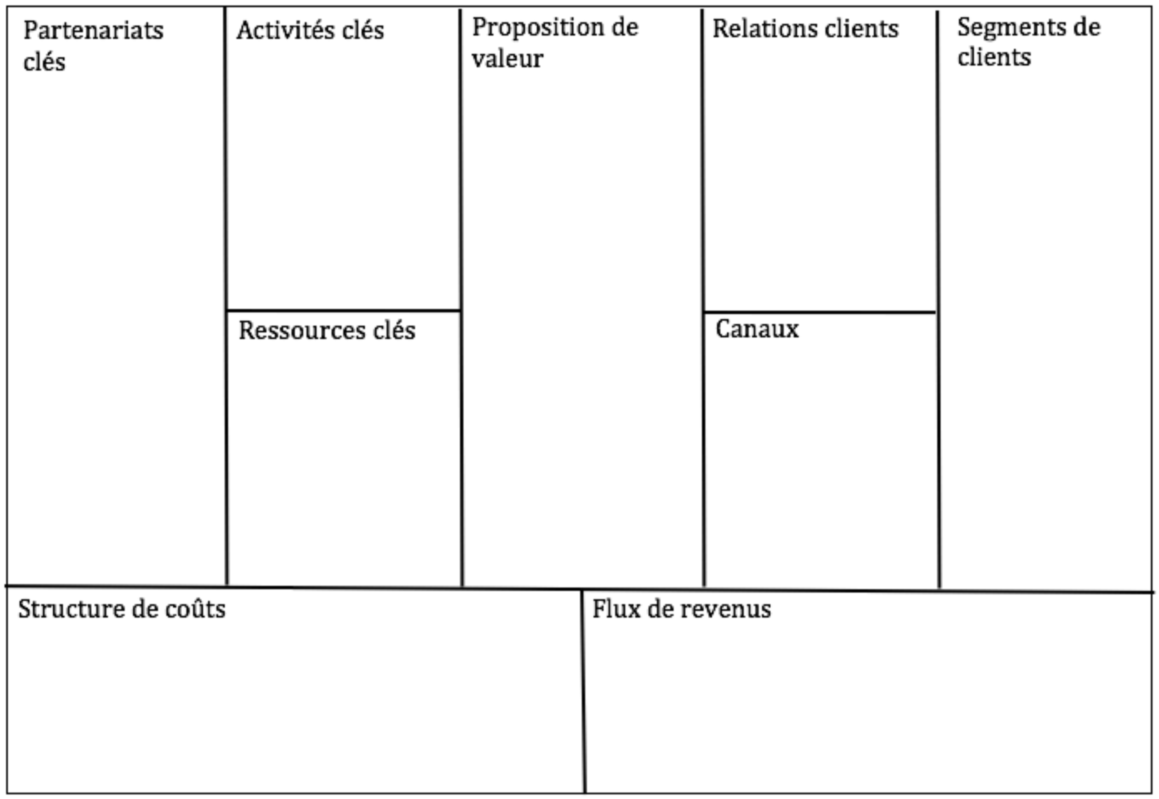

Figure 1 : Le canevas de modèle d'affaires

Source : Adapté d'Osterwalder et Pigneur, 2010

2.6.4 Modèles d'affaires innovants

Tel que mentionné plus haut, si les entreprises souhaitent demeurer compétitives et continuer d'exister, elles doivent constamment revoir leurs modèles d'affaires et parfois même innover en les définissant. Depuis les années 2000, beaucoup de travaux, quoique restreints en nombre par rapport à ceux portant sur les modèles d'affaires, ont été réalisés sur l'innovation des modèles d'affaires ou *Business models innovation*. Tout comme pour le concept de modèle d'affaires, les frontières de ce concept sont encore flous (Spieth*, et al.* 2014), mais les travaux sur la question ont principalement porté sur l'étude des facilitateurs de l'innovation des modèles d'affaires comme processus organisationnel et sur l'identification des nouveaux types d'entreprises (Foss et Saebi 2017). Par exemple, Euchner et Ganguly (2014) proposent une approche pour développer un nouveau modèle d'affaires et des étapes concrètes pour réduire les risques associés à ce changement. Ces innovations reliées aux modèles d'affaires pourraient même être mesurés (Spieth et Schneider 2016).

2.6.5 Modèles d'affaires en construction

Peu d'études dans le domaine de la construction ont été réalisées sous l'angle du concept des modèles d'affaires. Par contre, plusieurs études se sont intéressées à des aspects qui en font partie Par exemple, tel que discuté dans la section portant sur les « chaînes de valeur » de la construction, celles-ci ont une nature ponctuelle puisque reliées à des projets. Cette caractéristique intervient aussi dans les modèles d'affaires des entreprises en construction (Kujala, *et al.* 2010). Autre élément à prendre en considération est qu'une bonne partie des entreprises d'ingénierie et d'entrepreneurs (généraux ou spécialisés) liées aux bâtiments et aux structures livre des services à valeur ajoutée plutôt que des produits (Gann et Salter 2000).

Aki, *et al.* (2013) ont pour leur part conduit des entrevues en lien avec les modèles d'affaires auprès de huit gestionnaires expérimentés de compagnies de construction finlandaises. Celles-ci ont révélé que le concept de modèle d'affaires est compris différemment par les praticiens du domaine que le sens véhiculé dans le milieu académique. Les modèles d'affaires décrits par les gestionnaires parlent de projets livrés et de structures de contrats ou de segments d'entreprises plutôt que de comment leurs organisations offrent de la valeur à leurs clients. Les notions de création de valeur et de réponse aux besoins des clients sont ainsi mal comprises au sein de l'industrie de la construction. Deux années plus tard, Aki, *et al.* (2015) ont trouvé que les processus de décisions dans l'industrie de la construction sont d'avantage basés sur des facteurs à court terme tels les besoins de volumes de travail et les profits plutôt que sur des modèles d'affaires des entreprises.

2.6.5.1 Les modèles d'affaires en construction non-résidentielle structurale en bois

Un des arguments reliés à l'utilisation des structures en bois est qu'elles permettent l'utilisation de matériaux plus environnementaux tout en permettant de développer l'économie des territoires forestiers. Une adoption accrue des structures en bois dans les bâtiments non-résidentiels aura nécessairement des répercussions sur les modèles d'affaires des entreprises. Mokhlesian et Holmén

(2012) ont trouvé que la configuration de valeur, la structure de coût, le réseau de partenaires et de compétences sont les éléments les plus difficiles à changer lorsqu'une entreprise en construction souhaite rendre ses activités plus respectueuses de l'environnement.

Brege*, et al.* (2014) ont de leur côté réalisé une étude précisément sur les modèles d'affaires en lien avec les bâtiments multi-logements préfabriqués en bois. Ces multiples études de cas incluent cinq importantes compagnies suédoises. Une conclusion de leurs travaux est que le mode de préfabrication devrait être à la base des modèles d'affaires des entreprises oeuvrant en construction en bois et que les autres éléments du modèle d'affaires devront être adaptés à cette proposition de valeur. Mayo (2015) qui a étudié une trentaine de bâtiments non-résidentiels structuraux en bois abonde aussi dans le sens de l'intégration de la préfabrication dans le secteur des bâtiments non-résidentiels en bois.

Dans un rapport produit par FPAC (2013) à l'intention de ses membres, les auteurs spécifient que dans le futur, l'industrie des produits forestiers devra mettre en place une multitude de modèles d'affaires répondant à une variété de segments de marchés. Selon eux, la tendance voulant que ce soient des solutions ou des composantes de systèmes de construction qui soient livrées aux clients aura des effets sur l'organisation des chaînes de valeur et sur les interactions au sein de celles-ci. Effectivement, pour que cette pratique puisse continuer d'émerger, les modèles d'affaires en construction non-résidentielle structurale en bois devront intégrer un bon nombre de partenariats et d'alliances au sein de la chaîne de valeur de même qu'avec les autres acteurs de cette industrie (Hurmekoski*, et al.* 2015). Les objectifs ayant guidé les travaux réalisés dans le cadre de cette thèse seront présentés à la section suivante.

Chapitre 3 - Objectifs

L'industrie de la construction structurale en bois est présentement dans une phase de développement accéléré et les acteurs et entreprises de la filière tentent de suivre la cadence et de s'organiser adéquatement afin de rester dans la course ou de s'y insérer. De nouveaux produits sont développés et permettent l'apparition de nouveaux systèmes constructifs. Les façons de faire changent et évoluent puisque la construction structurale en bois pose des conditions différentes que celles bien connues de la construction en béton et en acier. Les entreprises tentent de s'adapter aux nouveaux marchés. Les modèles d'affaires de ces entreprises doivent être ajustés afin qu'elles puissent demeurer compétitives et si désiré, gagner de ces nouvelles parts de marchés.

Certains des industriels de la Chaire industrielle de recherche sur la construction éco-responsable en bois (CIRCERB) ayant mentionné le besoin de mieux connaître les marchés et les modèles d'affaires de l'industrie, l'équipe de ce projet est donc partie de cette intention pour élaborer les présents objectifs de recherche. Les questions de recherche suivantes ont donc été posées. Quels sont les barrières et les motivations en lien avec l'utilisation du bois comme matériau structural? Quels types de relations sont présentes entre les acteurs au sein de l'industrie de la construction structurale en bois? Comment une entreprise peut-elle organiser son modèle d'affaires afin de se positionner stratégiquement dans ce créneau en développement? Afin de pouvoir répondre à ces questions, les objectifs généraux et spécifiques suivants ont été poursuivis dans le cadre de ce projet de doctorat.

3.1 Objectif général

L'objectif général de cette thèse est donc d'établir les principales pratiques d'affaires en construction non-résidentielle structurale en bois en termes de connaissances du marché et des entreprises dans le but de proposer des éléments clés à intégrer aux modèles d'affaires de l'industrie afin de rendre les entreprises plus performantes et de leur permettre de se positionner comme *leader* dans le créneau.

Voici les trois objectifs spécifiques découlant de cet objectif général :

3.1.1 Objectif spécifique 1

Identifier les motivations et les barrières à l'adoption du bois comme matériau structural en construction non-résidentielle structurale en bois.

3.1.2 Objectif spécifique 2

Identifier et décrire les relations présentes au sein de la chaîne de valeur de la construction non-résidentielle structurale en bois.

3.1.3 Objectif spécifique 3

Cartographier les modèles d'affaires de l'industrie de la construction non-résidentielle structurale en bois afin d'en extraire les tendances.

Chapitre 4 - Rétrospective méthodologique

Afin d'atteindre les objectifs de recherche mentionnés précédemment, une stratégie de recherche a été mise sur pied. L'idée était de premièrement d'étudier les marchés de la construction non-résidentielle structurale en bois pour ensuite s'attarder aux modèles d'affaires des acteurs de la filière et de l'industrie qui devront inévitablement s'y adapter. L'intention était donc d'extraire les éléments clés des marchés et des modèles d'affaires afin de pouvoir orienter la croissance du secteur. Pour chacun des articles, des échantillons ont été sélectionnés et des analyses de contenu ont été conduites.

L'étude des marchés de la construction non-résidentielle structurale en bois dont traite l'article 1 est basée sur trois sources de données : de la littérature grise, de la littérature scientifique et des comptes-rendus de chantiers de construction. Le principe de triangulation a gouverné la méthodologie à trois étapes de ce premier article. Les premiers résultats, soit les motivations et les barrières ont été trouvés à partir de l'analyse de la littérature grise et scientifique. Ensuite, à partir de comptes-rendus de chantiers, des problèmes et des préoccupations vécus sur le terrain en ont été extraits. Ces problèmes et préoccupations ont été comparés aux barrières trouvées.

Dans le cas de l'étude de la littérature grise, l'échantillon sélectionné contient treize bâtiments multi-logements ou à bureaux bien connus, construits sur une structure en bois, situés sur trois continents, et qui ont été grandement étudiés. Ces bâtiments souvent présentés comme des études de cas possèdent entre six et quinze étages et ont été construits entre 2000 et 2017 (le bâtiment Origine est toujours en construction au moment d'écrire ces lignes). Ce type de littérature contient des documents variés, des articles de journaux et des rapports techniques. Voici le tableau rassemblant les treize bâtiments en question.

Tableau 1 : Projets de construction structurale en bois populaires dans le monde et utilisés pour la sélection de la littérature grise.

Nombre d'étages	**Année de construction**	**Pays**	**Nom du bâtiment**
6	2013 - 2014	Canada	District 03
6	2006	Canada	Fondaction
7	2008	Allemagne	*Esmarchstrasse 3*
8	2011	Allemagne	*H8 Bad Aibling*
8	2012	Autriche	*Lifecycle Tower One*
8	2009	Angleterre	*Stadthaus Murray Groove*
8	2010	Angleterre	*Bridport House*
8	2006 - 2009	Suède	*Limnologen*
9	2013	Italie	*Via Cenni*
10	2013	Australie	Forté *Building*
12	2000	Nouvelle- Zélande	*Scotia Apartment Tower*
13	2017	Canada	Origine
14	2015	Norvège	*Treet*

Pour sa part, la littérature scientifique concerne cinquante-trois articles scientifiques desquels des motivations et des barrières à l'utilisation du bois comme matériau structural pouvaient être tirées ou déduites. Six mots clés de recherche (motivations, barriers, opportunities, perceptions, timber buildings et multi-story buildings) ont été utilisés jusqu'à saturation des données dans les trois bases de données les plus souvent utilisées en sciences du bois (CAB Abstracts, Compendex et Web of Sciences) afin de sélectionner ces cinquante-trois articles.

Finalement, les comptes-rendus de neuf chantiers de construction québécois ont été analysés afin de vérifier l'adéquation des barrières trouvées dans la littérature avec les problèmes et les préoccupations rencontrées sur le terrain. Ils ont permis de confirmer les barrières identifiées.

Les données provenant de ces trois sources ont été traitées via une approche d'analyse qualitative en utilisant la méthode d'analyse de contenu. Selon L'Écuyer (1990), l'analyse qualitative est une méthode d'analyse souple, davantage inductive que l'analyse quantitative, et qui s'inspire du sens commun. Cette méthode consiste à décrire les particularités spécifiques des mots, phrases et idées regroupés dans chacune des catégories et qui se dégagent en plus des seules significations quantitatives. La signification du phénomène étudié réside dans la nature, dans la spécificité même des contenus du matériel analysé, plutôt que dans sa seule répartition quantitative. L'analyse qualitative constitue le fil conducteur de l'analyse de contenu dans sa recherche de sens. Elle consiste en une description minutieuse des différentes particularités qui ressortent des compilations faites et des traitements statistiques appliqués.

Les données recueillies ont été analysées à l'aide de la méthode d'analyse de contenu. L'Écuyer (1987) présente le processus de l'analyse de contenu en le décomposant en six étapes. Il s'agit 1) d'effectuer plusieurs lectures du matériel recueilli afin de 2) le découper en énoncés plus restreints possédant normalement un sens complet en eux-mêmes et qui serviront à 3) la catégorisation. Cette troisième étape consiste à construire des groupes avec les énoncés dont le sens se ressemble. Une catégorie est une sorte de dénominateur commun auquel peut être ramené tout naturellement un ensemble d'énoncés. Ensuite, il est possible de 4) quantifier les catégories en termes de fréquences, de pourcentages ou de divers autres indices. Vient par la suite 5) la description scientifique qui est basée sur l'analyse quantitative et sur l'analyse qualitative. L'analyse de contenu se termine par 6) l'interprétation des résultats.

L'analyse de contenu est donc une méthode scientifique systématisée et objective permettant de traiter du matériel très varié par l'application d'un système de codage conduisant à la mise au point de catégories. Ces catégories permettent d'analyser quantitativement et qualitativement les données. L'analyse qualitative comprend : « l'analyse des contenus manifestes, ultimes révélateurs du sens exact du phénomène étudié, et des contenus latents afin d'accéder au sens caché potentiellement véhiculé par les informations » L'Écuyer (1990). Pour cette étude, la version 10.2.2 du logiciel N'Vivo a été utilisée.

Les motivations trouvées sont celles-ci : la volonté de contribution au développement durable, le manque d'expertise, les coûts, la rapidité d'installation des structures et les aspects esthétiques du bois. Les barrières, pour leur part, sont les suivantes : le code du bâtiment, le transfert de technologies, les coûts, la durabilité et les autres aspects techniques du matériel, la culture de l'industrie et la disponibilité du matériel.

Puisque la catégorie de barrière de la Culture de l'industrie semblait avoir été moins étudiée et moins précise, la décision de s'y attarder a été prise. Pour ce faire, une étude des interrelations comprises entre les acteurs de la chaîne de valeur a été amorcée : elle constitue la recherche présentée par l'article 2 de cette thèse. De plus, comme les interrelations entre les acteurs d'un projet et de l'industrie font partie intégrante des modèles d'affaires des entreprises, cet objectif de recherche complète bien l'objectif 3 qui concernait l'étude des modèles d'affaires de l'industrie.

Afin de pouvoir réaliser les études reliées aux objectifs de recherche 2 et 3 de ce projet, quinze bâtiments non-résidentiels construits sur une structure en bois ont premièrement été sélectionnés. Cette fois, cet échantillon contient des bâtiments multi-étagés, des centres culturels, des hôtels et des édifices à bureaux.

Par la suite, tous les acteurs des chaînes de valeur de ces bâtiments ont été identifiés. Des courriels ont ainsi été envoyés aux architectes, aux ingénieurs en structure, aux constructeurs (entrepreneurs) et aux fournisseurs de matériaux ayant participé à la construction de ces bâtiments. Basé sur une quinzaine de réponses positives reçues et sur l'effet boule de neige (Heckathorn 2011) utilisé afin de compléter l'échantillon, un séjour et une tournée d'entrevue de trois mois a été réalisé par la chercheure en Europe. En effet, plusieurs acteurs rencontrés ont contacté des entreprises de la même région qui ont aussi acceptées d'être interviewées. Les entrevues ont eu lieu dans neuf pays : l'Autriche, l'Allemagne, la Suisse, l'Italie, l'Angleterre, l'Écosse, la Norvège, la Suède et le Danemark. Au total, vingt-trois entreprises ont répondu aux trente-deux questions. En complément, des académiques ont été sollicités pour des rencontres et 3 ont accepté. Le schéma d'entrevue utilisé pour l'interview des entreprises a été placé en annexe. Les questions concernaient deux thèmes majeurs, soit premièrement l'expérience des entreprises interviewées sur un ou deux projets de construction provenant de la liste de bâtiments préalablement sélectionnés et deuxièmement, les modèles d'affaires de ces entreprises. Afin de faciliter l'analyse des données, le cadre théorique clair et facile d'usage proposé par Osterwalder et Pigneur (2010) contenant neuf éléments structurant les modèles d'affaires des entreprises a été utilisé. Ces neuf éléments sont les suivants : les segments de marché, la proposition de valeur, les canaux de distribution, les relations avec les clients, les flux de revenus, les ressources clés, les activités clés, les partenariats clés et la structure de coûts. Un schéma d'entrevue contenant une trentaine de questions ouvertes permettant des réponses élaborées a été construit. Les entrevues ont été réalisées dans les bureaux de travail des participants à la recherche ou dans les bâtiments sur lesquels la partie du questionnaire en lien avec l'expérience professionnelle de construction d'un bâtiment structural en bois avait été acquise. Elles duraient entre une et deux heures selon la disponibilité de l'interviewé. Elles ont toutes été enregistrées et transcrites par la suite. Tout comme pour l'article 1, la méthode d'analyse utilisée est l'analyse de contenu telle que décrite plus haut dans cette même section.

L'article 2 concerne les interrelations comprises entre les acteurs de la chaîne de valeur de projets de construction structurale en bois et de l'industrie. L'analyse de données reliées à cet article s'est concentrée sur certains éléments du canevas de modèles d'affaires d'Osterwalder et Pigneur (2010) : les canaux de distribution, les relations avec les clients et les partenariats clés. Cette analyse a permis d'établir un réseau complexe d'interrelations de trois types, les contractuelles, celles liées à des projets de construction en bois et celles liées à l'industrie de la construction structurale en bois.

Pour l'article 3 portant sur les modèles d'affaires présents au sein de l'industrie, une analyse en profondeur de chacun des neufs éléments du canevas de modèles d'affaires d'Osterwalder et Pigneur (2010) a été réalisée. Les modèles d'affaires ont ainsi pu être cartographiés et les tendances des modèles d'affaires de cette industrie identifiées.

Chapitre 5 - Main Motivations and Barriers for Using Wood as a Structural Building Material

5.1 Résumé

L'acier et le béton sont couramment utilisés comme matériaux structuraux pour les bâtiments non-résidentiels et à logements multiples. Cependant, le bois possédant des propriétés structurales similaires, une variété de bâtiments structuraux en bois à plusieurs étages ont récemment été construits partout dans le monde. En se basant sur une analyse de la littérature grise concernant des bâtiments spécifiques et sur la littérature scientifique, cette étude a permis d'identifier les principales motivations et barrières à l'adoption du bois comme matériau structural. Les motivations trouvées étaient liées à la contribution au développement durable, aux aspects techniques, aux coûts, à la rapidité d'érection des structures et à l'esthétique des structures en bois. En revanche, les obstacles à son utilisation englobent la mise en œuvre du code du bâtiment, le transfert des technologies, les coûts, la durabilité du bois et ses autres aspects techniques, la culture de l'industrie et la disponibilité des matériaux de structure en bois. De plus, une analyse des comptes-rendus de chantiers de neuf projets de construction de bâtiments non-résidentiels structuraux en bois a été réalisée afin d'identifier les problèmes et les préoccupations retrouvés sur les chantiers. Ces problèmes et préoccupations sont en lien avec des problèmes d'assemblage, de conception du bâtiment, de calendrier et de relations avec les intervenants. Avec une meilleure compréhension des défis concernant l'utilisation du bois comme matériau structural dans la construction non-résidentielle, les entreprises seront en mesure d'adapter leurs modèles d'affaires et ainsi d'utiliser d'avantage la ressource bois pour développer des structures innovantes.

5.2 Abstract

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 are highlighted, based on an analysis of grey literature concerning specific 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, companies will be able to adapt their business models and use even more the resource to develop innovative structures.

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

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5.3 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 (StatistiquesCanada 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 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 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 wood multi-story construction projects over the world from a combination of systematic surveys of both grey and scientific literatures. Meeting minutes from nine 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. 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 while representing a rich source of information. 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.

5.3.1 Current Market Shares of Wood Structures in Non-Residential Constructions

The use of wood in 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 used as structural material have increased from 18% to 22% between 2006 and 2009 (Robichaud 2010)). Another study conducted on 72 architects and 27 engineers also showed that, between 2009 and 2012, the specification of wood for structural system remained relatively the same. This survey, furthermore, demonstrated that structural engineers tended to pick wood for building structures slightly more frequently than architects did (20% *versus* 17.8%) (Chamberland et Robichaud 2013)). 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 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 the main material (O'Connor 2006a). 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 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 major construction projects all around the world have used wood as the key 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.

5.4 Methods

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

5.4.1 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, global timber building projects. 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 wood building projects in Quebec, Canada. These three samples are detailed in the following paragraphs.

5.4.1.1 Major timber building projects in the world

Thirteen wooden multi-story buildings were analyzed. This sample included the most popular wood building cases over the world and multiple documents, news articles, technical reports, and grey literature 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 stair 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 where 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*) 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 et 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 in 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 2.

Table 2 : 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*

5.4.1.2 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 to 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.

5.4.1.3 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. They were, 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 preventing cost and schedule changes since they allow interested parties to provide valuable input before it impacts the projects (Stechyshyn 2015). However, because of the confidential data they contained, their use may have involved signing confidentiality agreements between the researcher and the companies. Even when this measure was agreed upon, not all companies were willing to share this information source. 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 must have been 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 which were more or less dense depending on the person responsible of their redaction. 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 are 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 an impressive 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 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.

5.5 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 non-residential 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.

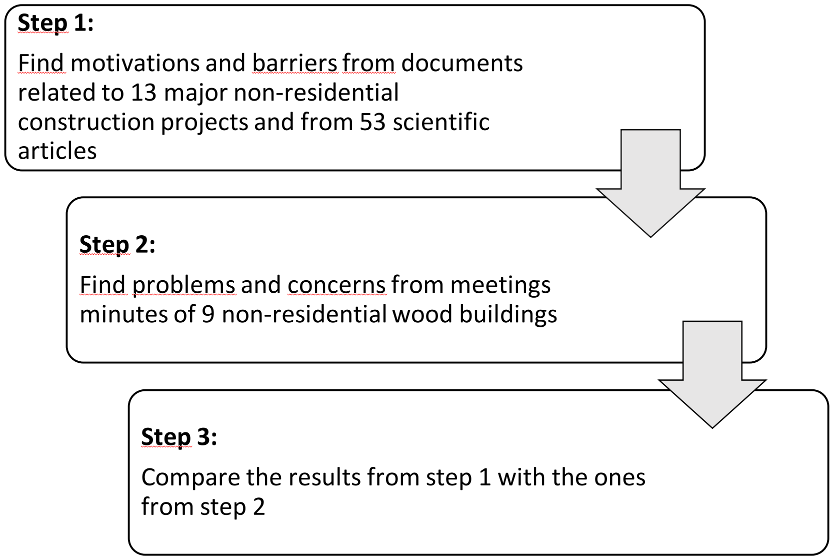

Figure 2: The three steps of the research design

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).

5.5.1 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 N'Vivo software suite was used to analyze the meeting minutes.

5.5.2 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 was 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.

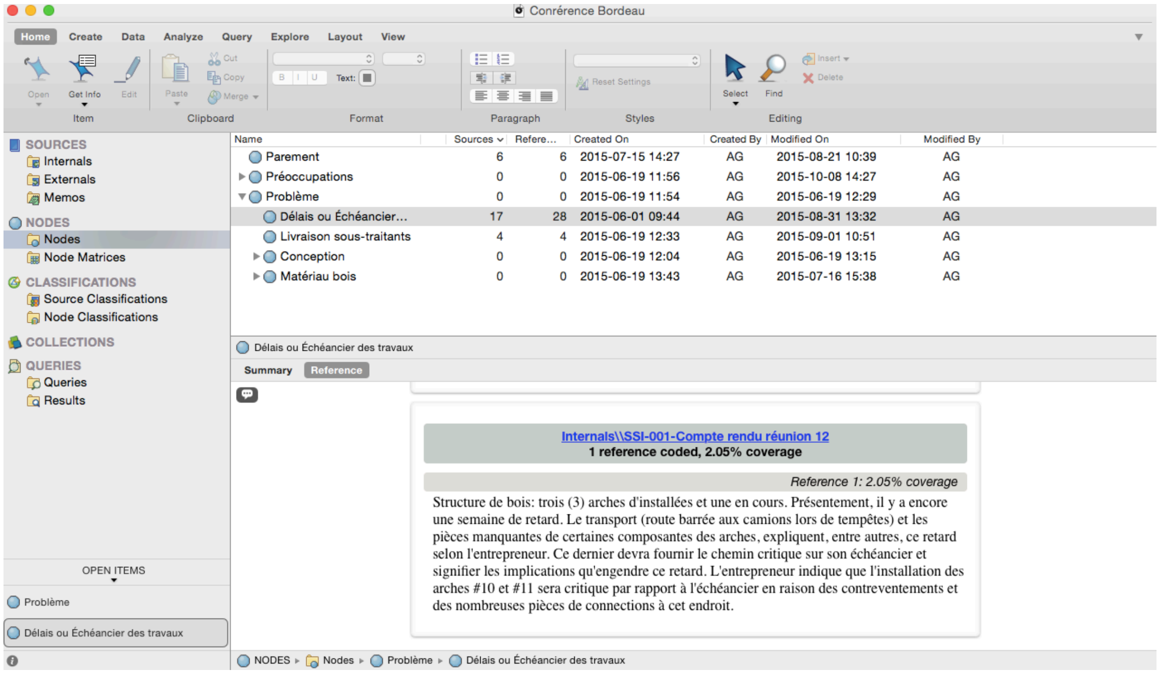

Figure 3 : Printscreen of the N'Vivo software used to build the categories and to conduct the analysis

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.

5.6 Result and discussion

5.6.1 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. 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 4 prioritizes and summarizes the motivations found.

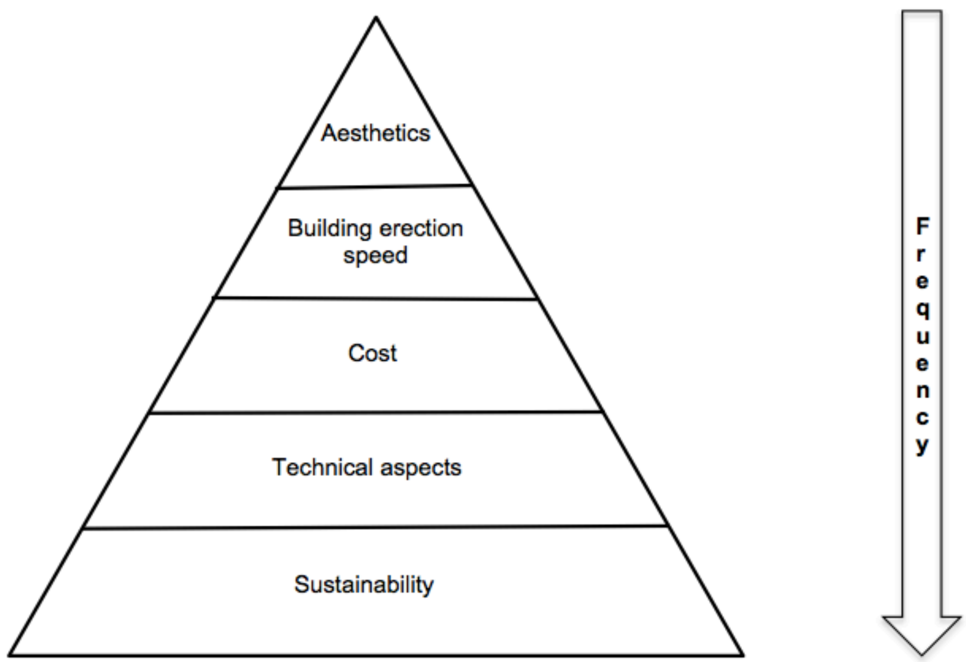

Figure 4: Motivations for the adoption of wood as structural material for non-residential buildings

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 the positive environmental performance of wood (Kozak 1995, O'Connor*, et al.* 2004, Roos*, et al.* 2008, Shmuelly-

Kagami 2008, Gold et Rubik 2009, Robichaud*, et al.* 2009, Roos*, et al.* 2010, Kuzman et Groselj 2011, Nolan 2011, Hemström*, et al.* 2011a, Mahapatra*, et al.* 2012, Schmidt et Griffin 2013, Thomas*, et al.* 2013, Manninen 2014, Hurmekoski*, et al.* 2015, Laguarda et Espinoza 2015) and its carbon sequestration capacity (Schmidt and Griffin 2013), as well as its energy efficiency (Bayne et Taylor 2006, Bysheim et Nyrud 2008, Bysheim et Nyrud 2009, Hemström*, et al.* 2010, Kuzman et Groselj 2011, Van De Kuilen*, et al.* 2011, Hemström*, et al.* 2011a, Lehmann*, et al.* 2012, Schmidt et 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. Performance related to fire (Bayne et Taylor 2006, Bysheim et Nyrud 2008, Roos*, et al.* 2008, Hemström*, et al.* 2010, Schmidt et Griffin 2013, Manninen 2014, Hurmekoski*, et al.* 2015), acoustics and insulation (Hemström*, et al.* 2010, Kuzman et Groselj 2011, Oliveira*, et al.* 2013, Robichaud 2014), good mechanical and physical properties (Bysheim et Nyrud 2008, Bysheim et Nyrud 2009, Kuzman et Groselj 2011, Hurmekoski*, et al.* 2015, Laguarda et Espinoza 2015), ease of working with the material (Kozak et Cohen 1999, Nolan et Truskett 2000, Nolan 2011, Mahapatra*, et al.* 2012, Hurmekoski*, et al.* 2015), hygrothermal performance (Oliveira*, et al.* 2013), durability (O'Connor*, et al.* 2004, Chamberland et Robichaud 2013, Hurmekoski*, et al.* 2015), stability (Hemström*, et al.* 2010), and lightness (Roos*, et al.* 2008, Birch 2011, Beaucher 2015) were all factors mentioned in the literature. 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 to double 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 material, construction, and maintenance costs (Kozak 1995, Kozak et Cohen 1999, Nolan et Truskett 2000, O'Connor et Gaston 2004, Walford 2006, Bysheim et Nyrud 2008, Roos*, et al.* 2008, Shmuelly-Kagami 2008, Williamson*, et al.* 2009, Eliasson et Thörnqvist 2010, Nolan 2011, Van De Kuilen*, et al.* 2011, Thomas*, et al.* 2013, Manninen 2014, Robichaud 2014, Hurmekoski*, et al.* 2015), while being closely linked to the 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 et 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. Ease of installation, construction speed, simplicity, flexibility, and lightness (Kozak 1995, O'Connor et Gaston 2004, Bayne et Taylor 2006, Walford 2006, Roos*, et al.* 2008, Hemström*, et al.* 2010, Van De Kuilen*, et al.* 2011, Mahapatra*, et al.* 2012, Chamberland et Robichaud 2013, Thomas*, et al.* 2013, Robichaud 2014, Hurmekoski*, et al.* 2015) were also frequently mentioned terms. 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: warm character, inviting, comfortable, attractive, aesthetic, interesting, enjoyable by occupants, welfare, health effects, natural design, visual beauty, and friendly feeling (Kozak 1995, Goetzl et McKeever 1999, Nolan et Truskett 2000, O'Connor et Gaston 2004, O'Connor*, et al.* 2004, Bayne et Taylor 2006, Walford 2006, Bysheim et Nyrud 2008, Roos*, et al.* 2008, Bysheim et Nyrud 2009, Gold et Rubik 2009, Kuzman et Groselj 2011, Nolan 2011, Oliveira*, et al.* 2013, Manninen 2014, Hurmekoski*, et al.* 2015, Laguarda et 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.

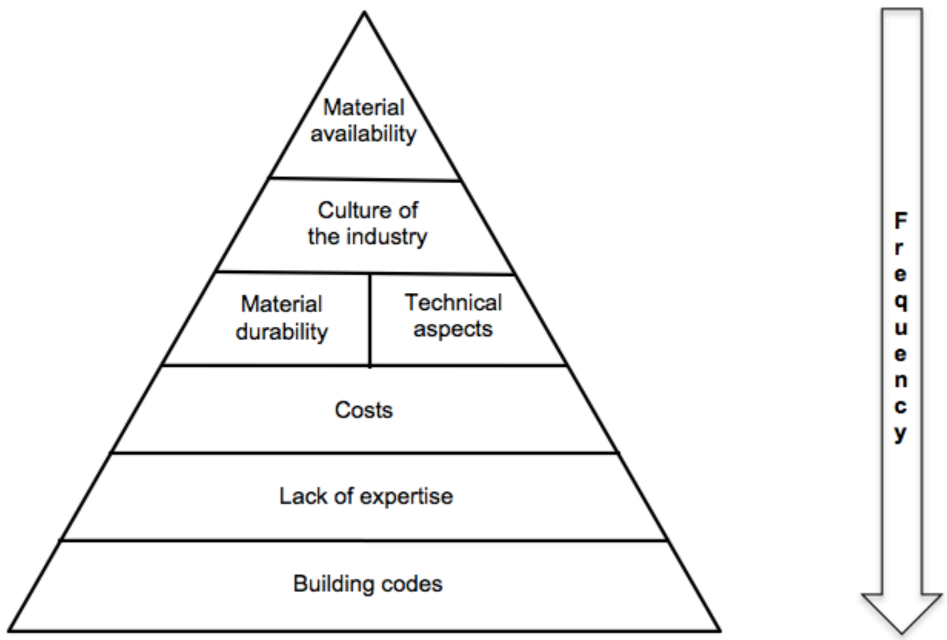

Figure 5 : Barriers to the adoption of wood as structural material for non-residential buildings

Difficulties related to the building codes were unquestionably the main obstacle to the adoption of wood as a structural material in buildings taller than 4 stories. Already in 1995, Kozak had noticed the same issue. National building codes included a variety of rules and limitations that seemed to constrain the use of wood as a structural material. The fire safety rules and the incorrect perception of wood fire resistance, presented in the building codes, were the most frequently cited elements (Vahik et Julie , Kozak 1995, Goetzl et McKeever 1999, Kozak et Cohen 1999, Gaston*, et al.* 2001, O'Connor*, et al.* 2003, Bregulla*, et al.* 2004, O'Connor et Gaston 2004, Östman 2004, Walford 2006, GeskinConseil 2008, Mahapatra et Gustavsson 2008, Roos*, et al.* 2008, Gold et Rubik 2009, Robichaud*, et al.* 2009, Williamson*, et al.* 2009, Griffin*, et al.* 2010, Robichaud 2010, Lehmann*, et al.* 2012, Mahapatra*, et al.* 2012, Robichaud 2014, Drouin 2015, Hurmekoski*, et al.* 2015, Roth 2015). Some authors also pointed out 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 et Gaston 2004, GeskinConseil 2008, Mahapatra et Gustavsson 2008, Griffin*, et al.* 2010, Robichaud 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, in Canada it is 4. 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).

The second main barrier referred to the lack of expertise and was explained by the following items: lack of research findings transferred to the industry, lack of academic, or continuing training (Vahik et Julie , Kozak et Cohen 1997, Gaston*, et al.* 2001, Bregulla*, et al.* 2004, Mahapatra et Gustavsson 2008, Williamson*, et al.* 2009, Manninen 2014, Robichaud 2014), lack of information (Nolan et Truskett 2000, O'Connor*, et al.* 2003, Bayne et Taylor 2006, Robichaud*, et al.* 2009, Griffin*, et al.* 2010), lack of support for technical aspects (Nolan et Truskett 2000, Gaston*, et al.* 2001, O'Connor*, et al.* 2003, Bayne et Taylor 2006, Roos*, et al.* 2010, Nolan 2011), and lack of experience/knowledge/skills towards wood (Vahik et Julie , Nolan et Truskett 2000, O'Connor*, et al.* 2003, O'Connor et Gaston 2004, GeskinConseil 2008, Mahapatra et 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 to compromise of the design team. 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 et Rubik 2009, Williamson*, et al.* 2009).

Cost, which was previously introduced as a motivation for wood use, also seemed to be considered as a barrier. Capital, material, construction, and long-term maintenance costs are often mentioned (Vahik et Julie , Kozak 1995, Kozak et Cohen 1999, Gaston*, et al.* 2001, O'Connor*, et al.* 2003, O'Connor et Gaston 2004, O'Connor*, et al.* 2004, Bayne et Taylor 2006, Wei*, et al.* 2007, Bysheim et Nyrud 2009, Bysheim et Nyrud 2010, Eliasson et Thörnqvist 2010, Griffin*, et al.* 2010, Roos*, et al.* 2010, Knowles*, et al.* 2011, Hemström*, et al.* 2011b, Lehmann*, et al.* 2012, Mahapatra*, et al.* 2012, Chamberland et Robichaud 2013, Riala et Ilola 2014, Drouin 2015, Hurmekoski*, et al.* 2015, Laguarda et Espinoza 2015, Roth 2015). Risk aversion of the construction industry (Emmitt 2001, Bayne et Taylor 2006, Bysheim et Nyrud 2008, GeskinConseil 2008, Mahapatra et Gustavsson 2008, Roos*, et al.* 2008, Bysheim et Nyrud 2010, Mahapatra*, et al.* 2012, Hurmekoski*, et al.* 2015, Roth 2015), fears related to the resale value (Oliveira*, et al.* 2013, Robichaud 2014), and lack of experience and of a skilled workforce could also affect construction costs (O'Connor*, et al.* 2004, GeskinConseil 2008, Mahapatra et Gustavsson 2008, Roos*, et al.* 2008). 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 et Gustavsson 2008, Robichaud 2014). As stated by Knowles*, et al.* (2011), the cost is an important factor in the choice of a structural material. Laguarda et 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 (Vahik et Julie , Kozak 1995, Kozak et Cohen 1999, Gaston*, et al.* 2001, O'Connor*, et al.* 2003, O'Connor*, et al.* 2004, Mahapatra et Gustavsson 2008, Gold et 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 et Espinoza 2015). Although durability was integrated into the category of technical aspects in the motivations categories, wood durability appeared so often as a barrier, the choice of creating two categories was made. Technical aspects concerned several characteristics of wood material: the acoustic performance, security feeling, stability and wood shrinkage, humidity, stiffness and strength, quality, technical defects, and the protection against vermin, insects, rot, water, wind, and earthquakes (Vahik et Julie , Kozak 1995, Kozak et Cohen 1997, Kozak et Cohen 1999, O'Connor*, et al.* 2003, O'Connor et Gaston 2004, O'Connor*, et al.* 2004, Bayne et Taylor 2006, Walford 2006, Roos*, et al.* 2008, Gold et Rubik 2009, Mahapatra et Gustavsson 2009, Williamson*, et al.* 2009, Eliasson et 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. The conservative attitude of the sector, the lack of openness, a high preference for established practices (GeskinConseil 2008, Tykkä*, et al.* 2010, Hemström*, et al.* 2011b, Robichaud 2014, Hurmekoski*, et al.* 2015), and the lack of standardization and organization of the industry have been mentioned several times (Vahik et Julie , Gaston*, et al.* 2001, O'Connor et Gaston 2004, Bysheim et Nyrud 2008, Roos*, et al.* 2008, Nolan 2011, Lehmann*, et al.* 2012). Comments on the fragmentation of the industry and the idea that stakeholders in non-residential construction did not interact enough with each others are also present in this document sample (Vahik et Julie , Williamson*, et al.* 2009, Roos*, et al.* 2010, Nolan 2011). Nolan (2011) mentioned a lack of construction-oriented solutions from wood manufacturers, while Oliveira*, et al.* (2013) pointed out the stigmatization of wood as a material dedicated to social housing. Lehmann*, et al.* (2012) brought the need of cultural, behaviors, organizational and policy changes.

Material availability was the last obstacle found to a greater use of wood in construction (Vahik et Julie , Kozak et Cohen 1999, Gaston*, et al.* 2001, Bayne et Taylor 2006, Mahapatra et Gustavsson 2008, Roos*, et al.* 2008, Robichaud*, et al.* 2009, Knowles*, et al.* 2011, Nolan 2011, Laguarda et Espinoza 2015). It was mentioned by the four focus groups conducted by Knowles*, et al.* (2011). Laguarda et Espinoza (2015) also 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 tend to be more skeptical.

5.6.2 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. 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.

5.6.2.1 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 the way they were supposed to. 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 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 had to be hung 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 lightning 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 was 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.

5.6.2.2 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 responsibilities 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 acceptable. 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 to 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 disigned 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 lightning 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 requirement. 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.

5.6.3 Discussion

As presented in Table 3, 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 load 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 2006a, Chamberland et Robichaud 2013). 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 fuelled 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 3: 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 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.

5.7 Conclusion

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 reached 14 stories. 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 in non-residential buildings would stimulate the forest products industry, while having a great impact for the Canadian economy.

2. An analysis of 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 in large non-residential and multi-story housing buildings. 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.

5.8 Acknowledgment

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Chapitre 6 – Characterizing supply chain relationships to enable the adoption of innovative wooden structures in construction

6.1 Résumé

Malgré des parts de marché encore limitées, l'utilisation des produits d'ingénierie en bois comme matériaux structurales est devenue plus populaire dans les dernières années. L'un des obstacles à la croissance de leur utilisation est la complexité des relations caractérisant la chaîne de valeur des bâtiments structuraux en bois. L'objectif de cette étude est d'identifier et de caractériser les relations partagées par les différents acteurs impliqués dans les projets de construction structurale en bois. Les différents niveaux relationnels retrouvés au sein de la chaîne de valeur des projets de construction en bois ont été identifiés à l'aide de vingt-trois entretiens semi-dirigés réalisées auprès d'architectes, d'ingénieurs en structure, de constructeurs et de fournisseurs de matériaux structuraux en bois, dans neuf pays européens. De l'observation participante et des données secondaires ont également contribués à la récolte de données. La triangulation et l'analyse qualitative ont été utilisées. Trois niveaux de relations ont été identifiés: contractuelles, de projet de construction en bois et de développement de l'industrie de la construction structurale en bois. L'utilisation de structures en bois impliquent des relations étroites et profondes plutôt que de simples relations linéaires et transactionnelles. Les relations entre acteurs se multiplient et adoptent une approche collaborative, soit de partage de l'information. Enfin, les systèmes préfabriqués permettent un processus plus fluide et plus efficace, limitent le nombre d'acteurs et facilitent les relations de même que l'innovation.

6.2 Abstract

Wooden structures in construction have become more popular in recent years. Nevertheless, besides the complexity of designing, contracting and building those structures, a barrier to their market growth is the complexity of their supply chain relationships encompassing architects, engineers, builders and suppliers. The objective of this study is therefore to identify and characterize the supply chain relationships shared by these stakeholders within a massive timber construction project. Twenty-seven semi-structured interviews with architects, structural engineers, builders and wood material suppliers from nine countries, participant observations, and secondary data were used to study the various relationship levels involved in wood construction projects. Triangulation and qualitative data analysis

were also conducted. Three levels of relationships were then identified: “Contractual”, “Massive timber construction project”, and “Massive timber construction industry development”. Results showed that wooden structures involve value-added stakeholder relationships rather than linear relationships. These relationships appeared closer and more frequent, and involved knowledge and information sharing. Prefabricated systems furthermore allow for smoother relationships by limiting the number of stakeholders while promoting innovative thinking.

Keywords: Construction, Supply Chain Relationship, Massive Timber, Supply chain.Paper type:

6.3 Introduction

Since the industrial revolution, concrete, steel and timber frame have been the dominant building materials used for all kinds of buildings. Most institutional, commercial, industrial and residential multi-story buildings stand on structures made from these three materials. Lately, new engineered structural wood products, such as Crossed Laminated Timber (CLT) and Glulam that allow mass timber construction, have been entering the market. Inspired by the traditional uses of wood at the beginning of the last century where trees were transformed into single-house structural pieces, modern engineered wood products have pushed boundaries in terms of use, strength and structural possibilities. Pieces from smaller trees glued together are now offering more building options. Nowadays, wood used as a structural material is a growing market (Robichaud 2010, Chamberland et Robichaud 2013, Drouin 2015).

Although the use of mass timber has increased, it is not yet a common practice. There exists a variety of studies aimed at estimating the market share for tall and large massive timber buildings. The most recent data indicate that wood is selected between 18% to 24% of the time for structural uses in Canada (Gaston*, et al.* 2001, O'Connor et Gaston 2004, Robichaud 2010, Chamberland et Robichaud 2013, Drouin 2015, Gosselin*, et al.* 2016). Gosselin *et al*. (2015), through a methodological use of extant literature, have identified barriers, divided into six categories, which seem to prevent the use of massive wood as a structural material: 1) code implementation, 2) technology transfer, 3) costs, 4) material durability and other technical aspects, 5) culture of the industry and 6) material availability. This paper focuses on identifying and characterizing the supply chain relationships between stakeholders of the mass timber building construction industry, one of the components of the fifth barrier. The research also intends to find enablers for the use of wood as a structural material. To achieve these goals, twenty-seven interviews with architects, structural engineers, builders and wood material suppliers from nine countries were conducted, combined with participant observation and secondary data analyses. The idea was to gather information concerning stakeholders' experience working on wooden buildings and the relationships established to conduct those projects. After analyzing the data collected, it appeared that the number of relationships developed during a construction project tends to be multiplied when using massive timber as the structural material. Moreover, networking, collaboration and prefabrication seemed to enable the use of wood in construction. Those observations allowed us to propose three levels of interactions to characterize the supply chain relationships shared among stakeholders in the structural wood building industry: the "contractual (C)" level, the "wood building project (P)" level and the "massive timber construction industry development (I)" level. Little research has been conducted on supply chain relationships included in massive timber construction projects. However, it remains important for professionals in the field to be aware of the successful management factors to put in place when using wood as a structural material so as to improve day-to-day processes efficiency while facilitating its use in construction. This paper examines the interrelationships as follows: First, the construction supply chain is defined and detailed. Subsequently, the methodology used to identify and characterize the relationships developed in a project involving wood is presented. Results follow and are then discussed before concluding.

6.4 Defining a construction supply chain

In 1985, Porter (1985) developed the concept of "value chain" with an underlying idea that members of a chain should focus on delivering value from their combined activities. The supply chain management (SCM) concept came about in the 1980s. It suggested a new way of thinking to enable a better performance of the "supply chain" by managing relationships using innovation and continuous improvement (Christopher 2005, Peck 2006, Pryke 2009, Blanchard 2010, Van Weele 2010, Fulford et Standing 2014, Behera*, et al.* 2015). According to Meng*, et al.* (2011), supply chain relationship models were first developed in the purchasing and supply sector in the mid-1990s and were then integrated into the construction industry.

Latham (1994) and Egan (1998) strongly criticized the construction industry in the UK and multiple studies have been carried out in response to these two reports. The largely sequential approach used in a construction project typically reflects a lack of integration between design, construction and maintenance methods, leading to inefficiencies, inferior value and poor margins (Holti*, et al.* 2000). Attempts have made to improve the performance of the SCM but challenges remain in the adoption of the proposed methodologies and concepts, often associated with a lack of new and more systematic approaches to its implementation (Saada*, et al.* 2002). Furthermore, in trying to demonstrate the effect of relationship management on project performance in construction, Meng (2012) found that the deterioration of relationships between project participants may increase the likelihood of poor performance.

Many studies have been conducted on the factors influencing the construction supply chain, such as supply chain integration, strategic partnerships and collaborative agreements between supply chain actors (Akintoye*, et al.* 2000, Holti*, et al.* 2000, Briscoe et Dainty 2005, Rimmers 2009). Some authors highlighted the fact that supply chain management, partnerships and collaborative work have been partly adopted by the industry as a means to improve relationships, and thus performance, among stakeholders (Briscoe*, et al.* 2004, Wood et Ellis 2005, Akintoye et Main 2007, Bygballe*, et al.* 2010). Few studies have aimed at describing the relationships that are developed within the supply chain itself. For instance, Akintoye and Main (2007) demonstrated that UK contractors share collaborative relationships to develop the construction sector. Meng*, et al.* (2011) suggested eight criteria to evaluate the maturity level of a construction supply chain: procurement, objectives, trust, collaboration, communication, problem solving, risk allocation and continuous improvement.

Procurement was identified as a key criterion since it heavily affects the construction supply chain. The type of contract procurement or project delivery system under which a construction project is completed certainly influences and often defines the relationships involved in the supply chain. Many types of contract procurements co-exist in construction industries around the world. Kantola et Saari (2016) argued that the design-bid-build system is the most used system worldwide. This mode is mainly characterized by the linearity of the process scheduling and the separation of the design and building steps. A figure was presented by Broft*, et al.* (2016) that illustrated the current procurement structure in the construction industry and the linear shape of construction supply chains (Figure 6).

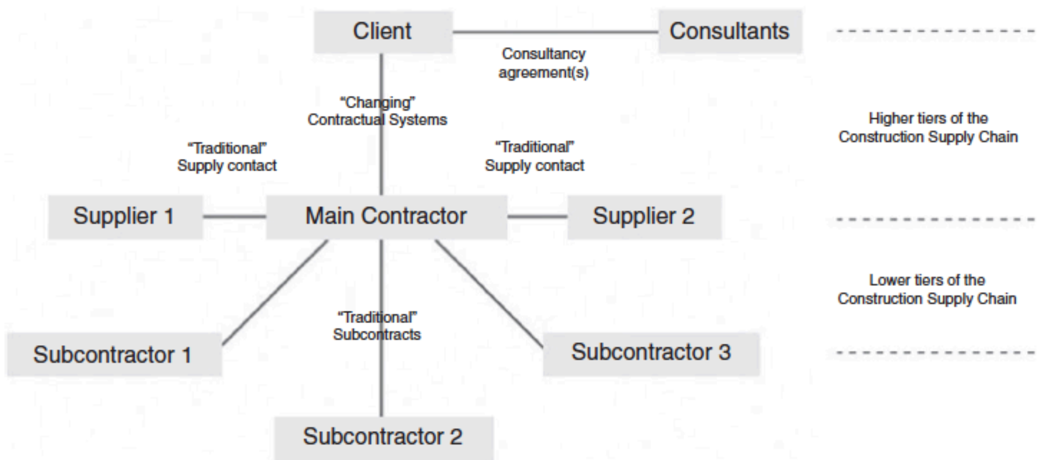

Figure 6 : Current procurement structure

(Broft et al. (2016); reprinted with permission: Emerald Publishing)

Behera, *et al.* (2015) proposed the following figure to represent the phases a typical construction supply chain must go through. Figure 7 shows the stakeholders involved in the five phases: concept, procurement, production, installation and winding up.

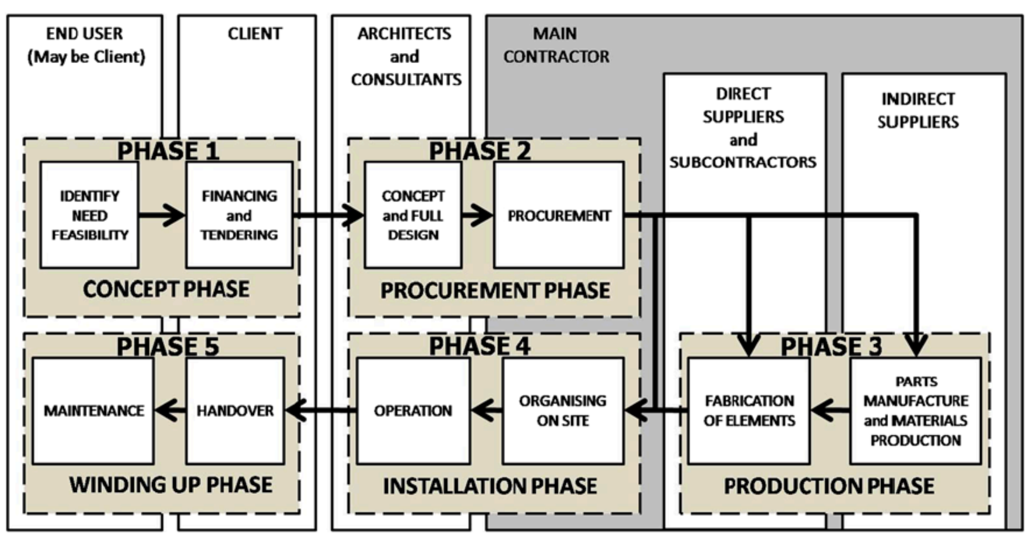

Figure 7 : Phases in a typical construction project

(Behera et al. (2015); reprinted with permission: Taylor & Francis Ltd, http://www.tandfonline.com)

Klein (2013) studied the design and construction process of building facades using the model in Figure 8.

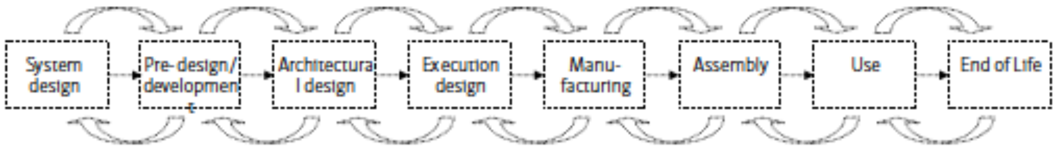

Figure 8 : Design and construction phases of a curtain wall

(Klein (2013); reprinted with permission: Klein)

The back and forth seen on this figure represents information sharing during the construction process, as well as interactions occurring between stakeholders. To complete a building, many actors must share certain information, knowledge, work time, material and money. A construction supply chain thus integrates many interactions. Figure 9, suggested by Hui (2017), represents and attempts to explain the situation. It shows information sharing between parties throughout the course of a construction project.

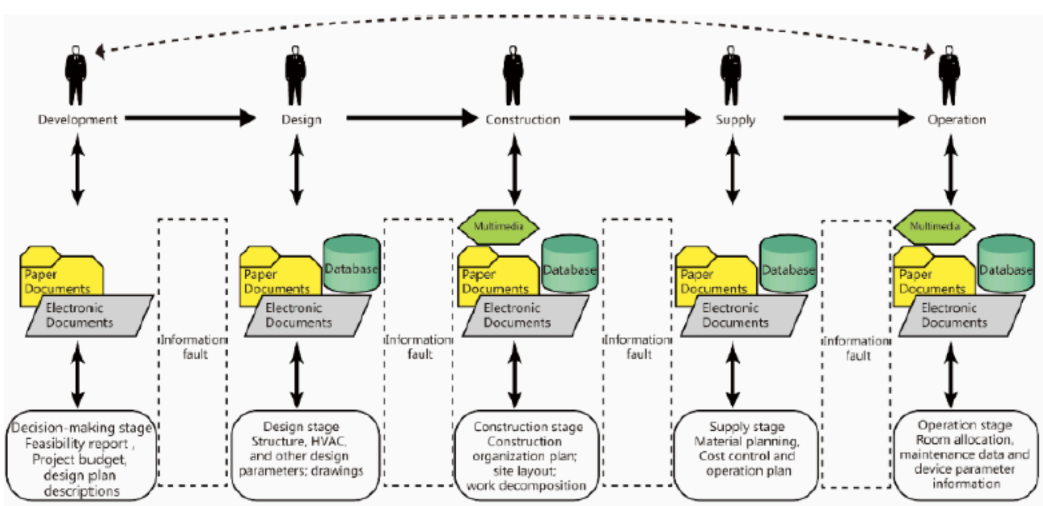

Figure 9 : Traditional building information value chain model

(Hui and Weishuang (2017); reprinted with permission: IOP Publishing, Ltd)

6.4.1 Defining a typical massive timber construction supply chain

Literature suggests that a typical construction supply chain should be mapped based on a linear shape, including many stakeholders and encapsulating various relationships. Behera*, et al.* (2015) stated that typical construction supply chains include architects and engineers, main contractors, specialty subcontractors and material suppliers. Departing from these figures and integrating the list of stakeholders from Behera *et al.* (2015), this article proposes the following representation of a typical massive timber construction supply chain (Figure 10).

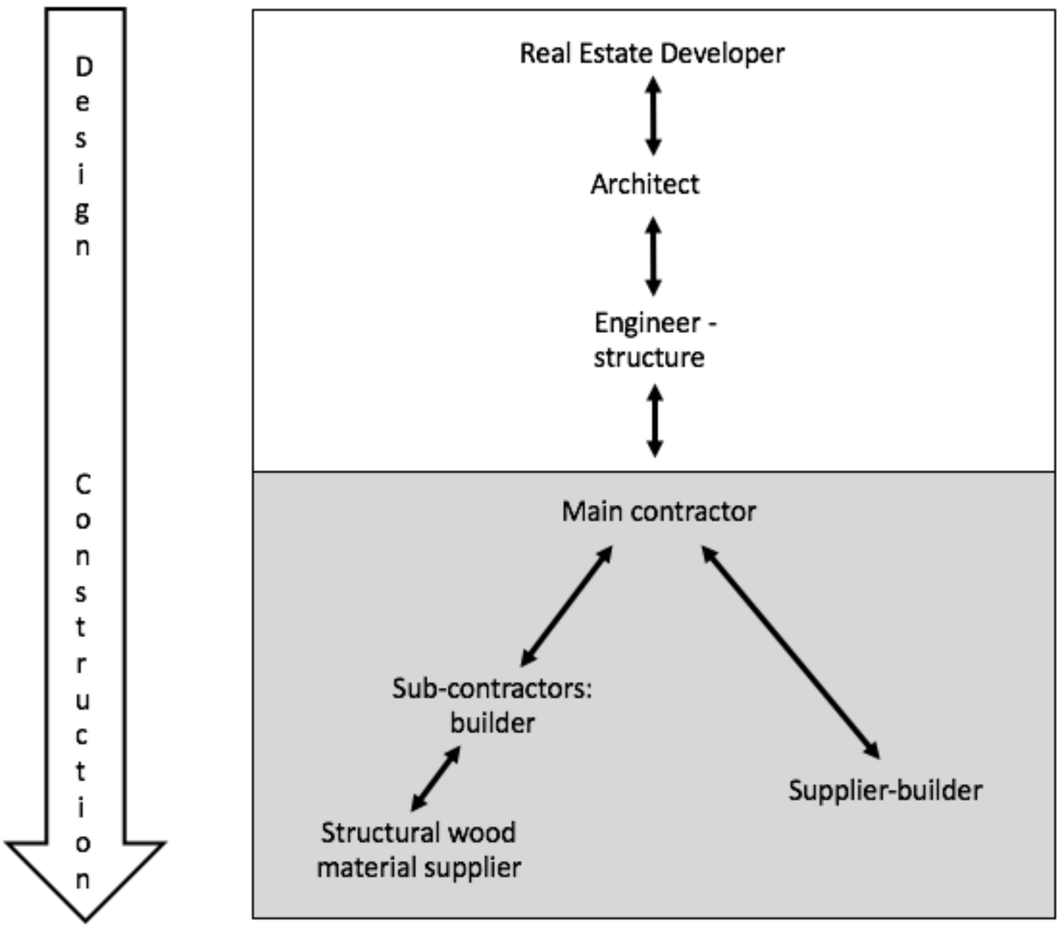

Figure 10 : Typical massive timber construction supply chain

A typical massive timber construction supply chain can integrate either five or six stakeholders depending on the construction mode. These two options are represented in Figure 10. From the main contractor, the project will either go left – a six main stakeholder path or right – a five main stakeholder path.

This paper examines the interrelationships as follows: The previous section was used to define the typical construction supply chain. The next section presents the methodology used to identify and characterize the supply chain relationships developed in a construction project involving massive timber. Results follow and are then discussed before concluding.

6.5 Research design and data collection

This study was conducted to answer the following two questions: 1) What are the supply chain relationships involved in the structural wood building industry? 2) What would facilitate the greater use of wood as a structural material? The hypothesis is that relationships are numerous and are an important aspect when building with wooden structures, but the way they matter is still unknown. To increase the validity of the results, three data sources were used and triangulated (Mathison 1988). A multi-method data collection procedure was used to seek an answer to the previous questions and involved interviews, participant observations and secondary data. The interview sample will be presented first and then the details of the interviews will be given. Information about the participant observations will also be provided. Finally, the associated secondary data used to complete the data will be detailed. The section will end with some explanations about the data analysis that was conducted.

6.5.1 Defining the Participant Sample

Since the research addressed supply chain relationships in massive timber construction projects, the sample of massive timber buildings to consider was first determined. Tall and large massive timber buildings made with wooden structures was the first criteria. Fifteen well-known wood buildings in Europe were therefore selected, based on the level of information available for these projects. An effort was made to diversify the sample and include different types of buildings: multi-story, cultural centers, hotels, institutional and office buildings. The architects, engineers, builders, and massive timber suppliers that contributed to these massive timber construction projects were then identified. The actors were reached by e-mail, through personal contact on LinkedIn, a professional social network, and with help from the responders themselves. Following this process, twelve interviews were scheduled. A snowball sampling technique was used to reach a second wave of key players and set up more interviews (Heckathorn 2011). Fortunately, chains bring stakeholders together and they end up knowing members of most of the other companies in their area. Companies that have worked on other massive timber construction projects were identified and integrated into the sample. Altogether, sixty-five companies were contacted and asked to participate in this study and twenty-seven agreed. The sample included nine architects, six structural engineers, three builders, three engineered wood product suppliers, three supplier-builders, one wood board supplier and two wood building technology developers. Seven members of wood Sciences departments, or their equivalent, from four universities were also interviewed.

Table 4: Sample details

Expert categories	Number of interviews
Architects	9
Structural engineers	6
Builders	3
Engineered wood product suppliers	3
Suppliers-builders	3
Wood board supplier	1
Wood building technology developers	2

The number of respondents was determined by the principle of data saturation, which stipulates that samples are complete when they no longer generate new and relevant information to the study (Mucchielli 1996, Poupart*, et al.* 1997).

6.5.1.1 Semi-structured interviews

Three months between mid-February and mid-May 2017 were spent in Europe to visit the respondents in their offices and conduct formal and mostly individual semi-structured interviews. Meetings are scheduled with the interviewees for this type of interview. The interviewer asks open-ended questions designed to enable the interviewee to express his or her feelings and interests. Each new question is adapted to the answers given by the interviewee to deepen the subject knowledge and to better understand the information (Lessard-Hébert*, et al.* 1995). The interviews were centered around two major themes: previous experience working on a specific wooden building and the relationships involved in the process. Each theme was broken down into different variables. The first variables were the enablers and difficulties related to the experiences of the interviewees working on one or two specific wood buildings. In this way it was possible to understand whether relationships were part of the drivers or constraints to the use of wooden structures in the buildings. The other variables were linked to the business model, strategic vision, and actions of the organizations. The questions were based on three elements composing a business model as described by Osterwalder et Pigneur (2010): customer relationships, channels and key partners. The information gathered from the interviews was completed by participant observation and secondary data.

6.5.1.2 Participant observation

Participant observation is a tool used to understand social phenomena and its mechanisms by looking at it from the inside. The idea is to enter the studied area and get the closest possible to its actors (Fortin 1987). As previously mentioned, three months were spent in Europe to visit twenty-seven companies in nine European countries, either in their respective offices or in buildings they had constructed. Some wood engineered product plants were also visited.

6.5.1.3 Secondary data

Secondary data was also used to complement information. Using unpublished data can provide a treasure trove of information but it has to be used rigorously (Herbert 1984). The data was gathered before, during and after the European visit, although written and indexed information was rather difficult to find. Before every meeting, the organization's website was visited as well as other webpages in order to contextualize the coming interview and buildings that were to be discussed. Also, company reports and technical booklets were provided by representatives of some of the companies themselves. When needed, more information could be found on the internet after the interview.

6.5.2 Qualitative analysis

Comprehensive field notes were taken while conducting the interviews. These addressed the content of the interviews and observations made in the offices, plants and buildings visited. These field notes were complemented with information from secondary data. Therefore, twenty-seven field note summaries were written along with the field work and semi-structured interviews, participant observations and secondary data. To analyze the data, content analysis was used. According to L'Écuyer (1990), content analysis involves describing the specific characteristics of different elements (words, phrases, ideas, etc.) grouped together into categories, which emerge in addition to their quantitative meanings. According to the research variables described earlier, a code system was established and coding was performed (Miles et Huberman 1994). Three types of relationships were found: contractual, project related and industry development directed. They are presented in the following results section.

6.6 Results & Discussion

6.6.1 Supply chain relationships between stakeholders in a massive timber construction project

In this section, results of the interviews, participant observation, and secondary data are presented. The relationships that occur among the stakeholders when working on the completion of a wood structural building and within the structural wood building industry are identified and characterized.

6.6.2 Relationships between stakeholders in a structural wood building supply chain

The data collected for this study made clear that innovating and building with a wooden structure results in a larger number of, and closer supply chain relationships. The observed relationships can be divided into three levels of interactions. The first level can be called the “contractual (C)” level, since they are mandatory exchanges in the construction of a building. Such relationships occur in every building project since they are linked to the contracts themselves. The second level of relationships is the “wood building project (P)” level. As explained later, they mainly exist to compensate the higher risks and uncertainties implied when building with a wooden structure. The third level of relationships will be referred to as the “massive timber construction industry development (I)” relationships since they exist to promote the structural timber used in construction. The supply chain relationships between stakeholders of massive timber construction projects defined through this research are presented in Figure 11.

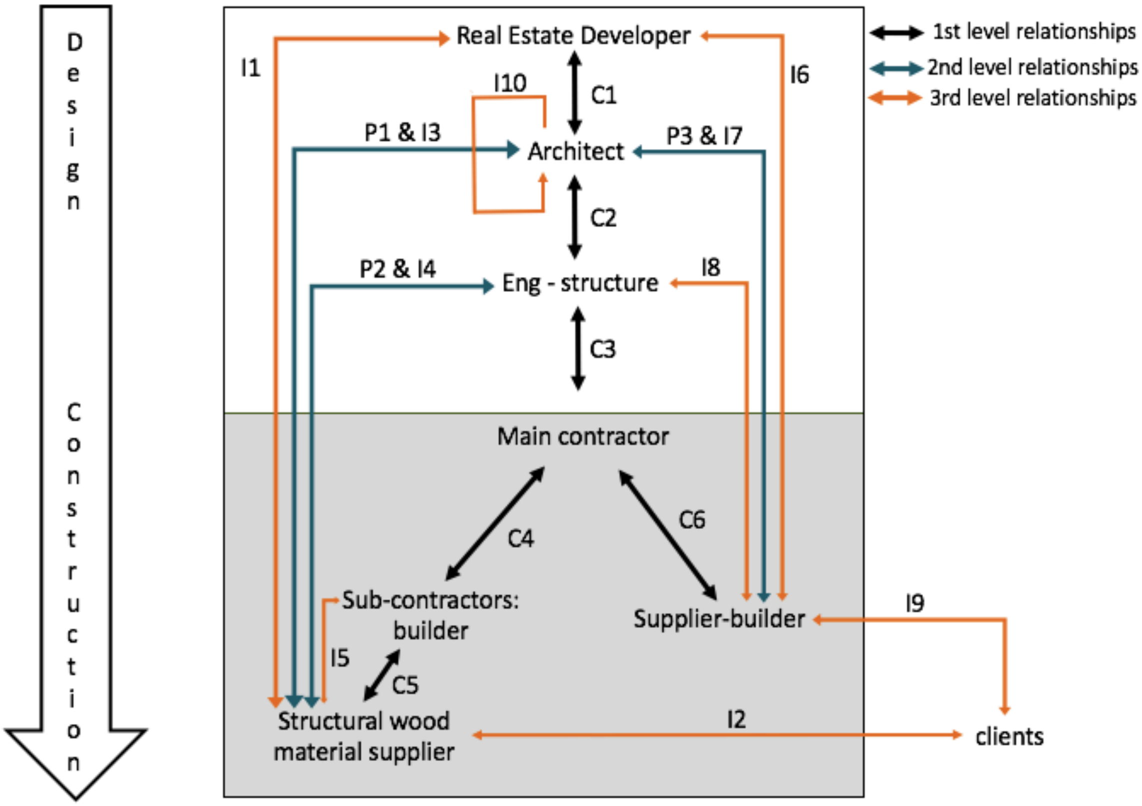

Figure 11 : "Contractual (C)", "Massive timber construction project (P)" and "Massive timber construction industry development (I)" supply chain relationships involved in a massive timber construction project.

6.6.2.1 First level - "Contractual (C)" relationships

Results indicate that "Contractual (C)" supply chain relationships coexist throughout the massive timber construction industry. The black arrows in Figure 6 represent the relationships developed between members of a typical massive timber construction supply chain. C1 - the real estate developer, will need an architect to conceive and design the building he has in mind; C2 - the architect then needs an engineer to make sure the design proposed will be structurally sound and to draw the structure with details; C3 - the main contractor will receive the plans conceived by the architect and the engineer; C4- the main contractor will need a builder to build the structure; C5 - the builder will need to find wood building material. The supplier will produce and provide it; C6 - the supplier integrates the building service into its value proposition. The supplier-builder will then use the plans provided by the main contractor to erect the structure using his own material. These relationships occur in every building project no matter which structural building material (concrete, steel or wood) is used.

6.6.2.2 Second level – "Massive Timber Construction Project (P)" relationships

The interviews revealed the need for more involvement from stakeholders in the building process when it comes to a wooden structure. Additional supply chain relationships will consequently become part of the model. Referring to the law of diffusion curve developed by Rogers (2003), they seem to mainly exist because massive timber buildings are in the early phase of innovation adoption – see Figure 12.

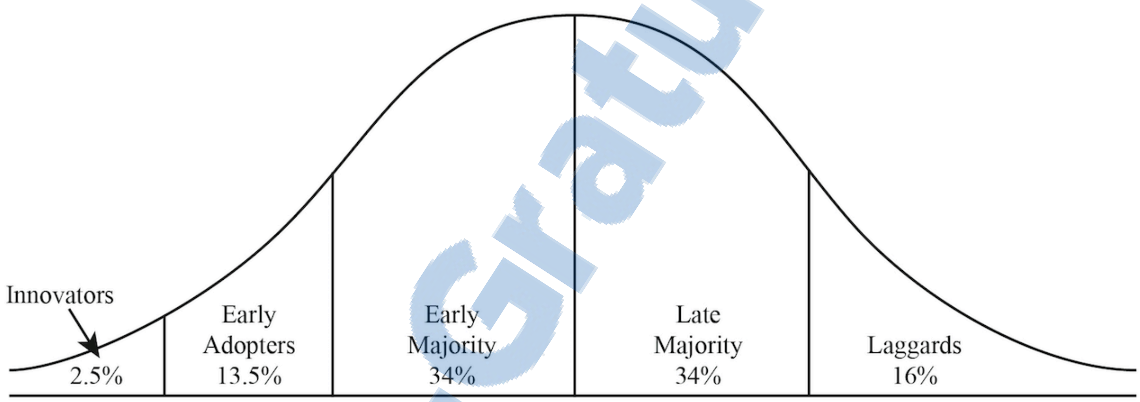

Figure 12 : Law of diffusion curve, adapted from Rogers (2003)

According to Rogers, "diffusion is the process by which an innovation is communicated through certain channels over time among the members of a social system" (p. 5). Since any innovation integrates risk and uncertainty, individuals attempt to reduce them by obtaining information from each other. This is what happens throughout the supply chain of a massive timber building. Since building with a wooden structure is still relatively new and not yet standardized, stakeholders seem to share information in order to protect themselves, as well as to reduce risks and uncertainties.

"Massive timber construction project (P)" relationships are represented by the blue arrows in Figure 6. P1 - from the data collected, it appears that there is a need for the early involvement of suppliers in the massive timber construction supply chain. One said:

"*we were involved in the project very early so that we could assess the engineers and the client and the other parties early on with our expertise in timber engineering and timber installation* (A016)".

Since engineered wood is a fairly new product, and not everyone is used to working with it, suppliers want to be involved in the design phase, even if it represents an additional cost:

"*we participated in these meetings and in that creative phase without getting paid* (A016").

By doing so they want to ensure that the architects design their buildings while having in mind the possibilities or particularities offered by massive timber products. Like any other building material, wood will enable some shapes and key attributes while making some others more difficult. If the suppliers are involved in the conception phase, less plan corrections and back and forth between the conception team and the suppliers are likely to be needed, thus saving time and money.

P2 - it is the same case with the structural engineers and suppliers. As expressed by the quotes in the previous paragraphs, suppliers also want and need to be in touch with the structural engineer early in the process. Another important point to understand when building with wood is that two structural engineers are often involved in a construction project. The structural engineer of the project, part of the conception phase, will be responsible for the structural design of the building. The suppliers are responsible for the production of the structural elements designed by these structural engineers. To do so, the supplier teams usually integrate another structural engineer. When the suppliers are asked to produce the specified elements for a specific building, they will do so in accordance with the structural plans transferred by the structural engineer responsible of the design. Usually some back and forth will occur between the two engineers until they reach an agreement. Most of the time, the engineers working for the suppliers have the most experience related to their installations and are aware of production capabilities. They therefore need to transfer their knowledge to ensure the structural elements suggested by the structural engineer are producible. The structural engineer of the project will then have to respect these specifications. These common steps or adjustments explain why suppliers are sometimes involved in conception phase meetings and processes. The examples of supplier involvement in the early stages of projects go against the idea of highly adversarial and fragmented approaches to relationships often present in the construction supply chain (Egan 1998, Bresnen et Marshall 2000, Chan*, et al.* 2003), which is an interesting point.

P3 - another very interesting relationship revealed by this study is the one where an architect worked with a supplier-builder plant to find a solution to produce a beam which the supplier had previously refused to produce. Together, they finally found a solution, and the beam was produced. This specific example shows how more involvement from the stakeholders can favor wood use.

6.6.2.3 Third level - "Massive Timber Construction Industry Development (I)" relationships

The "Massive timber construction industry development (I)" relationships are represented by the orange arrows in Figure 6. To develop their markets, suppliers and supplier-builders need to work on customer relationships. Suppliers appear to create links with most members of the supply chain, mainly through their marketing strategies, participation at conferences, their websites, media presence, private customer relationships and visits. I1 - results demonstrate that the suppliers try to connect with real estate developers; I2 - end-users, the future building or apartment renters (clients), are also part of the supplier's marketing strategies. These actors can influence the selection of wood as the preferred material and the suppliers would like to convince them that wood is the best material to use in many cases; I3 and I4 - architects and engineers, the conception actors, are also reached by the suppliers to make sure they learn about new wood construction systems; I5 - same with the builder, they are also contacted by the suppliers, this relationship implies lots of knowledge transfer to builders about how to build the structure. Wood involves new ways of working and builder employees can be overwhelmed by new work methods or by the implementation of different processes. The following quote might explain why some suppliers integrate the building services into their value proposition:

"*The challenge is to convince the entrepreneurs to try new things. And it's all wooden buildings. They don't know how to do it, and they give a little bit higher price. So, it's more expensive because they don't know how to do it*." (A019).

I6 - similarly, to develop their markets, supplier-builders will establish relationships with real estate developers, architects and structural engineers. The real estate developers need to learn about wooden buildings; I7 - for optimum design, the architect should be aware of the specifications offered by the wood supplier-builder plant. When this information is shared, it can substantially simplify the intersection between the conception and the construction phases; I8 - as explained earlier, to save time, effort and energy, the engineers responsible for the design of the building should know the capabilities of the supply plant before designing and detailing a structure; I9 - the supplier-builders will also need to sell their products and services to clients. Potential clients of new buildings will also be targeted by the marketing plan of the supplier-builder; For one of the supplier-builder companies studied, producing and delivering a highly specialized product and service means that the clients come by themselves. This is the case of a company prefabricating building modules. Clients are aware of these products and word spreads without using a specific marketing strategy. I10 - relationships between professional architectural corps themselves have also been witnessed; The nature of these relationships is a bit different. It occurs within the same stakeholder category. The interviews revealed a situation where a leading architectural firm specializing in massive timber construction offered wood building design training to other architectural firms. Another architectural firm also mentioned the tendency to get together and help each other when designing using wood. Although this firm is leading the field, they do not fear sharing their knowledge. Their objective is to see wood building market shares grow and not simply being the best firm. In the next section, elements seen as facilitators to the increase in the use of wood as a structural material will be discussed.

6.6.3 From the linear construction supply chain to a value network

A typical construction supply chain involves companies and stakeholders communicating with each other in a linear manner (Ledbetter 2003, Behera*, et al.* 2015). Nevertheless, the arrow network represented in Figure 6 indicates how stakeholders do not always follow a linear mode in their interactions. In fact, communication and supply chain relationships between the actors look more like a value network than a linear chain. To be able to cope with unknown technology development rates and technology interdependencies, as in the case of the massive timber construction industry, multi-technology firms - the architects, the engineers, the main contractors, the builders and the wood material suppliers - need to maintain “loose coupling networks”, meaning close relationships, to ensure they will have access to equipment, components and specialized knowledge when needed (Brusoni*, et al.* 2001). Overall, since risks, uncertainties and unavailable information are common when using a wooden structure, networking should be favored.

6.6.4 From simple relations… to collaboration

Construction innovations are strongly influenced by industry relationships (Dubois et Gadde 2002, Miozzo et Dewick 2002). Dubois and Gadde (2002) describe the relationships in construction as "loose couplings". This describes the temporary coalitions of firms and individuals that come together to complete a project and then disband. According to Blayse et Manley (2004) relationships are important because they facilitate knowledge flows between individuals and firms. The interviews have shown that deep communication and supply chain interactions are needed in the building process when using massive timber and that there is in fact a need for collaboration to innovate. Stakeholders of the massive timber construction industry seem to collaborate rather than simply interact. Meng (2013) showed that the UK construction industry has changed and moved toward supply chain collaboration. However, the construction industry context makes it unlikely that partnering will reach outside the project level. Gadde et Dubois (2010) stressed the need to modify some of the basic assumptions and norms of the industry to favor strategic partnerships.

6.6.5 Prefab: a collaboration accelerator

Some of the actors interviewed have chosen to enter the prefabricated wood structural product market. Having studied prefabrication in the construction industry, Cox et Piroozfar (2011) found decreased construction times and increased quality as its main advantages. According to the present study, it also appears that prefabrication in the building sector can be viewed as a collaboration enabler. If a company decides to incorporate building services into its value proposition, the number of actors involved in the supply chain becomes limited and collaboration can be optimized with client relationships existing within the same entity. Collaboration within the same organization is probably easier than between two companies from the same supply chain. Asad*, et al.* (2005) pointed out that innovative thinking across the supply chain can be very profitable for businesses. Adaptability, financial growth and improved service delivery can result from thinking and operating differently. Thus, prefabrication, seen as innovation thinking, could favor the massive timber construction industry.

6.7 Conclusion

This research was conducted to identify and characterize supply chain relationships present in the massive timber construction industry and to potentially discover enablers for the growth of this industry.

Semi-structured interviews, participant observation and secondary data were triangulated and analyzed through content analysis. Results of this research demonstrated the numerous relationships involved in massive timber construction projects. They were divided into three levels. 1- Contractual, 2- Massive timber construction project and 3- Massive timber construction industry development. The results showed the transition needed in the massive timber construction industry: thinking about a value network rather than a linear chain, and favoring collaboration between members of the network rather than simple transactional relationships. Finally, prefabricated elements and modules are facilitators to the growth of the massive timber construction industry since they limit the numbers of stakeholder relationships involved in the construction process. This research concerns the massive timber construction industry. It would be interesting to compare the results found with the supply chain relationships within the steel and concrete construction industries. It would also be challenging to think about a way to adapt the industry's business model in order to better capture this collaborative relationship need.

6.8 Acknowledgment

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Chapitre 7 - Mapping Business Models for the Wood Structure Building Industry

7.1 Résumé

L'utilisation du bois comme matériau de construction structural est en croissance. Un nombre croissant d'entreprises cherchent à profiter de ces nouveaux marchés. La chaîne de valeur de cette industrie intègre des architectes, des ingénieurs en structure, des constructeurs, des fournisseurs et/ou des fournisseurs-constructeurs. Toutes les entreprises ont leur propre modèles d'affaires. Cette recherche a été menée dans le but de cartographier les modèles d'affaires de l'industrie de la construction non-résidentielle structurale en bois et d'en examiner les patrons de répétitions et tendances potentiels. Les deux questions de recherche suivantes ont guidé ce travail scientifique: Quels éléments intègrent les modèles d'affaires de l'industrie de la construction non-résidentielle structurale en bois? Les modèles d'affaires de cette industrie sont-ils caractérisés par des patrons ou des tendances? A l'aide de la triangulation de données secondaires, d'entretiens semi-structurés et d'observation participante, les modèles d'affaires de vingt-trois entreprises membres de la chaîne de valeur de la construction non-résidentielle structurale en bois ont été étudiés. L'analyse des résultats démontre que le partage des connaissances est crucial et peut être rendu possible par une collaboration soutenue entre les membres de la chaîne de valeur. Par conséquent, les modes d'attribution de contrats de types collaboratifs ont été jugés les mieux adaptés à la construction non-résidentielle structurale en bois. L'établissement de relations étroites avec les fournisseurs et les fournisseurs-constructeurs sont de mises. De plus, les partenariats avec les universités sont communs dans le domaine et la préfabrication semble prendre de l'importance dans ces marchés. Ces résultats peuvent s'avérer utiles pour les entreprises qui souhaitent repenser ou redévelopper leurs modèles d'affaires afin d'être plus concurrentiels sur les marchés de la construction non-résidentielle structurale en bois.

7.2 Abstract

The use of wood as structural building material is growing and a greater number of firms are looking to enter this new market. Erecting a complex wood building usually involves combining the work of architects, structural engineers, builders, suppliers and/or supplier-builders, all of them having their own business models. This research was conducted to map wood structure building industry business models and find potential patterns. The two following research questions guided this scientific work: Which elements does the business model of wood structure building industry stakeholders integrate? Is there a pattern to those business models? To answer the previous questions, twenty-three stakeholder business models were studied using the triangulation of secondary data, semi-structured interviews, and participant observation. The analysis shows that knowledge sharing appears as crucial and may be achieved through sustained collaboration. As a result, collaborative contract procurement modes seem to be the most appropriate for timber construction. Tight relationships with suppliers and supplier-builders also appear as a prerequisite. Furthermore, stakeholder partnerships with universities are common in the field, while prefabrication is increasing in popularity. These findings can be useful to grasp the prevailing business model in this industry while better supporting the growth of the wood structure building market.

Keywords: Wood building, business model, collaboration, building design

7.3 Introduction

Since World War II, concrete and steel have been the main structural building materials used for the construction of tall and large buildings. Although wooden structures are popular within the residential building sector in some countries, their use is still quite sparse in commercial, institutional, residential multi-story and industrial buildings. However, since the 1990s, more and more of these buildings have been built using a wooden structure in Western Europe and North America. The market share for wood structure buildings is thus increasing (Gaston*, et al.* 2001, O'Connor et Gaston 2004, Robichaud 2010, Chamberland et Robichaud 2013, Drouin 2015).

Recently developed engineered wood products have opened multiple new building possibilities. To take advantage of these new options, stakeholders in the construction value chain, namely real estate developers, architects, engineers, general contractors, timber builders and wood material suppliers, have been adapting their practices. Reinventing the way to deliver value may also involve rethinking some aspects or the whole business model. Nevertheless, research on the wood structure building industry and on its underlying business models remain in their initial stages and only a few studies have been published on this particular topic.

The purpose of this research is therefore to establish a baseline for business models found in this emerging niche. More precisely, the objective of the paper is to identify contents and potential patterns within wood structure buildings industry business models, aiming to answer the following two key questions: Which element does the business model of wood structure building industry stakeholders integrate? Is there a pattern in those business models? The Osterwalder and Pigneur (2010) business model canvas was used to structure data gathering. This canvas integrates nine key elements composing a business model: value proposition, customer segments, clients, channels, revenues, key partnerships, key resources, key activities and costs. Secondary data, interviews, and participant observation techniques were triangulated to gather relevant information about those nine key business model elements. Data were then further analyzed to answer the two research questions.

This paper's contribution is twofold. First, it maps out the business models of the wood structure building value chain stakeholders. Second, it examines trends and patterns found among those business models, thereby making this paper an original contribution to the construction management literature, if only for the integrative and business model oriented perspective it brings, which sets this paper apart.

The following section presents theoretical issues underpinning business models; the state of research in the wood structure building industry, and research efforts on business models in this industry. The methodology used to lead this research follows introducing secondary data collection, semi-structured interviews and participant observation tools as well as the data analysis performed. Results are presented according to the nine elements presented in the Osterwalder and Pigneur (2010) business model canvas detailed in the following section. This paper ends with a summary of the wood structural building industry' business models, some trends observed in the sector, an analysis of the use of this business model canvas in the industry and with a conclusion.

7.4 Defining a Business Model

The origins of theoretical conceptualization around business models coincide with the rise of the Internet in the 1990s. Still at an early stage of its development, the field is undergoing rapid transformation and opportunities for greater formalization abound. Several authors have suggested definitions for the notion business model (Timmers 1998, Amit et Zott 2001, Chesbrough et

Rosenbloom 2002, Magretta 2002, Morris*, et al.* 2005, Osterwalder*, et al.* 2005, Gulati 2007, Johnson*, et al.* 2008, Osterwalder et Pigneur 2010, Teece 2010, Casadesus-Masanell et Ricart 2011, Goerge et Bock 2011, Zott*, et al.* 2011). Business models mostly explain how their different parts create a coherent model as a whole (Magretta 2002, Osterwalder*, et al.* 2005). Timmers (1998) proposed the following definition: "An architecture for the product, service and information flows, including a description of the various business actors and their roles; and a description of the potential benefits for the various business actors; and a description of the sources of revenues". Amit et Zott (2001) suggested a more concise and value-driven definition: "A business model depicts the content, structure, and governance of transactions designed to create value through the exploitation of business opportunities". Taking a more concrete stand, Magretta (2002) put forth the following proposition that posited the business model as a narrative:

"Business models, though, are anything but arcane. They are, at heart, stories-stories that explain how enterprises work. A good business model answers Peter Drucker's age-old questions: Who is the customer? And what does the customer value? It also answers the fundamental questions every manager must ask: How do we make money in this business? What is the underlying economic logic that explains how we can deliver value to customers at an appropriate cost?".

Morris*, et al.* (2005), for their part, linked key ideas from contemporary strategic management: "A business model is a concise representation of how an interrelated set of decision variables in the areas of venture strategy, architecture, and economics are addressed to create sustainable competitive advantage in defined markets". They further identified six fundamental components in a business model: value proposition, customer, internal processes/competencies, external positioning, economic model, and personal/investor factors. Gulati (2007) went further with an approach that explains how a business should be organized to operationalize the strategy of focusing on and thus meeting consumer demand; in other words, a business model explains how to sell solutions that meet the needs of consumers rather than just selling products. Gulati promotes the establishment of four types of action and attitude within companies: coordination, cooperation, capacity building, and connection. Casadesus-Masanell et Ricart (2011) argue that: "A business model […] is a reflection of the firm's realized strategy". Osterwalder et Pigneur (2010) eventually devised a leading conceptualization in the field with the following definition: "A business model describes the rationale of how an organization creates, delivers, and captures value". They further decompose a business model into nine elements: value proposition, customer segments, client, channels, revenues, key partnerships, key resources, key activities, and cost structure. They represent business models using the following canvas:

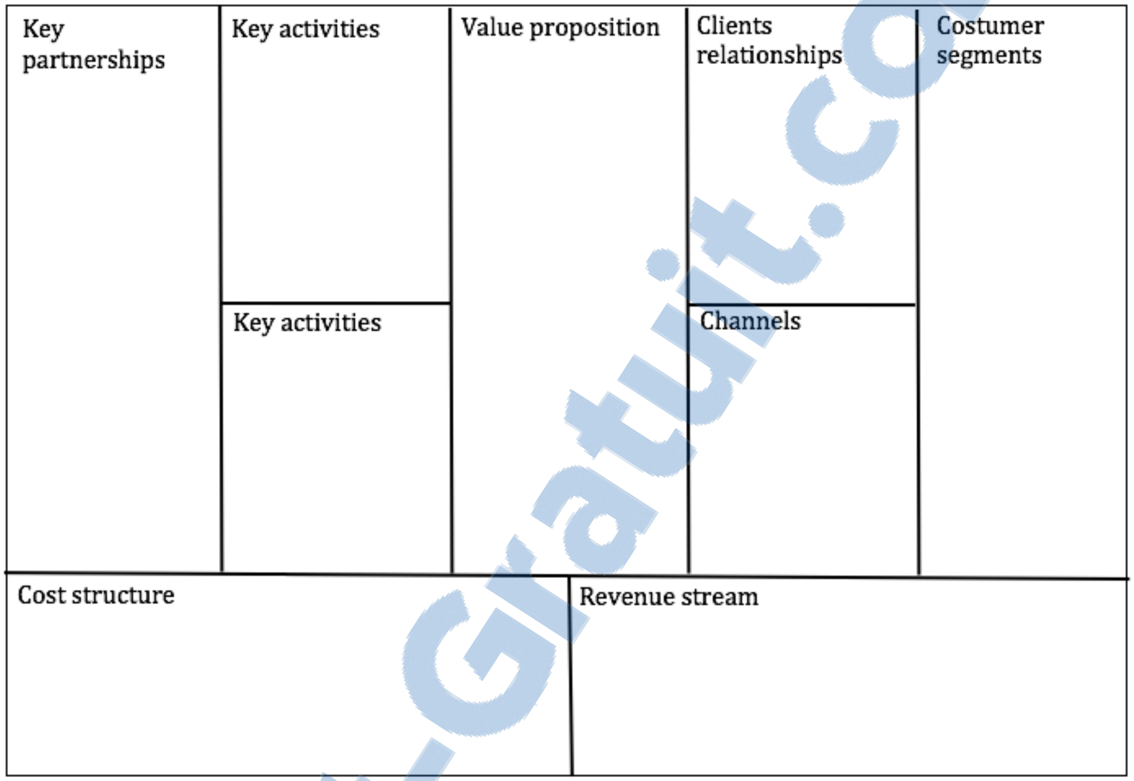

Figure 13 : Business model canvas; adapted from Osterwalder and Pigneur (2010)

The business model definition and conceptualization from Osterwalder and Pigneur (2010) was the one used to conduct this research because of its ease of use while facilitating the establishment of the semi-structured interview structure and data analyses. According to the model they developed, value proposition is understood as the services or products the company delivers to its customers to solve their problems or satisfy their needs. Customer segments are customer groups with similar needs, attitudes and habits. Customer relationships are the type of relationships involved with each customer segment. Channels are the ways a company interacts with its customers. Revenue streams define the money the company makes with each customer segment. Key activities are the actions a company must undertake to be able to deliver value. Key resources are the resources, financial, material or human, a company uses to deliver value. Key partnerships are the alliances a company forges, usually with other companies, to reduce risk and improve its business model. Cost structure is what it costs to operate the business model.

7.4.1 Business Model Innovation

Porter (1985) mentioned that to be competitive, a company must stand out and maintain its competitive advantages over time. As to the competitive specification of today's world, companies should continuously improve their products and services with innovative ideas and be synchronized with their competitors (Johnson*, et al.* 2008, Demil et Lecocq 2010). They should dynamically renew their business model and think about their long-term growth strategy (Linder et Cantrell 2001, Doz et Kosonen 2010, Teece 2010, Zott*, et al.* 2011, Spieth*, et al.* 2014, Spieth and Schneider, 2016, Foss and Saebi, 2017). For instance, in the house-building industry, strong attention is given to off-site construction potential and its impact on companies' business models (Pan*, et al.* 2007, Pan*, et al.* 2008, Pan et Goodier 2012). .

7.4.2 Business models in the construction industry

The pressure to change is also a staple of the construction industry. While there are still few studies related to business models within the construction field, Aki*, et al.* (2013) conducted interviews with eight experienced managers of Finnish construction companies and showed that the concept of business models is understood differently in the business world compared to academia. The business models described by managers entail project deliverables and contract structures or business segments, rather than how their organizations deliver value to customers. Aki*, et al.* (2015) investigated project selection at different firms. Results showed that project selection was not guided by any specific business model, but rather through a decision-making process dominated by short-term factors such as need for work and profitability. Thus, estimated know-how largely determines the kind of projects companies are willing to consider, regardless of their ability to deliver them.

7.4.3 Business models in the wood structure building industry

Research on business models in the wood structure building industry is rather scarce. Brege*, et al.* (2014) studied the link between business models and multi-unit buildings. Their multiple case studies include five major Swedish companies producing prefabricated wood building components. Their conclusions suggest that prefabrication should be the main element of business models and the rest of the model should be adapted to this core. Mayo (2015), who studied the cases of thirty non-residential wood buildings, also came up with similar findings. A report produced by FPAC (2013) – the Forest Products Association of Canada – highlighted the trend toward building system components that will affect the organization of value chains and the interactions within members of this chain. Structural wood building business models will need to include partnerships and alliances within the value chain (Hurmekoski*, et al.* 2015).

7.5 Methodology

In order to map wood structure building industry business models and identify common as well as distinctive elements from this industry, we began with research questions that in turn drove our use of diverse methodological tools to gather the information we needed and further our analyses that would then be translated into actionable findings for academics and practitioners alike. The research questions were formulated as follows: 1- Which elements should the business model of wood structure building industry stakeholders integrate? 2- Is there a pattern in the business models of companies involved in the structural wood building industry? The research design and methodological tools used to conduct the research are presented below.

7.5.1 Research design and methodological tools

This research is based on a post-positivist paradigm. Post-positivist paradigm is based on critical realism and its practitioners think reality is imperfectly and probabilistically apprehendable (Lincoln et Guba 2008). Data were collected using a multi-method data collection procedure (see figure 2) with a view to triangulating the results offered by these techniques (Mathison 1988). First, secondary data were gathered from business documents produced by professional bodies linked to the industry. Second, twenty-three semi-structured interviews were conducted in order to deepen the insights and findings gathered while mining the secondary data. Finally, participant observation was used to better contextualize how business models and their constitutive dimensions could be refined while allowing for a deeper understanding of the context for their application through on-site field observations.

7.5.1.1 Methodological tool 1: use of secondary data

The first methodological tool used was the gathering and analysis of secondary data. Secondary data are mainly data coming from studies made by others (Cooper et Schindler 1998, Ghauri et Gronhaug

2005). Prior to completing the field portion of the research, an initial survey of the technical, trade and scientific literature was carried out for the fifteen European wood structure buildings originally selected in this study. These fifteen wood structure buildings were selected because they are globally recognized wood building cases and because multiple documents, articles, technical reports, and grey literature related to them were readily available. The names of those buildings are not disclosed for confidentiality reasons. Indeed, drilling down business models associated to the value chains around these buildings made competition-related stakeholder information more visible and the executives met in subsequent stages of the research felt that outright disclosure would damage their firms' respective competitive advantages. For every stakeholder member of the value chain who participated in the completion of these fifteen buildings, respective corporate websites and documentation were also analyzed in depth using the business model framework suggested by Osterwalder et Pigneur (2010) and integrating nine key elements: value proposition, customer segments, clients, channels, revenues, key partnerships, key resources, key activities and costs. Sixty company business models were then detailed prior to field interviews.

Secondary data were also used during and after the three-month field interview period carried out to gain a finer-grained understanding of the issues faced by stakeholders and to complete the information. This generated a lot of new and original data that had to be filtered and categorized as the use of unpublished data must be carefully set (Herbert 1984) as not to delve into meaninglessness. Before every interview, the respondent's company websites were consulted to add extra contextualization to the questions. Some technical booklets, company reports, and marketing documents were gathered after the interviews, most of which came directly from respondents themselves, other materials were sometimes provided by their personnel. These were later used in the process to enrich the data output from the interview or to better contextualize it.

7.5.1.2 Methodological tool 2: Semi-structured interviews – sample

The fifteen European wood structural buildings selected include diverse building types: multi-story residential buildings, cultural centers, hotels, institutional and office buildings. The architectural and engineering firms, the construction company and the wood material supplier for each building were identified and contacted through various channels (e.g. e-mails *LinkedIn, etc.)*. Sixty contacts were initiated and twelve provided positive responses (round 1 – see figure 2). The initial round of interviews was carried out in person at the location of the respondent, thereby allowing facility/project visits at the same time. Interviews were conducted in nine countries (Austria, Germany, Switzerland, Italy, England, Scotland, Norway, Sweden and Denmark) over a period of three months. Many of the respondents suggested we interview other leading wood structure building companies located in the same areas. Thus, a second round of interviews was carried out leveraging these opportunities through this snowball technique that helped find more respondents (Heckathorn 2011). The sample was judged complete when further interviews did not uncover new elements; the sample saturation effect was then reached (Mucchielli 1996, Poupart, *et al.* 1997).

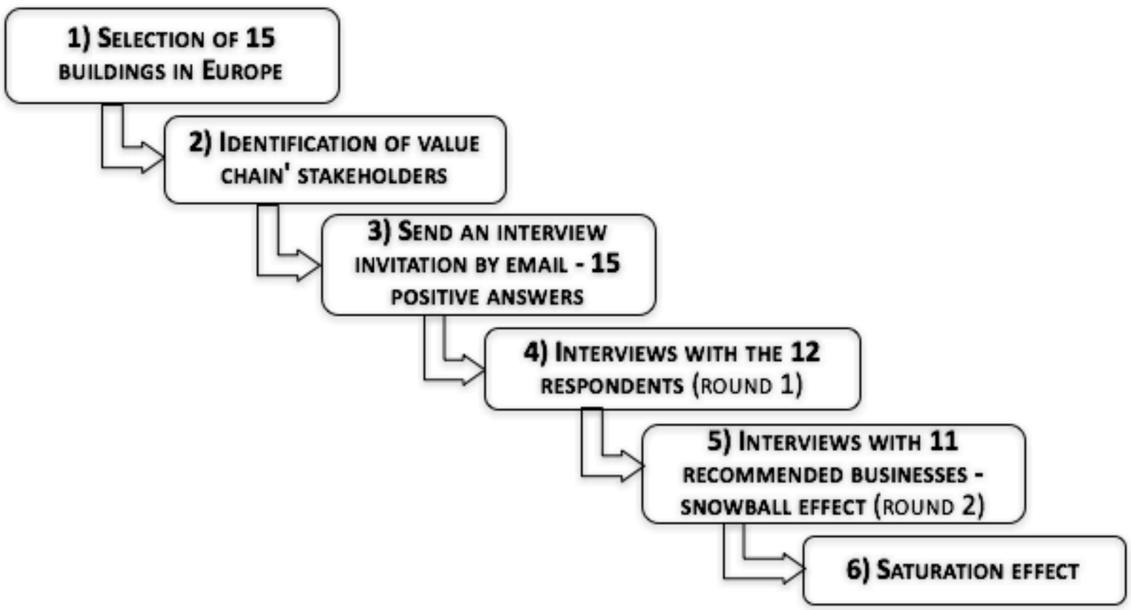

Figure 2: Interviewees selection process

Finally, business model mapping was conducted for nine architectural, five structural engineering and three building firms, as well as for three engineered wood products (EWP) suppliers and three supplier-builders. Additional interviews were arranged with one wood board supplier, two wood building technology developers and three academics recognized in the field. These additional interviews helped reach a broader understanding of the industry. They were used for their confirmatory value and to increase the validity of our research, which is why their business models were not mapped.

Table 5 : Sample details

Expert categories	Number of interviews	Countries
Architects	9	Austria, Denmark, England, Germany, Italy, Sweden, Switzerland
Structural engineers	5	Austria, England, Norway, Switzerland
Builders	3	Austria, England, Norway
Suppliers-builders	3	Austria, Germany
Engineered wood product suppliers	3	Austria, Norway, Scotland
Wood board supplier	1	Sweden
Wood building technology developers	2	Scotland
Academics	3	Austria, Germany, Scotland,
Total	29	9 countries

The interviews with one or two members of every companies consisted of thirty open-ended questions included in an interview guide (Bryman et Bell 2015). These thirty questions were based on the various dimensions laid out by Osterwalder and Pigneur (2010) business models. Semi-structured interviews and open-ended questions were preferred since they allowed respondents to express complete ideas, experiences, opinions and feelings from their own perspective (Saunders*, et al.* 2012). Two main themes were addressed: 1-The respondent's experience related to the construction of a specific wood structure building and 2-their company's business model. Themes were broken down into variables. The first variables were linked to the respondent's experience with a wood structure building project so as to extract business model elements according their actual field experience. The other variables were the nine business model elements suggested by Osterwalder and Pigneur (2010) in their above-mentioned framework. Meetings were held in the respondent's office or in the building project they had constructed. The interviews lasted between one and two hours. Although the questions were determined beforehand, they were asked in a way to keep the conversation fluid. New questions were adjusted while remaining faithful to the original research objectives (Lessard-Hébert*, et al.* 1995). The interviewer made sure the discussion focused on the theme and variables previously mentioned. The information was further improved upon with participant observation.

7.5.1.3 *Methodological tool 3: participant observation*

The third methodological tool used was participant observation. Participant observation is a methodological tool derived from the social sciences where the goal is to see and experiment a social phenomenon and its mechanisms from the inside (Tedlock 2000, Bryman et Bell 2015). The researcher's goal is to then get as close as possible to the reality lived by the actors (Fortin 1987). Mintzberg (1979) used the terms "Direct" research to express this simple way of visiting professional offices. Three months were spent in the field (Europe). Most respondent offices and/or building projects were visited throughout interviews. Documents, resources and company workers were observed. Three plant tours were also carried out. Free-flow field notes were taken. All the gathered information were then analyzed using a qualitative approach and the content analysis method.

7.5.1.4 Content analysis

To reach results, the data collected were analyzed using a qualitative method. Qualitative results enable precise and flexible outputs mainly coming from words rather than numbers (Silverman 2000, Ghauri et Gronhaug 2005, Lincoln et Guba 2008, Saunders*, et al.* 2012, Bryman et Bell 2015). In particular, the data collected through secondary data, semi-structured interviews and participant observations were analyzed using the content analysis method. Content analysis consists in placing phrases, words and ideas into categories to describe their characteristics (Bryman et Bell 2015). The sense of the studied phenomena can then be extracted and explicated in addition to the quantitative aspects of the material analyzed (L'Écuyer 1990). The material collected was read many times and broken into smaller parts (Osterwalder and Pigneur's business model elements). These smaller parts were categorized using the N'Vivo software package according to a coding tree connected to the nine variables previously mentioned. A scientific description emerged from the quantitative and qualitative aspects of these categories (L'Écuyer 1987). Data interpretation was then performed. Content analysis was rigorously performed to ensure study quality meaning results reliability, “the extent to which an experiment, test or any measurement procedure yields the same results on repeated trials” and validity, “the extent to which a measurement reflects the specific intended domain of content” (Carmines et Zeller 1979, Cooper*, et al.* 2009). Results will be presented in the following section.

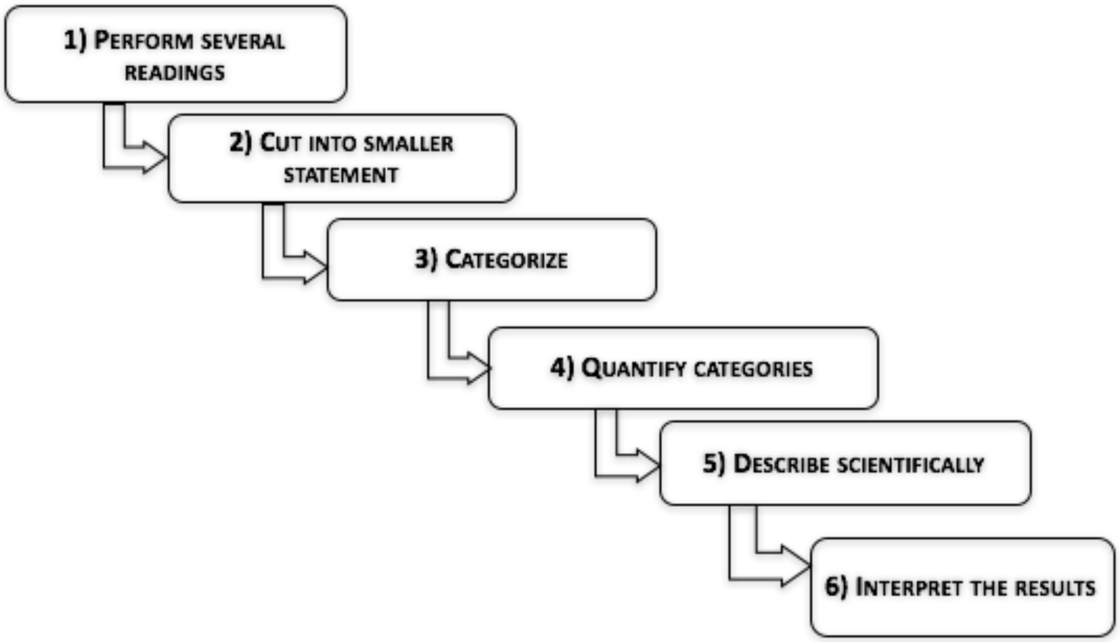

Figure 14 : Content analysis steps performed using N'Vivo software package

7.6 Results

As mentioned before, every stakeholder's business models were analyzed according to the nine main elements included in the business model proposed by Osterwalder and Pigneur (2010).

7.6.1 Value proposition

7.6.1.1 Architects

The architect's value proposition involves creating built or living environment. They also “design” at different levels of detail. Most of the architects we met demonstrated a strong preference for pursuing detailing to its final stage: “If we design it, we're going to detail it, and build it, and do those things we don't like to stop doing after planning, and we don't like to take other people's work and turn it into details for construction (A010)”. Integrating sustainable development and/or energy efficiency into the design appears as most important for them. Depending on the contract procurement mode used, their job is also to manage projects. An interesting aspect encountered in the field was the willingness of some architectural firms to help their competitors. As an example, one of the architect firm met offers training sessions to other architectural firms. Knowledge sharing and collaboration seems thus to be part of the value proposition of some architectural firms.

7.6.1.2 Engineers

The value proposition of the engineering firms is structural design. Engineers work to produce detailed designs based on architectural designs, which can also include connectors designs. “So the client had the architect’s design and then on that one, we worked for the client with the architect up until sort of a detailed design. […] and did the connection design as well (A013)”. Structural design encompasses different calculation types, statistical calculations as well as fire and wind protection. “In this project I was involved in global aesthetics and the dynamic calculation for the project (A017)”. Engineers’ value proposition also integrate the willingness and ability to collaborate with suppliers and supplier-builders to make sure that the decision they make are compatible with the rest of the value chain needs.

7.6.1.3 Builders

Builders’ value proposition is the installation of wooden structures. They can also act as a general contractor following the client’s preferences and provide support in structural design if needed.

7.6.1.4 Suppliers

The value proposition of suppliers is the production of various engineered wood products (EWP) including Glued Laminated Timber (Glulam), Crossed Laminated Timber (CLT) and/or Laminated Veneer Lumber (LVL). They produce the wooden elements based on calculations achieved by the structural engineers. Thus, suppliers’ value proposition offers early involvements in the process so they can influence the drawings, thereby insuring the elements will be producible by their respective mills. Just in time deliveries also appear as part of suppliers’ value proposition.

7.6.1.5 Supplier-Builders

Supplier-builders are typically responsible for building wood structures and sometimes delivering and installing them on site. They often prefabricate timber elements or modules. “What we deliver […] is the skeleton, the timber skeleton of the building. Meaning, a lot of timber columns, a lot of timber beams, diagonals, CLTs, staircases, elevator shafts. […] We deliver that as a self-standing structure (A016)”. Supplier-builders’ value proposition also involves taking part in the design in the early phases of the projects to make sure calculations and proposed structures can easily be produced and installed.

7.6.2 Customer segments

Within this industry, it appears that all stakeholders mainly get hired by governments or real estate developers. Their work is to participate to the completion of buildings, bringing in their respective knowledge and competencies. In various cases and depending on the contract procurement mode, they may hire each other to complete different work segments and projects. Aside the suppliers and suppliers-builders who work only with wood, architects, engineers and builders can either work only with wood or also with concrete and steel. Among the stakeholders met, a tendency toward wooden specialization. Timber frame, CLT, glulam and prefabricated projects can be executed. Some stakeholders focus exclusively on a specific building type although they mainly work on all types. They accept both private and public contracts and work with different contract procurement modes.

All stakeholders met mostly are active on regionals markets except for suppliers for which markets are definitively worldwide. One of the architect firm has also international projects due to its excellent reputation. Suppliers and suppliers-builders have more specific customer segments. For instance, one of the suppliers interviewed has segmented its clients into three categories (A, B or C) according to their consumption habits. The first supplier-builder we met focused on the very specific private market of high quality regional hotels offering between 30 and 60 rooms. The second supplier-builder interviewed offered glulam. Its market is mostly in the countryside. The third offers timber frame prefabricated systems, in three packages: standard, plus pack and enhanced.

7.6.3 Customer relationships

When working on public contracts, customer relationships are built through competition since stakeholders work together and get to know each other. For private projects, stakeholders have stable customer relationships: these are the ones they work with repeatedly. New customer relationships are developed through the channels described in the next section.

Another important element that stood out is the collaborative dimension of the relationships established within this growing industry. They usually last for the time of a project but sometimes over a longer period. Since working with wooden structures requires high levels of involvement from all parties, it appears that strong collaborative relationships are developed while being viewed as necessary for successful projects.

7.6.4 Channels

Rules in the construction industry shape the way clients get services. As already mentioned, for public projects, all stakeholders get in touch with their clients through competition. For private projects, stakeholders use personal contacts and marketing strategies to reach potential customers. Established relationships are maintained also through personal contacts.

Personal contacts are established through previous working experiences or projects, phone calls and emails but also by working on high profile buildings, winning a bid, having a good reputation, being recommended by others or when company names are spread through word of mouth. Personal meetings and visits to other stakeholders in the region can also occur. Employees' movements from one firm to another also contribute to the development of customer relationships.

While small firms seem not to promote themselves at all or to work with a marketing agency, bigger firms either work with marketing agencies or have a marketing department in their organization. One of the supplier-builders met does no marketing at all and has a full calendar. Clients come by themselves. This supplier-builder offers a specialized modular, prefabricated product. So it appears that the more specialized is the service or product offered, the less marketing is needed. Going to conferences, exhibits, fairs and/or mass timber events or show appears as a must in this industry. All interviewed companies mentioned participate to such event. Marketing strategies also include visits of building sites, some being public, others exclusive. Articles are published in specialized magazines, newspapers or architectural journals. Many companies do television interviews, exhibits and prepare client events. Some also teach at universities. Web pages, Facebook and flyers are also used. Suppliers sometimes write guidelines, data sheets, test results and communicate these.

7.6.5 Revenue streams

For architects and engineers, projects are usually billed on an hourly basis. Wages can also be based on the total cost of the project, being a percentage of the total cost of the building. One of the interviewees mentioned that since using structures made from engineered wood product is new, it is sometimes more difficult to make profits. Mistakes or extra work have impacts on the money a company will make working on a project but with experience they become more scared.

Builders revenues are flat rates; they receive a percentage of the total cost of a building. They make money with project management and savings they make on the estimated costs for their services. Suppliers and supplier-builders main income is the sale of the material they produce and since thy interact with worldwide competition, prices must be thought and adequate.

7.6.6 Key activities

Every stakeholder has its own respective activities and they are closely linked to their value propositions. Architects main activity is to develop built or living environment and draw plans. Depending on the procurement mode, project and site management are also important activities. Architects in the field also have a tendency to invest into research and development. Engineers produce plans and calculations for projects of different sizes. Depending on the contract type, structural designs can be required at three different levels of detail: building design; detailed building design; and piece design, which includes connectors, “how many screws, how many holes, where should the holes for the screws be (A017)”. The third design level is usually done by suppliers, but engineering firms can be sub-contracted. Structural design mainly includes considerations for services, seismic activity, fire and acoustics. Builders mainly manage projects. They can either do overall site management while also hiring a sub-contractor to erect the timber structure or do all the work themselves. Builders specialized in timber structure can be asked to detail the structural design to make it producible by the supplier. Those three stakeholders include communication and collaboration aspects to their main activities. When realizing their specific duties, very often they have to interact with stakeholders among the chain.

The suppliers and supplier-builders' key activity is to produce, sell and supply the engineered wood products. Supplier-builder also install the structure on site. To do so, they must often adapt the structural design they receive. Another important activity is to develop the business (building systems) and its markets. They write guidelines, propose datasheets and try to popularize their product by explaining how to design with these new products. Although "competitors can have access to the design and repeat it, but this is what we have to do to create the markets (A001)". They also get involved in research and development programs to keep competitive. Transferring knowledge to architects, engineers and builders is a very important task for suppliers and supplier-builders. They often have to participate to the conception of the building either in formal or informal ways. They also deliver on site.

7.6.7 Key resources

Architectural and engineering firms integrate senior and junior professionals with university backgrounds. Upon hiring, those professionals may or may not have experience in timber design. Overall, they mostly learn and are trained once hired. One architectural firm also hires engineers to make sure designs are acceptable from an engineering point of view. Interviews revealed a shortage of structural engineers specialized in wood structures, the expansion of structural engineering firms being limited by this lack of competencies. Employee or timber structure specialists within firms are limited, internal knowledge transfer becomes very important.

Builders and suppliers hire carpenters, looking for versatile employees since working on a wood structural building sometimes means to operate in a context of low standardization.

7.6.8 Key partnerships

When asked about their partnerships, architects and engineers mentioned their contracts with other architectural firms to complete a bigger project or subcontracting during a project. They also mentioned their numerous collaboration relationships with suppliers. One of the most experimented firms specified having collaboration relationships with other architectural firms to transfer knowledge. At least half of the nine architectural firms met and some engineering firms mentioned collaborative research projects with universities.

Builders also have repetitive collaborations with engineering firms. One of them mentioned having had a closer than usual relationship when working on a specific timber building. They drove to the supplier “to learn about the product and each other and establish a tighter relationship (A018)”. Builders also share contractual relationships and collaborations with other stakeholders. According to architects, engineers and builders interested in leading timber building construction projects are difficult to find and recruit.

Not much was heard about formal partnerships with suppliers to execute building projects. As already mentioned, suppliers develop relationships with all members of the value chain and also with universities. A large proportion of their research and development is done through academic studies.

7.6.9 Cost structure

Numbers related to costs were difficult to obtain. Cost categories are thus presented in this section. In the UK, the largest expenditure for architects and engineers is rent. Elsewhere it is labor or working hours: “It's about 75, 80% of the budget (A022)”, that are the most expensive. Elsewhere time cost the most. Wood expertise training is also costly: “The teaching of all the people (A004)”. Deadline extensions also represent costs or money lost. Research also costs money, but can sometimes be used as a tax deduction. Buying computers, software and marketing were also mentioned.

For builders, labor and product purchases seem to be the costliest.

For suppliers and supplier-builders, raw material, employees and electricity were mentioned as the most costly. Fire and acoustics were cited as the most important cost drivers in wood construction. A supplier-builder explained: “So you can say 25% employee cost, 25% material, 50% subcontractors (A007)”. Investment in the development of the product and certification and adaptation to construction industry regulations is major for suppliers and supplier-builders. They are the ones having to prove the product they are offering respects laws and regulations and is the best option. They also have to invest time and/or money into their formal or unformal participation to conception phase of most projects.7.7

7.7 Discussion – Putting the pieces together: the business models of the structural wood building industry

Combining Osterwalder and Pigneur (2010) canvas with the analysis conducted, the structural wood building business models of the industry could thus be mapped as follow:

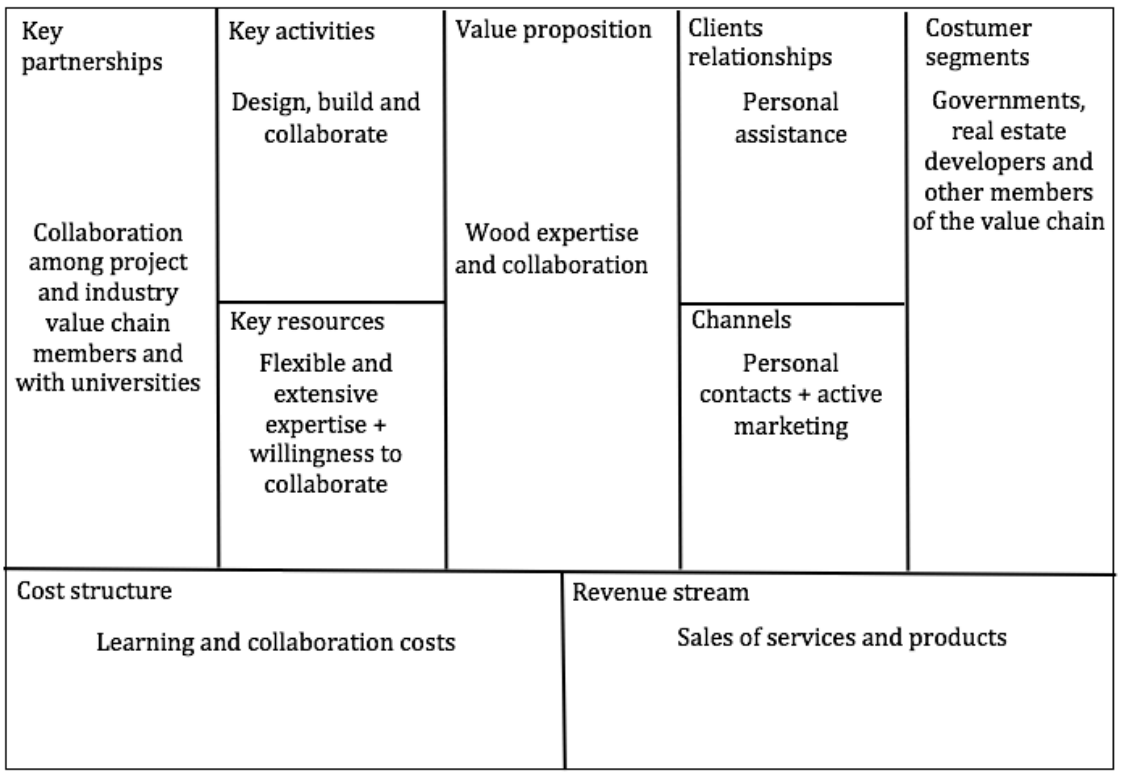

Figure 15 : Wood building industry business model summary

From this figure, different trends among the industry can be observed. They are presented in the following section.

7.7.1 Trends in structural wood building industry business models

From the results presented above, some patterns or trends of the structural wood building industry business models can be identified. First, collaboration between stakeholders appeared to be crucial. Second, collaborative contract procurement modes are appropriate for timber constructions. Third, tight relationships with suppliers are necessary. Fourth, partnerships with universities are common in the wood structure building industry. And finally, prefabrication is part of the picture and might lead the industry in the future.

7.7.1.1 Knowledge sharing - collaboration between stakeholders is crucial

It has been observed in this study that knowledge about wood engineered products and timber construction needs to be shared. This need promotes a collaborative environment within the timber construction value chain even among potential competitors. Since working with these new products is risky and not yet standardized, stakeholders need to share information and even help each other. Rogers (2003) has confirmed that, when an innovation is in its early stages, interaction, communication and collaboration are high to compensate the risks.

Almost every stakeholder has mentioned attendance at conferences as being a way to share knowledge. Participation in conferences should be part of all business models since it is probably where the most advanced ideas are exposed. Missing conferences would potentially prevent businesses from keeping up with this fast growing industry.

7.7.1.2 Collaborative contract procurement modes are appropriate for timber construction

When design and construction phases are planned simultaneously, construction times are usually better than when they are planned in subsequent phases. Collaborative types of contract procurement modes seem to be needed and justified. This way, there is less back and forth needed between architects and engineers responsible for design and the other stakeholders in charge of the construction.

7.7.1.3 Tight relationships with suppliers are deemed necessary

The data gathered in this study indicate that suppliers and supplier-builders are leading development in the industry. These stakeholders develop their respective wood engineering products and the rest of the industry tries to follow. Architects are learning to design for timber structures but the participation of suppliers and supplier-builders is often needed, or drawings must often be redone or adjusted if they have not participated. Only a few structural engineers are autonomous in every country.

7.7.1.4 Partnerships with universities are a common feature within the industry

The data collected showed an intimate link between leading timber industry stakeholders and universities. Many architects, engineers, suppliers and supplier-builders have commented on their collaboration with universities. They either do research in collaboration with university partners or have been (or are) professors. Suppliers and supplier-builders, especially, collaborate with universities to develop their products or certify them.

7.7.1.5 Prefabrication is an important part of the industry's future

Four respondents were involved in prefabricated timber building systems. Prefabrication main advantage is that conception, construction and installation are often led by the same team. Suppliers are involved in the conception process. The architects and engineers still must design and calculate the building and the structure, but the other steps involve less organizations since production and assembly are done by the main stakeholder. Diminishing the complexity of a project and the number of workers and exchanges between them will naturally favor the performance of the building process. Data also suggested that less marketing efforts need to be carried out by prefab specialists.

7.7.1.6 Rethinking Osterwalder and Pigneur's business model canvas for the construction industry?

While using Osterwalder and Pigneur's business model canvas to structure data gathering for this study, some observations were made. Respondents' answers related to Value proposition and Key activities were really close from one another. When asked about Customers relationships, answers were also partial and unclear. Precise information about costs and revenues were also difficult to obtain but some participants nevertheless agreed to provide general information. Partnerships seen as formal agreements between two firms being were not well understood by interviewees. However, as already discussed, many interactions were rather presented as collaborative relationships.

As it can be noticed in Figure 4, the word collaboration appears quite frequently in the canvas. Collaboration in the Wood Building Industry appears as central to project success. This word is found in many elements but there is no specific box related to the concept. A way to improve the canvas so it better suits the industry would be to include an expression of the importance of collaboration a major juncture for the industry's many players. As such, an additional box on that particular topic could be added to the canvas.

Difficulties to use the business model canvas in the Wood Building Industry can be at least partially explained by Aki et al. (2013) who pointed out how business models in the industry are differently understood than in the academy. In the industry, business models are often expressed as business sectors. The construction industry is based on projects, bringing an ephemeral nature to value chains. Paradoxically, this industry is also very structured and regulated. Stakeholders cannot act independently since projects are executed in teams. Their respective business models are affected and modeled by the other construction chain members' respective business model. This later aspect results in few possibilities of business model differentiation which lead to the argument that Osterwalder and Pigneur's (2010) business model canvas would benefit from further adaptation to better suit the Wood Building Industry.

7.8 Conclusion

Wood used as a structural material in the non-residential building sector is gaining popularity. The literature proposes various definitions and conceptualizations for business models. Yet, few studies exist on non-residential wood building business models. The purpose of this study was to map and examine potential patterns within the business models of the companies leading the wood structure building industry. Using secondary data, semi-structured interviews, participant observation and content analysis, an answer to the following two research questions was sought: Which elements does the wood structure building industry business models integrate? Are there tendencies or patterns in the business models of companies involved in the structural wood building industry? Although some distinctive cases do exist, wood structure building industry business models integrate a wide number of similar attributes. Knowledge sharing is crucial for stakeholders to understand each other's, which explains why collaborative contract procurement modes better suit wood structural building projects. Tights relationships with suppliers and supplier-builders are also essential. Partnerships with universities are strong within this emerging industry. Prefabrication is a growing part of the picture and will probably increase in the near future. These results establish the baselines for wood structure building industry business models. Managers in the industry can use these results to adapt their business models to enter the emerging wood structure non-residential building market. Many research opportunities and subjects remain to be explored. For instance, wood structure building industry business models could be compared with ones describing the steel and concrete building industry to find out what is specific to the timber building sector.

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Chapitre 8 – Conclusion

Étant donné l'importante croissance du secteur de la construction non-résidentielle structurale en bois, une étude a été entreprise afin de répondre aux questions de recherche suivantes : quelles sont les barrières et les motivations en lien avec l'utilisation du bois comme matériau structural? Quels types de relations entre les acteurs sont présentes au sein de l'industrie de la construction structurale en bois? Comment une entreprise peut-elle organiser son modèle d'affaires afin de se positionner stratégiquement dans ce créneau en développement?

Dans un premier temps, les motivations et les barrières à l'adoption du bois comme matériau structural en construction non-résidentielle ont été identifiées. Une analyse de contenu de la littérature grise reliée à treize projets renommés dans le monde reposant sur une structure en bois et de cinquante-trois articles sur le sujet tirés de la littérature scientifique a permis de trouver ces motivations et barrières. Les principales motivations liées à l'utilisation du bois comme matériau structural identifiées sont la volonté de contribution au développement durable, les aspects techniques du bois, les coûts réduits, la rapidité d'installation des structures et les aspects esthétiques du bois. Pour leur part, les barrières trouvées sont liées au respect du code du bâtiment, au manque de transfert de technologies, aux coûts, à la durabilité et aux autres aspects techniques du matériel, à la culture de l'industrie et à la disponibilité du matériel. Une analyse de treize comptes-rendus de chantiers de construction a permis d'identifier des problèmes et des préoccupations vécus sur les chantiers de construction et les barrières ont pu être confirmées.

Ensuite, les relations présentes au sein de la chaîne de valeur de la construction non-résidentielle structurale en bois ont été identifiées et décrites. La tournée d'entrevues semi-dirigées ayant mené à rencontrer vingt-trois intervenants tant professionnels (architectes, ingénieurs en structure, constructeurs et fournisseurs de matériaux) et trois académiques a permis d'identifier trois types de relations : les contractuelles, celles reliées à des projets de construction en bois et celles reliées à l'industrie de la construction structurale en bois. Les données collectées ont aussi montré que les parties prenantes entrant dans le domaine de la construction structurale en bois doivent adopter une nouvelle mentalité. Les relations partagées sont plus proches de la collaboration que de simples relations transactionnelles. Celles-ci sont plus étroites, plus fréquentes et elles impliquent le partage d'information reliés aux projets et aux matériaux. De plus, la préfabrication peut être considérée comme un moyen de réduire le nombre et la complexité de ces relations et ainsi, d'agir comme un facilitateur de l'utilisation du bois comme matériau structural.

Finalement, les modèles d'affaires de l'industrie de la construction non-résidentielle structurale en bois ont été cartographiés et des tendances parmi ceux-ci ont pu être identifiées. Effectivement, à partir de la même tournée d'entrevues semi-dirigées, vingt-trois modèles d'affaires ont été résumés selon les neuf éléments du canevas de modèle d'affaires proposé par Osterwalder et Pigneur (2010). La proposition de valeur, les segments de marché, les canaux de distribution, les relations avec les clients, les flux de revenus, les ressources clés, les activités clés, les partenariats clés et la structure de coûts des modèles d'affaires des architectes, ingénieurs en structure, constructeurs, fournisseurs de matériaux et fournisseur-constructeurs rencontrés ont été décortiqués. Il en ressort que le partage d'information au sein de la chaîne de valeur de la construction non-résidentielle structurale en bois est crucial, ce qui est favorisé par l'adoption de modes d'attribution de contrats de types collaboratifs. L'établissement et l'entretien de relations serrées avec les fournisseurs de matériaux bois est très importante, tout comme l'établissement de partenariats avec les universités. Finalement, la préfabrication fait maintenant partie intégrante de l'industrie de la construction structurale en bois et risque de prendre de plus en plus d'ampleur dans le futur.

Somme toute, ces études ont permis de répondre à l'objectif général émis au début de ces recherches doctorales. Elles ont contribué à renchérir les bases encore limitées de la recherche dans le domaine de la construction non-résidentielle structurale en bois, tant du point de vue de la connaissance des marchés que des modèles d'affaires présents au sein de cette industrie. Les recherches reliées à ce projet de doctorat ont également rendu possible l'identification de tendances susceptibles de stimuler le développement de cette industrie en croissance, si intégrées aux modèles d'affaires des entreprises du secteur. Les entreprises visionnaires et plus favorables au risque devraient pouvoir grandement profiter du développement de cet économie. En conclusion, la construction structurale en bois s'avère un secteur d'avenir et prometteur pouvant à la fois stimuler l'économie des pays à grandes ressources forestières tout en contribuant à la lutte aux changements climatiques. Considérant ce fort potentiel, il serait aussi intéressant d'assister à un plus grand engagement de tous les paliers gouvernementaux, municipal, provincial, fédéral et international, et de voir apparaitre de sérieux incitatifs à l'utilisation du bois comme matériau structural.

8.1 Recommandations

La réalisation de cette étude a permis d'émettre quelques recommandations. Premièrement, les motivations liées à l'utilisation du bois comme matériau structural pour les bâtiments non-résidentiels devraient être utilisées afin de promouvoir la sélection de ces matériaux auprès de l'ensemble des acteurs de la filière. Ensuite, toute entité qu'elle soit politique ou économique voulant mousser le développement de l'industrie de la construction structurale en bois devrait travailler à diminuer l'incidence des barrières à l'utilisation du bois comme matériau structural pour les bâtiments non-résidentiels en bois trouvés dans le cadre de cette étude. Elles devraient être traitées par priorité telle qu'indiqué dans la figure 5. De plus, lors de la réalisation de projets de construction de bâtiments non-résidentiels structuraux en bois, les modes d'attribution de contrats où les équipes de conception et de construction travaillent ensemble devraient être favorisées. Dernièrement, les tendances trouvées parmi les modèles d'affaires des entreprises de l'industrie de la construction non-résidentielle structurale en bois devraient être considérées par toutes entreprises voulant entrer ou rester dans ce marché: partager l'information et mettre en place des mécanismes de partage de connaissances et de collaboration, établir des relations étroites avec les fournisseurs de même que des partenariats avec les universités, préférer des modes d'attribution de contrats collaboratifs et finalement, planifier l'intégration de la préfabrication aux modèles d'affaires.

Évidemment, puisque les travaux sur les marchés et les modèles d'affaires de la construction non-résidentielle en bois sont encore limités, il existe un énorme potentiel pour la réalisation d'éventuelles recherches reliées à ce sujet. Comme tous les acteurs de la chaîne de valeur tentent de développer des modèles d'affaires adaptés à l'industrie, des travaux sur des modèles d'affaires collaboratifs pourraient notamment être entrepris. Il serait bien de mieux comprendre quels mécanismes de collaboration pourraient être mis en place et comment leur adoption pourrait être favorisée au sein de l'industrie. De plus, il serait intéressant d'explorer davantage les modèles d'affaires en Amérique du Nord, afin de voir les écarts avec les modèles européens, et de s'inspirer de ces derniers lorsque pertinent. Dans certains cas, des entreprises du Québec et du Canada pourraient ainsi profiter de l'expérience européenne dans le domaine.

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Annexe 1- Schéma d'entrevues

Let's talk first about your experience working on the ________ building.

1. What was your role on this project?

2. Was/Were it/they (an) exceptional or routine project for your business for you and your enterprise?

3. Why was wood chosen as structural material for this/these buildings?

4. What were the positive elements for you company about working on this/these building(s)?

5. What were difficulties or challenges faced when working on this/these building(s)?

6. How did the relationships between the other actors go? With whom you had to interact? The architect? The builder? Was the atmosphere different with this contract than with the buildings made of concrete or steel?

7. If your company had to do this/these project(s) over again, what would you do differently?

8. Would you like to share something else related to this/these project(s)?

I would now like to know your business better and about how you managed to maintain your hold on the market.

9. Could you briefly tell me about your company's history?

10. What is the size of the company? (Nbr of employees, annual turnover)

Value Proposition

11. What products/services is your company offering?

12. In your opinion, what are its main strengths, what distinguishes your organization from its competitors? what are the main reasons why customers decide to work with you?

Key Activities

13. Can you tell me about the company's main activities and about its structure?

14. What expertises are your clients seeking when they come to you?

15. What are your missions? Types of projects? Types of contracts?

Client Relationships

16. Who are your most important clients? Sectors? Companies?

17. What kind of relationships do you have with your clients?

18. How do you start a relationship?

19. How do you maintain them over time?

Customer Segments

20. The CIRCERB Chair was created especially to promote the wooden building, something you are already doing brilliantly. How did you come to value wood constructions? What are the motivations that lead your company to work on projects with wooden structures?

21. How important is the use of wood as a structural material for non-residential buildings within your company today?

22. What other markets does your business occupy? are they complementary or rather dominant compared to wood? (% wood vs. steel)

Key Resources

23. What is the level of expertise and training of your employees with wood? Professionals, technicians?

24. Are your employees comfortable to work on buildings with wooden structures upon hiring? How they develop the skills that allow them to work with wood?

25. Could I get a copy of the Operation "flowchart"?

26. Can you describe the company's human resources?

Key Partnerships

27. In your wooden structure projects what type of business relationships was established? (contracts, JVs, consortiums, suppliers, etc.)

Channels

28. Who gets to know about your services and how do they learn about them? How do you reach your customers? What main visibility elements is the business using to be known or to improve its notoriety?

29. Do you have some examples of project that reflect your core business? Are projects your business card?

Costs

30. What are the main cost sources for your business? What are the drivers of these costs (client requests, supplier issues, unforeseen difficulties on a technical level, etc,)?

Revenues

31. What are the main revenue sources?

32. Do you have anything to add?

Annexe 2 - 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 (StatistiquesCanada 2016)]. 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 (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). In 2013, the Quebec's Province forest industry offered 60 082 jobs which 23 969 of them were related to the forest product industry (StatistiquesCanada 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 (Schreyer 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 (Buildup 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 (WoodSolution 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 et 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 (CECOBOIS 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 (Robichaud 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 %) (Chamberland et Robichaud 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 2006b).

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.

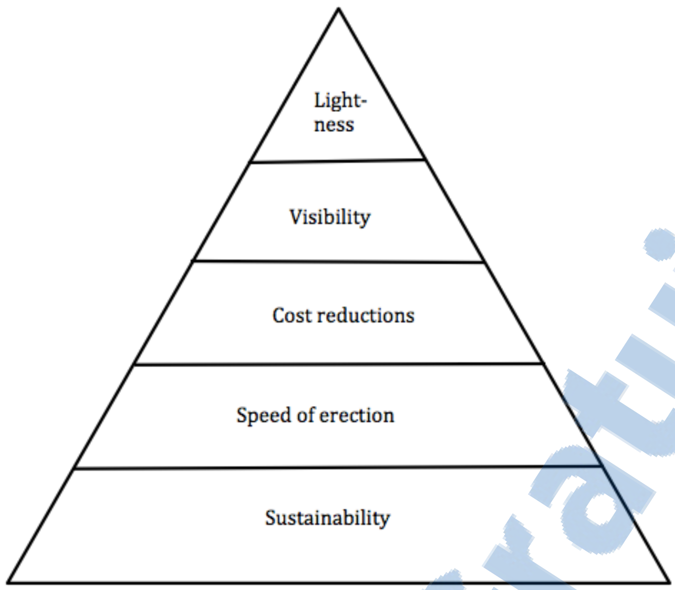

Figure 1 – Motivations to the adoption of wood as structural material for non-residential buildings.

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 et Griffin 2013); (O'Connor*, et al.* 2004); (Roos*, et al.* 2010, Laguarda et Espinoza 2015) and its energy related specificities (Schmidt et Griffin 2013) (!!! INVALID CITATION !!! 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 (Buildup 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 et Gaston 2004, Roos*, et al.* 2010) (Bysheim et Nyrud 2009) (Riala et Ilola 2014) (Schmidt et 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 et Espinoza 2015) and its appearance are examples of particularities that seem being appreciated [O'Connor and *al.*, 2004; Bysheim and Nyrud 2009; (Laguarda et Espinoza 2015)]. (Schmidt et Griffin 2013) [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.

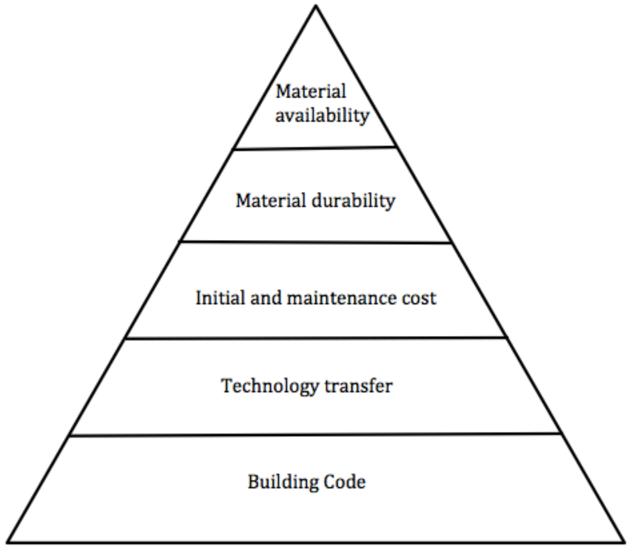

Figure 2 – Barriers to the adoption of wood as structural material for non-residential buildings.

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 et Griffin 2013), 2013; (O'Connor*, et 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*, et 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*, et 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 (Stechyshyn 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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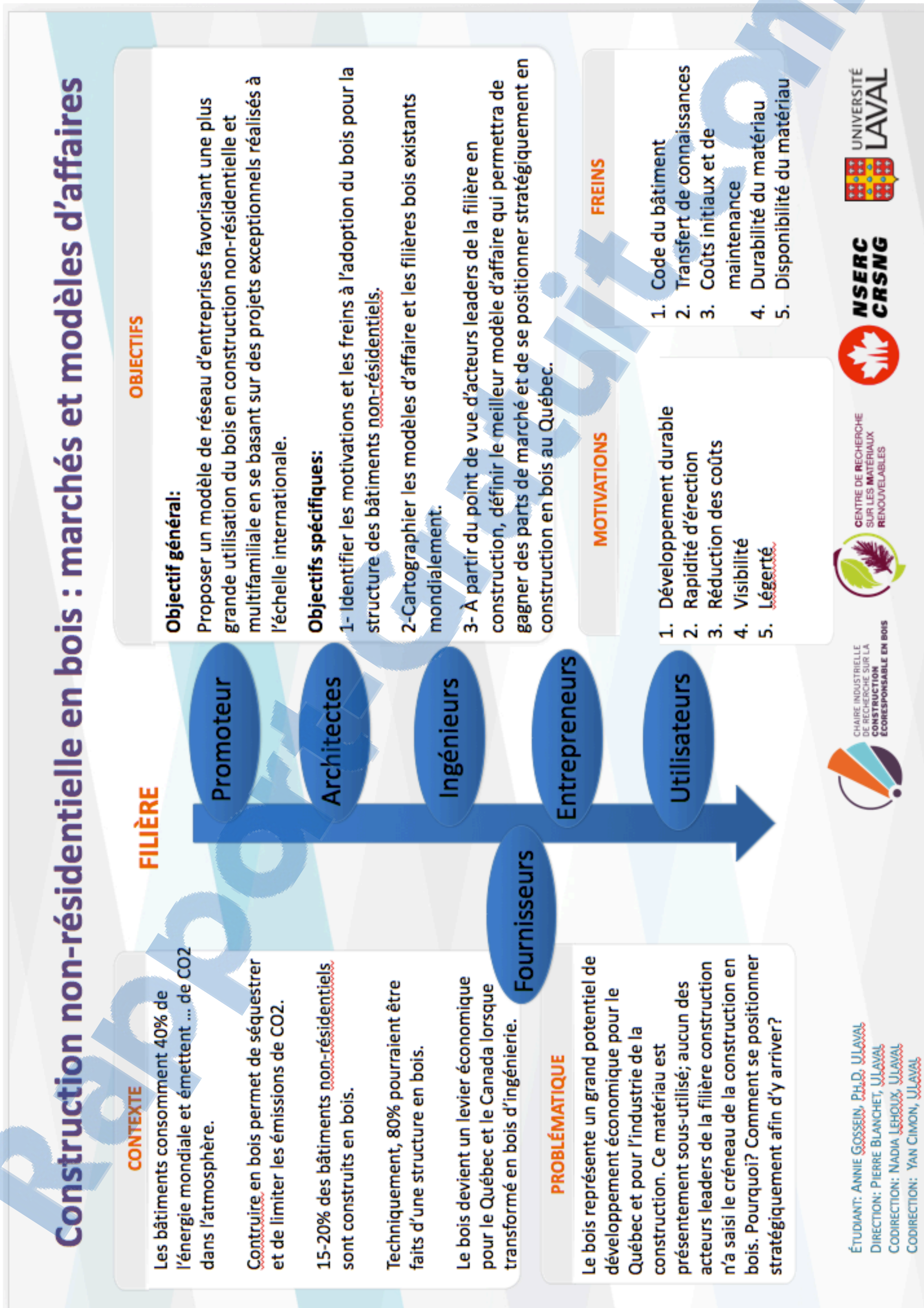
Annexe 3 - Affiches



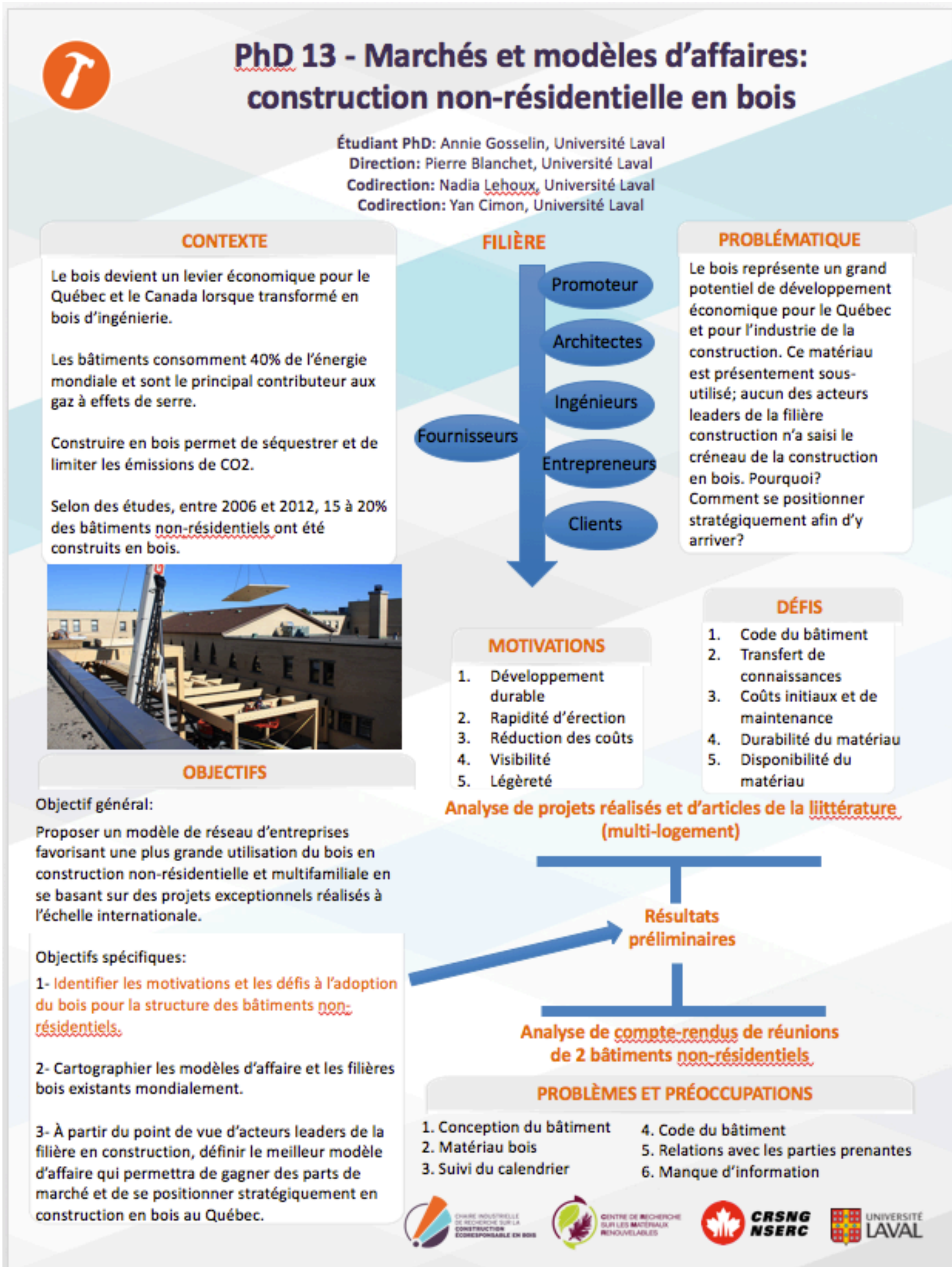
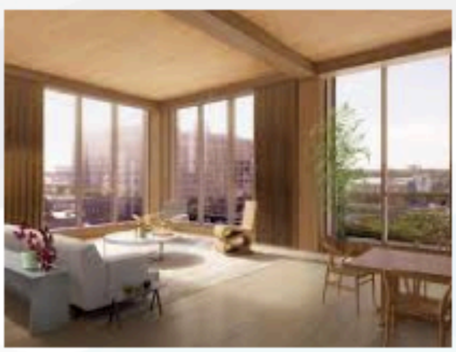

PhD 13 - Marchés et modèles d'affaires:
construction non-résidentielle en bois
Étudiant PhD: Annie Gosselin, Université Laval
Direction: Pierre Blanchet, Université Laval
Codirection: Nadia Lehoux, Université Laval
Codirection: Yan Cimon, Université Laval
CONTEXTE
Le bois devient un levier économique pour le Québec et le Canada lorsque transformé en bois d'ingénierie.
Les bâtiments consomment 40% de l'énergie mondiale et sont le principal contributeur aux gaz à effets de serre.
Construire en bois permet de séquestrer et de limiter les émissions de CO2.
Selon des études, entre 2006 et 2012, 15 à 20% des bâtiments non-résidentiels ont été construits en bois.
FILIÈRE
Promoteur
Architectes
Ingénieurs
Fournisseurs
Entrepreneurs
Clients
PROBLÉMATIQUE
Le bois représente un grand potentiel de développement économique pour le Québec et pour l'industrie de la construction. Ce matériau est présentement sous-utilisé; aucun des acteurs leaders de la filière construction n'a saisi le créneau de la construction en bois. Pourquoi? Comment se positionner stratégiquement afin d'y arriver?
DÉFIS
1. Code du bâtiment
2. Transfert de connaissances
3. Coûts initiaux et de maintenance
4. Durabilité du matériau
5. Disponibilité du matériau
MOTIVATIONS
1. Développement durable
2. Rapidité d'érection
3. Réduction des coûts
4. Visibilité
5. Légèreté
OBJECTIFS
Objectif général:
Proposer un modèle de réseau d'entreprises favorisant une plus grande utilisation du bois en construction non-résidentielle et multifamiliale en se basant sur des projets exceptionnels réalisés à l'échelle internationale.
Objectifs spécifiques:
1- Identifier les motivations et les défis à l'adoption du bois pour la structure des bâtiments non-résidentiels.
2- Cartographier les modèles d'affaire et les filières bois existants mondialement.
3- À partir du point de vue d'acteurs leaders de la filière en construction, définir le meilleur modèle d'affaire qui permettra de gagner des parts de marché et de se positionner stratégiquement en construction en bois au Québec.
Analyse de projets réalisés et d'articles de la littérature (multi-logement)
Résultats préliminaires
Analyse de compte-rendus de réunions de 2 bâtiments non-résidentiels
PROBLÈMES ET PRÉOCCUPATIONS
1. Conception du bâtiment
2. Matériau bois
3. Suivi du calendrier
4. Code du bâtiment
5. Relations avec les parties prenantes
6. Manque d'information
CRSNG
NSERC
UNIVERSITÉ LAVAL

Photo de l'étudiant ici

PhD RDC 13 - MARCHÉS ET MODÈLES D'AFFAIRES: CONTRUCTION NON-RÉSIDENTIELLE EN BOIS

Étudiant PhD: Annie Gosselin, Université Laval
Direction: Pierre Blanchet, Université Laval
Codirection: Nadia Lehoux et Yan Cimon, Université Laval



Problèmes

Malgré les propriétés techniques performantes du bois, le potentiel de développement économique que son utilisation représente de même que son fort potentiel de contribution à l'atténuation des changements climatiques, le bois en construction non-résidentielle est encore peu utilisé et peu d'entreprises québécoises sont reconnues comme étant des leaders dans le domaine. Notamment, peu de grandes firmes de génie-conseil n'ont encore saisi le créneau.

Résultats – caractérisation du marché: Motivations et barrières à l'utilisation du bois

Motivations

Barrières

BARRIERES - DOCUMENTS, RAPPORTS TECHNIQUES ET LITTERATURE		PROBLEMES ET PREOCCUPATIONS - COMPTES-RENDUS DE CHANTIERS	
Codes du bâtiment		Sécurité incendie et sismique Vent et charges de neige	
Transfert de technologies		Enjeux d'assemblages sur les sites	
Coûts		Augmentation des coûts	
Durabilité du matériau	Autres aspects techniques	Entreposage et protection	Acoustique, retrait, taux d'humidité
Culture de l'industrie		Relations entre les intervenants Retards sur la planification des travaux Volume de travail	
Disponibilité du matériau		Commandes et livraisons	

(OSTERWALDER ET PIGNEUR, 2010)

Retombées pour l'industrie

- Bénéficier d'une meilleure connaissance du **marché bois**
- Profiter de **conseils** liés à l'élaboration de **modèles d'affaires** adaptés au créneau de la construction en bois
- Être **mieux outillés** pour développer et devenir leader dans le créneau

PhD 13 - MARCHÉS ET MODÈLES D'AFFAIRES: CONTRUCTION DE GRANDE ENVERGURE EN BOIS

Étudiante : Annie Gosselin, Université Laval
Direction : Pierre Blanchet, Université Laval
Codirections : Nadia Lehoux et Yan Cimon, Université Laval

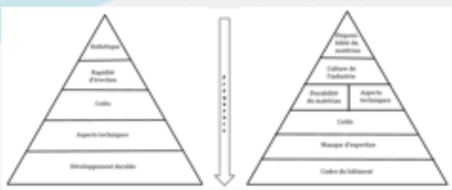
Source: Waugh Thistleton Architects

Problèmes

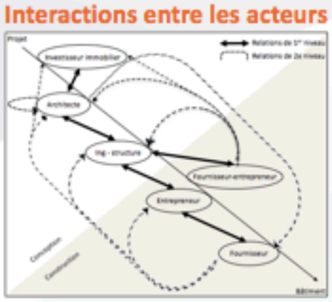
Il a été démontré que le bois comme matériau structural possède de bonnes propriétés physiques et mécaniques et qu'une telle structure pourrait être utilisée pour un plus grand nombre de bâtiments. Un peu partout dans le monde, son utilisation est d'ailleurs en augmentation. Il s'avère être un bon choix en réponse aux changements climatiques et peut dans certains cas limiter le coût des bâtiments de même que favoriser leur efficacité énergétique.

Cependant, le bois en construction de grande envergure est encore sous-utilisé par rapport à son potentiel et encore peu d'entreprises québécoises sont reconnues comme étant des leaders dans le créneau. Les caractéristiques du marché et les interactions au sein de la chaîne de valeur sont encore peu connues. Il en est de même pour les modèles d'affaires des entreprises impliquées.

Choisir une structure en bois



Interactions entre les acteurs



Canevas de modèle d'affaires

(Osterwalder et Pigneur, 2010)

Résultats

Caractérisation du marché: des motivations et des barrières à l'utilisation des structures en bois ont été identifiées (article scientifique 1).

Une plus grande compréhension des interactions entre les acteurs de la chaîne de valeur a été gagnée (article scientifique 2).

Une plus grande connaissance des modèles d'affaires existants en Europe a été acquise (article scientifique 3).

Retombées pour l'industrie

Bénéficier d'une meilleure connaissance du **marché de la construction en bois** afin de pouvoir **s'y insérer** si désiré.

Connaître l'ensemble des **interactions** impliquées dans la construction d'un bâtiment structural en bois afin de **mieux performer**.

Profiter de **conseils** liés à l'élaboration de **modèles d'affaires adaptés** au créneau de la construction en bois.

Être **mieux outillés** pour développer et **devenir leader** de cette industrie.