Investigating the Benefits of BIM for Mid-Rise Timber Buildings in Canada: A Qualitative A Qualitative Study

Shibani, A., Bhavsar, A., Hassan, D., Saidani, M. & Agha, A.

Original citation:
Shibani, A, Bhavsar, A, Hassan, D, Saidani, M & Agha, A 2021, 'Investigating the Benefits of BIM for Mid-Rise Timber Buildings in Canada: A Qualitative A Qualitative Study', IJRDO - Journal of Mechanical And Civil Engineering, vol. 7, no. 1, pp. 1-32.

http://www.ijrdo.org/index.php/mce/article/view/4079

ISSN 2456-1479

Publisher: IJRDO Journal

Investigating the Benefits of BIM for Mid-Rise Timber Buildings in Canada: A Qualitative Study

Dr Abdussalam Shibani, Anjli Bhavsar, Dyaa Hassan, Messaoud Saidani , Araz agha

ABSTRACT

Timber has recently gained global popularity as a material for taller building typologies. It is a material much less intensive in resource and energy use and accounts for far less greenhouse gas emissions over its life cycle in comparison to steel and concrete; the two most dominating materials in the Canadian construction industry. Mass-timber is an engineered product, which requires the use of prefabrication and CNC machining. Although this process creates much safer working environments and significantly improves the quality of the delivered products, theoretically allowing mass-timber buildings to go even higher, it requires a high level of collaboration and automation at the beginning stages of the project. It requires strong building information modelling (BIM) which is also a relatively new technological process in the industry. Several tall mass-timber projects have recently been constructed however; there has been limited documentation of the strategies and processes needed for a successful project, ultimately hinging the up-take of this typology. This study takes on a qualitative research approach to unfold the processes, techniques, successes and challenges experienced by industry professionals working with BIM in the context of timber construction. Analysis of the responses shows that there are many benefits associated with BIM, which are also present in the context of timber construction. At the same time however, industry professionals noted that more research, education for both the workforce and clientele, and a stronger push from regulatory boards should be addressed in order for the industry to boom in all of the benefits and success factors that BIM has to offer. Based on the results of this study, it can be concluded that acknowledging these ‘lessons learned’ and implementing the noted strategies more rigorously could be very advantageous for tall-timber construction in the Canadian construction industry.

Key Words: Tall-timber construction, BIM, Prefabrication

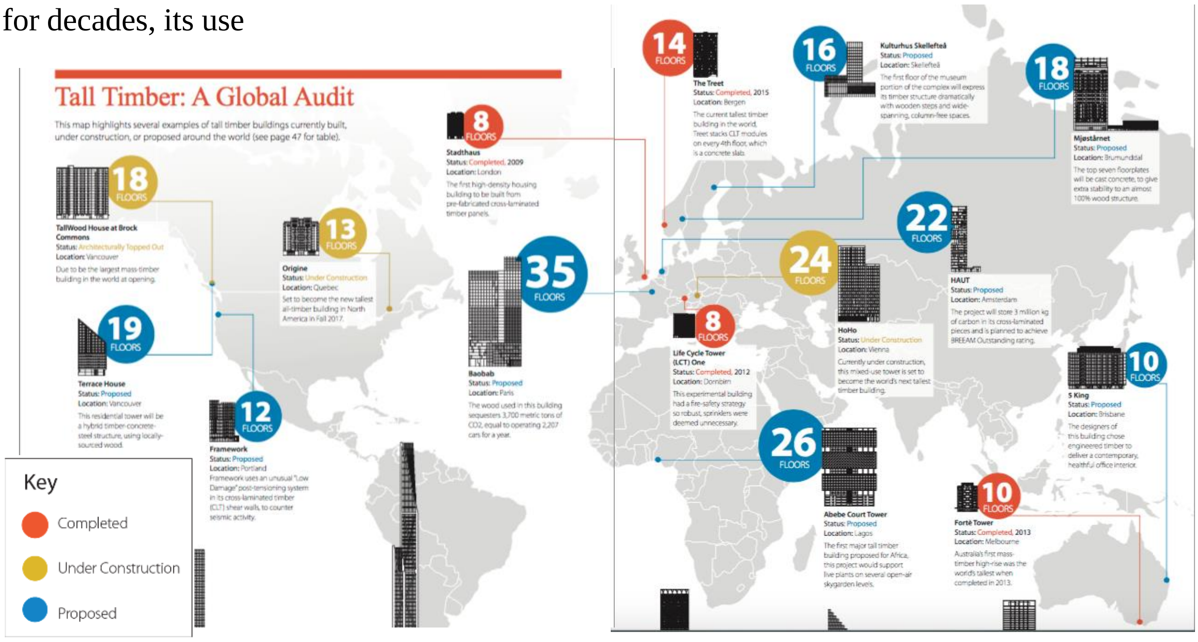
1. INTRODUCTION

2. Timber has recently gained popularity as a material for larger buildings (Merschbrock 2014). In 2017, the Council on Tall Buildings and Urban Habitat published an audit on tall timber buildings, which stated that there have been 26 tall timber buildings (seven storeys and up) developed and constructed globally. In Canada, the Brock Commons building in British Columbia stands as the tallest wood building at 18 storeys high (Bickis 2019). Its construction used building information modelling (BIM) and cross-laminated timber (CLT), ultimately delivering the tallest timber building in the world in 2016 (Duncheva et al 2018). Timber is much less intensive in resource and energy use and accounts far less greenhouse gas emissions over their life cycle (Natural Resources Canada 2018) than steel and concrete; the two most dominating materials in the Canadian construction industry. Additionally, timber uses off-site computer numerical controlled (CNC) fabrication processes that shift resources and labour from the jobsite to the factory floor (Mortice 2019). This not only creates much safer working environments but also significantly improves the quality of the delivered products, theoretically allowing mass-

Figure 1. Tall Timber Audit (Council on Tall Buildings and Urban Habitat 2017)

timber buildings to go even higher (Merschbrock 2014).

Timber has many associated benefits however; although it has been used for construction for decades, its use



in tall construction is fairly new. BIM and tall-timber construction are both very niche and emerging technologies in the building industries. There is limited literature that has documented the processes, techniques, successes and challenges associated with using BIM for mid-rise timber building, ultimately bringing resistance to industry adoption. For this reason, the purpose of this research was to investigate the benefits of BIM for mid-rise timber buildings through a qualitative study that will bring fourth industry professionals' experiences, processes, strategies and challenges associated with tall-timber construction.

2.1. Context and Recent Developments in the Canadian Construction Industry:

I.Urban Sprawl and Climate Change: Urban sprawl and its contribution to climate change are two critical controversies associated with the Canadian construction industry (Skullestad, Bohne and Lohne 2016). Urban sprawl is the expansion of human populations away from dense urban centres, to smaller, less concentrated communities (Renewable Resources Coalition 2016). Statistics Canada (2017) census showed that 53.6 per cent of dwellings are single-detached houses and only 9.9 per cent of dwellings are apartments

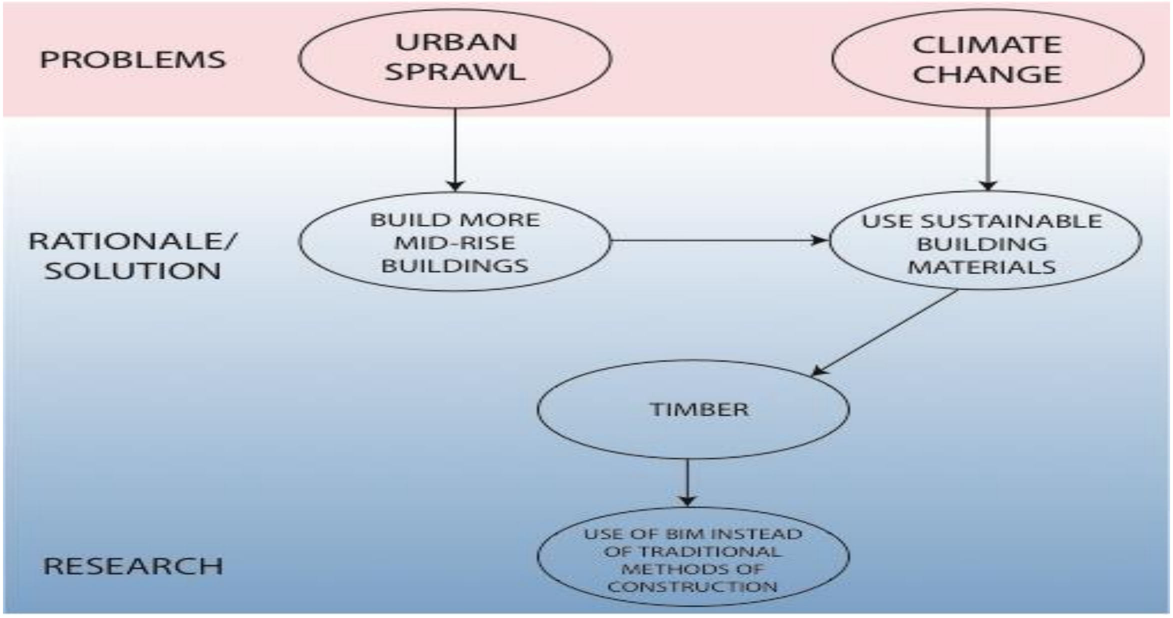


Figure 2. Research rationale (Bhavsar 2019)

with five or more stories. This is causing the suburbs of Canada to expand uncontrollably and building such de-concentrated dwellings requires a large consumption of nutritious land. If this trend continuous, the city will eventually need to build on top of Canada's Greenbelt, which are, protected areas of farmland, green spaces, wetlands and forests. As such, there is an on-going effort to construct more mid-rise (six to ten storey) buildings in the Canadian suburbs over the next few years while using more sustainable building materials (Bhavsar 2019). Considering the ecological benefits of timber, researchers and industry professionals have begun developing frameworks for the implementation of BIM and tall-timber construction within their organisations.

Furthermore, Sustainable Forest Management in Canada (2018) states that Canada is the second largest wooded land country in the world with 30% of the world's overall forest cover and a large portion of this wood can be used in the construction of non-residential and mid-rise buildings. Additionally, cutting down the aged trees actually helps the environment as it eliminates the amount of the CO2 that it has absorbed from getting re-released back into the environment. As there will be a significant increase in the number of mid-rise buildings that will constructed over the next few years (Ontario Ministry of Municipal Affairs and Housing 2017), this research would be a great contribution in the on-going effort to choose more sustainable materials such as timber for the construction of new, tall buildings.

II. **Technology Advancements:** Year after year, new technological advancements continue to leverage change in construction and bring the industry forward (Ghaffarianhoseini et al 2017). Technology has brought forth immense possibilities for building stronger, complex, and more energy efficient structures around the world while also improving worker safety. Technology has made it possible for teams to work geographically dispersed through exceptional collaborative processes and capabilities. This not only allows for extreme levels of productivity and efficiency but also makes it possible to create some of the most iconic buildings around the world. Despite clear benefits of these developments, the construction industry has always been known to be slow to adapt to new changes. Dr. Motawa, Price and Sher (1999) state that the high level of uncertainty associated with innovative products and processes is a barrier to implementing new changes. Furthermore, the research suggests that acknowledging all technological, financial and perceptual aspects for any new implementation within an organisation is one of the most effective ways to bring all team members on board.

BIM is an example and one of the most key technological advancements in construction (Ghaffarianhoseini et al 2017). It is a rapidly popularising construction process that has been proven to enhance design, construction and maintenance of buildings. Becerik-Gerber, Jazizadeh and Ku (2012) and Bhavsar (2019) claim, “BIM allows project team members to collaborate at deeper levels which can ultimately lead to testing of new innovations and techniques for construction”. In mass timber, BIM is used to design the parametric details for the CNC machining units to produce the wooden elements with unique parameters (Merschbrock 2014). It becomes a necessity for timber buildings and is therefore the basis of developing a strong foundation for an efficient construction process of wood buildings.

Table 1. Tabulated previous literatures (Bhavsar 2019)

TOPICS OF INVESTIGATION IN PRIOR RESEARCH PAPERS			BIM			WOOD AS A BUILDING MATERIAL	BUILDING TYPOLOGY		LOCATION OF STUDY	
TITLE OF PAPER	AUTHOR(S)	YEAR	GENERALLY ADDRESSES BENEFITS AND CHALLENGES OF BIM	INVESTIGATION OF SPECIFIC BIM TOOLS	BIM FOR STRUCTURES	WOOD AS A SUSTAINABLE MATERIAL CHOICE	WOOD FOR MID-RISE BUILDING STRUCTURES	WOOD FOR HIGH-RISE BUILDING STRUCTURES	CANADIAN CONSTRUCTION INDUSTRY	EUROPEAN CONSTRUCTION INDUSTRY
A Compartive Life Cycle Assessment of Mid-rise Office Building Construction Alternatives: Laminated Timber or Reinforced Concrete	Adam Blake Robertson	2011								
Building Information Modeling (BIM) partnering framework for public construction projects	Atul Porwal and Kasun N. Hewage	2013								
Use of wood in green building: a study of expert perspectives from the UK	Lei Wang, Anne Toppinen and Heikki Juslin	2014								
Digital Collaboration in the Wood-based Construction Industry: Deployment of Building Information Modeling	Christoph Merschbrock	2014								
Context, drivers, and future potential for wood-frame multi-story construction in Europe	Elias Hurmekoski, Ragnar Jonsson and Tomas Nord	2015								
BIM-Enabled Structural Design: Impacts and Future Developments in Structural Modelling, Analysis and Optimisation Processes	Hung-Lin Chi, Xiangyu Wang and Yi Jiao	2015								
Efficiency in the delivery of multi-story timber buildings	Antti Ruuska and Tarja Häkkinen	2016								
Procuring Innovation in Construction: a review of models, processes and practices	British Columbia Construction Association	2017								
BIM-Enabled Health & Safety Analysis of Cross Laminated Timber Onsite Assembly Process	Duncheva, Samer BuHamdan, Robert Hairstans,	2018								
BIM Report for the Greater Toronto Area	The University of Toronto	2018								
Mid-rise Construction in British Columbia: A case study based on the Remy Project in Richmond BC	Canadian Wood Council	n.d								

I. What is BIM?

Project delivery in the Architecture, Engineering and Construction industry across the globe has traditionally always been very fragmented. There are numerous participants on any given construction project that while working in traditional, document-based (digital or paper form) project delivery methods, can cause many inefficiencies, errors, risk, and missed opportunities. Furthermore, it can cause a plague of waste and cost overruns (Hardin 2015). Because of the hard-bid delivery method in traditional project delivery, team members remain both financially and contractually isolated and each solely look out for his or her best interest (Hardin 2015). For this reason, the industry has been starting to focus its direction towards BIM. BIM and its definition are perceived in many ways within the construction industry. The most comprehensive definition used within the Canadian construction industry is the one provided by the National Institute of Building Sciences (NIBS) that describes it as:

> "*The digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward"* (NIBS 2007).

In recent literature, practitioners and researchers have recognised a significant amount of potential that BIM can have on project delivery processes and outcomes (Hardin 2015; Eastman et al 2011; Ghaffarianhoseini et al 2017; Kivits and Furneaux 2013). BIM first became an exciting new tool and significantly drew the attention of the construction industry in 2009. At this time, Brad Hardin wrote the first version of *BIM and construction Management: proven tools methods and workflows.* The book was one of the first to formalise the integration process for BIM in the construction industry and its benefits through the use of case studies and real-world examples therefore, it was a reliable source to use for this literature review. BIM essentially builds a building in virtual form previous to physically constructing it, which is a great potential for practitioners as it allows them to design, analyse, sequence, and explore a project thoroughly through a digital environment. Making any changes in this virtual project is far less expensive than in the field during construction where changes are exponentially more costly (Hardin 2009). Figure 3 shows the Macleamy Curve, which illustrates how an integrated project delivery (IPD), provided through BIM processes, could leverage design decisions earlier on in the construction process to control cost overruns. This curve was first introduced in the Construction User's Roundtable (2004) and has been used in various literatures for promoting BIM as seen in the study conducted by Staub-French et al (2018). Since the early 2000 to present, BIM has been a large topic of research and has recorded many practical potentialities. Ghaffarianhoseini et al (2017) wrote a paper that reviews BIM, its implementation, risks, challenges and benefits. Through the various literature reviewed in the study, Ghaffarianhoseini et al (2017) concluded that BIM is

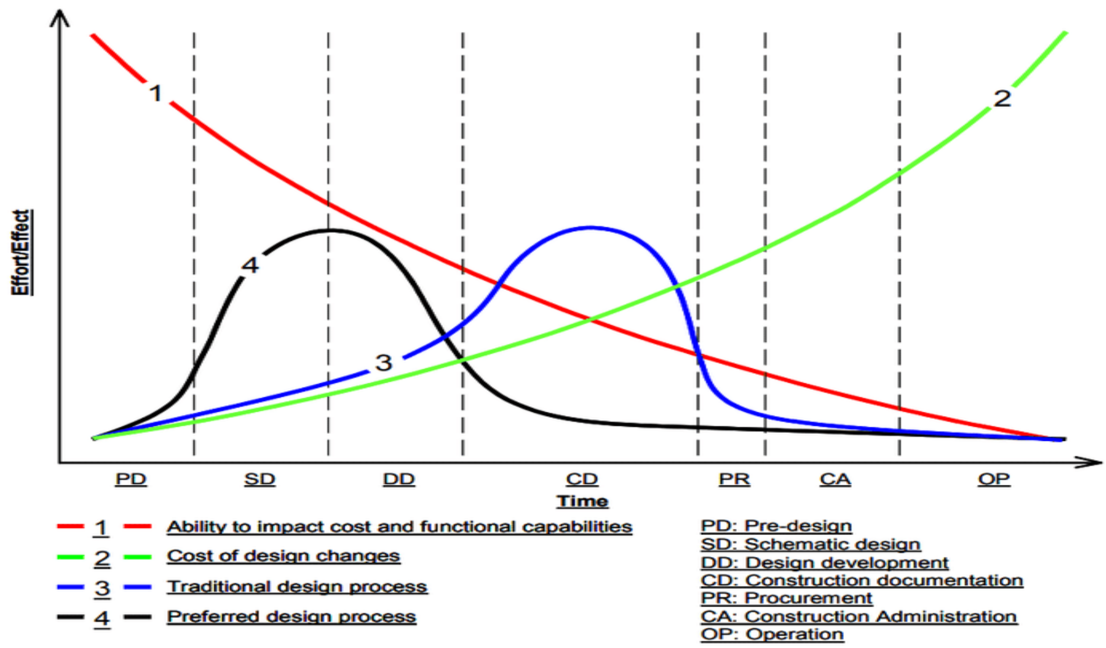


Figure 3. Macleamy Curve (Gumbarević et al 2019)

expected to have 'transformational impacts' in the industry. Some benefits reviewed in the literature are technical benefits, knowledge management benefits, standardisation benefits, diversity management benefits, integration benefits, economic benefits, building LCA benefits, decision support benefits and planning/scheduling benefits. Furthermore, the study reveals that the uptake of BIM has yet to match the level of benefits it has to offer and suggests that countries should actively aim to adopt BIM and consider it to be a process. Kivits and Furneaux (2013) did a unique study to review the implementation benefits and challenges of BIM as a way to enhance knowledge management for sustainability and asset management. By an in-depth analysis of various case studies of projects with BIM application, the report identifies the following as prominent uses of BIM; increased utility and speed, enhanced collaborations, better data quality, visualisation of data and enhanced fault finding Kivits and Furneaux (2013). All of these benefits are achieved through enhanced collaboration at all stages of a project lifecycle, which therefore can facilitate sustainability and asset management. With abundance of literature in the benefits of BIM, further research needs to be done to explore how these benefits are applied in the context of tall-timber construction.

II. BIM Implementation and the Canadian Construction Industry

Currently, and despite many documented case studies and a rich literature review showing the practical benefits of BIM (Hardin 2015; Eastman et al 2011; Ghaffarianhoseini et al 2017; Kivits and Furneaux 2013; Tahrani et al 2015; Forgues and Staub-French 2011) the Canadian construction industry is still lacking the motivation to widely adopt this technology (Tahrani et al 2015). One of the biggest hindrances to BIM adoption in Canada is that unlike the United Kingdom and other parts of the world, it's usage in projects is not mandated and therefore, projects are still being delivered with traditional methods. Tahrani et al (2015) outlines key factors and strategies for implementing BIM in Canada. Tahrani et al (2015) used the research done by Wong, Wong and Nadeem (2010), which analysed global strategies for BIM implementation and developed specific attributes, and key drivers that seem to be necessary for the widespread adoption for the implementation of BIM. These attributes are namely; public sector as a driver, governmental policy mandating BIM on all public projects, BIM standards and guidelines, clear information exchange requirements and open standards, designated organisations responsible for BIM implementation, reporting and promotion of BIM and BIM research programs (Tahrani et al 2015). Forgues and Staub-French (2011) conducted a study comparing the adoption of BIM in Canada and the United States and the results noted that the overall usages of BIM tools on projects were systematically lower in the Canadian industry. To close gaps like these, Tahrani et al (2015) states that the transition to BIM would have to be endorsed by implementing all of the specific drivers in Canada and also recommended ways in which this could be done in the study. This was a beneficial study for this research because the specific factors for implementing BIM within the construction industry could further be used as a basis to implement BIM for timber construction.

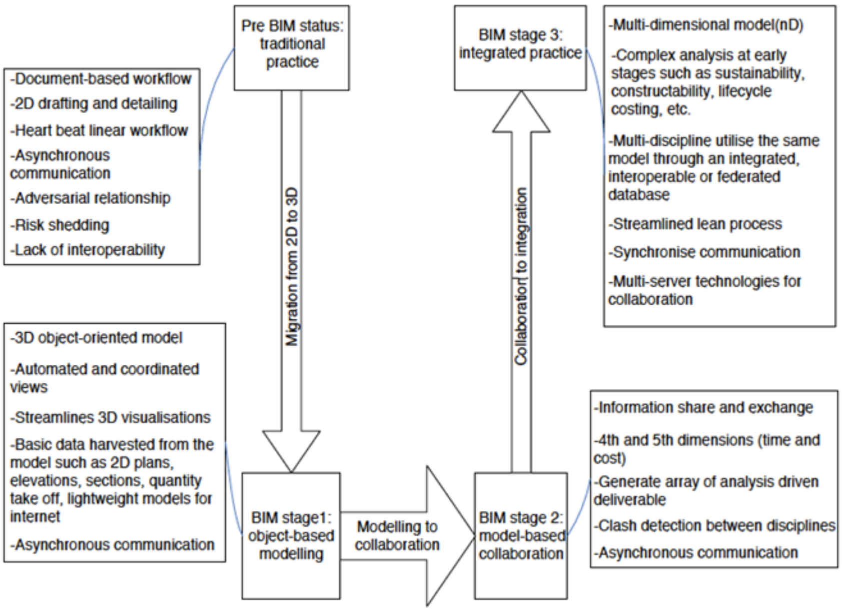


Figure 4. Succar's BIM maturity stages (Khasrowshahi 2010)

Many other frameworks for implementing BIM have also been developed over the last century that could be beneficial to understanding the potentials of BIM for tall-timber construction. Jung and Joo (2011) presented an implementation manual that showed a detailed guide for the systematic implementation of BIM for companies working with BIM in the future. Bernstein et al (2013) studied the level of BIM maturity in different countries by taking into consideration the client satisfaction, financial investment and the technological information used. One of the most famous is Succar's maturity framework. Khosrowshahi and Arayici (2012) used Succar's maturity framework as a tool to evaluate their interview responses in order to identify the level of BIM implementation in the UK construction industry. Figure 4, developed by Khosrowshahi and Arayici (2012), summarises Succar's maturity framework. As seen in Figure 4, this framework consists of three stages and each stage has specific BIM attributes, creating a systematic framework to implement BIM processes within an organisation.

III. BIM for Timber Buildings in Canada

Canada has been making its way up as a world leader in high-rise timber construction with government program such as Natural Resources Canada (NRCan) and the Canadian Wood Council (CWC) showing a growing interest in building projects that demonstrate innovative wood building solutions. The change in building code in Ontario and British Columbia that increased the height allowance of timber buildings to six stories has also brought more importance of mass-timber buildings in the Canadian Construction industry (Ministry of Natural Resources and Forestry 2017; Tesfamariam and Stiemer 2014). Furthermore, two recent publications, "Technical Guide for the Design and construction of Tall Wood Buildings in Canada' by FPInnovations and 'the Case for Tall wood Buildings' published by the CWC, are also testament to the renewed interest in tall timber buildings. One of the most recurring topics in these publications is the importance of prefabrication. Mass timber buildings are made out of CLT, an engineered, prefabricated product that requires a high level of collaboration and precision (Mortice 2019). Literature states that it is the process of prefabrication that improves the quality of timber, which allows it to go to taller heights (Merschbrock 2014; Mortice 2019; Le Roux, Bossanne and Stieglmeier 2016). Prefabrication and the need for integrative planning processes and 3D digital models for information exchange are some of main reasons why BIM is needed for timber construction (Le Roux, Bossanne and Stieglmeier 2016). A study conducted by Staub-French et al (2018) identified the synergies between BIM and Design for Manufacturing and Assembly (DfMA) for mass timber construction. This was done by reviewing lessons learned from implementation initiatives, and the usage of tools and technologies from across the globe in order to help the implementation of BIM and DfMA in the British Columbia construction industry. One of the most elite examples of mass timber construction in Canada is the Brock Commons building in British Columbia (Figure 5). It is the tallest hybrid mass-timber building in Canada and the project used BIM and VDC for its construction process (Kasbar 2017), highlighting the importance of BIM for timber structures.

Figure 5. Brock Commons Hybrid Structure (Hasan 2017)

IV. Challenges with the Construction of Tall-Timber Structures and BIM

Timber buildings use the efficient processes of prefabrication manufacturing and in order to exploit the associated benefits of these processes, an integrated design process that can bring the project team together at an early stage of planning is necessary. Boton and Forgues (2017) further states that the design of tall wood buildings requires a much broader perspective in which designers must take into account "the integration of all building systems, the building envelope, and performance detailing, as well as architectural form, function, and flexibility from the outset of the design process". This reinforces the need for project teams to use innovative approaches for integrative project planning and simulation tools such as those proposed in a BIM based project delivery. As such, it can be seen that BIM software platforms need to be improved for the development of timber construction however, as mentioned earlier in this literature review, the challenge is that in Canada, the use of BIM is not mandated in projects which is hindering full use of its potential in the industry. Research has been conducted to look at some of the other challenges associated with the use of BIM for timber construction. For example, Patlakas, Livingstone and Hairstans (2015) looked at the benefits, challenges and limitations associated with BIM for offsite timber construction. Using surveys, questionnaires and interviews, they found that the main limitation is the lack of a standard or framework for transitioning from design to manufacturing. Through this method, they identify the need for BIM enabled data sets which make it possible to communicate the industry-required data for timber products, straight into BIM-enabled software platforms. If the project began with BIM-enabled software's, this challenge could be mitigated. Furthermore, Le Roux, Bossanne and Stieglmeier (2016) identified that "although BIM tools have matured for steel and concrete constructions, BIM tools and processes for modelling wooden frame structures are still much behind in time". Le Roux, Bossanne and Stieglmeier (2016) and Mortice (2019) realise the need for higher degree of detail in planning and a closer link between planning and manufacturing in timber construction in comparison to concrete or steel construction, and therefore requires unified building information exchange process. Le Roux, Bossanne and Stieglmeier (2016) states that there needs to be a general BIM process guideline established by the timber industry that makes it easy to recognise benefits offered by BIM platforms. One way in which this could be done is by reviewing completed projects and formalising the successes and challenges associated with each. The limited literature available in these areas stood as the purpose for conducting this study.

2.1. Chapter Summary

BIM is quickly expanding in the construction industries as a construction process that offers new opportunities for improved project delivery throughout the entire lifecycle. It is a construction process that establishes a digitally shared, central location to store all of the information of a building project. This process creates a high level of collaboration between different stakeholders in the project, which has resulted in an effective, and efficient project delivery, and outcome. BIM has benefitted projects in many ways in terms of finances, sustainability innovations, risk allocations and achieving schedule targets. BIM has also been used been used for tall timber buildings in Canada. For example, BIM and VDC were used for the Brock Commons building in British Columbia, which stands as the tallest timber building in Canada. However, the gap in knowledge is that there is limited research that formalises the benefits BIM can have on timber buildings because there has not been a post-construction audit of the success and challenge factors with construction tall-timber buildings with BIM. With abundance of literature in the benefits of BIM and multiple tall timber projects completed around the world, further research needs to be done to explore how BIM has been useful for timber construction and identify the best way to implement it.

3. RESEARCH METHODOLOGY

3.1. Introduction

Research methodology is the combination of techniques used to inquire a specific phenomenon and methods are individual techniques to collect and analyse data (Easterby-Smith, Thorpe and Jackson 2012). Establishing the choice of philosophies and techniques allows the researcher to situate his/herself to conduct a study and have a justified reason to their conclusion (Abadi 2014). Starting off with the research philosophy, this chapter will then discuss the population and sample size, data collection protocol, interview design, interview content, data validity, and method for analysing data that was applied for this study.

3.2. Research Design

3.2.1. Research Philosophy

The research philosophy reflects the researchers underlying assumptions, theoretical perspective and mentality in understanding the phenomenon under investigation (Abadi 2014; Khosrowshahi and Arayici 2012). Research philosophy has two main branches or areas of assumptions, which are ontology and epistemology. Ontology is the philosophical standpoint regarding the nature of reality and all that exists while epistemology is the philosophical standpoint regarding what we perceive reality to be. As seen in Figure 6, each aforementioned philosophical branch has meta-theories that constitute research objectives, methods, validity and reliability (Khosrowshahi and Arayici 2012). Objectivism believes that social phenomenon and their meanings have an existence that is independent of their social actors. In terms of this research, an objectivism ontological position was well reflected in understanding and applying existing knowledge of BIM, the benefits of BIM, and the implementation of BIM to timber construction. This objectivism ontological data was collected in Chapter Two; literature review of this report. The ontological stance is crucial as it is a prerequisite for the choice of the epistemological stance, which then subsequently leads to shaping the research methodology (qualitative or quantitative) to be deployed (Panas and Pantouvakis 2010). On the other hand, interpretivist believes that meanings of reality should be built around the experiences that people provide. In this position, the researcher is drawn to interpret elements of the study and reflect all of the different perspectives. For this research, the interpretivist standpoint was well fitting in understanding how BIM is currently being used in companies working with tall-timber construction. The interpretivist standpoint allowed the researcher to analyse BIM processes and BIM tools that the participants find most beneficial for timber

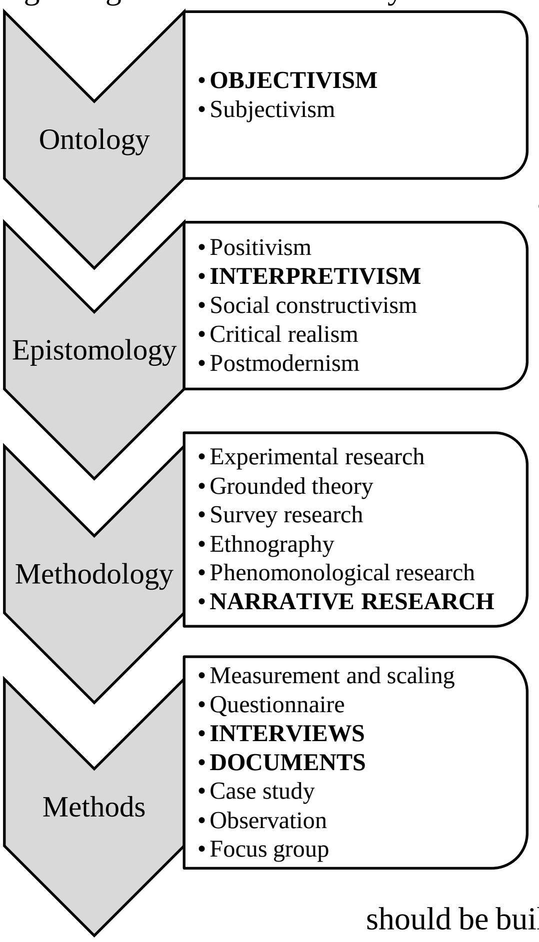


Figure 6. Research process (adapted from Crotty 1998 and Abadi 2014)

construction through their experiences associated. By using both the objective and the interpretivist standpoint, the researcher was able to investigate the benefits of BIM for tall-timber buildings and achieve the aim of this study.

3.2.2. Research Approach and Strategy

After a thorough review of the literature, the need to assess the current state of how BIM is being used in organisations in Canada that deal with timber construction became evident. The aim was to apply existing knowledge about BIM implementation from literature and industry experience to propose strategies that are believed to bring more benefits to tall-timber construction. The research took on a qualitative approach. Semi-structured interview process was used to obtain first-hand the experiences, opinions and feelings of industry professionals who have been a key member in tall-timber construction projects.

Each of the three research objectives (RO) were accompanied by three of four interview questions that are strategically curated to get respondents to discuss the benefits of BIM whether they were explicit benefits, challenges that they saw as becoming benefits and strategies they felt would help industry achieve more benefits of BIM for timber construction. Appendix 2 presents the interview questionnaire. Furthermore, the questions were designed to be non-prescriptive and non-leading so that the participants have the most freedom to express their views (Bhavsar 2019).

3.3. Data Collection Method

3.3.1. Primary Data Collection

Primary data collection involves directly obtaining relevant data from the sample population. To understand the subjective experiences and understandings of best practices within the topic of research, semi-structured interview methods were carried out for primary data collection for this study. There have been several mid-rise timber buildings built in Canada over the past couple years, along with a number of buildings planned for the future. There are a few key companies that have had an extensive interest and influence on mid-rise timber buildings and have succeeded with positive feedback and a smooth construction process (Mgb Architecture and Design 2012). An understanding of the processes used by these companies was intended to help with the identification of how BIM processes are being used by timber building constructors. In order to be able to obtain the most conversational and get an idea of the most honest feelings, experiences and opinions of industry professionals, semi-structured interview were used for data collection (Kothari 2004). In this way, the interview simply aimed to encourage the respondent to talk about the given topic with minimal direct questioning, allowing the respondent to express their feelings and beliefs under a frame of reference posed within the question (Kothari 2004).

3.3.2. Secondary Data Collection

Secondary data collection is the process of gathering information from sources such as journal articles, news reports, and any peer-reviewed documents and literature accessed in person or electronically. It provides an important source of data to support the primary data and ensure reliable result. The secondary data collection for this study is been presented in chapter two of this study.

3.4. Sampling and Study Population

3.4.1. Sampling Method

There two main methods of choosing sample; probabilistic and non-probabilistic (Acharya, Prakash and Nigam 2013). In the probabilistic method, each individual in a population has an equal chance of being selected whereas in the non-probabilistic sampling strategy, participants are selected randomly (Etikan, Musa and Alkassim 2015). Considering the researchers limited exposure in the industry and limited access to potential interviewees, a non-probabilistic sampling method was used for this study. There are three main types of non-probability sampling; purposeful sampling, quota sampling and snowball sampling. For the interviews of this study, a purposeful sampling method was used. Using this technique, participants were chosen based on their knowledge, experience in the topic of study (Morse 1991).

3.4.2. Sample Recruiting and Size

The rationale behind selecting the participants for this study was to choose individuals that are familiar with the variables; timber and BIM to be able to give informed, analytical and critical perspectives for the research. In order to recruit participants who were most likely to be experienced in the topics of study, a search was conducted on Google to identify companies that have submitted proposals for tall-timber buildings, have been involved in constructing tall-timber buildings and large companies that have had the most experience in BIM were identified and contacted via email and phone call to seek their interest in a semi-structured interview. A total of ten participants were sought within the disciplines of architects, researchers' manufacturers and project managers.

3.5. Data Analysis Technique, Validity and Reliability

Once the interviews are transcribed in verbatim form, a content analysis was undertaken manually. Content analysis, also known as thematic analysis, is a comprehensive process where the researcher aims to identify numerous cross-references and evolving themes from the interviews (Ibrahim 2012). According to Nowell et al (2017), there are six steps to conducting a thematic analysis; familiarising oneself with the data, generating initial codes, searching for themes, reviewing themes, defining and naming themes and producing the report. The researcher reviewed the responses for each question repeatedly to search for meanings and patterns. The next step was to create codes and attached them to sections that relate to a common theme or issue in the data (Nowell et al 2017). A detailed explanation of how the content analysis was undertaken is presented in Appendix 3. The researcher ensured that the codes had explicit boundaries and were not interchangeable or redundant. Then the codes were extracted into themes by bringing together ideas that would seem meaningless when analyzed individually. The themes were reviewed several times and were removed or new ones added. Each code was given a unique number to associate it with the overlying theme and a frequency count should be done at this stage to get an understanding of which themes and codes are most prominent. After the themes were reviewed and deemed reliable, the report was produced. A detailed analysis and logical, non-repetitive information associated with each theme is discussed in the Findings and Discussion chapter.

3.6. Chapter summary

This chapter presented a detailed description of the adopted research methodology. Research philosophies are the underlying basis of any conducted research and the ontological and epistemological assumptions held by the researcher are the foundation to informing the research design, data collection and interpretation of the findings. The purpose of this research is to use the existing knowledge of BIM, BIM implementation and the benefits of BIM to understand how BIM can be applied and provide the best results for tall-timber construction. As such, establishing objectivism ontology and interpretivist epistemology standpoints were the most appropriate philosophical standpoints for this study. Once this was established, the research methodologies were designed and lead this study to take a qualitative research approach. Literature review was the first data collection technique to identify existing knowledge of BIM in the industry. Next, interviews were used to collect data regarding industry experiences in BIM and tall-timber construction. Interview questions were designed for each research objective (RO) using themes identified through a detailed literature review on the various variables of this study. In addition to the primary research framework for the study, this chapter also included details of research period, population and sample size and data analysing protocol. A content analysis was chosen as the data analysing protocol, which allowed the researcher to draw conclusions for the research.

4. FINDINGS

4.1. Introduction

The purpose of this research was to understand the benefits of BIM for timber construction. There have been many timber buildings built in the past couple of years however there has been very little documentation of the design to construction process and a 'lessons learned' of the challenges and benefits associated. In this chapter, the findings from the processes and procedures described in the methodology chapter are presented. The chapter will discuss the emerging themes from the respondent's answers and the questions posed to them, prominently featuring participant's own voices throughout.

4.2. Response Rate

The response rate to the requests for interviews with various selected participants was fairly encouraging. The aim was to have approximately 10 interviews with architects, project managers and manufacturers. Invitations were sent out to five researchers, 10 architects and project managers/coordinators each and five manufacturers. Given the fast-pace and day-to-day tasks the industry faces, three times more invites were sent out than intended target goal to ensure at least 10 respondents. Of the 30 invites, two project managers/coordinators, three architects/architectural partners and three researchers responded and participated, totalling to eight interviews. Unfortunately, no manufacturer was available to be interviewed.

4.3. Findings from Interview Data (Emerging Themes)

The responses were analysed using a content analysis. Manually reading and re-reading all of the responses from the eight participants, the researcher identified twenty-four key words. The codes are further categorised within eight themes and given unique code numbers (see Table 2). Conducting a frequency count of the themes ensured reliability and importance of the data and is presented in Table 1. The more prominent themes (i.e. FC=92 versus FQ=26) will be discussed in more details in the next chapter. Appendix 4 presents the complete coding scheme and Appendix 5 presents the coded verbatim transcripts of interviews with the eight participants. In this findings chapter, the eight themes are organised under the research objectives (RO) they answer, and the main findings are presented.

Table 2. Data analysis

Research Objective	Theme (concluded from content analysis)	Unique Code	Frequency Count (done manually)
RO2: Current Status of BIM for tall-timber buildings	Prefabrication and Technology	TECH	92
	Information Exchange	INFO	35
	Modelling and Productivity	MODEL	88
	Workforce Organisation	WORK	79
RO3: Challenges and knowledge gaps that could easily be overcome and become benefits	Prefabrication and Technology	TECH	92
RO4: Strategies to implement to obtain more benefits of BIM and tall-timber buildings	Invest to Adopt	INV	60
	Processes	PROC	27
	Government	GOV	26

4.3.1. *Research objective 2: Current benefits of BIM for tall-timber buildings*

This research objective was accompanied by three interview questions that focused on getting to understand the most predominant benefits of BIM on tall-timber construction. The questions alluded to success factors, tools used and overall how BIM has improved tall-timber construction however responses to the interview questions designed for RO3 and RO4 also brought forth information regarding current status. Four themes were identified throughout the eight responses; prefabrication and technology, information exchange and modelling and productivity and workforce organisation.

I. *Theme: Prefabrication and Technology*

Architects, project manager and researchers all indicated using Revit as the primarily used technological BIM software in the industry. This is due to industry's familiarity with the software resulting in the most efficient construction process. However, the respondents also acknowledged that other programs such as Katia, Tekla, Dietrich's etc are much better for timber construction. This is because with mass timber buildings, one would want to take advantage of CNC milling and pre-manufacturing everything ahead of time (PN 003), which is one of the main benefits of tall-timber buildings. As another architect (PN 002) stated:

> *'Being able to develop the software and the typology and systems within the BIM environment, which can be passed on to the fabricator in the factory setting, is where we will see a huge take-up and benefit and innovate the entire industry'.*

This respondent further stated that their office invested in building their library and families of their materials, which they claimed was one of the biggest advantages they had on their timber project. The library was made of customised elements needed per project and they allotted one team member to become a professional in this so that he/she can design assist the fabricator/installer. *'Then, there's less need for interpretation between the two parties' (PN 002).*

II. *Theme: Information Exchange*

All three interviewee categories indicated information exchange as another direct benefit of BIM for tall-timber buildings. BIM creates a *'common, synchronised information base'* (PN 001), which not only keeps an up-to-date track of all project related matter but also allows for an improved project design. It establishes a common base for all team members to make decisions off of. This is reiterated by PN 001 as they stated, *'parametric information helps us not only improve the design but also create better designs and structural components*.' Project members are able to show a proof of concept to clients and other team members and all aspects of the project can be discussed in detail. Furthermore, PN 002 states:

> *'Everyone understands the design from all branches; electrical, mechanical, structural- which makes it much easier when it goes to fabrication. There's less interpretation and that's where we see more success*es.'

This high level of information exchange and transparency also minimises errors on site, which ultimately reduces the need for change orders, and unnecessary time delays due to re-work. The Brock Commons building- the tallest timber building in Canada, had a very intricate BIM model, which was heavily used in design, construction planning and this added a lot to the overall success of the project (PN 006).

III. *Theme: Modelling and Productivity*

Every single respondent (n=8) named the ability to run clash detection as one of the most beneficial aspect of BIM for timber buildings. Timber lends itself to prefabrication, and for this, every single hole and penetration needs to be detailed and modelled (PN 003). That is where clash detection plays a huge role because it can flag down any conflicts or errors, saving enormous amounts of time and money (PN 001). PN 006 also elaborated, *'Brock commons had a very intricate BIM model which was heavily used in design, construction planning and this added a lot to the overall success of the project.'* This allowed the construction to take less time than planned largely due to the speed at which they were able to erect it through the details, scheduling, and how we were able to organise the site. '*Everyone knew exactly how the building was going to be put together everyone knew what was going on and interpret.'* (PN 006)

IV. *Theme: Workforce Organisation*

Workforce organisation, in terms of the level of coordination, collaboration and communication that BIM brings to projects is another benefit proclaimed by architects, project managers and researchers. One of the most advantageous characteristics of BIM is the potential to do a clash-detection test and this is only made possible with a high level of coordination amongst all of the team members. PN 004 states that conducting a weekly coordination meeting to help contractors to create more accurate models has been one of the best processes they've established on their timber projects. This is because they '*are then able to go through our clash detection report, all the conflicts and try to see what to do next. It gives every party a chance to speak up'*. Many of the respondents also stated that they now started to require their primary consultants to work with BIM, which has helped greatly (PN 002; PN 004)

4.3.2. *Research objective 3: Challenges and knowledge gaps that could easily be overcome and become benefits*

This research objective was also accompanied by three interview questions that aimed to develop an understanding of the most prominent challenges associated with BIM and tall-timber construction. The first of the three questions asked "what are some challenges associated with timber construction and BIM. This was followed by the second question asked, "what are some project related issued that can be overcome by the implementation of BIM". The purpose of this was to prompt the interviewees to think about which of the challenges described in the first question, they felt could actually be a benefit or, project related issues that could be resolved- for timber construction. The next question asked what knowledge gaps they feel are present. This prompted respondents to talk about what exactly is holding back the industry from flourishing in the added benefits.

I. *Theme: Prefabrication and Technology*

Many of the benefits of BIM for tall-timber construction that were mentioned in RO2, also had challenges associated. One of the biggest challenges is under the theme prefabrication and technology. Many of the respondents noted that Revit is currently used as the primary BIM software in their offices however also noted that they felt that it is not the best tool for timber. PN 001 noted *'the current Design software cannot export needed quality to the software of CNC machines and vice versa.'* The problem is that the model exchange process between designers and manufacturers is yet to be designed. The current software's are unable to achieve the level of detail (LOD) necessary for fabricators to develop the components in an efficient way. There needs to be more research done for the industry to move towards *'further standardisation where there would be a Kit of Parts. If architects and engineers had a standard kit of parts to work from and manipulate what's there, then we would have competitive bids from various contractors.'* (PN 004)

4.3.3. *Research objective 4: Strategies to implement to obtain more benefits of BIM and tall-timber buildings*

This research objective was accompanied by four interview questions that focused on understanding what industry professionals see as the most effective way to implement BIM and tall-timber projects within their working environment. The questions prompted them to discuss what research, assistance and strategies and activities needs to be undertaken in order to flourish from all of the benefits of BIM and tall-timber construction.

I. *Theme: Invest to Adopt*

Almost all of the respondents noted that the time and money they invested in BIM was one of the most important steps for success and prospering in the benefits of BIM for timber construction. As PN006 states:

> '*Firms need to be able to make the investment into people and time by providing training for staff from experienced individuals. Education in schools would also be bumped up immensely. The hierarchical system also has a lot of older people, so we need to ensure that training for them is effective. The training needs to be user-friendly to ensure that generation is able to grasp it and use it.'*

One of the issues is that the people '*at the front end- the architects- are still not investing'* (PN 003). The reason for this is that there is not a lot of experience and comfort with working with either BIM or tall-timber construction. PN 004 and PN 007, both from companies leading in timber construction, also noted they are investing in speaking-tours and study-tours respectively, to try and educate their clients while also trying to educate themselves on the best practices to tall-timber construction.

> *'…every fabricator is producing something different and there are so many ways to do one thing. So, we want to know how we can consolidate the gaps so we can compare apples to apples for procurement. We understand the level of coordination we need and understand what means and levels we need. So, what's important is we are taking the time to do the research and plan it properly.'* (PN 007)

II. *Theme: Processes*

Architects, project managers and researchers also particularised the mandating of processes of IPD, Lean and July-in-time delivery would be beneficial to BIM and tall-timber construction. These three philosophies, methods and processes have recently made fundamental changes within the construction industry and complement each other very well when used together (Fakhimi, Sardroud and Azhar 2016). PN 001 states:

> *'It [IPD] encourages early involvement of manufacturer and LOD350 models can be possible to some extent which can make more precise and higher resolution information during design development.'*

With IPD, the manufacturer is brought on board at the beginnings of the projects, which greatly helps with sorting out details and understand the fabrication process. The issue is that these processes have a higher cost associated with it, which clients are very slowly starting to see (PN 003). By implementing the tri-fecta of Lean, BIM and IPD, tall-timber construction would benefit greatly.

III. Theme: Government

Architects, researchers and project managers all agreed that government enhanced standards and regulation would be one of the most valuable strategies for the industry to adopt BIM and tall-timber construction quicker. PN 003 explicitly noted *'government mandating and providing incentives'* would be the most effective assistance for offices to implement BIM within their practices. Furthermore, another big challenge preventing the industry from booming in the benefits of BIM and tall-timber buildings is that:

> *'Timber is not represented well in our building code, so companies are not pushing for investment into timber construction. There are also a lot of premiums that offices need to pay for timber buildings'* (PN 004)

Separately, PN 006 also noted that the government should to facilitate new contract arrangements, which mandates IPD and lean process in order to involve all team members at an earlier stage of the project.

4.4. Chapter Summary

Interestingly, it turned out that all three interviewee categories had very similar things to say for each of the posed questions. This is justifiable because both BIM and tall-timber construction are very niche and emerging technologies hence, the individuals working with either would have very specialised and similar experience and knowledge. The interviewees targeted for this research were individuals who have worked with or are working with BIM and tall-timber construction thus; similarities in the answers were justified and expected.

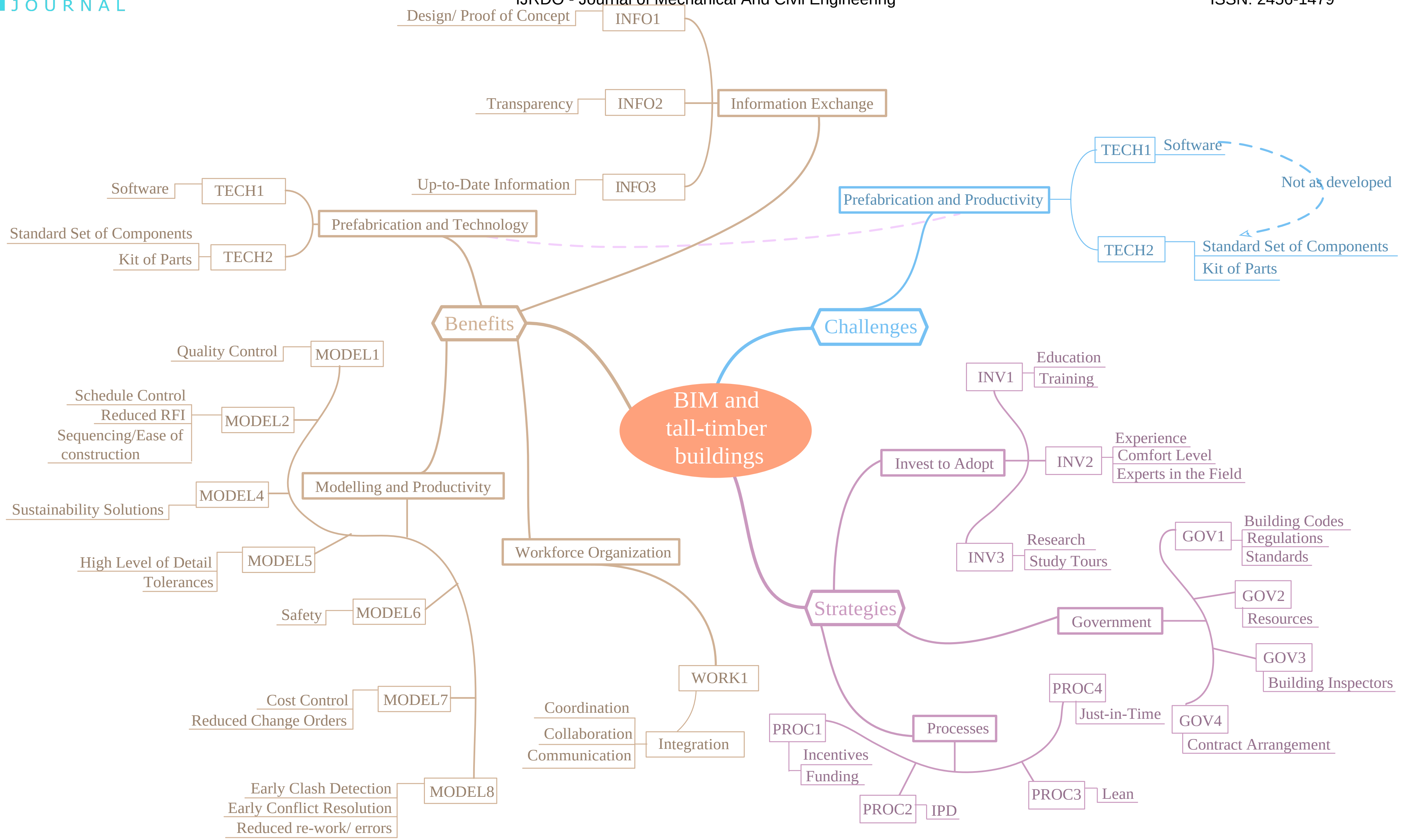


Figure 7. Integration of themes and sub-themes from data collection

5. DISCUSSION

5.1. Introduction

This chapter puts into broader context the findings of this study and the foundational information from the literature review chapter to provide insight into the key implications of both data sets on the research question. The chapter is presented by the research objectives and each addresses themes and subthemes that were triangulated from the interview data. Figure 7 shows the integration of themes and sub-themes. This mind-map was a necessary process to help the researcher approach conclusions that are well informed by the data and to make authentic recommendations.

The literature review presented in chapter two of this report explored what is BIM and how BIM has been working its way into the Canadian construction industry. Literature review and the interview data from this study show that BIM is a necessity for timber buildings due to prefabrication. Despite the number of tall-timber buildings that have been constructed over the past several years, the initial search for the literature review showed that there has been limited documentation of the 'lessons learned' or the process of constructing timber buildings. The trends of events have prompted the research question of this study: *Investigating the Benefits of BIM for Mid-Rise Timber Buildings in Canada.* While the initial literature review explored the general adoption, benefits and challenges of BIM in the construction industry, this study focused on gathering qualitative data on BIM practices for tall-timber construction through the use of semi-structured interviews. In the sections below, the findings of this research from the literature review and the interview data will be synthesised in a critical manner to help understand the benefits of BIM for tall-timber construction.

5.2. Discussion

5.2.1. Benefits of BIM and Tall-timber Construction

Many benefits of BIM for tall-timber construction were identified through the interview data collected for this study and are listed in Table 3 below. BIM provides a strong platform for information exchange and workforce organisation for the team to turn to for decision making and project updates. It keeps a transparent process and establishes a level of trust and cooperation, which is the key to a successful project. The nature of the model, which is possible due to the high level of collaboration and coordination between the team, reduces time spent on making changes, fixing errors and quality issues which have always been a challenge within the construction industry. As Hardin (2009) stated, these challenges have costed the industry a plague of waste and cost-over-runs. Staub-French et al (2018) conducted one of the most influential studies done in the BIM and mass-timber construction industry. This study used the lessons learned from the globe to promote and facilitate BIM and Design for Manufacturing and Assembly (DfMA) for mass-timber construction. The study resulted in a detailed recommendation plan on implementing BIM and DfMA into the industry. Similarly, this study was conducted to identify the benefits of BIM in the context of tall-timber construction and additionally put into perspective the strategies that industry professionals felt could help them pursue more tall-timber buildings. Table 3 shows a comparison of the themes identified from the data of this study to the uses of BIM in the context of tall-timber construction identified in Staub-French et al (2018). It can be seen that there are many similarities in the data.

Table 3. Benefits comparison

Theme	Benefits concluded from this study (codes)	Benefits concluded from Staub-French et al (2018)
Information exchange	-Design/Proof of concept -Transparency -Up-to-date information	-'Single source of truth'
Prefabrication and technology	-Software (Revit, etc) -Standard set of components/ Kit of parts for design to prefabrication	-Produces a high coordinated model in a machine interpretable format that can be deployed in a factory setting.
Modelling and productivity	-Quality control -Schedule control, reduced -RFI/Sequencing/ease of construction -Sustainability solutions -High Level of Detail/tolerances -Safety -Cost Control, Reduced Change orders -Early Clash Detection and conflict resolution (Reduced Errors/re-work)	-Helps provide an understanding of the building assemblies -Eliminates the risk of error -Efficient project performance and schedules
Workforce organisation	-Integration (Coordination, Collaboration, Communication)	-Enables collaboration -Produces a high coordinated model

5.2.2. Challenges and Knowledge Gaps Seen as Potential Benefits

Prefabrication and Technology

The interviewees stated that obtaining all of the potential benefits of BIM on tall-timber required a change in technology and process. Two key codes were identified through the content analysis; *software* and *standard kit of parts*. One of the biggest issues seems to be that the current design software, which is Revit for most of the industry, is not designed to export the level of detail and quality required for direct coordination with CNC machines. Furthermore, this challenge was also identified as one of the greatest limitations in the study conducted by Patlakas, Livingstone and Hairstans (2015), which ultimately brought forth the need to create a BIM-enabled software to communicate the data set required for timber products. This goes to say that the lack of knowledge in the standardisation within the timber industry is one of the biggest challenges and drawbacks of pursuing tall-timber buildings. However as identified through one of the interviews conducted for this study, implementing a new position within their company to facilitate the technology and prefabrication process had been one of the key elements to their success in constructing tall-timber buildings. As explained by Mortice (2019) and Boton and Forgues (2017), timber products such as CLT production needs to take into consideration a high level of precision, integration of all building systems and all performance detailing. This process is much different than standard projects thus; it is essential for companies to establish new roles and positions. As identified through the interview process, companies who are at the forefront of this construction typology, it is possible to overcome this challenge and make it a potential benefit if there's more push internally. Construction companies that have done their research, investment and alterations to the software and design to fabrication process have seen great benefits and success. This was also elaborated through the interviews as one respondent, who's company is currently working on a mid-ride timber building in the heart of downtown Toronto, stated that they are going on study tours to be able to consolidate as much knowledge and information as possible regarding fabrication processes, lessons learned from other designers, construction processes and more. They want to be able to compare *'apples to apples'* (PN 007) and understand the level of work that needs to be put in to achieve the most success. One of the most beneficial steps in their study tour was visiting the potential timber fabricators. By understanding their standards, products and tolerances, the design team would be able to use the information in their processes and achieve the highest level of detail to their ability, which then enabled improved capabilities and services. Le Roux, Bossanne and Stieglmeier (2016) also elaborated on the need for higher degree of planning and closer link between the designing and manufacturing team in timber construction due to the level of detail required for prefabrication. *'Having a standard kit of parts for architects, engineers and prefabricators to work from and manipulate what's there, then there would be more competitive bids from timber fabricator based on that kit of parts and that would close the knowledge gaps'* (PN 004).

5.2.3. Strategies to Implement to Achieve Further Benefits

BIM and timber are still very niche and recently emerging technologies in the construction industry. The interviewees of this study were all associated with either the procurement or designing of tall-timber buildings. Using their experiences, the respondents noted several strategies they felt had either helped them be successful in their project or feel would help them achieve more benefits of BIM processes for tall-timber construction.

Investing to Adopt

As stated in section 5.2.2 of this study, the interview data showed that companies working with tall-timber took the time and money to invest into adopting BIM and the processes necessary for tall-timber construction. Three main codes were established under this theme; *Education (university)/training, Experience /comfort level/ experts in the field* and *Research/study tours*. There needs to be a push from both internally and externally and educating both parties (offices and clients) because it seems that this is going to be the only way there will more willingness and encouragement to pursue tall-timber buildings. This was further elaborated by Wong, Wong and Nadeem (2010), who listed the public sector as a driver for the adoption and implementation of BIM. It can be seen that organisations are actually up-taking this process as seen through the interview respondents PN 004 and PN 008 who are doing speaking-tours and study tours to educate both the clientele and themselves respectively. By associating oneself with experts in the field and taking into consideration all of the lessons learned, more and more of the industry will begin feeling comfortable with these new technologies. Furthermore, respondents also expressed the need for education within school environments also need to be up-scaled.

Government

As stated earlier in this study in the literature review, the government in the Canadian construction industry does not mandate BIM usage. From the interviews, it seems that industry professionals feel that timber is not well represented in the building codes, which is a drawback. Additionally, there are no incentives for office to pursue timber-construction of the use of BIM. Instead, it is stated through the interviews that there are actually premiums that offices need to pay for timber construction. Although the Canadian government has been advocating for timber construction through the use of programs such as NRCan and the CWC, and implementing a height increase in the building code, there needs to be a greater push to mandate BIM. This way, all key players of construction will be able to move towards a BIM based workflow, which will benefit timber construction. Patlakas, Livingstone and Hairstans (2015) also discussed the need for a standard or a framework in order to make prefabrication possible. Having the entire team essentially forced to work in BIM will allow for the level of collaboration and level of detail to be achieved which is necessary for timber fabrication. Wong, Wong and Nadeem (2010) also noted governmental policy mandating BIM as on all public projects as a key driver for BIM adoption. Providing more resources such as building inspectors that have proper background knowledge to push the industry forward (PN006), and facilitating contractual arrangements enforcing BIM are all governmental strategies that that the industry professionals indicated would help them achieve more benefits of BIM for timber buildings. IPD contracts are the most beneficial for this type of arrangement, which further brings with it the benefits of lean construction. All in all, the government is the gatekeeper of the industry, dictating the degree of innovation on projects. Fully exploring these strategies indicated by the industry professionals themselves would help eliminate some of the barriers and challenges that is keeping the industry from increasing promoting a greater market value for tall-timber construction.

6. CONCLUSION

6.1. Introduction

This final chapter reflects on the overall study and presents the concluding thoughts of the researcher. A number of steps were carried out to investigate the benefits of BIM in the context of tall-timber construction are first also discussed in this chapter. Firstly, the chapter outlines the philosophy behind this research and outlines the key findings and contributions. This chapter also discusses some of the limitations associated with this study and recommends future studies to help better understand the implications of the results of this study.

6.2. Summary, Contributions and Key Findings of the Research

BIM and tall-timber construction have been two of the most recent new innovative practices in the construction industry. However, this study showed that a commonly shared set of processes and standardisation is lacking because of the complexity of the technical aspect and a slow push from regulatory boards. The review of literature revealed an abundance of pragmatic studies of BIM and timber buildings on conducted through case studies and global comparisons. There's been a limitation of research that takes on an interpretivist approach that aims to undercover the experiences, challenges and benefits that industry practitioners believed were associated with BIM in the context of tall-timber construction. In an industry that contains a web of social relationships, taking on a pragmatic, rationalistic approach has the ability to neglect the reality of what occurs at the roots of a project. As such, this research carried out a qualitative study by conducting eight in-depth interviews with architects, project managers and researchers specialised in BIM and tall-timber construction in Canada. This research approached benefits of BIM in an objective standpoint through past literature and an interpretative standpoint in debriefing the interviews. The findings of the study indicate that there are many benefits associated with BIM in the context of tall-timber construction. Many of the generic benefits of BIM that were depicted in literature such as information exchange, prefabrication, modelling and productivity and organisation, were also noted as benefits for timber construction within the interview data of this study. What was of more interest in the results of this study were the challenges that industry professionals felt could become benefits and the strategies they felt would help achieve additional benefits of BIM for tall-timber construction. These were rarely noted in other literature because there has been limited documentation of the lessons learned and the processes of tall-timber construction. Acknowledging these challenges and strategies within the industry could potentially bring more attention and encouragement for the up-take of tall-timber construction and BIM adaptation.

6.3. Research Limitations

Limitations of this research are present within the methodology and situations arising by the researcher. Firstly, relying on interviews as the prime and only data collection technique in qualitative research runs the risk of having more interpretations than other forms of data collection might have had. Participants in this method of data collection contribute more idealised accounts, which would in some way deter details that occur in actuality (Abadi 2014). Furthermore, in the interpretative stance taken in this study, the result of the research has the possibility to be influenced by the researchers own interpretation of the participant's responses. As such, another researcher may have different accounts and narratives to present the data. Additionally, both BIM and tall-timber construction are very niche and emerging technologies so there a lack of previous studies on the topic. For this reason, the researcher not only had limited access to data but also faced limited access to respondents. The researcher originally intended to interview manufacturers along with the other industry professions however none of the invited participants had responded. The data can still be considered reliable as multiple professions participants (architects, project managers and researchers) however the researcher suggests future studies to accommodate for this limitation.

6.4. Recommendations for Future Studies

Further research is needed to determine the relationship and processes to be established between manufacturers and the designing and engineering teams of tall-timber projects, as this was unable to be completed within this study. Additionally, quantitative data could also help to better understand the implications of these results. Future studies could focus on investigating the construction performance of timber buildings against other materials such as steel and concrete in terms of cost and life cycle analysis. Establishing a stronger discourse on how timber is a much more sustainable option could bring more attention and up-take of tall-timber projects. Lastly, further research into specific themes and sub-themes that have appeared in the coding of transcripts of this study may also help being meaning to the discourse.

WORD COUNT: 10,171

7. REFERENCES

Abadi, A. (2014) 'A Study of Innovation Perception within the Construction Industry'. *University of Manchester* [online] available from https://www.research.manchester.ac.uk/portal/files/54559942/FULL_TEXT.PDF [12 June 2019]

Acharya, A.S., Prakash, A., and Nigam, A. (2013) 'Sampling: Why and How of it?'. *Indian Journal of Medical Specialties* [online] 4(2), 330-333. Available from https://www.researchgate.net/profile/Anita_Acharya/publication/256446902_Sampling_Why_and_How_of_it_Anita_S_Acharya_Anupam_Prakash_Pikee_Saxena_Aruna_Nigam/links/0c960527c82d449788000000.pdf [18 June 2019]

Becerik-Gerber, B., Ku, K. and Jazizadeh, F. (2012) 'BIM-Enabled Virtual and Collaborative Construction Engineering and Management'. *Journal of Professional Issues in Engineering Education and Practice* [online] 183, 234-245. Available from https://www.researchgate.net/publication/233897987_BIM-Enabled_Virtual_and_Collaborative_Construction_Engineering_and_Management [27 February 2019]

Bernstein, H., Jones, S., Russo, M., Laquidara-Carr, D., Taylor, W., Ramos, J., Lorenz, A., and Terumasa, Y. (2013) *The Business Value of BIM for Construction in Major Global Markets*. New York.

Bhavsar, A. (2019) 'The Benefits of Adopting BIM for Timber Structure Construction in Mid-rise Buildings in Canada'. *Coventry University Module 7069 EXQ submission*

Bickis, I (2019) 'Tall timber towers taking root in Canada as builders look to go green'. *CBC News* [online] available from https://www.cbc.ca/news/canada/british-columbia/tall-timber-towers-taking-root-in-canada-as-builders-look-to-go-green-1.4986080 [15 June 2019]

Boton, C., and Forgues, D. (2017) 'Construction Industrialization and IT Integration: How Tall Wood Buildings Can Show the Right Path Towards Construction 4.0'. *2017 Modular and Offsite Construction Summit & the 2nd International Symposium on Industrialized Construction Technolog* [Online] 201-207. available from http://espace2.etsmtl.ca/id/eprint/18344/1/Boton%20C%202017%2018344.pdf [9 June 2019]

Council on Tall Buildings and Urban Habitat (2017) Tall Timber: A Global Audit [online] 2, 47-49. available from http://global.ctbuh.org/resources/papers/3350-TBIN.pdf[June 15, 2019]

Crotty, M. (1998) 'The Foundations of Social Research'. *Meaning and Perspective in the Research Process.* Australia. Sage.

Dr. Motawa, I., Price A. D. F., and Sher, W. (1999) 'Implementing Construction Innovations'. *15th Annual ARCOM Conference* [online] available from https://www.researchgate.net/publication/267823693_IMPLEMENTING_CONSTRUCTION_INNOVATIONS [10 June 2019]

Duncheva, T., BuHamdan, S., Hairstans, R., and Al-Hussein, M. (2018) 'BIM-Enabled health & safety analysis of cross laminated timber onsite assembly process'. *International Conference on Modeling and Applied Simulation* [online] available from https://www.napier.ac.uk/~/media/worktribe/output-1303256/bim-enabled-health--safety-analysis-of-cross-laminated-timber-onsite-assembly-process.pdf [12 June 2019]

Easterby-Smith, M., Thorpe, R., and Jackson, P. (2012) 'Management Research'. Sage Publications

Eastman, C., Eastman, C. M., Teicholz, P., and Sacks, R. (2011) 'BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors'. John Wiley & Sons.

Etikan, I., Musa, S.A., and Alkassim, R.S. (2015) 'Comparison of Convenience Sampling and Purposive Sampling'. *American Journal of Theoretical and Applied Statistics* [online] 5(1), 1-4. Available from https://www.researchgate.net/publication/304339244_Comparison_of_Convenience_Sampling_and_Purposive_Sampling [17 June 2019]

Fakhimi, A.H., Sardroud, J.M., and Azhar, S. (2016) 'How Can Lean, IPD and BIM Work Together?' . *33rd International Symposium on Automation and Robotics in Construction* [online] available from https://www.researchgate.net/publication/304894993_How_can_Lean_IPD_and_BIM_Work_Together [9 June 2019]

Forgues, D., and Staub-French. S. (2011) 'The Inevitabile Shift Towards Building Inofrmation Modelling (BIM) in Canada's Construction Secotr: A Three-Project Summary'. *CEFRIO* [online] available from https://media.thebimhub.com/user_uploads/construction_ict_final_summary_report_march_20_2014.pdf [9 July 2019]

Ghaffarianhoseini, A., Tookey, J., Ghaffarianhoseini, A., Naismith N., Azhar, S., Efimova, O., and Raahemifar K. (2017) 'Building information modeling (BIM) uptake: Clear benefits, understanding its implementation, risks and challenges'. *Renewable and Sustainable Energy Reviews* [online] 75, 1046-1053. Available from https://www.sciencedirect.com/science/article/pii/S1364032116308413 [14 June, 2019]

Gumbarević, S., Milovanović, B., Bagarić, M., and Gasl, M. (2019) 'Possibilities of Using BIM for Deep Energy Renovation Analysis'. *International Conference on Sustainable Materials, Systems and Structures* [online] 221-228. Available from https://www.researchgate.net/publication/331983271_Possibilities_of_using_BIM_for_Deep_Energy_Renovation_analyses [9 August 2019]

Hardin, B. (2009) 'BIM and Construction Management: Proven Tools, Methods and Workflows'. Indianapolis, Wiley Publishing, Inc.

Hardin, B. (2015) 'BIM and Construction Management: Proven Tools, Methods and Workflows'. Indianapolis, John Wiley & Sons, Inc

Hasan, Z.G. (2017) 'Inside Vancouver's Borck Commons, the World's Tallest Mass Timber Building'. *Archdaily* [online] available from https://www.archdaily.com/879625/inside-vancouvers-brock-commons-the-worlds-tallest-timber-structured-building [10 August 2019]

Ibrahim, A.M. (2012) 'Thematic analysis: a critical review of its process and evaluation'. *WEI International Euopean Academic Conference Proceedings* [online] available from https://www.westeastinstitute.com/wp-content/uploads/2012/10/ZG12-191-Mohammed-Ibrahim-Alhojailan-Full-Paper.pdf [14 June 2019]

Jung, Y., and Joo, M. (2011) 'Building Information Modelling (BIM) Framework for Practical Implementation'. *Automation in Construction* [online] 126-133. Available from https://www.sciencedirect.com/science/article/pii/S0926580510001391?via%3Dihub [30 June 2019]

Kasbar, M (2017) 'Investigating the Performance of the Construction Process of an 18-Storey Mass-Timber Hybrid Building'. *University of British Columbia* [online] available from https://open.library.ubc.ca/cIRcle/collections/ubctheses/24/items/1.0347252 [14 July 2019]

Khosrowshahi, F., and Arayici, Y. (2012) 'Roadmap for Implementation of BIM in the UK construction industry'. *Engineering, Construction and Architectural Management* [online] 19.6, 610-635. Available from https://pdfs.semanticscholar.org/bb59/a2cdceefad41fb4742595154a2ac0bf070d0.pdf [12 June 2019]

Kivits, R.A, and Furneaux, C.W. (2013) 'BIM: Enabling Sustainability and Asset Management Through Knowledge Management'. *The Scientific World Journal* [online] available from https://www.researchgate.net/publication/259268594_BIM_Enabling_Sustainability_and_Asset_Management_through_Knowledge_Management [29 July 2019]

Kothari, C.R. (2004) 'Research Methodology Methods and Techniques'. *New Age International Publishers* [online] 1-401. Available from http://www.modares.ac.ir/uploads/Agr.Oth.Lib.17.pdf [4 June 2019]

Le Roux, S., Bossanne, E., and Stieglmeier, M. (2016) 'Investigating the Interaction of Building Information Modelling Construction in the Timber Industry'. World Conference on Timber Engineering [online] available from https://www.researchgate.net/profile/Simon_Le_Roux/publication/307205224_Investigating_the_interaction_of_building_information_modelling_and_lean_construction_in_the_timber_industry/links/57c448f108ae32a03dad3e3c/Investigating-the-interaction-of-building-information-modelling-and-lean-construction-in-the-timber-industry.pdf [25 June 2019]

Merschbrock, C. (2014) 'Digital collaboration in the wood-based construction industry: deployment of Building Information Modeling'. *University of Agder* [online] available from https://brage.bibsys.no/xmlui/handle/11250/194080 [14 March 2019]

MGB Architecture and Design (2012) 'The Case for Tall Wood Buildings'. *The Canadian Wood Council* [online] available from http://cwc.ca/wp-content/uploads/publications-Tall-Wood.pdf [9 July 2019]

Ministry of Natural Resources and Forestry (2017) 'Ontario's Tall Wood Building Reference'. Available from https://www.omfpoa.com/wp-content/uploads/2017/11/Ontarios-Tall-Wood-Building-Reference-2017.pdf [7 June 2019]

Morse, J.M. (1991) 'Qualitative Nursing Research', Newbury Park, California, Sage Publications, Inc.

Mortice, Z. (2019) 'Tim-ber! Builders herald the coming wave of mass-timber construction'. *Redshift by Autodesk* [online] available from https://www.autodesk.com/redshift/mass-timber-construction/ [15 June 2019]

National Institute of Building Sciences (2007) 'National BIM Guide for Owners'. [online] available from https://c.ymcdn.com/sites/www.nibs.org/resource/resmgr/nbgo/Natl_BIM_Guide_for_Owners.pdf [8 August 2019]

Natural Resources Canada (2018) *Greening out built environment with wood* [online] available from https://www.nrcan.gc.ca/forests/industry/products-applications/16834 [14 March 2019]

Nowell, L.S., Norris, J.M., White, D.E., and Moules, N.J. (2017) 'Thematic Analysis: Striving to Meet the Trustworthiness Criteria'. *International Journal of Qualitative Methods* [online] available from https://journals.sagepub.com/doi/pdf/10.1177/1609406917733847 [15 June 2019]

Ontario Ministry of Municipal Affairs and Housing (2017) *Protecting Water for Future Generations* [online] available from http://www.mah.gov.on.ca/Page17658.aspx [14 March 2019]

Panas, A., and Pantouvakis, J.P. (2010) 'Evaluating Research Methodology in Construction Productivity Studies'. *The Built & Human Environment Review* [Online] 3(1), 63-85. Available from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.403.4785&rep=rep1&type=pdf [19 June 2019]

Patlakas, P., Livingstone, A., and Hairstans, R. (2015) 'A BIM Platform for Offsite Timber Construction'. *BIM Concepts* [online] 597-604. Available from http://papers.cumincad.org/data/works/att/ecaade2015_73.content.pdf [21 June 2019]

Renewable Resources Coalition (2016) What is *Urban Sprawl?* [online] available from https://www.renewableresourcescoalition.org/urban-sprawl/ [14 March 2019]

Skullestad, J.L., Bohne, R.A. and Lohne, J. (2016) 'High-rise Timber Buildings as a Climate Change Mitigation Measure – A Comparative LCA of Structural System Alternatives'. *Energy Procedia* [online] 96, 112-123. Available from https://www.sciencedirect.com/science/article/pii/S1876610216307512?via%3Dihub [26 February 2019]

Statistics Canada (2017) *Dwellings in Canada* [online] available from https://www12.statcan.gc.ca/census-recensement/2016/as-sa/98-200-x/2016005/98-200-x2016005-eng.cfm [14 March 2019]

Staub-French, S., Poirier, E.A., Calderon, F., Chikhi, I., Zadeh, P., Chudasma, D., and Huang, S. (2018) 'Building Information Modelling (BIM) and Design for Manufacturing and Assembly (DfMA) for Mass Timber Construction' *BIM TOPiCS Research Lab, University of British Columbia* [online] available from https://www.naturallywood.com/sites/default/files/documents/resources/bim_and_dfma_for_mass_timber_construction.pdf [12 July 2019]

Sustainable Forest Management in Canada (2018) *Overview- Canada's Forests* [online] available from https://www.sfmcanada.org/en/canada-s-forests [14 March 2019]

Tahrani, S., Poirier, E.A., Aksenova, G., and Forgues, D. (2015) 'Structuring the Adoption and Implementation of BIM and Integrated Approaches to Project Delivery Across the Canadian AECO Industry: Key Drivers from Abroad'. *5th International/11th Construction Speciality Conference* [online] available from https://pdfs.semanticscholar.org/f629/6f748f1279d3ece6e1ee0ef13f0ce80f7448.pdf [12 July 2019]

Tesfamariam, S., and Stiemer, S. (2014) 'Special Issue on Performance of Timber and Hybrid Structures', *Journal of Performance of Constructed Facilities* [online] available from https://www.researchgate.net/publication/275183143_Special_Issue_on_Performance_of_Timber_and_Hybrid_Structures [25 July 2019]

Wong, A. K. D., Wong, F.K.W., and Nadeem, A. (2010) 'Attributes of Building Information Modelling Implementations in Various Countries'. Architectural Engineering and Design Management [online] 288-302. Available from https://www.researchgate.net/publication/233498762_Attributes_of_Building_Information_Modelling_Implementations_in_Various_Countries [13 June 2019]