

The State of Prefabrication in Canada

A Market Study of Mass
Timber, Panels, and
Volumetric Modular
Construction

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Photo: KK Law, courtesy naturallywood.com

TABLE OF CONTENTS

| | |
|--|-----------|
| ACKNOWLEDGEMENT | i |
| FOREWARD | ii |
| EXECUTIVE SUMMARY | iii |
| MARKET BACKGROUND - PREFABRICATION IN CANADA | 1 |
| Introduction | 1 |
| Mass Timber..... | 1 |
| Panels..... | 9 |
| Modular Construction..... | 16 |
| WHY PREFABRICATION – WHY NOW? THE “CONTEMPORARY” ADVANTAGES OF PREFABRICATION ... | 34 |
| The Five Current Drivers for Prefabrication Adoption..... | 34 |
| OPPORTUNITIES TO GROW PREFABRICATION | 41 |
| Offsite Construction and Sustainability Targets | 41 |
| Growing Housing Supply..... | 44 |
| New Markets for Mass Timber | 48 |
| Adopting Technology to Solve Construction Productivity | 49 |
| CHALLENGES, CONSTRAINTS AND BARRIERS TO ADOPTION | 54 |
| THREATS FACING CANADA’S PREFABRICATION INDUSTRY | 63 |
| LESSONS FROM THE FIELD | 67 |
| How Best to Utilize Prefabrication..... | 67 |
| Culture and Contracts | 68 |
| Overcoming the Finance and Insurance Hurdles..... | 69 |
| Education and Retention | 70 |
| The Role of Government..... | 71 |
| RECOMMENDATIONS AND AREAS FOR FURTHER STUDY..... | 78 |
| APPENDIX A | 84 |
| Methodology..... | 84 |
| APPENDIX B | 85 |
| Bibliography | 85 |

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FOREWARD

Canada has a long history on the use of prefabricated construction. Some of the earliest known prefabricated structures were developed by B.C. Mills as early as 1905 and were shipped across Western Canada for use as banks and portable classrooms (Mills & Holdsworth, n.d.). While prefabrication has matured since then, there are new drivers that are heralding in a greater push toward industrialization and prefabrication in this country. Lack of affordable housing, an emphasis on sustainability and green buildings, and supply and demand pressures in construction are among the forces driving change in our built environment. Add in the recent government policies to boost economic recovery such as infrastructure spending and expanded immigration, and the pressure for delivering housing and construction will further escalate.

It is well known that the construction industry is a laggard when it comes to productivity. McKinsey's report on Reinventing Construction (McKinsey Global Institute, 2017) documents this well. Globally, the construction sector's labour productivity growth averaged a meagre 1% per year over the past 20 years compared to almost 3% growth for the total world economy and almost 4% growth in the manufacturing sector. Canada is not immune from these global statistics.

The construction labour pressures are real. Construction employment in this country is expected to rise by nearly 6% over the next decade, but this is in the face of an aging labour force and the need to replace almost 260,000 workers (almost 22% of the current labour force) as they retire over the next decade (BuildForce Canada, 2021). This will mean the industry will need to recruit, train, and retain just over 309,000 new workers just to meet demand all while the construction industry struggles with low productivity, lack of attractiveness for a career path for young individuals and new workers, and an unsatisfactory reputation.

As a result, we will not have the labour force to deliver what Canada needs by utilizing traditional construction methods and on-site labour. We must innovate and look to construction technology and modern methods of construction (MMC) if we are to have a chance of solving these crises. Other countries have recognized the need for change and have begun to grow their adoption of offsite construction. The UK, Japan, Sweden, Germany, and the Netherlands have all embraced prefabrication technology with Japan and Sweden having been at the forefront for the past 20 years.

So, it is with this context that we examine the status of the prefabrication market here in Canada. Through review of published research and interviews with thought leaders and those stakeholders involved with prefabrication, we will explore the current market dynamics, drivers and barriers to adoption that are present for mass timber, panelization, and modular construction. This report will provide recommendations and a challenge to government, stakeholders and industry to commit to prefabrication and stimulate discussion on more effective use of offsite construction.

EXECUTIVE SUMMARY

Wood Prefabrication in Canada

There are three primary forms of wood prefabrication here in Canada – Mass Timber, Panels, and Volumetric Modular construction. Of these methods of prefabrication, mass timber is currently receiving significant attention due to the sustainability benefits it offers and the technical and market development efforts to encourage its use. While there are many different types of mass timber, the focus for this study is on cross-laminated timber (CLT) and Glulam structural systems. From a production capacity and market penetration perspective, mass timber in Canada still has a long way to go to reach the maturity of its European counterparts. However, with public sector demand, government support, research, and industry project profiles, the market perception and acceptance for mass timber is growing.

The panel industry is represented by open panel and one side closed panel producers in Canada. Across the country, the market is very much in its infancy and is extremely fragmented with open panel providers varying from low tech operations to highly automated ones. The open panel industry is currently represented by structural wood and truss associations, while the closed panel sector is unrepresented. However, using the European panel industry as a yardstick, with Canada's 2020 National Building Code release, there will be an opportunity for government and industry to support the growing movement toward panel prefabrication to meet new high-performance building targets.

Volumetric modular construction has had a long and checkered past in Canada. The industry is divided into two main sectors – Residential and Commercial. The former is very well established coast-to-coast with a retail and manufacturer market building single family homes. The residential modular market is in transition having moved away from a negative stigma of 'mobile homes' to 'manufactured housing', and now has an opportunity to benefit from the movement toward sustainable housing and collaborate with builders in the multi-family residential market. The commercial modular market in Canada is very much in transition as well having moved away from workforce camps and industrial construction to hospitality, education, healthcare, and multi-family and affordable housing. However, over its long history the industry has been affected by boom-and-bust cycles and has lacked continuity of a pipeline of projects which has stunted investment. The new opportunity to solve Canada's affordable housing crisis exists if industry and government work together to implement programs that enable certainty of production backlog for manufacturers that will allow companies to invest and grow.

The following table provides an industry overview of the current state of the three forms of prefabrication.

Uptake of Prefabrication in Canada

| | Mass Timber | Closed Panels - One Side Closed | Residential / Commercial Modular |
|----------------------------------|-------------------|-----------------------------------|----------------------------------|
| Time on Market | 10-15 yrs + | <10 yrs | 60+ yrs |
| Technology | High-Tech | Low-Tech | Low-Tech |
| Design | High | Fragmented | Advancing |
| Business Practices | Advanced | Fragmented | Advancing |
| Manufacturers | Small but Growing | Few / Some High-Tech, Many Ad-hoc | Established |
| Recent Investment | Significant | Low | Low |
| Uptake | Advancing | Very Slow | Advancing |
| Mass Market Applicability | Moderate | High | Low |

Drivers of Prefabrication

This new age of prefabrication is seeing five drivers that are different from ones previously witnessed.

1. **Productivity Drivers** – An aging and retiring labour force is creating a lack of skilled trades that is creating pressure to hire, train, and retain construction workers. The industry is being forced to build more efficiently and look to innovative methods to build the infrastructure we need.
2. **Time Performance Drivers** – As existing traditional construction grapples with productivity challenges, it also struggles with meeting owners schedule expectations. Offsite construction has shown to accelerate project schedules up to 50% and provide schedule certainty when executed properly.
3. **Cost Performance Drivers** – On-site construction suffers from an acceptance of cost over-runs among owners. Offsite construction has been proven to deliver on cost certainty by integrating design and construction teams early in the design process to reduce construction execution risk.
4. **Quality Performance Drivers** - With the labour shortage and inadequate supervision on project sites, on-site construction quality of the finished building product has inevitably suffered. Moving prefabrication to a climate-controlled facility with greater attention on QA/QC procedures and ability to enact 'design freeze' prior to construction all equates to a better end product.
5. **Sustainability Drivers** - Standards within Canada and internationally have begun to reflect the growing priority of protection of the environment and reducing GHG emissions. Offsite construction is extremely efficient in managing the resources with very little waste generated during the fabrication process. Optimization using automated processing equipment produces far less waste, and what waste is produced is more likely to be salvaged or reused. Add in the embodied carbon benefits, and there are tremendous synergies that exist using prefabricated wood systems.

There are many opportunities to grow prefabrication in Canada. The new wave of leadership in sustainability has begun to emphasize more comprehensive methods to evaluate and reduce environmental impacts from buildings. By aligning our construction practices and employing whole building life cycle assessment, we can utilize prefabrication to address national sustainability targets. Of more important concern is the need for growing our housing stock to address lack of affordable housing options. Prefabrication offers the benefits of increasing the housing supply with less reliance on labour and being able to scale and deliver it in a shorter period of time. If leveraged correctly, prefabrication can also solve one of our most pressing issues - the lack of adequate housing within Indigenous communities. Prefabrication systems are ideal for this reason since they lend themselves to energy efficient, low maintenance housing solutions in remote locations.

Challenges to Prefabrication

However, a number of challenges are facing prefabrication here in Canada. There is a general lack of understanding from owners, architects, and the contracting community on how to use prefabrication since it requires a different process of engagement than conventional construction. There may be strong awareness among the construction community for mass timber, panelization and modular, but few know how to use it correctly. It's the lack of proven examples, documentation of process, and best practices that creates hurdles to adoption. Add in the lack of understanding with transportation and logistics required with offsite construction, and it is imperative that these items are brought forward early and well understood prior to projects being designed.

Among the other challenges currently facing prefabrication is an engrained construction process in which offsite construction must fit if it is to see any uptake and adoption. Unfortunately, particular contract types do not work well with prefabrication; namely Design-Bid-Build contracts. A more integrated approach to construction by ensuring all project parties are at the table early in the process leads to a better executed offsite project. Hence, Integrated Project Delivery (IPD), Design-Build, and Construction Management with early preconstruction engagement contracts work well with offsite construction.

It's also this entrenched construction method which creates issues for owners when it comes to financing and insuring offsite construction. The requirements for prefabrication's higher up front cash outlays required to purchase the offsite building components in advance of construction, and the inflexibility and lack of understanding of banking institutions on how to tie the offsite components to the land for collateral creates resistance to adoption. Also, there remain gaps in the insurance field that must be overcome – specifically for mass timber. Owners are still seeing increased insurance premiums on mass timber buildings which shows that more education around the fire ratings and the properties of mass timber is required.

Offsite construction is also confronted with the struggle of quantifying the potential benefits from undertaking an offsite project. The construction sector utilizes hard construction cost data to make decisions on whether a project proceeds. This culture is detrimental to offsite construction, as it is difficult to put hard cost figures to the benefits of offsite's shorter time schedules, higher quality standards, decreased risk from weather related delays, better worker safety, and perceived LCA advantages.

As prefabrication grows in Canada, the industry must be aware of the threats that could derail its progress. On the radar for all mass timber companies in Canada is the impending growth of the U.S. mass timber market and its potential to attract Canada's top talent. It's important the industry begin developing a healthy, innovative, and supportive ecosystem here in Canada that showcases our ingenuity and expertise by which it will encourage people to stay.

Recommendations

It was through the stakeholder and thought-leader interviews that were undertaken as part of this study that there were several resonating themes around prefabrication that are needed to be acted upon. The common threads include better documentation around the processes for undertaking prefabrication, better collaboration among parties, more cooperative contractual models that should be implemented when undertaking prefabrication, and early education among lenders and insurance providers prior to starting a project. The interviews also suggested more training in both professional and vocational skills to ward off the potential labour constraints that will likely be present in this growing industry. There was also a strong message that government at all levels needs to play a more active role in supporting the industry which will consequently solve many of the housing and construction labour challenges that are present in this country.

It's with these themes in mind that several recommendations are put forward to encourage greater adoption of prefabrication and to begin solving our construction productivity, sustainability, and affordable housing issues. The recommendations are as follows:

1. Reframe mass timber and panels as a single industry for market development
2. Develop 'Best Practices' guides for each form of prefabrication from early engagement to erection and turnover
3. Standardize and develop specific contract language for prefabrication
4. Change public sector procurement practices for prefabrication
5. Develop an ecosystem that attracts and retains top talent for mass timber
6. Encourage government and industry work together to develop policies that specifically support offsite construction
7. Develop ways to collect and standardize data across all forms of prefabrication
8. Identify standards for Building Information Modelling specific to prefabrication

In addition, there are a number of technical research recommendations specific to all forms of prefabrication that have been identified that will reduce the barriers to adoption and will eliminate the uncertainty among those decision makers interested in offsite construction.

MARKET BACKGROUND - PREFABRICATION IN CANADA

Introduction

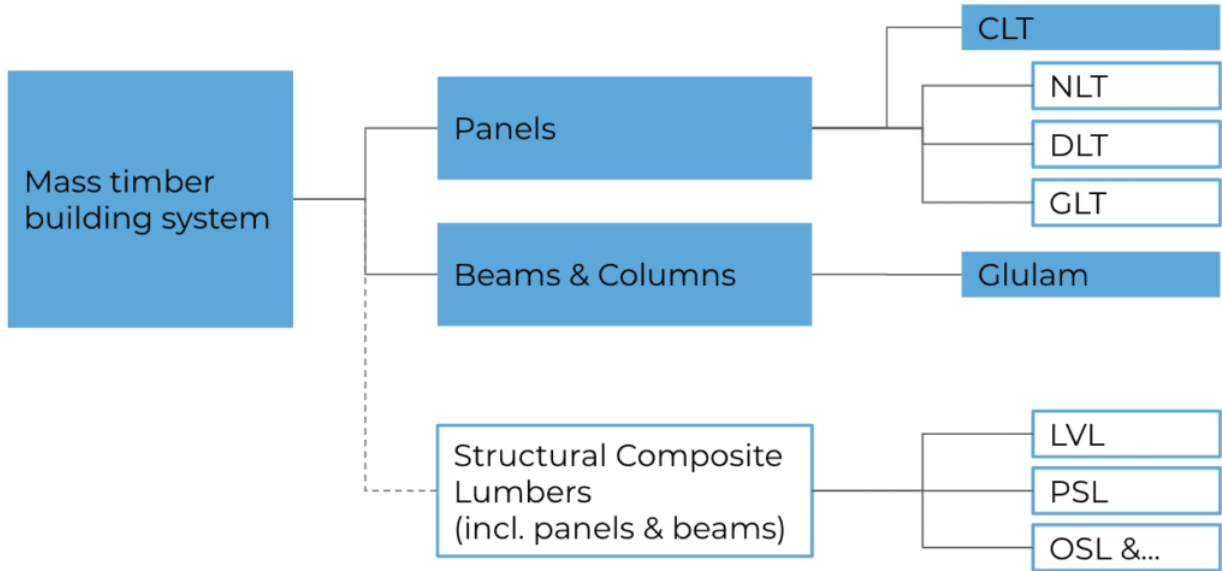
While offsite construction encompasses many different forms, this market study on prefabrication will emphasize wood products with a specific focus on the Canadian market for Mass Timber (which will focus on Cross Laminated Timber (CLT), Nail Laminated Timber (NLT), Dowel Laminated Timber (DLT), and Glue-laminated (Glulam) products), Panel products (both Open and Closed panel systems), and Volumetric Modular Construction (six-sided factory constructed modules). The term “offsite construction” will be used interchangeably throughout this report along with the term “Modern Methods of Construction” (MMC) and can be defined as “the design, planning, manufacture and pre-assembly of construction elements or components in a factory environment, prior to installation on site at their intended final location”.

Mass Timber

Overview

Mass Timber has seen considerable growth over the past decade due to its significant advantage of being a more sustainable choice in the construction of buildings versus the traditional forms of steel and concrete. There has been significant investment from forest industry advocates and stakeholders to develop and implement research and obtain the necessary approvals and certifications for it to become a stand-alone industry.

Products in the mass timber family are configured and laminated differently. One way to understand the different products is to divide them into panels and beams. Panels are large slabs used for walls, floors, and roofs; a typical panel is 1-3 meters wide and can be fabricated up to 18 meters long. Beams tend to be long and robust, used for horizontal or vertical weight bearing applications and can be anywhere from 3 to 20 meters long.



Source: Mantle Developments

In buildings, the classic mass timber configuration is CLT panels with a Glulam beam structural frame. It should be noted at this point, that North America also produces CLT panels for industrial matting purposes but is not the focus of this report.



Source: Structurlam

History

The first modern mass timber development occurred in the 1970's when a Swiss engineer reintroduced NLT into the European market and began to develop CLT prototypes which really became the basis for our current industry. Over the next few decades, additional work in software design and more technologically advanced construction methods contributed to producing larger and more sophisticated wood composites for structures. It was around 2010 that the first North American production lines for CLT were established (Natural Resources Canada, Canadian Forest Service, Green Construction through Wood, 2021).

With increased research and development of mass timber, 2017 marked a milestone in the industry with the construction of Origine – a 13-storey mass timber project in Quebec constructed by Chantiers Chibougamau / Nordic Structures. In the same year, the 18-storey mass timber hybrid project – Brock Commons, constructed by Urban One, became the tallest mass timber tower in the world.



Origine by Nordic Structures



Brock Commons by Urban One Builders

The past few years have seen tremendous interest and acceptance toward tall wood buildings in North America. In Canada, a number of provinces have adopted Tall Wood. The 2020 edition of the National Building Code of Canada (NBCC) will allow mass timber in buildings up to 12 storeys tall. The International Code Council (ICC) has just adopted Tall Wood Buildings into the 2021 International Building Code in the United States. The new codes will allow wood buildings up to 18 storeys

Mass Timber Market Capacity and Demand

Production Capacity

Canada is still far behind Europe in capacity, both in Glulam and CLT. As of 2020, Europe produces approximately 10 times the glulam than that of North America. These economies of scale allow European manufacturers to export into North America at a lower cost per unit than its North American counterparts. However, the impacts of shipping industry supply and associated cost escalation that has occurred during the pandemic has not showed signs of changing anytime soon. In the short to medium term, it is unclear as to whether this will put North American manufacturers at an advantage over their European counterparts.

With CLT, Europe has more than enough capacity to meet future demands within their region. However, production capacity may not be as clear here in North America with a full 75% of all CLT capacity is in the Pacific Northwest which is putting pressures on supply of lam stock. It is expected that by 2025 additions to the North American CLT supply chain could double capacity on the continent.

This increased capacity includes a Canadian company's first production facility in the US. Announced in late 2019, BC's Structurlam, is opening a new CLT/Glulam Arkansas facility to tie into the development of the new Walmart Mass Timber head office campus. This new facility should be up and running by end of 2022.

Also recently announced, is that Austrian Mass Timber company, Binderholz, will make an entry into the North American market with two CLT/Glulam plants in the US Southeast – Live Oak, Florida and Enfield, North Carolina. They purchased two sawmills in each of these. The fear for many North American producers is their ability to add capacity to the market without a lot of overhead since they will be utilizing their Austrian back-office functions to support the business.

Another CLT supplier from Europe, Stora Enso, also has received approval to ship into the US and Canada. In late 2020, it received approval from the ICC that it had complied with the ANSI/APA standard for performance rated CLT and has also confirmed compliance with the 2015 NBC of Canada.

Currently, there are 20 mass timber manufacturing facilities in Canada with BC having 8 facilities making up 40% of the total Canadian production. This is followed by Quebec with 5 facilities and 25% of overall production.

In Canada, Kalesnikoff Lumber and Nordic Structures are the only integrated mass timber companies with both having transitioned to mass timber out of their milling operations. The companies harvest, mill, and offer full engineering, design, and production of mass timber structures.

The main producers in Canada including locations and products produced are below:

| COMPANY | LOCATION | PRODUCTS |
|--------------------------------|--------------------------------|------------------|
| Element5 | St. Thomas, ON Ripon, QC | CLT, LVL NLT |
| Kalesnikoff Lumber Co. | Castlegar, BC | Glulam, CLT, GLT |
| Nordic Structures | Chibougameau, QC | Glulam, CLT, GLT |
| StructureCraft Builders | Abbotsford, BC | DLT |
| Structurlam | Penticton & Oliver, BC | Glulam, CLT, GLT |
| Western Archrib | Boissevain, MB Edmonton, AB | Glulam, GLT |
| Timmerman Timberworks | New Lowell, ON | NLT |

There is also one new Canadian entrant in the production of CLT and Glulam. ECO Development Group is establishing a new plant in Parry Sound, Ontario, that will initially import European product and utilize CNC machines to finish the material in Canada. Phase two of their development will see production of CLT and GLT domestically.

World and North American Demand

Proponents of mass timber see the continued growth trend continuing, as demand grows more widespread. There are several factors driving this growth - a heightened focus in the industry on construction's carbon impact, new technologies that allow builders to build quickly and efficiently with mass timber, and code and policy changes that allow for taller structures in mass timber. While the recent growth in mass timber has been rapid, it still holds a very small slice (<1%) of the overall construction materials market. For comparison, mass timber's \$575M North America 2020 market size is dwarfed by the \$277.7 billion construction materials market. Over the next 5 years, it's expected the global market will reach USD \$3.562 billion up from an estimated USD \$1.71 billion in 2020 with a compound annual growth rate (CAGR) of 12% (Market Research Future, 2021).

In North America, from 2018 to 2019, the demand for mass timber more than doubled, albeit from a small base. This growth was due to large broad sector demand rather than from a few large projects. It's expected that there will be a backlog of demand due to the pandemic as projects got delayed. In conversations with manufacturers and builders, lead times with manufacturers through 2021 are currently pushing 6-8 months out.

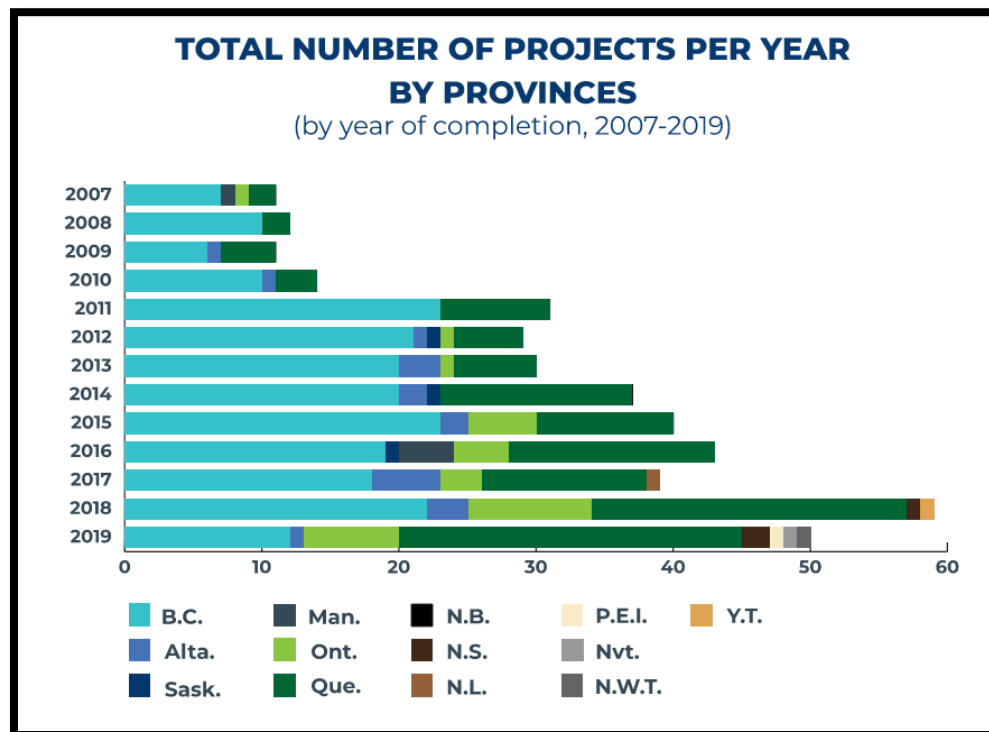
As the movement toward low carbon environmentally sustainable construction awareness increases, mass timber will continue to grow exponentially. With the upcoming 2020 NBC code change in Canada, and the recent US adoption of 18 storey Tall Wood in the U.S. IBC, the interest and uptake of mass timber and hybrid solutions will drive demand and offer an alternative to the traditional forms of concrete and steel construction.

Importing and Exporting Dynamics

It is currently difficult to estimate the volume of CLT being imported into Canada from Europe. CLT from Europe is currently produced cheaper than in Canada. Many developers here in Canada are preferring to support the Canadian supply chain, than go offshore. However, as lead times lengthen, many are hedging and considering fall back plans in obtaining materials from the big European producers. One of the other pressures currently at play that may prevent importation from Europe is the increased cost of shipping over the past 18 months. The shipping industry has seen up to 1,000% spot price increases in shipping since early 2020 as a result of a drop in consumer demand during covid, port congestion, shortage of containers, and severe lack of vessels (Global Maritime Hub, 2021). This may be to the benefit of Canadian producers in the short to medium term before the shipping industry returns to normalcy.

Mass Timber in Canada

While there are a few mass timber types, the focus of this study as it relates to construction will be concentrated on the CLT, Glulam, and NLT/DLT use. According to the *State of Mass Timber in Canada* database, there were less than 10 mass timber projects completed in 2007 and by 2011 this number had tripled. As of 2021, over 550 projects have either been completed, under construction, or planned in Canada (Natural Resources Canada, 2021).

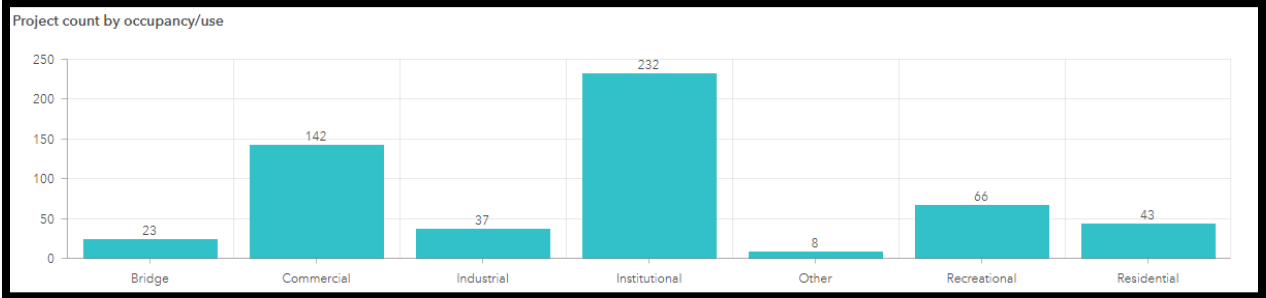


Source: *The State of Mass Timber in Canada 2021*, Natural Resources Canada

Since CLT requires a structural system for support, many of these projects have utilized Glulam as its structural member. To date, over 352 projects have used Glulam and 101 projects have used CLT, and over 200 projects have utilized more than one type of mass timber in its construction (Natural Resources Canada, Canadian Forest Service, Green Construction through Wood, 2021)

Of these 550 projects, almost half are institutional and public projects (232) with next largest being commercial (141) and recreational projects (66). The Residential sector shows great promise, but as of 2021 only 23 projects have been completed in Canada with the majority being in southern BC.

Canadian Mass Timber Project Count by Occupancy/Use

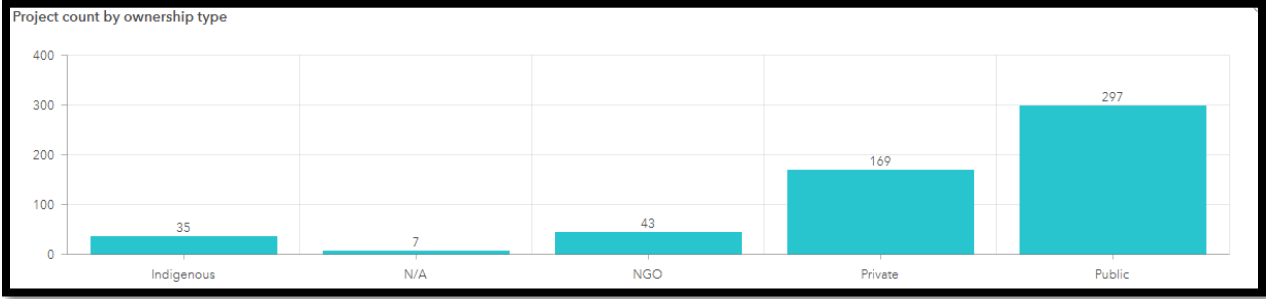


Source: The State of Mass Timber in Canada, Natural Resources Canada

Over 85% of mass timber projects are currently less than 4 storeys (487), but this is sure to change with the adoption of Tall Wood into the building code. This will also contribute to growth in hybrid mass timber construction systems (such as incorporating steel and wood), as it capitalizes on strengths of each system to achieve the best design and performance.

The greatest number of projects are public sector projects, with private projects following close behind along with Non-Government Organizations and Indigenous led projects. Approximately half of these projects are less than 2,000 m², with the largest share of these completed projects having come from BC and Quebec, with growth being seen in Ontario and Alberta.

Canadian Mass Timber Project Count by Unit Type



Source: The State of Mass Timber in Canada, Natural Resources Canada

Demand for mass timber has mostly come in the form of low and mid-rise buildings (85% being 1-2 storeys, and 10% being in the 3-6 storey range) and has largely been delivered for offices and community buildings. The non-residential sector is expected to see continued growth in mass timber construction as a result of government initiatives such as BC's "Wood First" program for provincially funded buildings, as well as the Mass Timber Demonstration Program. Of the 98 projects scheduled for completion between 2019 and 2021, 33 were institutional, and 24 were commercial with half of them being public buildings.

The growth in mass timber demand from customers has been largely driven by sustainability initiatives and public policy around carbon reduction. In addition, many of the interviewees stated that demand for exposed wood and the biophilia properties of wood has been one of the drivers of demand, especially for public buildings, and thus has resulted in less price sensitivity in comparison to other building materials. This type of demand has been the basis of a US developer, Hines Development, employing mass timber in several their developments to meet their own environmental, and social governance targets. But it has also meant good business as clients are starting to pay more in certain markets for the biophilia nature of wood.

Mass Timber Builders

Crucial to the growth of the industry in Canada is the ecosystem of expertise that has developed. The supply chain of engineering, design and erection companies is well developed in BC and Quebec where most projects in Canada have been constructed. While most manufacturers have in-house designers and engineers, there are several companies offering value added services to the owner and project teams.



Source: Kinsol Timber

Canadian Companies such as Seagate Structures, Kinsol Timber Systems, StructureCraft Builders, and Timmerman Timberworks work with project teams to provide engineering and design services along with mass timber erection. They often source and supply the mass timber components from manufacturers both in Canada and internationally. It's these companies who take on the execution risk

of putting the projects together on site. With so few experienced mass timber engineering and installation companies in North America, these companies have addressed the increasing demand in the US by offering installation services for projects in the US and more recently many have opened US offices. These companies have also led the way in successful execution of projects to date and have paved the path for new companies entering the market. With the projected growth of mass timber projects, large and small construction companies in Canada are adding mass timber erection expertise to their offerings as they see the benefit of prefabrication and smaller erection teams required versus conventional construction.

Panels

Overview

Light frame wood is the North American residential building system of choice. There have been years of technical research and performance testing that make wood the proven choice among residential builders. There are very few barriers to entry for this type of construction as a result of a deep understanding among designers, contractors and suppliers of residential wood construction where this is unmatched anywhere else in the world (Canadian Wood Council, 2002).

Over the years there have been advances in wood construction which include I-joists, laminated veneer lumber (LVL) and other engineered wood products which has increased the dimensional stability of the resource and the speed of construction.

Further innovations over the past decade have seen two-dimensional prefabricated panels become common place among residential builders for the speed and reduction of waste.

Utilizing the classification types identified by two FPInnovations studies (Helen Goodland A. L., 2019) (Wimmers D. G., 2020), prefabricated panels can be segmented into three types –

1. Open panels (known as Level 1) – standard Light Wood Frame (LWF) construction with or without sheathing
2. Closed panels
 - i) One Side Closed (known as Level 2A) - standard light wood frame (LWF) construction, with sheathing, exterior cladding, insulation, windows
 - ii) Both Sides Closed (known as Level 2B) - standard light wood frame (LWF) construction, with sheathing, exterior cladding, insulation, windows, electrical or conduit, plumbing, heating components and interior boarding
3. Structural Insulated Panels – SIP – two layers of sheathing (typically OSB) glued between an insulating foam core

The focus on this study will be on open and closed wall panels systems (Level 1, 2A, 2B).

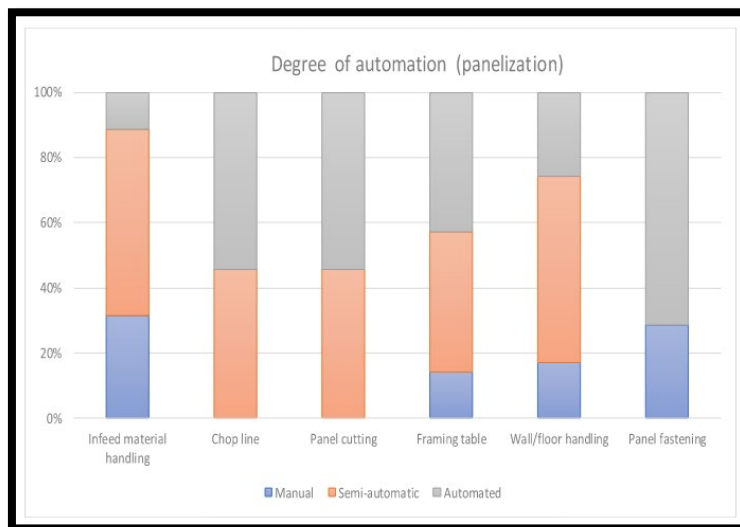
Open Panels

The open prefabricated panels market in Canada is extremely fragmented. The degree of prefabrication of open panel construction in Canada ranges from fully automated providers to onsite framing crews utilizing construction tables close to a project site to frame up wall and floor panels before being hoisted into place by a crane. Open panels are also being produced truss manufacturers who have expanded their product lines to include wall and floor framing packages. The industry tends to be local in nature and is serviced by operations located close to project sites.

In general, the open panel sector tends to be comprised of low-tech operations, categorized by single trade functions utilizing traditional carpenters constructing panels on framing tables within warehouses, and flat-packing orders and sending to construction sites where the panels are erected quickly by a site framing crew. Despite the low-tech nature, this method of prefabrication leads to better quality framing than what is seen onsite and leads to a generally accepted approximate 30% time savings versus site framing.

With the growth in wood multi-family projects across Canada, there are several semi-automated panelized companies who have streamlined the open panel industry by employing more digitization and various stages of automation into the construction by using 3D modeling, automated nailing machines and conveyors and framing tables (Panels.ca, Panelized Building Solutions, Phoenix Building Components to name a few). These companies are supplying the low rise and mid-rise wood frame multi-family markets, typically 2-6 storeys. From prior research about 74% of panelized systems are utilized in the multi-family sector with 23% used in the single-family sector (Li, 2020).

One of the high production open panel builders is Mitsui Home Canada Inc, in Delta, BC. Taking pages from their Japanese operations, they began it's "Total Quality Management System" and began a semi-automated open panel floor, wall, and stair panel business in 2005 and have now supplied over 9,000 residential units in Canada and the US with a focus on low and mid-rise wood multi-family. They take a more coordinated approach to open panels by considering seismic, MEP and other services into the design, and in many cases are adding windows into their wall systems. Across Canada, there tends to be a mix of automated, semi-automated and manual processes within these facilities.



Source: FPInnovations – Overview of FPInnovations Industrialized Construction Program in 2019-2020

Contributing to the fragmentation, is the fact there is no clear voice representing this industry and further to other studies, many companies tend to associate themselves with a different industry sector (Koo, March 2020). The Canadian Wood Truss Association is the only group representing panelized builders in this country, along with its provincial truss association counterparts.

The fragmentation and regional nature of this sector has spawned opportunities for some consolidation among producers and family-owned truss companies. One such buying group is Atlas Engineered Products (AEP, TSX-V) who has recently acquired six truss companies across Canada over the past 3 years to seek standardization opportunities and economies of scale. These economies of scale are occurring in the Ontario market, with fourteen (14) Ontario Structural Wood Association members producing panels, seven (7) have multiple operations.

In the near term, the open panel industry will continue to be serviced by either on-site framing crews or will be serviced by both truss companies and dedicated open panel fabricators. As building codes change toward more higher performing wall systems, some of these low-tech companies may not be able to keep up to the pace of change and the demand for more complex and higher value systems.

Closed Panel

One only has to look to Europe where early moves toward high performance building codes and the culture toward quality has resulted in a high adoption of closed panel prefabrication.

In the UK, the shift in acceptance to MMC has resulted in wood open panels being replaced by closed panel systems (Amigo, 2017). In Germany, one in seven single family homes is constructed using closed panel systems and market penetration of prefab is about 30% (Castenson, 2020). As Dr. Mohamed Al-Hussein puts it, the culture there “sees buildings more as multi-generational and are built to last”, whereas here in Canada, “we move and redevelop”. There are some good examples of high-quality, high-performance panelized housing systems such as German company Baufritz. Not only do they prefabricate closed passive house panels, but they also utilize wood shavings for thermal insulation. In Sweden, over 80% of the country’s single family housing market is built offsite using panels. It has a long history of prefabrication with some family-owned panel companies having been around for over 80 years with the first closed panel wall line having been developed in 1985 (Built Offsite, 2020). The Swedish prefabrication sector has evolved such that the industry is now very organized with prefabrication existing in many forms including precast concrete, SIP’s and various wood framed systems. As of 2017, there were 38 integrated manufacturer/builders using closed panel systems, another 12 manufacturers focused on supplying both residential and non-residential construction (schools and seniors housing) builders, and 17 builders utilizing panels for residential and non-residential construction (Steinhardt & al, 2019). The integrated firms also offer turnkey offerings for clients. This widespread full service offering in Sweden is lacking here in Canada among open and closed panel companies.



Source: Lindbacks, Sweden

Here in Canada, adoption of closed panel systems (level 2A) is still in their infancy. There are currently only two large scale companies employing full automation in construction of level 2A closed panels – H+ME and ACQBuilt.

The latter are arguably the most advanced single and multi family home panel builder in Canada. With their state of the art 150,000 sq.ft facility in Edmonton constructed in 2004, they design, manufacture, transport and install. They model their homes in 3D and utilize framing software that coordinates with the automated framing machines. They are one of very few in prefabrication here in Canada that are able to build a predictable prefabrication model that gives certainty to the process, and ultimately gives certainty to the customer. ACQBuilt only utilizes engineered wood due to the dimensional stability and quality of the material demanded by automation. Despite engineered wood being more expensive, according to those close to their development company, Landmark is able to offer its homes at the same price in the market as others, even with it being a more superior product. Logistics play a large part in the construction process with foundations being installed in advance of panel delivery and installation. ACQBuilt also has an in-house logistics crew to ensure the panels are loaded in the order of craning onto transport trucks with specialized vertical racking, all of which speeds up the installation for the site crews at the project site. According to a source close to ACQBuilt, Landmark Homes had 94 superintendents on staff prior to developing ACQBuilt. They now have 9 with the same volume of work. Often overlooked in moving to prefabrication is ease of accounting. Landmark previously had 20 people on staff processing 160,000 invoices per year, they are now able to write one purchase order to ACQBuilt and cut costs exponentially.



Source: ACQBuilt

The lack of uptake and investment in this sector can be attributed to the current building code's lack of complexity in framing systems and ease of which wood framing can be constructed on site. However, changes are on the horizon, and we only need to look to the European model to see what could occur here in Canada. More stringent European Building Energy Codes have been in existence longer than Canada and as a result these markets are more mature and have advanced the role of prefabrication to meet the more stringent requirements (Young, 2014). With the upcoming release of the 2020 NBC and the move toward Net Zero Energy Ready by 2030, the transition in codes will require builders to increase the RSI value of walls and pay attention to airtightness.

This evolution toward advanced panel construction due to code changes has recently been studied. In a paper presented by Guido Wimmers and Alison Conroy, the adoption of performance building codes will shift the wood construction industry from mainly on-site to offsite methods over the next decade (Wimmers & Conroy, 2019). The rationale is that wall systems will become more complicated to construct in the field in paying attention to air tightness detailing and requirements. In addition, with added complexity of framing comes weight. Exterior insulation and furring strips increase the handling ability of crews on site. With a BC Energy Step Code - Step 5 or Passive House equivalent roof assembly now becoming 42-77% heavier and up to 100% thicker than standard code requirements, there are considerable opportunities to move toward prefabrication of closed panel systems.

Also, the complexity of on-site framing will become more difficult and costly as airtightness performance metrics will have to be verified with onsite testing. This can lead to costly rework from contractors if they are unable to meet the performance metrics by site framing. Add in the continued skilled labour shortage and the lack of proper training and supervision on construction sites, and it will push contractors to look for other more efficient framing methods. In a conversation with Wayne Hand at BCIT, the school is recognizing that high performance standards are pushing the industry toward offsite construction. It is also forcing trades to become more integrated with BIM and forcing more integration with MEP contractors at the design stage.

There are a few panel builders in Canada that have begun to meet the requirement for high-performance assemblies. One of the leaders and oldest companies in this sector is BC Passive House. Located in Pemberton, BC Passive House offer high-performance panels for sale directly to builders but are also one of few passive house builders to offer a turnkey panelized approach to building. Working with their construction arm, Durfeld Constructors, they offer an integrated approach to construction.



Source: BC Passive House

At this stage in the high-performance panel evolution, the companies serving this sector tend to be small and are low-tech operations utilizing framing tables and overhead cranes within warehouses. There are now a few beginning to employ automation, as the demand for high-performance panels begins to increase. Some of the well-known high-performance panel companies in Canada are listed below.

| NAME | LOCATION | MARKET |
|--------------------------|----------|---|
| Adaptive Homes | BC | Single Family |
| BC Passive House | BC | Single Family / Multi Family / Commercial / Institutional |
| Collective Carpentry | BC | Single Family / Multi-family / Commercial / Institutional |
| Tag Panels | BC | Single Family / Multi-family |
| Factor Building Panels | BC | Single Family |
| Paradigm Panels | BC | Single Family / Multi-family |
| Tree Construction | AB | Single Family |
| Quantum Passivhaus | ON | Single Family / Multi-family / Commercial / Institutional |
| Simple Life Homes | ON | Single Family |
| Green Giant Design Build | ON | Single Family |
| Maison Elements | QUE | Single Family |
| ConceptMAT | QUE | Single Family |

One of the concerns voiced by research papers and interviews on the future of closed panel systems in Canada is the need for dimensional stability of the resource. It is an extremely important factor in the scaling of production and if we are to increase automation in our panel systems. Better quality product from the forest industry will greatly assist the growth toward automation. In an interview with Stefan Maunz of Paradigm Panels, a start-up utilizing automation in open panels and high-performance closed panel systems, dimensional stability is the key for growth of automation. There have been many hurdles in programming of software to solve the issue of dimensional lumber quality meeting the tolerances demanded by the machines. Stefan noted the use of finger-joint lumber in Europe to achieve the dimensional stability but has not seen cultural acceptance here in Canada. Paradigm is taking lessons learned from the German residential market and bringing the philosophy that high-performance buildings should only be constructed offsite. While still in its infancy, Paradigm is looking to get established ahead of the national code changes and is hoping to become a market leader in supplying high-performance panels to builders.

The evolution of high-performance closed panel systems here in Canada is sure to coincide with the growth in mass timber. There are long-standing companies in Europe who have perfected the use of timber facades. Austrian company, Rubner, is a leader in this field with specialties in both single family homes and large-scale projects and is fully integrated offering manufacturing and fabricating of heavy timber panels and timber and glass façade systems. CREE Building System of Germany, has taken it a step further and developed an integrated all-in-one heavy timber system for buildings, utilizing a hybrid system to integrate the entire structural and façade assemblies, much like a curtain wall.

Here in Canada, one such company is emulating the European model for heavy timber high-performance panels. Timber Engineering in Vancouver has been perfecting the construction of a hybrid mass timber system and has recently constructed what is likely the first North American prefabricated mass timber Passive House building complete with exterior envelope.



Source: Naikoon Contracting – oN5 Building

Their project called 'oN5' will be a tremendous case study for how to construct infill mass timber office buildings with an integrated finished envelope system. As the uptake in tall wood buildings grows and panel fabrication begins to take hold, one area that will require development is the need for a high-performance closed wall hanging panel with cladding for buildings over 6 stories. There are currently no standardized systems that have been developed thus far.

Modular Construction

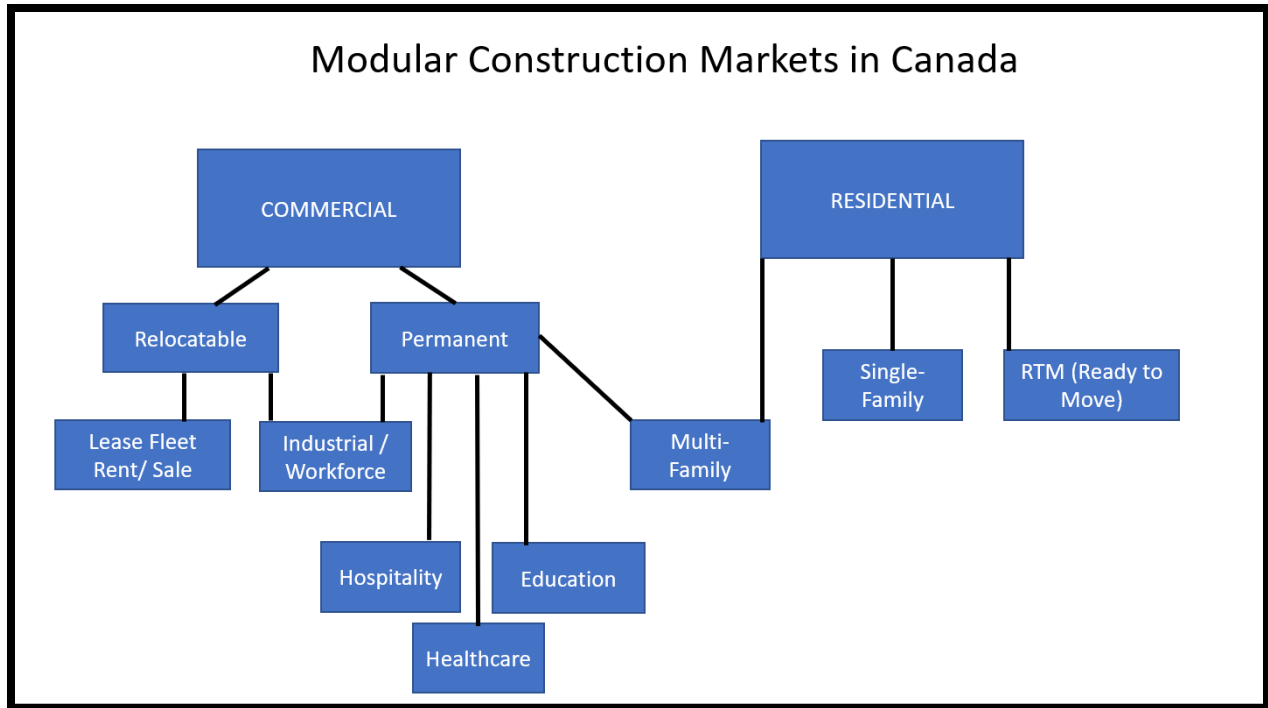
Overview

Volumetric modular construction, or commonly known as “Modular”, has been well established in Canada for over 70 years. Modular systems are the most involved form of prefabrication with multi-trade disciplines assembling walls and components into a finished 3-dimensional box. Here in Canada, the modular construction market can be divided into two distinct sectors – Residential and Commercial.

Residential modular construction in Canada began with mobile home parks in the early 1960's with the sector having been created out of demand for economical housing in more rural areas. The residential market has evolved considerably in the past decade, with many modular manufacturers operating in a B2B transaction with developers supplying finished modules for their single family and multi-family development projects.

The commercial modular sector can be classified as a pure B2B distribution. Historically, this sector in Canada has been well known for its industrial remote workforce housing, site trailers and classroom portable markets, and has often been thought of as providing 'temporary' structures. The temporary or relocatable market continues to be strong in Canada but has been overshadowed in the past decade with the growth of permanent modular construction. Canada has seen numerous examples of mostly low-rise modular multi-storey applications in hospitality, affordable housing, and student accommodations across Canada.

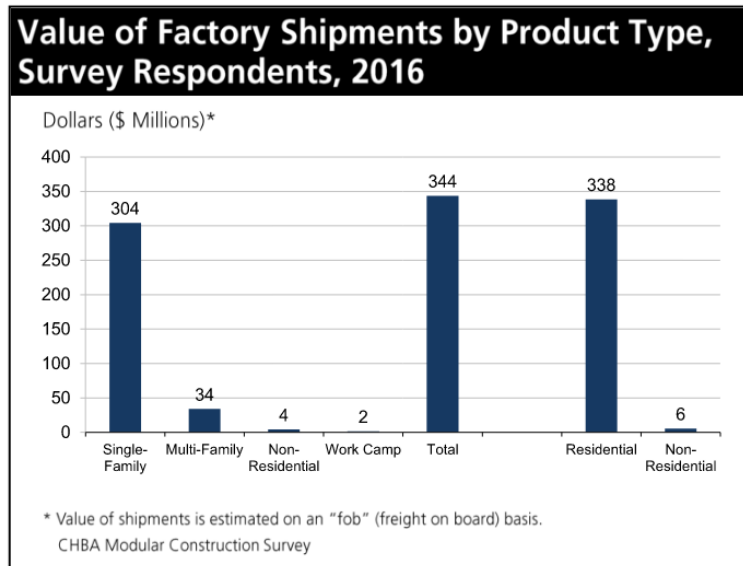
Modular Construction Markets in Canada



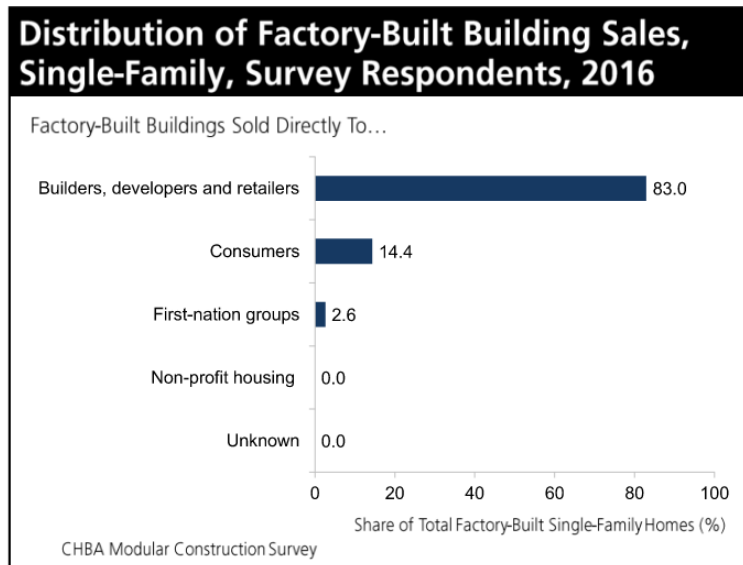
Residential Modular

Modular housing in Canada has evolved from the early 1960's and it's single wide 'trailers' seen at mobile home parks throughout Canada. The term 'mobile home' was replaced in the 1990's with the term 'Manufactured Housing' and as such the industry developed to provide more than just single wide structures. The historical distribution model for this sector is well established and remains the main channel of product to market even today. The distribution is one of manufacturers selling their models to representative retailers, who in turn manage the sales transaction and installation with the eventual homeowner. As a result, the demand for this type of residential single family modular housing in Canada is driven largely by consumer demand at the retailer level. The more recent evolution of modular housing in Canada has seen developers and builders designing and procuring modules from factories to supply their single family and multi family projects. It's at this point the developer or contractor manages the logistics process of transportation and installation of the modules on their site installed foundation before selling the homes to the new homeowner.

A smaller segment of the market has dedicated factories selling custom modular homes direct to the homebuyer. This can be seen by the two graphs below which details the sales channel and the distribution between single family and multi family.



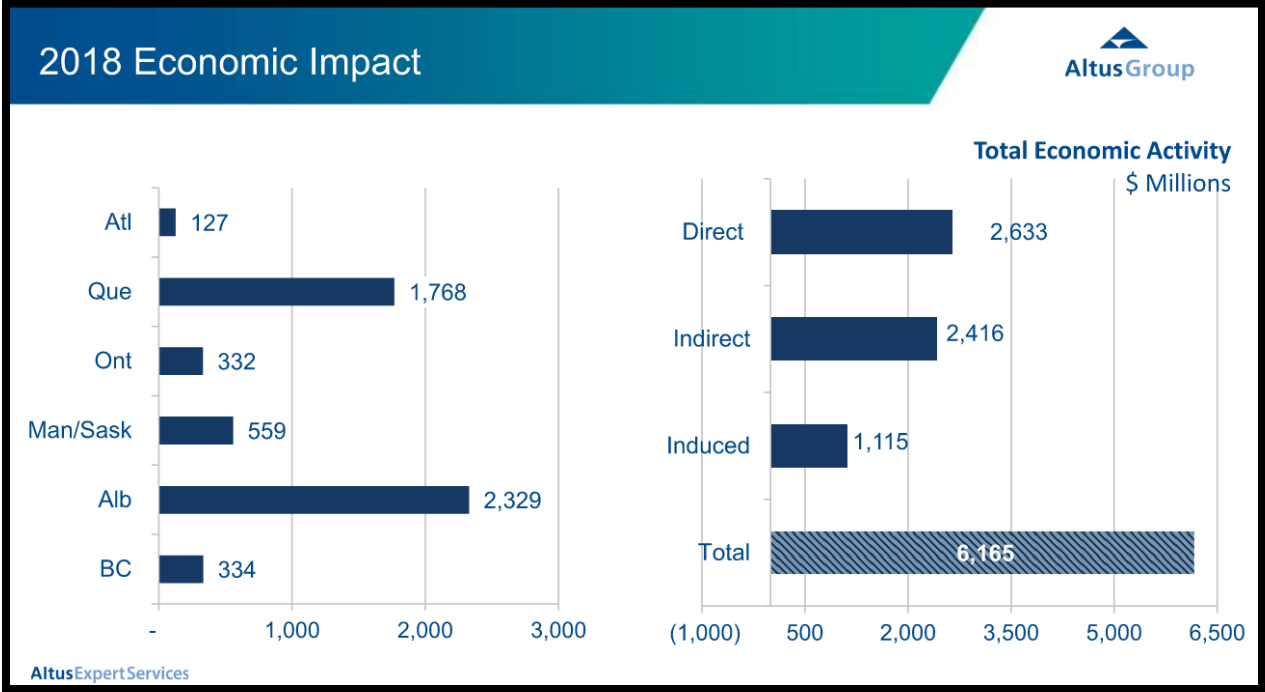
Source: CHBA Modular Construction Survey



Source: CHBA – Modular Construction Council 2016 Annual Report

As of 2018, Manufactured Housing residential starts accounted for approximately 15% of the single-family home market in Canada (Lohman, 2021), and generated approximately 30,000 full time jobs with \$6B in total economic activity (direct and indirect activity). There is also distinct distribution within the sector. The largest regions for demand are Quebec and the Prairies.

An Altus report commissioned by CHBA found that 32% of the economic activity in modular housing came from Quebec and over 53% came from the Prairie provinces, which highlights that most of the housing in this sector is in rural areas (Norman, 2018). This can also be seen in the data for the BC market with 50% of the manufactured housing produced in 2018 was delivered to the Okanagan and Thompson regions of the province.



Source: Altus CHBA Factory-Built Construction Industry Economic Impact 2018

Manufacturers and Retailers

The industry is heavily reliant on the established Manufacturer-Retailer relationship. Retailers align themselves to a particular manufacturer for which that manufacturer produces and supplies them with a number of predesigned models.

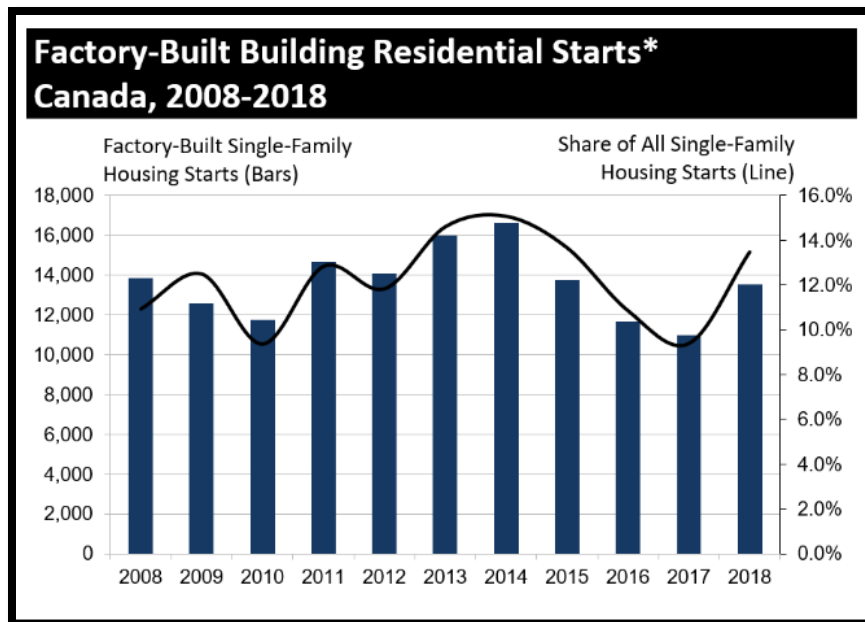
In North America, the largest and oldest modular housing builder is Champion Homes, headquartered out of Michigan and with 28 manufacturing facilities in North America. In Canada, they operate 5 factories in Western Canada and sell directly to an independent retailer network across BC, the Prairies, and Northern Canada. In Eastern Canada, most modular housing manufacturers are in New Brunswick with five large factories servicing the majority of the Maritimes and the Quebec market and producing up to 2,000 homes per year.

Under the Manufacturer-Retailer model, each manufacturer develops standardized modules and finishing packages that they make available to their retail partners. The retailers will often forecast and book production space in advance based on estimated demand for the following year. Factory order lead times tend to be quite short (less than 60 days), as it's retailers' goal to try and secure the orders quickly and in turn get the building produced quickly for the homeowner. It is an extremely price

sensitive market, with factories having well developed supply chains based on standardized specifications. Factories are profitable when they are able to drive supply chain costs lower while increasing productivity output.

Manufacturers and Builders

The residential modular market in Canada has been cyclical. Its number of shipments from factories in Canada has varied between 10% and roughly 15% of overall single-family residential starts in Canada but hasn't shown signs that it will grow beyond that threshold. It's the cyclical nature that has contributed to lack of investment in technology in automation, as most operations tend to be low-tech enterprises. The real opportunity for the future growth of modular residential construction in Canada is to develop the B2B Manufacturer–Builder relationship.



Source – CHBA 2018

As the multi-family market grows in Canada, the opportunities for collaboration between manufacturers and builders also increases. One of the early examples of a successful model was between Guerdon (a Boise, ID based modular manufacturer) and Devereaux Developments (a Saskatchewan based developer) who worked together to build almost 1,500 multi-family units over the period from 2010 to 2015. This model opened the doors for other partnerships, namely Big Block Construction (a Saskatchewan based 'modular focused construction service') and Grandeur Housing (a Winkler, MB modular manufacturer). After four years of intense collaboration, this relationship has successfully led to over 20 multi unit residential developments totalling over 1500 homes built within Saskatchewan and has led to one of Canada's first modular Net Zero ready developments.

Factory Certification

Regulations on the construction of the mobile and modular homes began in the late 1970's with a CSA Z240 Manufactured Housing (MH) standard (homes on their own running gear also known as RTM's or Ready-To-Move structures), and CSA developed a new certification standard for in-factory inspections to ensure that the homes conformed with the National Building Code. This was referred to as CSA A-277 Certification and has been in place with licensed manufacturers of prefabricated structures to this day. As of 2019, there were 147 factories in Canada certified under CSA A277 to build residential structures, with another 36 factories in the US and other areas of the world certified to build under A277 (Lohman, 2021). In BC, all recorded shipments from the factories are registered with the provincial database for Manufactured Homes Registry for Z240MH and A277 homes and can be registered with the Personal Property Registry in other provinces.

It is important to note that homes manufactured under either of the two standards listed above absolves Authorities Having Jurisdiction (AHJ) from not requiring to inspect elements constructed in the factory under those standards. It is only onsite where the connection of the modular components to the permanent foundations and any site-built elements where building officials have jurisdiction.

There is a movement within Canada to have CSA A277 updated. In some provinces it may be referenced in Part 9, but not in Part 3. In addition, there are various editions that are referenced in Canada with the 2008 version being referenced in the 2015 NBC for example. These variations result in an uneven regulatory landscape (CSA, 2020).

Associations

The industry is currently represented by one national association, the Canadian Home Builders Association (CHBA) – Modular Construction Council and three regional associations – BC Manufactured Housing Association (MHABC), Manufactured Housing Prairie Provinces (PP), Manufactured Housing Association of Atlantic Canada (MHAAC). CHBA – Modular Construction Council was established in 2017 after members of the Canadian Manufactured Housing Institute (CMHI) and Manufactured Housing Institute Canada joined forces to create the council and have one voice across Canada to support the modular construction in the building industry. The recent alliance with CHBA has given manufactured housing more credibility and a single voice which has been instrumental in removing the decades old stigma of cheap and inferior mobile homes.

As Kathleen Maynard, Executive Director of CHBA Modular Council puts it, “the fact that there is now a direct tie to CHBA and their Net Zero Council, bodes well for the future of the industry”. This tie to CHBA has resulted in members creating relationships with builders who see the value in modular construction and are beginning to create a channel for products in the future.

The CHBA Modular Construction Council and its regional counterparts are critical for advocacy on behalf of its members. Some of the key issues the association has addressed includes working with provincial ministries responsible for transport and advocating for wider buildings. This lobbying has resulted in greater efficiencies in manufacturing plants by being able to build larger floorplates.



Source: Big Block Construction

Commercial Modular

This segment of the industry is represented by all other uses of volumetric modular construction outside of single-family residential construction and includes both relocatable buildings (RB's) and permanent modular construction (PMC). The commercial industry can be further divided into industrial, hospitality, education, healthcare and multi-family applications.

Relocatable Buildings

The relocatable segment is defined as “Buildings that are constructed of one or more modules that are designed and constructed to be readily transported, installed, connected together, disconnected and uninstalled without damage numerous times over the service life of the modules. Modules may be transported on their own running gear or on separate transport equipment (Modular Building Institute, 2019).”

This segment of the industry maintains fleets of RB's who lease and sell temporary relocatable structures such as job site office trailers, classroom portables, and remote workforce accommodations. It is estimated that there are 100,000 of these such structures in use in Canada today.



Source: Britco

Permanent Modular Construction

Globally, the Permanent Modular Construction segment is the fastest growing segment of the volumetric modular construction business. It is only in the past decade that North American owners have seen the potential applications and begun to grow this segment of the market.

Industrial

Industrial modular buildings have been iconic in the Canadian Marketplace. Worldwide industrial building leader ATCO Structures has been a household name here in Canada. Headquartered in Calgary, AB, ATCO Structures and Logistics is part of a \$22 billion diversified conglomerate which was born out of the need to service Alberta's booming oil industry in the late 1940's. The requirement for temporary accommodations and industrial offices in Canada's resource sector spurred the growth for industrial modular product and contributed to the evolution of a large and robust relocatable building segment here in Canada. There are currently three large publicly listed multi-national fleet owners in Canada offering both workforce accommodations and relocatable offices (ATCO, Black Diamond Group, WillScot). Of the three, only Willscot is American owned. These three have diverse revenue streams, and up until the past seven years were heavily focused on the Canadian oil and gas market supplying large accommodation facilities across Canada's north.

Based on data from the MBI Canadian Annual Report (Modular Building Institute, 2020), of the reporting companies, the average revenue was over \$26M per operation with the median being \$2.9M, which shows the disparity in size of operations. Despite industry consolidation, there continues to be a large number of regional and local fleet owners servicing the Canadian market.



Source: LNG Canada

Collectively, of the reporting companies in the MBI annual report, fleet owners currently own over 16,000 units, and it wasn't until recently the industry has had to broadly diversify to survive without large oil and gas revenues. In Western Canada, the industry has been able to rebound with supporting gas pipeline infrastructure, LNG facilities, and hydroelectric projects. In Eastern Canada, the market is much more diverse and supports both the resource sector and largely focuses on the education markets.

The RB industry in Canada is made up of independent manufacturers who build for fleet owners (ATCO being the exception as they manufacture and are also a fleet owner). In this sector, there are an estimated 26 modular manufacturers in Canada, operating in approximately 50 manufacturing locations. Many of the manufacturers concentrate on a particular segment of the market, but many are diverse and build volumetric modular buildings across the residential, multi-family, industrial and permanent commercial spectrum.

It should be noted that all relocatable buildings in Canada are primarily made of wood construction and tend to have been built by low-tech manufacturing operations using framing tables and nail guns, and either in-house or subcontracted Mechanical, Electrical, Plumbing (MEP) trade contractors to fit out the buildings. Design resources are either subcontracted or brought in-house. The industry is structured such that particular manufacturers will build for specific fleet owners and will build a catalogue of standard size offerings for each owner, complete with their own branding. Geographically, the manufacturers are dispersed more broadly across Canada than the actual office and yard locations for RB fleet operations. The RB fleet operations tend to be more local in nature and service the demand for RB's within specific urban and metropolitan areas. The geography of operations tends to be a function of the cost of transport for shipping volumetric modular structures since there is a finite geographic area where it becomes cost prohibitive to ship into competing markets.

The industry is supported by an extremely small number of dedicated specialized transport carriers and dedicated modular installation crews. Many of the transport companies and the modular installation companies provide services to the relocatable and the permanent modular market and tend to cover broad provincial or interprovincial areas. There is no formal training or certification to become a specialized modular transport hauler other than standard transport carrier licensing. This lack of formal training is consistent among modular installation companies. Training of employees has often been passed down by owners or by senior experienced personnel who have been operating in this field for decades. This lack of formal training and fragmentation of knowledge poses future risks for the industry.

Commercial Permanent Modular Construction

Overview

Permanent Modular Construction is not new to Canada, but there has been a new wave of interest in PMC as owners and contractors look to new methods of construction because of supply chain escalation and skilled trade shortages. In North America, the old reputation of modular being ugly, cheap and of poor quality has shifted to a new view focusing on sustainability, forward thinking design, and incorporation of digital technology. New demand for PMC is coming from such areas as healthcare, hospitality, education and student accommodation, and affordable housing. All are seeing the benefits of speed and standardization and are well suited to modular's constraints.

North America has lagged the rest of the world in the adoption of PMC, but shifts are beginning to occur as interest from investors, developers and builders see this sector as a disruptor in the construction space. There is plenty of room for market share growth within North America, as commercial modular construction makes up less than 5% of the overall construction industry revenue totals (Modular Building Institute, 2020).

Supply and Demand

Several factors determine whether a market is ready to embrace PMC. The two biggest determinants are real estate demand and the availability and associated costs of skilled construction labour (McKinsey and Company, 2019). This appears to be consistent worldwide, as adoption is strong in Europe and Asia with plenty of low-rise to high-rise modular construction examples both in the public and private sectors.

As of 2019, there has been an estimated \$9B worth of modular construction projects built in Europe and it has enjoyed steady growth of 3.5% to 5.5% per annum (Modular Building Institute, 2020). However, both the Asia and European modular markets differ from that of North America in the type of material being used. Steel is the prevailing construction material in these regions utilizing steel moment frames or a steel skeleton system. Average module sizes in these areas tend to be smaller than North America with average size of modules being 3m wide to 10m long. The smaller modules in Europe have been designed to accommodate tighter roadways in urban areas, while North America it is not uncommon to see modules sizes up to 22m in length.

The only market that has not adopted steel modular construction in Europe is Sweden. It is the world leader for wood modular in automation, sustainability, and domestic market share. Greater than 10% of its multi-storey projects in hospitality and multi-family are now volumetric. The modular industry began out of the panel industry as they saw the opportunity to add more value and produce 3D boxes. Many have since become vertically integrated and are now able to offer complete design and engineering services through to onsite erection and construction. The maturity of this market has developed to where regulations allow 8 storey light wood frame (LWF) volumetric modular which is now able to compete with concrete.



Source: Randek

In North America, there are very few examples of modular structures over 6 stories. Due to building codes, any projects that have been constructed over 6 stories are made of non-combustible steel construction. It should be stated that there are very few experienced steel modular companies operating in North America and those who have started operations have found the market and pipeline for work to be challenging with many having scaled back or shuttered operations. As a result, many opportunities for mid-rise above 6 stories and high-rise construction projects in North America have been supplied by European or Chinese manufacturers who have gained the experience from their local markets and are exporting that know-how into North America. However, the main growth in PMC in North America has been under 6 stories and has been primarily in the low-rise markets using LWF volumetric construction.

Most commercial modular manufacturers in Canada tend to build a variety of building types to fill backlog of production. For commercial modular factories to be profitable, production must be booked a minimum of 4 months in advance of production to allow enough time for procurement of materials and shop drawing development. In addition, all design decisions must be made in advance of construction with all materials used in the construction process available at the time of construction. Commercial modular projects tend to be much more custom than its single-family residential modular counterparts, and thus are not able to react as quickly to fill holes in the production pipeline.

The ability to diversify is a key characteristic of Canadian commercial modular manufacturers, as the size of projects and demand for one specific type of commercial modular tends to be very cyclical in nature. Diversification is also important, as AHJ project approval schedules tend to be uncertain which results in production planning challenges. Many companies, such as Kent Homes in New Brunswick, build a mix of commercial and residential product just for this reason.

In Canada, the new PMC market lacks maturity and could be classified as still being in the early adoption phase. Based on North American numbers, and extrapolating for Canada, it currently makes up less than 5% of overall construction revenue in this country. The MBI estimates there are 26 LWF manufacturers of modular structures in Canada (Modular Building Institute, 2020). Of those, all manufacturers tend to be low-tech operations with little automation. Conversations with various stakeholders believe many of these low-tech operations will be left behind if they are not able to invest in technology.

However, there has been recent investment in modular with ED Modular (a division of Ellis Don, one of the top three GC's in Canada), developing a steel modular operation with Z Modular. It has recently constructed a 300,000 square foot greenfield operation in 2019 in Stony Creek, ON to service the Southern Ontario market. The decision to go with a steel frame structure complements the experience of Ellis Don in their conventional construction division and the acceptance of steel construction in the southern Ontario market. Steel modular also allows flexibility to compete with concrete high-rise construction above 6 stories and gives the company to opportunity to provide non-combustible infill projects.

In late 2017, Bird Construction, a large Canadian general contractor, purchased a 50% interest in Stack Modular, a company with manufacturing operations in China. This integrated model has Stack producing steel volumetric modules, shipping them from China to North America, where they are erected by it's GC partner Bird Construction.

Consolidation has also occurred in the wood frame market with the acquisition of NRB from Horizon North in 2019, and subsequently the Horizon North/Dexterra merger earlier in 2020. This created a national player in the wood PMC market with manufacturing facilities in BC, Alberta, and now two in Ontario. This new PMC division has retained the NRB brand. NRB is vertically integrated and has been at the forefront of leading the Design-Build low-rise multi-family modular affordable housing push in Vancouver and Toronto.

Like the RB market, the cost of transport often becomes a factor in the viability of projects. However, with very few experienced PMC companies in North America, the distance of shipping modules becomes less of a factor as the project size and complexity grows. Canadian companies can even compete with their US counterparts when there are favorable exchange rates.

The companies with scale operating in Canada include:

| COMPANY | FOCUS | MATERIAL | LOCATION(S) |
|---|--|----------------|-----------------------------|
| ATCO Structures and Logistics | Industrial, Affordable Housing, Student Accommodations, Offices | Wood | Calgary, AB |
| ED Modular | Affordable Housing, Seniors Accommodations, Other | Steel | Stony Creek, ON |
| Grandeur Housing | Single Family, Multi-Family Residential | Wood | Winkler, MB |
| Kent Homes | Single Family, Multi-Family, Industrial, Offices and Other | Wood | Bouctouche, NB |
| Nomodic <i>(Reseller / PM of Modular Projects)</i> | Affordable Housing, Hospitality, Industrial | Wood and Steel | Calgary, AB |
| NRB Modular | Affordable Housing, Hospitality, Student Accommodations | Wood | Kamloops, BC Calgary, AB |
| RCM Groupe | Hospitality, Multi-Family, Student Accommodations, Seniors Accommodations, | Wood | St-Benoit-Labre, QC |
| Stack Modular / Bird | Hospitality, Affordable, Multi-family | Steel | China |

There are many small regional manufacturers across Canada as well. However, both the large and small manufacturers have suffered from a very cyclical history of boom and bust. The cyclical nature and lack of certainty of pipeline has created the perfect conditions for lack of investment, and lack of spending toward research and development, and technology. From a customer perspective, the boom and bust of the industry has resulted in a very fragile supply chain with few experienced manufacturer and suppliers that can execute complicated projects.

Market Segments

There are several sectors that have begun to show growth and uptake in modular. These sectors are learning how best to use modular and how to leverage the strengths of what modular has to offer.

Hospitality

Marriott International challenged the North American modular industry at their annual conference back in 2014 to see if there was interest in making modular construction a viable alternative to traditional stick building. Marriott was looking for innovative ways to offset construction timelines and return ROI to its franchise partners. After a modular company selection process, Marriott launched its pilot

modular initiative at its 2015 Connect conference. Since then, the company has spent time working together with the early adopting owners and educating lenders about financing such projects.

Since that launch, the company has opened 31 Marriott-brand modular hotels (Electrical Wholesaling, 2020) in their low-rise Fairfield, Courtyard, AC Marriott, and Towne Place Suites brands in North America. Their approach to the market has been to design a prototypical standard for their suites that can be replicated across jurisdictions in North America yet be flexible enough to allow for differences in manufacturing methods. Prior to the pandemic, Marriott made a commitment that 10% of its brands would employ the use of modular technology for guest rooms or bathroom pods.

Since Marriott's foray into modular construction, a number of other brands have followed suit. Hilton, IHG, and Hyatt have all developed modular design guidelines.

Canada's traction into this market has been sporadic. While the promise of repeatability, scale, and backlog appealed to manufacturers, modular hotel deployment in this country has been slow to get going. Modular construction is more expensive than site construction, and because of the lack of good examples and knowledge among hotel developers in Canada, the number of projects utilizing modular have been few. In addition, few Canadian manufacturers are interested in building hotels due to the oversight required by many of the corporate brand standards for the hotel chains, and the intense coordination required with urban locations. A good example of such hurdles comes from the Quebec based Germain Group, who went overseas to Poland to find a builder for their steel mid-rise projects, as there weren't any good examples of projects undertaken by Canadian manufacturers.



Source: Hyatt Prince George – Built by NRB

A number of Canadian manufacturers have taken on design-build projects in this sector and have struggled, while others have worked with general contractor's under a subcontract agreement on a supply and install basis. There is no indication on which method results in a successful execution, but if the US model is any indication, an integrated team approach with the manufacturer acting as a trade contractor with early engagement appears to be a successful model.

In the near and mid-term, as the tourism sector comes out of the effects of the global pandemic, new capital available for modular hotels will be slow to rebound.

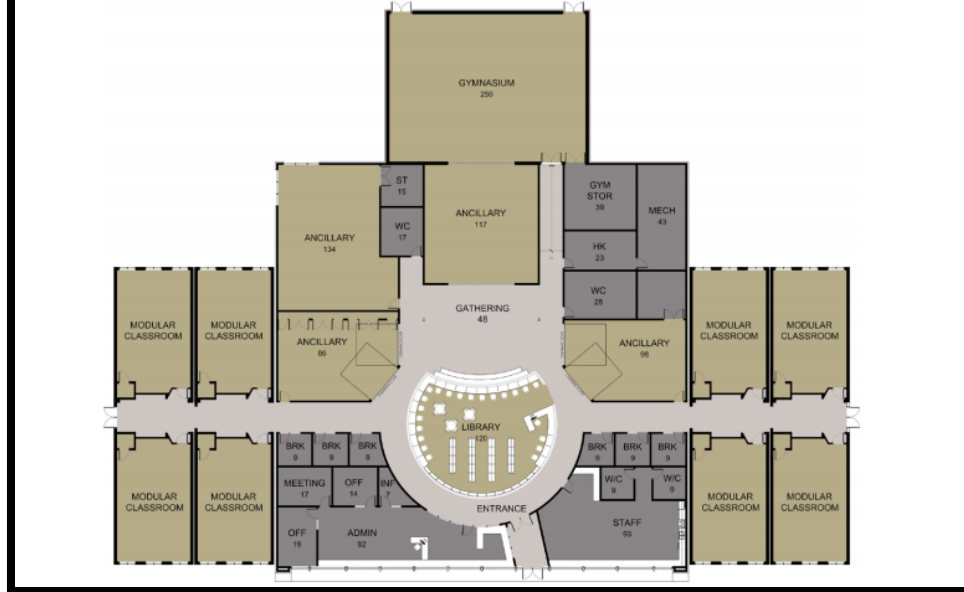
Education

The education sector in Canada has long been a big consumer of modular facilities with portable classrooms having long been a ubiquitous part of a Canadian students' education. The portable construction market continues to grow with demand being strongest in Quebec and Ontario (Modular Building Institute, 2020). It continues to grow in all areas of the country and is largely served by local and regional modular builders working in tandem with their local school district or the province's ministry of education. The appeal for manufacturers is the standardization and throughput for these buildings, as the design and construction details within each province tends to be very consistent. The demand for this product continues to grow in most jurisdictions as the trend toward density and urbanization within our metropolitan areas has caused site-built schools into overcrowding situations. With mandated class sizes within most provinces, the most economical way to house students is to procure portable classrooms and install them on existing school sites.

A pioneer in the modular education facility field who's been taking a long-term approach to planning education facilities has been Infrastructure Alberta. In 2007, the province set upon developing an elementary school program that consisted of developing a site-built core with modular classroom wings that could be added or removed depending on the enrollment of the surrounding neighbourhood (Alberta Infrastructure and Transportation, 2007).

This program continues to be well funded. In the 2021 Alberta capital budget, \$89m has been allocated to the modular program, which equates to over 300 modular classrooms being added. In addition, the past five years has seen the modular classrooms moving toward high-performance standards and approaching the international Passive House standard for energy efficiency requirements. These are now procured under a fixed price stipulated sum contract with prequalified modular builders. Through numerous iterations over the past 5-7 years, the program has developed to a standardized method of construction to which prequalified builders can build. With capital budgets constrained among all provincial education ministries, many lessons can be learned from this program that can be deployed across Canada in delivery of schools and being able to employ a more economical and standardized approach to facilities.

FLOOR PLAN



Source: Alberta infrastructure – Modular Classroom Program

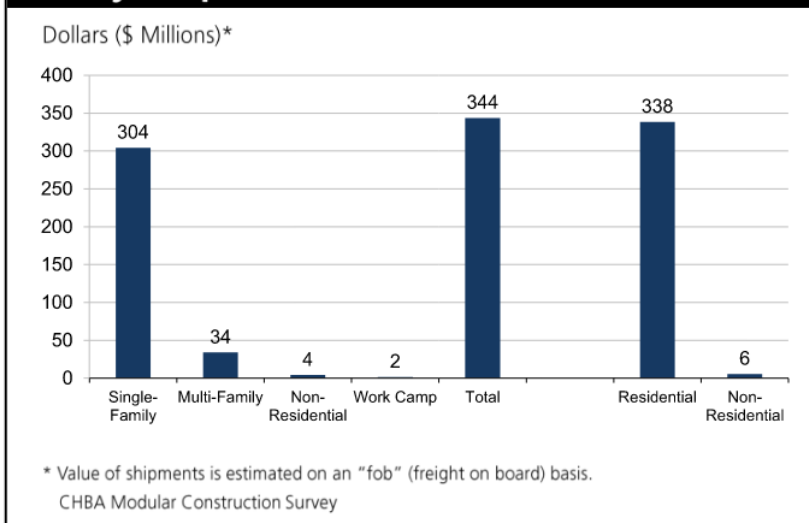
Multi-family Residential and Affordable Housing

The multi-family sector holds the most promise for deployment of modular construction and is currently the fastest growing sector for modular construction.

Traditional low-rise multi-family construction consists of ‘double loaded corridors’ which for modular manufacturers optimizes the production floor space to production value ratio. Therefore, many modular manufacturers in both the residential and commercial modular sectors are looking to capture market share in this sector.

A CHBA study of members reported approximately 10% of modular work was for multi-family projects in 2016. Since that time, there has been significant growth in the public sector for multi-family, but private multi-family developers in Canada are lagging.

Value of Factory Shipments by Product Type, Survey Respondents, 2016



Source: CHBA Modular Construction Survey – 2016 Annual Report

Despite a growing trend among owners utilizing modular for this market, there are very few successful case studies across Canada which give private multi-family developers and builders confidence in execution. The prior examples of the project cases in Saskatchewan remain one of the few examples in Canada of successfully scaled offerings with private developers in Canada.

Developers in the US have begun to make the shift toward using modular, as there are now successful examples of multi-family modular in many cities. In 2019, the US commercial modular industry manufactured over 2000 multi-family units, with the driver being cost certainty and accelerated time to market.

Even though multi-family starts utilizing modular construction was up 13.6% in Canada in 2020, the overall number of actual projects remained low but still amounted to almost half of all new construction opportunities amongst MBI members (Modular Building Institute, 2020).

For more adoption to occur in this market, more successful multi-family modular demonstration projects are required in order for owners, architects, and builders to see proof of concept.

A defined subset of the multi-family residential sector is the affordable housing sector. It has been the most active modular sector in Canada the past 5 years.

In 2016, CMHC funded the first modular relocatable affordable housing project in the City of Vancouver in partnership with Vancouver Affordable Housing Agency. Horizon North (now NRB Modular) was the successful proponent and delivered a 40-unit transitional housing project on land slated for future re-development. With a moveable foundation, and modules that can be dis-assembled and relocated, it was the first of its kind in Canada.

Since that first project, the City of Vancouver has delivered well over 600 units of relocatable affordable housing on city land slated for future development. Through experience and scale, NRB has delivered

the prototypical project in an average of 6 months from contract signing versus 14-16 months for a typical site-built construction project of similar size.

This model proved so valuable that the provincial housing agency – BC Housing, developed a similar program (called the Rapid Response Housing Program) to develop quick deployment of both temporary *and* permanent transitional modular housing in the province. Since the start of the program 5 years ago, BC Housing has developed over 2000 units of low-rise affordable housing under that program by using five prequalified modular companies to deliver the program.



Source: Graphic - CMHC

In the past two years, the City of Toronto has taken the Vancouver model and redesigned it for use in that city. Thus far, the city has developed two low-rise wood *permanent* modular housing projects and utilized NRB for that program. They were successful in delivering the first project in only 9 months after being approved by City Council.

It should be noted, the BC Housing, City of Vancouver, and City of Toronto programs are ideally suited for modular, as they have developed a prototypical layout that has been given to industry to replicate according to manufacturers' system of construction. Most units in the transitional housing program tend to be studio units and lend themselves very well to replicability.

Recently, CMHC released funding for its Rapid Housing Initiative (RHI), in which it issued two tranches of funding worth \$2.5B by specifying modular and prefabricated approaches to address affordable housing in the country.

The first \$1B was released in 2021, with the funding release for the next \$1.5B being released this fall. The funded programs are for shovel ready projects that can be constructed in 12 months, hence the requirement to use offsite methods

The funding for these programs has created excitement within both the residential and commercial modular industry, but with the limited number of capable factories in Canada able to build to the requirements and with the current backlog, it's not very likely that Phase 1 of the RHI program will be completed within the funding timeframes.

Associations

The commercial modular industry in North America (and now Europe and South America) is represented by the Modular Building Institute (MBI) – a 400+ member non-profit trade organization of manufacturers, suppliers, developers, and fleet owners providing research, education, and government relations assistance to members. Its mission is to expand the use of offsite construction through innovative construction practices. It's been in existence for almost 40 years and has watched its focus grow from representing the needs of RB fleet owners and manufacturers to now representing a broad cross section of owners, architects and technology companies. MBI has recently created a Canada Council dedicated to addressing the needs of Canadian commercial modular companies.

The MBI has been instrumental in working with CMHC to change its financing and underwriting language to include modular construction, and in the US has been working with Fannie Mae to develop a “Lenders Toolkit” for modular. They are also active in contributing to the development of the standard for modular high-rise construction (CSA Z250).

WHY PREFABRICATION – WHY NOW?

THE “CONTEMPORARY” ADVANTAGES OF PREFABRICATION

The Five Current Drivers for Prefabrication Adoption

There are many perceived and genuine advantages of using various forms of prefabrication. However, one must look at the current drivers of why prefabrication is seeing the growth in various sectors around the world. A good conceptual framework was developed in a 2019 study by Wuni and Shen and forms the basis for this study (Wuni & Shen, 2019).

Productivity Drivers

Since the McKinsey 2017 report highlighting the poor track record of the global construction industry and its meagre 1% per year labour productivity, there have been plenty of other studies and opinions of how to solve the productivity crisis in construction.

One of the real drivers of turning to prefabrication is the ability to reduce the reliance on labour. Here in Canada (as elsewhere), construction will continue to ‘grapple’ with an aging construction labour force and the need to replace almost 260,000 (or 22%) of those workers expected to retire in the next decade. If we consider the growth and demand for construction, the building industry will have to recruit, train, and retain just over 309,000 new workers between 2020-2030. (BuildForce Canada, 2021).

Without the workers available to build projects, we are going to require other innovative means of getting projects built. Offsite construction shows promise of being able to deliver as there is less reliance on local labour conditions for a large portion of the project activity. By moving 30-60% of the construction project offsite and moving toward a production-based system, there is possible productivity boost of 5-10X, as labour is better managed in an offsite facility (McKinsey Global Institute, 2017). Within a climate-controlled facility, it's also much easier to attract labour and use Lean Construction principles than on a project jobsite.

When it comes time to erect the offsite components in the field, the erection crews required are often specialized and much smaller in size, which lessens the demand on the overall local workforce. In addition, having a smaller crew leads to better supervision, and typically better execution. Having a smaller crew and better supervision has additional benefits such as higher quality, higher worker safety, optimization of site materials which leads to less waste, and better focus on schedule.

Time Performance Drivers

In a recent US survey, the number one reason for design firms and contractors to implement prefabrication and modular construction over the next three years was “Improves Project Schedule Performance” (Dodge Data And Analytics, 2020). Using the UK as an example, only 69% of traditional site-built construction projects were completed on budget and only 40% on time (KPMG, 2016). In addition, almost 50% of all onsite construction projects couldn't accurately predict their completion dates. In a recent US survey, 90% of GC's and CM's reported increased schedule certainty as one of the main impacts of moving to prefabrication (Dodge Data And Analytics, 2020).

“There appears to be a general acceptance of failure and underperformance both by industry itself but also begrudgingly by clients” writes offsite thought leader Mark Farmer (Farmer, 2016). However, many owners and contractors are beginning to tire of the track record of on-site construction. Through an integrated planning and design approach to construction, all offsite prefabrication activities and decisions are required in advance of setting up a construction site. Many have commented on how intense this upfront planning can be (which can also lead to extended design timelines), but with many of the decisions decided and a playbook developed for execution, the outcome is often a 30-50% improved construction schedule that far outweighs the up-front effort involved.

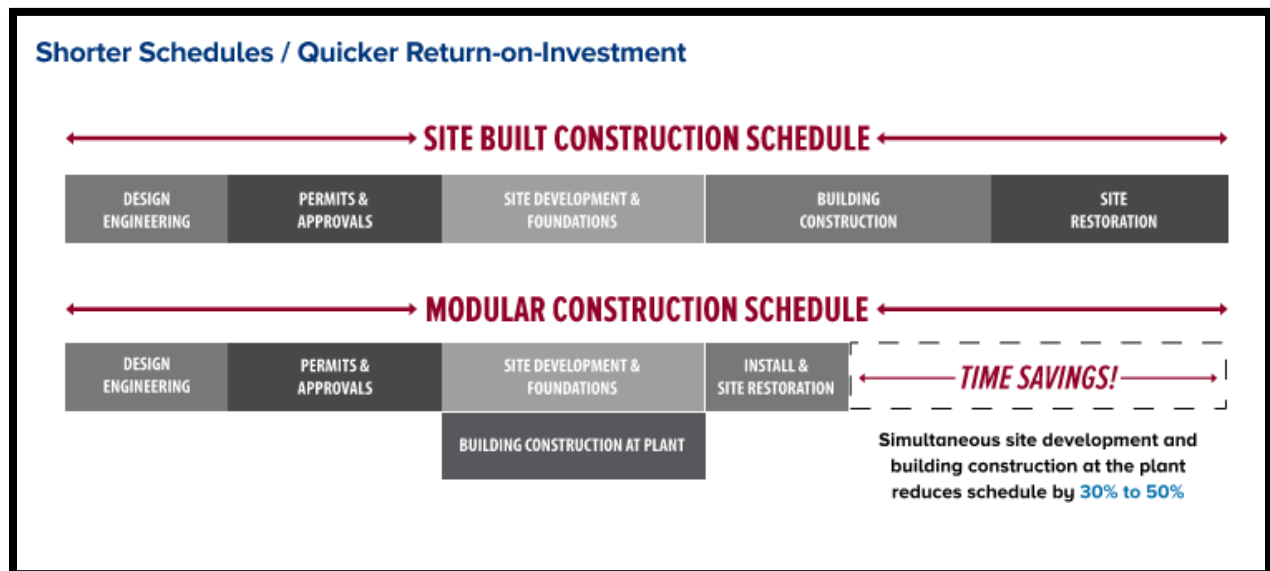
Of traditional construction: “There appears to be a general acceptance of failure and underperformance both by industry itself but also begrudgingly by clients” Mark Farmer

The real benefit reported by groups has been the exponential accelerated design times on subsequent offsite projects when the same project teams were pulled together to deliver on successive prefabricated projects. The culture of the team working together combined with deployment of repeatable designs, inevitably leads to resultant time savings.

This time driver also has financial implications. Offsite project schedules lead to construction financing periods that are shorter which results in lower borrowing costs. And since project teams aren't on site as long it results in lower General Requirement contracting costs. However, the big driver for turning to offsite construction is for revenue generating assets. For rental apartments and hotels, the sooner a project opens, the earlier the income stream. This is also important for owners from a market timing perspective as it lowers project risk for market timing and delivering the project when expected.

A study by Mark Taylor and published by FPInnovations, considered the impact on financing and potential revenue generation for various offsite methods versus site built construction. For a 50-unit apartment project the differences between a purpose built modular project and a site built project was less than 1% different in cost, and came with all of the benefits of prefabrication (Taylor, Industrialized Construction: Light Wood-Frame Construction Costing Comparison - Site-Built vs Closed Panelized vs Modular, 2020).

Unfortunately, it's extremely difficult to quantify all the benefits of offsite construction and remains one of the hurdles of adoption to be discussed later.



Source: Modular Building Institute

Here in Canada, time performance for projects can be especially critical where there are location challenges due to weather or short building seasons. With offsite construction's requirement of advance activity planning, this leads to certainty of project completion time and enables planning for onsite erection work to be scheduled at times when weather is not a factor in disrupting onsite project construction. Many projects can take advantage of undertaking factory construction in a climate-controlled environment during the winter, so the components are ready for installation in early spring.

Cost Performance Drivers

Further to Farmer's comments regarding acceptance of failure among those utilizing traditional construction, owners too have begrudgingly accepted cost over-runs on construction projects. In a worldwide survey, an average of 68% of projects from the five regions of the world were overrun and of those 68% of project budgets were overrun by 23% (Rivera & al, 2017).

Cost Overrun by Regions (PBSRG, 2016)

| Region | % Project Over budget | % Over budget amount |
|---------------|------------------------------|-----------------------------|
| Africa | 69% | 29% |
| N. America | 98% | 28% |
| Asia | 59% | 16% |
| Europe | 50% | 29% |
| Middle East | 65% | 15% |

Source: Identifying the Global Performance of Construction

Construction cost certainty is what owners are striving for when developing project budgets. Offsite construction can assist them in getting closer to the actual cost as the integrated design is one of the main features of reducing construction risk. BC Housing had noted between 2017-2019, escalation in the general construction industry had increased 16% while modular construction only had a 2% increase and was better able to control costs.

However, the lure of efficiency and time savings through offsite construction leads owners to think they can get it cheaper as well. Many owners perceive the manufacturing approach in other industries leads to driving costs lower and feel prefabrication will offer the same benefit.

However, it should be stated that offsite construction is not always cheaper, and in many cases is more expensive than traditional site-built construction.

Depending on the degrees and types of prefabrication, cost savings are obtainable. In the US, a study of architects, General Contractors and Construction Managers, almost 60% of them who utilized prefabrication in some capacity over the past 3 years reported cost savings (Dodge Data And Analytics, 2020).

Often offsite construction has a higher upfront capital cost and a longer breakeven period which results in little or no construction cost savings. Add in the hard costs of labour, material, and transportation, and offsite construction will be more expensive than conventional projects. However, there are advantages to mass timber systems specifically when there are poor ground conditions, or the building is in a high seismic zone. Mass timber buildings weigh approximately 1/5th that of comparable concrete buildings, which in turn reduces their foundation size, seismic forces, and embodied energy (Think Wood, 2020). This high strength-to-weight ratio enables mass timber to perform well during seismic activity and as a result mass timber buildings will often be less expensive than a comparable concrete building with the same requirements.

One recent area of study that is garnering attention in prefabrication circles is the overall Life Cycle Cost (LCC) of buildings. Because prefabrication requires owners to make up-front decisions on design, and the process results in higher quality, it's understood that these decisions can result in a reduction in occupant energy use, maintenance, renewal, and repair costs over the life of the asset.

And further to LCC development, a recent focus of the building industry is deconstruction. Because prefabrication requires design decisions to be made in advance of construction, many of the end-of-life decisions can be integrated into the design for easy deconstruction and or re-use. Modular construction and mass timber forms are great examples of whereby large components can be deconstructed, re-used and relocated for use in other buildings, thereby reducing the overall life cycle cost of the building.

However, many of the soft benefits discussed only offer anecdotal evidence at this stage with no hard data to support these claims. Unfortunately, without quantitative cost-benefit analysis it will remain unclear as to whether offsite construction offers true cost savings (Nick Blismas, 2006).

Quality Performance drivers

As the construction industry struggles with a labour shortage and inadequate supervision on its project sites, the result is that the quality of the finished building product inevitably suffers. A UK report found that 58% of all supplier and contractor respondents had identified skills shortages as contributing to poor quality of work (Farmer, 2016). As contractors seek qualified labour to complete their projects, many of the highly skilled employees are already employed. This leaves the unskilled and typically untrained to supplement existing project teams, all without adequate supervision. This was identified as an issue in several interviews, as quality control is almost non-existent with only spot checks being employed on construction sites.

In addition, many site contractors continue to complain about quality of drawings and lack of design details since consultant teams are often overworked and can't get detailed designs out to the field to adequately construct in time. Due to the lack of time in design, many projects are seeing 'Cut and Paste' errors, and lack of critical thinking in design that can affect timelines on the project at hand. It's these types of costs that often aren't captured in any project proforma.

“It is these very design changes, as well as construction build quality defects, that are often the most detrimental to project delivery success...with the total cost of rework amounting to 5% of total project costs(Robin McDonald)” SmartMarket Report

Owners are seeing the possibilities of improved quality control from taking large components of their building offsite in a controlled environment. Personnel dedicated to the manufacturing process provide oversight on a manufacturing floor with a defined QA process and most established offsite manufacturers have a Quality Control Manual which details the construction process within the facility.

Another advantage to owners and consultants is the ease at which mock-ups and prototypes can be used. Many owners in the hospitality and multi-family residential industry can see a full modular suite mock-up prior to beginning an entire production run within a modular facility. It gives all parties the ability to confirm fit and finish and constructability of the suites prior to construction and to confirm overall build quality. This process and the subsequent manufacturing of the project leads to consistency of build and eventually reduced defects. Interviews with several owners agreed that prototypes and mock-ups were of benefit, and that initially undertaking a smaller prefabrication project was a lower risk venture before tackling something much larger. Marriott hotels uses this approach by encouraging their franchisees try using bathroom pods before undertaking a larger project.

For those using an Integrated Design Process (IDP), all design decisions can be made up front which then allows individual manufacturers to benefit from early input into the building design. In an IDP, because manufacturers are generally at the design table early, they have input into standardization of components, a say into how the components get constructed, and input on which components would benefit of being constructed offsite. This leads to better constructability and replication of elements, which then leads to labour and efficiency savings that can be passed onto owners.

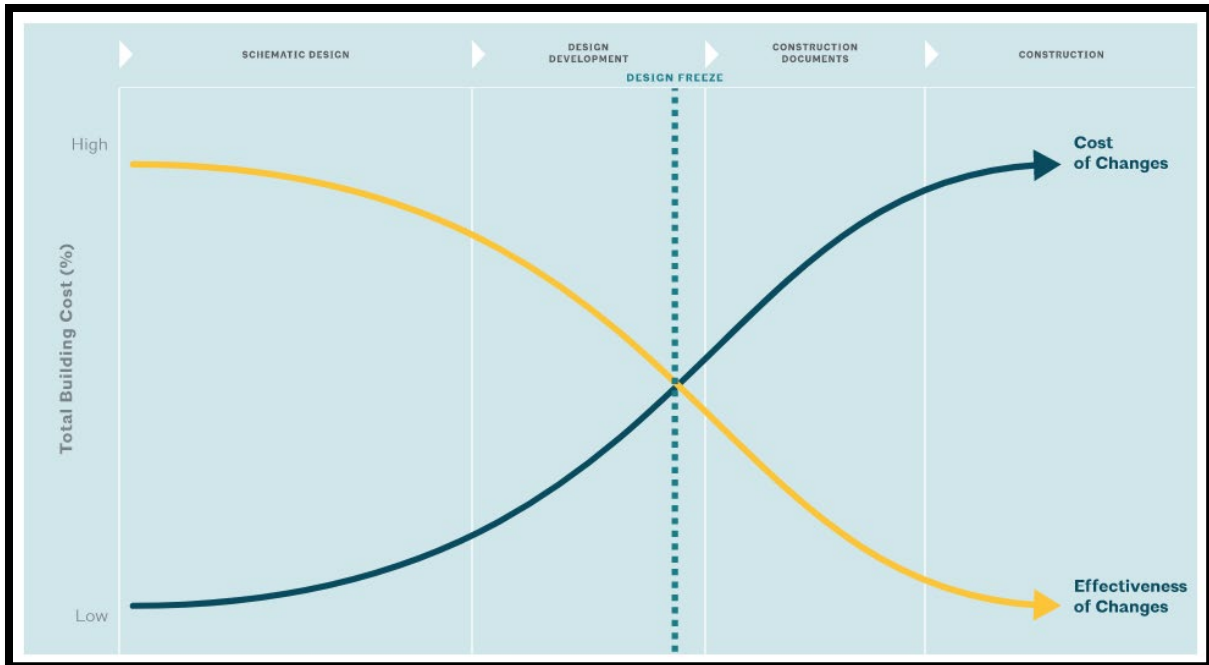
New technology is also playing a role in which many owners are starting to take notice. Many project teams are now integrating 3D modeling and BIM in prefabrication. The Mechanical and Electrical trades have been merging BIM and offsite construction for years which has resulted in tremendous gains in productivity and quality. Those trades have realized they can execute more projects during the course of a year with fewer people.

Many automated facilities are also using RFID tags for tracking purposes and for providing key data on components that have been produced.

The benefits of clash detection among various trades, and the abilities of framing and CNC software to integrate into the into the production process are game changers when it comes to quality.

Finally, the ability to freeze design prior to construction is to the benefit for all involved. The heavy lifting of decisions is done early, which allows project teams to proceed with erection once it gets to site, without having to wait for design and consultant details. Well executed offsite projects also have much fewer change orders and a smaller "punchlist" at turnover.

The effects on cost of changes and effectiveness of changes after the point of Design Freeze in prefabrication can be seen below.



Source: The American Institute of Architects

Sustainability Drivers

Standards within Canada and internationally have begun to reflect the growing priority of protection of the environment and reducing GHG emissions. It's this increased social awareness that has directed local governments to develop climate action plans and new building bylaws that have an impact on the materials and performance levels that are now required for buildings.

Unfortunately, construction activities continue to be extremely wasteful. Construction and demolition waste generated by the Canadian construction industry accounts for 27% of the total municipal solid waste disposed in landfills (Muluken Yeheyis, 2012). Further, new construction waste makes up 11% of the overall waste generated by Construction, Renovation, Demolition here in Canada, with only 16% of that being diverted from landfills (Light House, 2021). This is forcing many public sector owners and municipalities, such as BC Housing and City of Vancouver to name a few, to demand contractors track their waste during the construction process.

Companies are looking at their environmental, social and governance messaging and are looking to minimize their impact from construction. And it's using offsite construction that offers many advantages to firms wanting to be leaders in their sector. Big global companies such as Walmart, Microsoft, and Google are all using mass timber for their new offices due to the whole life cycle sustainability benefits it offers.

Offsite construction is extremely efficient in managing the resources with very little waste generated during the fabrication process. Optimization using automated processing equipment produces far less waste, and what waste is produced is more likely to be salvaged or reused. Volumetric modular is the most efficient by reducing waste on site up to 90% compared to conventional construction (WRAP and Mtech Consult Ltd).

As city sites become more compact and the ability to have large construction laydown areas diminish, erecting offsite construction components requires a smaller footprint onsite if coordinated properly. Just in time delivery of components needed during erection can be managed with timely delivery of trucks from a nearby staging yard. Because the erection of buildings tends to happen much faster, this results in reduction of dust and construction noise which leads to a decrease in neighbourhood disturbance. In addition, with fewer truck trips as compared to traditional construction, vehicle emissions are less. A study by the University of Alberta calculated a reduction of 26 tonnes of CO² emissions using modular during the construction process in crew trips alone for a low-rise wood apartment building (Al-Hussein, Manrique, & Mah, 2009).

Outside of the embodied carbon of the material itself, it's the additional advantages such as resource management and reduction in transport trips to job sites that will contribute to prefabrication having significant benefit to method of construction decisions when utilizing whole life cycle analysis.

The other benefit that often gets overlooked is the sustainability of the workforce. Offsite construction projects are safer and have overall lower worker compensation rates versus their traditional construction counterparts. The manufacturing environment is more comfortable, and ergonomics and lean construction processes are more easily managed within a manufacturing environment. In addition, recent developments in the field of robotics allows manufacturers to focus skilled labour in key areas of production. This all leads to better worker retention and a better working environment. Also, when it comes to the erection of the offsite elements, the size of the crew tends to be smaller as well, which leads to less labour and supervisor burden. This has been especially important during the pandemic, as we've seen conventional labour markets been disrupted.

OPPORTUNITIES TO GROW PREFABRICATION

Offsite Construction and Sustainability Targets

Background

In Canada, Greenhouse gas emissions from buildings make up 12% of the country's overall emissions with only the oil and gas and transportation sectors emitting more (Government of Canada, 2021). Worldwide, the building sector contributes 39% of the overall GHG emissions, with 11% of these emissions associated with the manufacturing of construction materials and the construction of buildings (UN Environment Program and International Energy Agency, 2017).

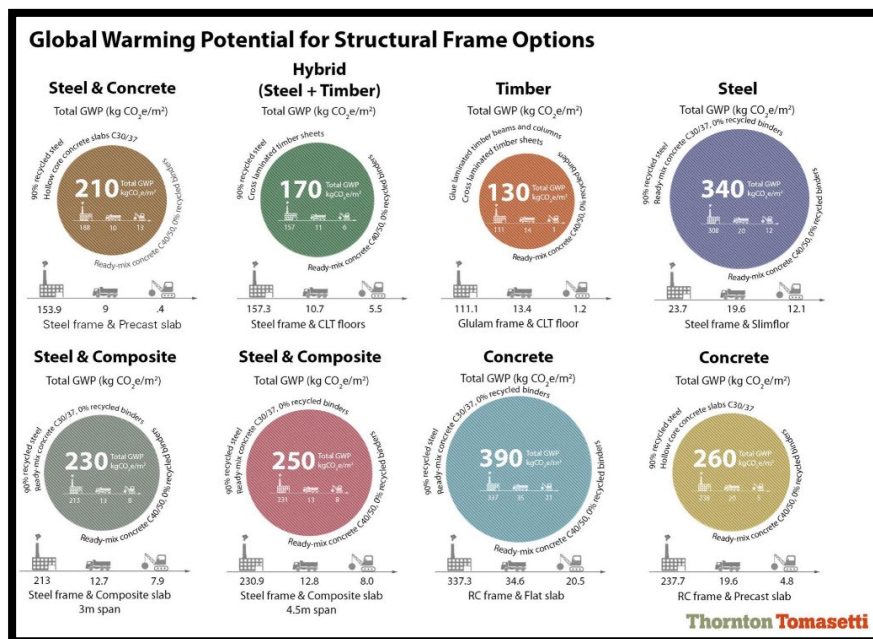
In 2017, Canada developed the Pan-Canadian Framework on Clean Growth and Climate Change in response to its commitment toward the Paris Climate Accord. The commitment to meet the 2030 GHG emission targets means making new buildings more energy efficient through development of a model "net zero energy ready" building code that will allow all builders to adjust to the changes and ultimately offer lower lifecycle costs (Government of Canada, 2017).

Sustainability Movement within our Cities and Provinces

In advance of the latest national model code, a number of provinces and cities have also mandated specific changes for their regions. The Western provinces have been leading the net zero movement with BC developing their own “BC Energy Step Code” in 2017 and municipal adoption these new higher levels of performance for buildings. At the local level, Vancouver has adopted the Greenest City Action Plan which requires buildings to be zero emissions by 2030. Toronto has the Green Standard which its latest version (Version 4) which requires tracking of embodied emissions in building materials used in construction.

The new wave of leadership in sustainability has begun to emphasize more comprehensive methods to evaluate and reduce environmental impacts from buildings. The whole building life cycle analysis is a more holistic approach to assessment of buildings and its ‘cradle to grave’ view of buildings has gained significant following. Using Life Cycle Assessment (LCA) tools as assessment devices for understanding energy use, owners and architects can now compare materials and the construction processes involved in constructing buildings. This includes the phases of raw material procurement, manufacturing, construction, operation, and end of life decommissioning. A study by McKinsey released during the pandemic identified how disruption in construction is creating a rising customer sophistication and is tied to demands for “performance total ownership costs and sustainability”. It’s this movement that will continue to evolve and create further demand for offsite construction and industrialization (McKinsey and Company, 2019).

The comparing of materials choices is where wood has an advantage. Since 80% of a building’s embodied carbon comes from the structure of the building, wood prefabrication will have a significant advantage over other forms of construction.



Source – Thornton Tomasetti, 2019

Also, part of the LCA equation is identifying the waste from the construction process. As waste tracking in construction becomes more commonplace among cities and public procurement, so too will be a focus on the optimization of resources. When considering the overall construction and demolition waste from construction, the offsite benefits can be quantified against the waste generated from a traditional construction site (Kasun Hewage, 2012). New technology and better supervision during the offsite construction process results in many manufacturers having less than 2% waste in the manufacturing process. Moreover, offsite construction can offer owners substantial re-use opportunities if factored into the design at the start of the project. By looking at the structural connections of offsite construction for future re-use, large components can be either recycled for use in future buildings, or in the case of modular construction, be dis-assembled and reconfigured in another location. This flexibility of offsite for future use has only begun to be explored but will be an increasingly relevant topic for future LCA analysis.

Sustainability at the Company and Project Level

In Canada, as of 2021, there have been 277 mass timber publicly funded projects that have been completed thus far with 20 still in the planning and construction phase. Public projects such as community centres, schools, and childcare centres make up over 50% of the total mass timber projects in Canada. As public entities and municipalities begin to align their sustainability initiatives with emissions targets, the opportunity for greater adoption of mass timber exists for these types of public buildings.

Large private enterprises have also begun to respond to social pressures with their own sustainability initiatives as part of their social corporate responsibility messaging when constructing their facilities. Walmart's new head office campus reflects a commitment to employing a high efficiency design in partnership with Structurlam to build their new head office using mass timber. Microsoft is planning on utilizing offsite techniques and CLT construction for its Silicon Valley Mountain View campus, and Google is finishing its first mass timber project in Sunnyvale, California where it's estimated that its carbon emissions on the project are 96% lower than if they constructed with steel (Forest Economic Advisors, 2021).

As the new model energy ready code is about to be released, thicker envelope assemblies will be required to meet the new performance requirements. This results in an increase in weight, volume and airtightness detailing that can increase on-site construction time significantly, thus pushing the industry toward prefabrication (Wimmers & Conroy, 2019). In addition, since energy modelling is becoming required for all new buildings, it requires collaboration at the early schematic design phase of a project which is something that is familiar to those in offsite construction. Bringing offsite manufacturers and engineers into the process at this stage results in higher project collaboration which reduces the execution risk during the construction.

However, if the offsite industry is going to leverage the sustainability conversation as a key advantage, it must be able to quantify the sustainability benefits between onsite and offsite construction methods if it's to offer a persuasive argument versus the status quo.

To date, there are very few studies that have tackled the subject. A 2009 study by the University of Alberta, was one of the first studies to compare CO2 emissions on an apartment project between using modular and traditional construction. Between the vehicle trips, worker commuting, winter heating, and construction waste it was estimated that emissions were reduced by 43% (Al-Hussein, Manrique, & Mah, 2009). By being able to quantify the GHG emissions and assign values to the savings, more of these representative studies will allow owners to make sound sustainability decisions.

Growing Housing Supply

Overview

Availability of housing is top of mind for many Canadians and is the top issue facing all levels of government.

A Scotiabank report in 2021 put it bluntly – “the fact remains that the principal challenge facing the housing market—and the underlying cause for rising prices and diminished affordability—is the substantial insufficiency of supply relative to demand” (Perrault, 2021).

In short, housing construction has not kept up with the demand. Internationally, Canada has the lowest number of housing units per 1,000 residents of any G7 country, with the number of housing units per 1,000 Canadians falling over the past five years due to population growth. Canada’s population is largely urban with over 81% of the population living in urban centres. However, recent trends are seeing more people beginning to migrate away from the dense urban centres to neighbouring areas which is leading to even more urban sprawl. Even before the pandemic, increased housing costs were pushing people to find more affordable housing with more space outside of the main urban centres (Statistics Canada, 2020).

Across Canada, average buyers must now spend 52% of their income to cover the costs of a typical home (Heaven, 2021) with Vancouver and Toronto at 75% and 68% respectively. According to the Canada Mortgage and Housing Company (CMHC) “housing is considered to be affordable when a household spends less than 30% of its pre-tax income on adequate shelter. Households that spend more than 30% of their income on shelter are deemed to be in core housing need”. If using simple supply and demand economics, the continued shortage of available housing suggests that housing prices are likely to continue upward for the foreseeable future.

In 2017, CMHC released the National Housing Strategy – a 10 year \$70+ billion plan creating a new generation of housing in Canada. Through various funding initiatives, such as the National Housing Co-Investment Fund, and the Affordable Housing Innovation Fund, the initiatives prioritize partnerships between governments, non-profits and the private sector for low cost and/or forgivable loans, and for new ways to deliver housing (CMHC, 2017).

However, the funding initiatives are missing the mark if we want to make up the housing shortfall. There are two critical areas that the funding doesn’t address – lack of skilled trades to deliver housing, and the lengthy planning and approval process.

The linear approach to conventional construction means that construction can only go as fast as the availability of trades and the supply chain. The pandemic hasn't helped with getting the country back building. Supply chains have been disrupted, and worker shortages have still hampered the productivity of the industry, which has led to even longer timelines to construct. With the current skilled labour shortage and a drop in new immigration, the problem of productivity will not be solved without looking at it differently. With continued lagging productivity in the construction sector and a widening gap for housing in the 'missing middle', the opportunity to deploy housing faster exists by looking at modern methods of construction.

The other big hurdle facing housing supply is the planning and permitting process. For multi-family housing, rezoning and development approvals in many urban areas can take upwards of 3-4 years before a building permit is granted. The bureaucratic processes often delay or derail development applications, and add in under-resourced planning departments, no wonder we have a widening housing supply gap. If we are going to deliver more housing, we must encourage provincial governments to assist municipalities by developing new frameworks and processes for accelerating permitting approvals for developments. In BC, a process review is underway with a 2019 report developed by the Minister of Municipal Affairs and Housing titled the Development Approvals Process Review (DAPR). Through stakeholder interviews, it set out to "address challenges and identify opportunities for improvement in the current development approvals process and to support local governments in eliminating barriers to affordable housing and accelerate the construction of the homes" (BC Ministry of Municipal Affairs and Housing, 2019)

Other countries in the world are tackling their housing affordability by taking on an industrialized approach to construction. In the UK, there has long been a momentum to push housing forward using offsite construction. Recent reports included the House of Lords Committee report on MMC and the recently published report by De'Ath and Farmer outlining a further expanded initiative for housing delivery by using MMC to deliver the housing needed and to move their economy to a "greener future and increased opportunities" (Mike De'Ath, 2020).

In Singapore, the government developed its "Buildability Framework" to make offsite the default method for larger projects. Back in 2014, it established a Productivity Fund to build its integrated construction and to build precast elements and volumetric modules (Sweet, 2021).

Dovetailing with the need for accelerated development approvals here in Canada, is the use of MMC to deliver housing faster. BC Housing was among the first public organizations to utilize modular construction to address the homelessness issue by building shelters and transitional housing. The City of Vancouver has even developed a program to build repeatable temporary modular transitional housing on city owned lots deemed for redevelopment. These temporary three storey buildings can be relocated to another area of the city once the land is ready to be redeveloped. The City has developed a pilot program called 'SHORT' – the Social Housing Rental Tenure Program which reduces the development approval timelines by 40 weeks for the rapid deployment of modular affordable housing. The program has been so successful that an average three-storey building can now be delivered in 5 months from contract signing.

Toronto is beginning to follow suit by utilizing the Vancouver model to build permanent transitional housing. Create TO (the City's real estate agency), has built two multi-storey residences in 9 months from contract award and has plans for two more. Toronto has developed a process called "Concept to

Keys” which expedites the reviews for affordable housing and modular to take advantage of the condensed time frames. As Abi Bond with City of Toronto puts it, “Political leadership is the key. We don’t see ourselves as risk takers, since the risk of doing nothing is riskier”. The opportunities to extend this framework to every municipality exist but require new programs to accelerate approvals and political leadership to make it happen.

At the federal level, CMHC announced the \$1 Billion Rapid Housing Initiative (RHI) in the fall of 2020 which funded affordable housing shovel ready projects requiring the use of prefabricated systems to turn over the funded project within 12 months. Since then, the government has committed a further \$1.5B to fund another round of affordable housing projects around the country.



Source – Element5 – Waterloo RHI Affordable Housing

Indigenous Housing

One of the biggest opportunities for using offsite construction comes in the form of addressing the housing stock in Indigenous communities. A report in 2017 by Indigenous and Northern Affairs Canada (INAC) for on-reserve housing found widespread issues of overcrowding, poor states of repair, inadequate infrastructure, as well as lack of affordability. It was also critical of its own approach to funding as it “has not resulted in long-term broad improvements and was seen by evaluation participants as short-sighted and non-strategic” (Canada, 2017).

The existing housing stock on many reserves is tremendously inefficient resulting in enormous operating expenses to maintain and heat the homes. The argument for more energy efficient housing for those people on the margins is a strong one. When people must make decisions on whether to heat the home or put food on the table, it results in a continued cycle of poverty. By providing more energy efficient housing to communities, it frees up funds that can be earmarked for other programs. This example was proven out by Yale First Nation who embarked on building the first two modular multi-family passive house projects in Canada. Yale First Nation saw utility bills drop 250% and saw their maintenance and operations cost drop by \$60,000 per year by turning to energy efficient offsite construction. (CMHC, 2018).

The use of offsite construction has tremendous opportunity for Indigenous communities. Many nations are situated in remote locations with very short building seasons, have an absence of skilled labour, and have poor quality and inefficient housing stock. Offsite construction can address all these issues and provide housing quickly and often cheaper in many of these locations than traditional construction.



Source: CMHC Yale First Nation Passive House

Student housing

Post secondary institutions around the country are also feeling the affects of the affordable housing crunch. Over the past few decades, many universities across the country have been reluctant to add to their student housing stock as the return on investment wasn't viable since student occupancy generated income for only 8 of the 12 months of the year. Most students were often able to find economical off campus housing close to the universities and colleges. With the lack of housing availability, off campus housing rent inflation, and influx of international students, it has meant a shortage of housing which has affected enrollment numbers for those schools that weren't able to offer accommodations for students.

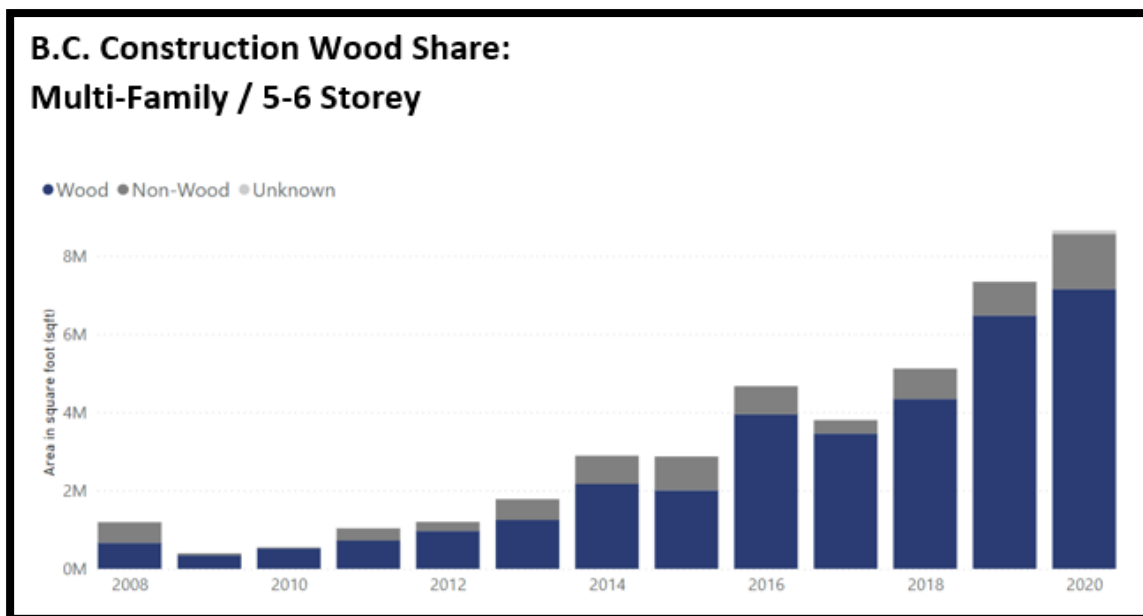
Due to the on-campus disruption of capital projects, many schools are looking to delivering student housing faster with greener and more innovative methods of construction. Publicly funded projects in BC have specified "Wood First" and in many cases have asked for modular and mass timber in order to deliver the projects faster than conventional construction. There are tremendous opportunities across Canada for prefabricated student housing, as standardization of floor plates leads to replicability and therefore faster and more efficient delivery than conventional construction.

New Markets for Mass Timber

As we look to the future, the big mover for prefabrication will come from changes to Canada's model Building Code and the change to allow Mass Timber to 12 stories, and the IBC's change to allow 18 stories in the US. With BC and Quebec having well developed mass timber ecosystems with expertise in tall wood design, engineering, and construction, it will open up further opportunities to export this knowledge to the US market.

In advance of the NBC release, there are currently 22 mass timber projects over 8 stories in design development. It is unlikely that all projects will get built, but if the last code change that allowed light-wood-frame to 6 storeys is any indicator, then owners and builders will be sure to add mass timber to the construction method decision.

By looking at the growth of the multi-family market in LWF for 5-6 storey buildings in BC (see chart below), one can potentially believe that Mass Timber may follow a parallel trajectory with the introduction of code changes. Only time will tell.



Source: FII

As more adoption of mass timber takes place and there are further successful examples to exhibit, there will be other markets that will open up. One sector that has potential for utilizing mass timber is the warehousing and light industrial space. Currently, this market is owned by concrete tilt up and pre-engineered steel buildings due to its ease of erection and relatively low cost. However, mass timber offers a number of benefits that the other forms don't have – faster erection with a small crew, a more sustainable option versus other structural forms, and fire resistance ratings that exceed 2-hour code minimums.



Source: Times Colonist - Studio 531 Architects Mass Timber Warehouse

Another ancillary use of mass timber is being seen in low-rise and mid-rise buildings for elevator shafts made from CLT panels. They offer significant advantages over existing methods, namely speed of erection and increased tolerances over cast-in-place concrete. Using CLT works well when used with other forms of prefabrication too since CLT elevator shafts can match the tolerances demanded by offsite systems.

Adopting Technology to Solve Construction Productivity

With the ongoing skilled labour shortage facing construction here in Canada, there is a tremendous opportunity to utilize prefabrication and drive digital and automation technology to solve many of our construction issues. Luckily, there are many successful examples around the world on how countries successfully embraced technology and automation in construction.

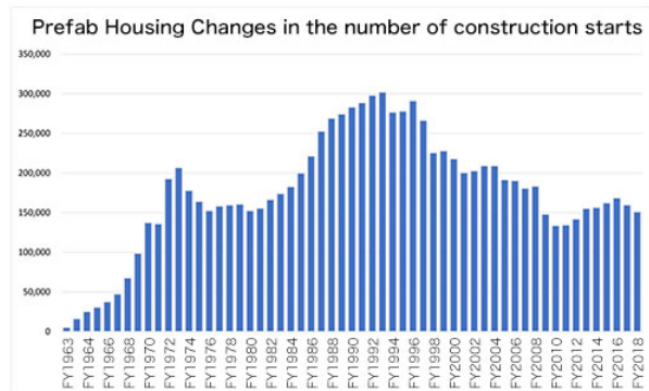
Japan is currently the most automated and vertically integrated market in the world when it comes to panelization and modular construction. They are currently so far ahead of other countries in automation that they haven't had to replace much of their 20-year-old equipment (Dodge Data And Analytics, 2020). Although light gauge steel is the primary material, an important factor in that growth is a regulatory and inspection system that is specific to the sector.

Prefab Housing Supply Performance

The Japan Prefabricated Construction Suppliers and Manufacturers Association was established in 1963.

In the half-century since then, more than 10 million high-quality prefab residential units have been supplied (as of March 31, 2019).

| | | | Subtotal | |
|---------------------|-----------------------|----------------|-------------------|-----------|
| Detached Homes | Wooden | 1,295,828 | 4,630,256 | |
| | Iron and steel | 3,180,987 | | |
| | Concrete | 153,441 | | |
| Apartment Buildings | Low-rise | Wooden | 346,266 | 3,525,771 |
| | | Iron and steel | 2,955,088 | |
| | | Concrete | 224,417 | |
| | Medium- and high-rise | Wooden | 7,565 | 1,893,517 |
| | | Iron and steel | 613,594 | |
| | | Concrete | 1,272,358 | |
| Total | | | 10,049,544 | |



(Japan Prefabricated Construction Suppliers and Manufacturers Association, n.d.)

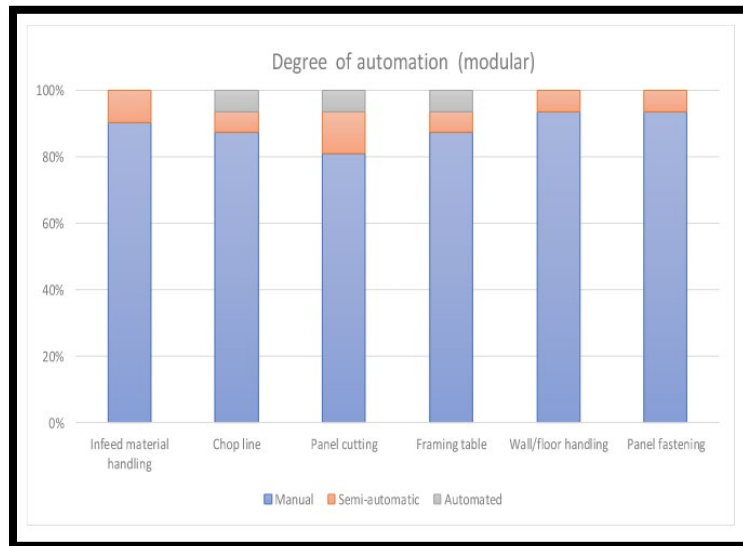
Sweden is close behind with 45% of its housing using some form of automated offsite construction and having 80% of single-family homes using prefabrication (Valentine-Selsey, 2020).

Unfortunately, in Canada the costs to adopt MMC is, at least or has been, higher than traditional construction, which of course reduces the incentive to change. However, we are currently at a critical juncture in many regions in Canada where many are poised to begin adopting more offsite construction technology due to specific driving forces of cost and availability of labour and government intervention.

Manufacturing Technology

Mass Timber production in Canada follows much the same process to that of Europe. In closed one-side panels in Canada, there is a mixed level of automation being employed with some facilities being highly automated, and some that are not. The opportunity to move to closed both-sides panels is the ultimate goal, and is what is seen in Sweden, Germany, and Austria, but is rarely achieved here in Canada (Wimmers D. G., 2020). The opportunity here to adopt more automation comes with the adoption of higher performance code requirements, as we will be seeing over the next decade. Wall assembly detailing becomes more complicated and heavier which results in a push toward prefabrication. For modular construction, many European companies utilize their panel production lines before assembling into a 3D volumetric 'box'.

Here in Canada, we use very little automation in the construction of volumetric modular, which reduces its potential productivity and accuracy. Without increasing the amount of automation, the industry also leaves itself exposed to labour shortages. The opportunity in the future is for modular to begin to utilize automated panel lines before assembling them into volumetric boxes. For modular companies, this may be a shift in thinking that requires larger capital outlays for the equipment. The new opportunity may



Source: FPIinnovations 2019-2020

well be a hybrid of what is employed in Europe with modular manufacturers having a panel business as well. Modular in Canada is very much a manual process that has been taken indoors and optimized with framing tables and an advanced workflow approach to construction.

With the interest in offsite construction comes investment. Despite the demise of Kattera, in the US there continues to be significant venture capital that is being injected into this industry. One shining example is Autovol in Boise, Idaho. Their investment partner Pacific West Group of Companies, one of the largest multi-family home builders in the western US invested \$50M in a 400,000 sq.ft automated modular facility. The facility is one the most automated Volumetric modular plant in North America with ABB robotics and can complete almost 400m² per day of finished residences. It's this use of technology that is appealing to younger workers, as the average age of worker in the Autovol factory is 32 years old. There are other major players in the US such as Greystar, the worlds largest rental property owner, who have built their own bathroom pod facility to better streamline their own site construction business.

However, there are a few companies in Canada that have made the investment for the future and are prepared to move forward with their commitment toward automation and technology.

Intelligent City is one such company. Utilizing mass timber, with ABB robotics and design software, Intelligent City is marketing their integrated construction "Platforms for Life" by taking a more scalable, yet standardized prefabrication approach to sustainable multi-family construction. In using parametric design and a family of potential suite layouts, they can rapidly determine the most efficient mix of suites for a given site. They are currently in start up mode, with their first project slated to come online in 2022.

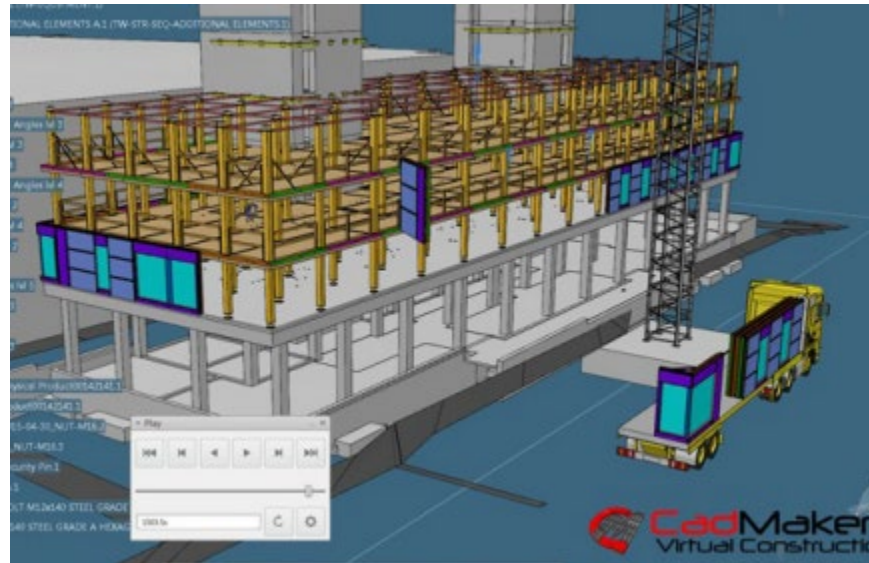


Source: Intelligent City

When it comes to investment in offsite automation, the industry in Canada has been extremely cyclical with no sustained periods of growth. Experience has proven that in order for companies to grow and invest there has to be enough production backlog and confidence of pipeline for owners to commit capital to new automation technology.

Digitization

There are significant advances in digitization occurring in the offsite industry. Generative and parametric design is a recent advance with now a number of technology companies offering tools to quickly assess the feasibility of development sites using standardized components. This is a game changer for the offsite industry as optimization of Floor Area Ratio (FAR) by developers dictated the design of buildings and prefabrication often didn't fit into the designs developed. Now with parametric tools such as Kreo Modular, one of the biggest hurdles for offsite adoption has been removed. As one of the interviewers called it – “Hidden Repetition”, the idea that buildings are optimized for prefabrication methods.



Source: CadMakers Inc.

The other big move in technology is the ability to 3D model and seamlessly build digital twins of buildings. This level of engineering is currently occurring within the mass timber industry in Canada as the coordination between onsite and offsite elements requires and demands digital coordination of systems prior to manufacturing. The evolution in digital twinning is already being seen by developing virtual construction studies and simulations (called Virtual Design and Construction or VDC). This process occurred on the 18 Storey Mass Timber Brock Commons that allowed the contractor and the trades to develop logistical and construction sequencing and build it digitally in advance of installing the actual mass timber components in place.

Recently, with the oN5 project in Vancouver (one of the first projects in North America to utilize a prefabricated exterior cladded, mass timber passive house panel for a commercial building), they used VDC to digitally construct the building 7 times before arriving on site. As a result of using 3D simulations, they were able to plan their construction schedule down to 15-minute increments.

From a design to automation perspective, there are many proven software programs that are on the market that have applications and plug-ins from design/drafting (CAD) to computer aided manufacturing (CAM) and building information modeling (BIM).

The use of BIM for prefabrication will continue to grow, as many projects are now demanding the use among consultants and trades. Among the top reasons to use BIM is the increased coordination among design and construction teams, with improved schedule performance as being one of the main drivers for trades and contractors (Dodge Data And Analytics, 2020). In the future, the use of BIM with parametric design that factors in manufacturability and assemblability will allow earlier design freeze ability and address the issues of poor design flexibility (Li, 2020). This move to treat construction more like manufacturing and using a DMfA approach will break down some of the current design hurdles and offer more predictability in the design process.

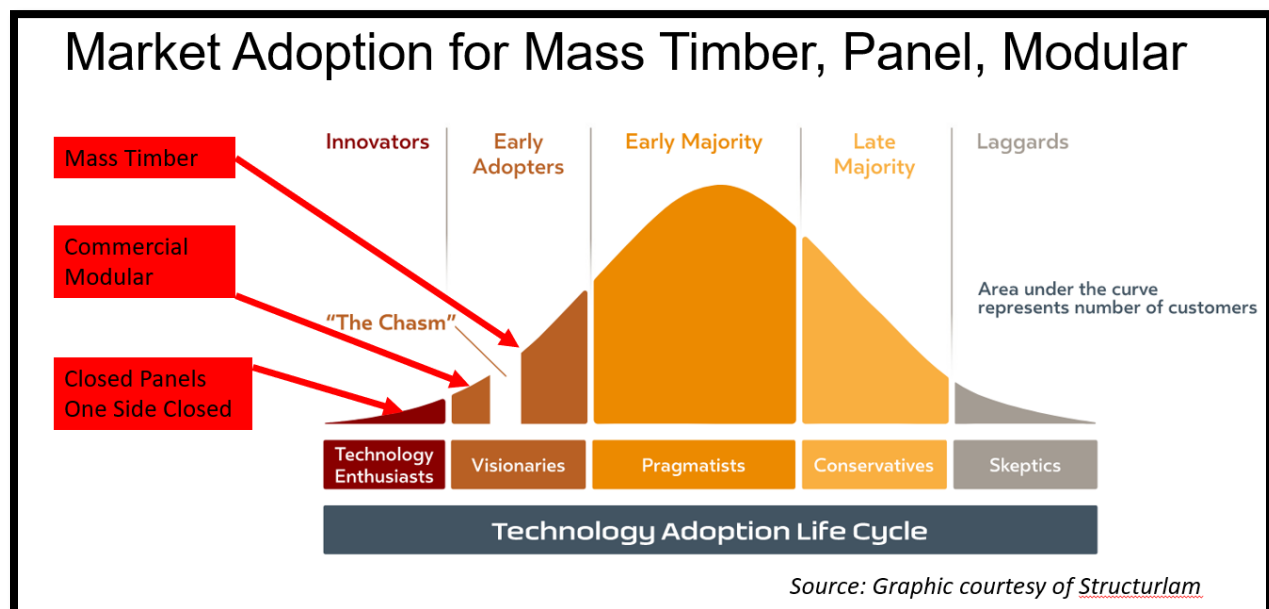
There has been much discussion about adopting BIM standards as seen in the UK under their standard BS1192. Recently, an ISO standard ISO19650 was developed here in Canada using the UK standard as

the basis which CanBIM has adopted. There is a tremendous opportunity for the prefabrication industry to lead a fragmented construction industry toward the full adoption of BIM. With the collaborative nature of prefabrication, a centralized platform for information sharing will not only increase the efficiency of the build but will offer value through its project lifecycle.

CHALLENGES, CONSTRAINTS AND BARRIERS TO ADOPTION

Overview

Offsite construction promises to save the construction industry from its lack of productivity, address the skilled labour shortage, increase quality and address sustainability. So why hasn't it had more uptake? One can look at where the industry sits on the innovation adoption curve to realize the entire prefabrication industry in Canada is still in its infancy.



In Canada, there are many past stigmas associated with "Prefab". Some of these still linger within the older construction community, while the younger generations are beginning to see prefabrication as 'cool' and innovative. Both the residential and commercial modular industry have, and still are to a degree, suffering from the history of the cheap and ugly mobile homes of the past and the industrial job site 'trailers' as being representative of what is being produced today. There is also a misconception that modular is intended primarily for temporary, single storey applications (Tarek Salama, 2018). In addition, many in the design community see modular as 'restrictive' in design and therefore lacks the design freedom. Unfortunately, it's far from the truth as today's prefabrication is of high quality and can have very innovative designs. In a study within the Irish offsite and prefabrication industry, design teams referenced the unsuitability for smaller projects, the inflexibility to adapt to late design changes and limited availability of design options as being the main barriers to adoption (Reddy, 2020). However, these barriers were highly contingent on the level of experience with prefabrication.

Thankfully, panels and mass timber don't carry any of modular's baggage, as these new forms of prefabrication are seen as original and cutting edge with high degrees of innovation. The mass timber movement that is taking place in Canada has been able to overcome many hurdles of adoption in a relatively short period of time (<10 years) although BC is further ahead in adoption than other provinces. The effort of all stakeholders has obtained government support, delivered education, developed testing, provided assurances to both regulatory officials and the insurance industry, and provided data and case studies through demonstration projects. However, as Williams Munoz from Nordic put it, "the market segments for mass timber are not well organized yet", and outside of those companies dedicated to mass timber erection "many constructors are not very good at coordinating the items before the work".

Permanent modular construction (PMC) and closed panel systems in Canada have lacked the wider support and large-scale examples of success that is needed for adoption. With PMC, there are so few case studies of successful PMC projects and not enough success stories and commitment from owners in adopting modular construction as part of their construction strategy. Many contractors and owners have begun to investigate prefabrication with internal resources devoted to it. However, for those companies who don't have a clear path or strategic commitment to using offsite construction will inevitably lack internal buy in to move forward with prefabrication when status quo exists.

Unfortunately, it's also negative experiences from owners, architects or contractors that end up with doubts about the merits of prefabrication, and how the expectations of what was being sold wasn't met. Modular factories in Canada have had a spotty track record with many examples of company failures which has left numerous owners with little recourse in being able to complete their projects. It's these types of experiences that has had a detrimental effect on any sustained uptake thus far.

Lack of Experience and Understanding

The construction industry is known to be resistant to change as processes have been so ingrained along with the methods, roles and tasks (Ajayi, 2019). As a result, there is a general lack of understanding from owners, architects, and the contracting community on how to use prefabrication since it requires a different process of engagement than conventional construction. There is strong awareness among the construction community for mass timber, panelization and modular, but few know how to use it correctly.

Owners are one of the key stakeholders who, unfortunately, suffer from low awareness of prefabrication and its benefits. Without proven examples or access to offsite facilities, there need to be comparisons and case studies to enable owners to make decisions. Worldwide, the lack of documentation for lessons learned on offsite projects and lack of owner's knowledge about hybrid construction (compatibility with other structure types and materials) has also been identified through study (Tarek Salama, 2018).

This combined lack of understanding from owners and the construction community creates a barrier to adoption if the use of prefabrication is not entertained early in the project idea phase. It's the lack of knowledge on how to implement it correctly that will create uncertainty among the owner or project lead and the idea will be killed before being able to gestate.

It's this lack of a defined process for design teams has been identified as one of the main hurdles. The required collaboration for a successful offsite project along with its heavy upfront design load and early design freeze requirement means the role of architects change from that of design lead to more of coordinator, since many of the prefabrication companies take on the detailed design. In addition, owners and architects are used to traditional Design-Bid-Build contract forms, which unfortunately do not work well with offsite construction. The offsite industry can also do itself a favour and begin to share its standard details and design knowledge in an open-source platform. As several interviews suggested, the perception of intellectual property barriers need to be removed if the industry is serious about increasing adoption.

With mass timber, many studies have highlighted the gaps and unknowns that are present to owners and builders. Those that have been identified include valuation of risk and impact of insurance, lack of documentation, and lack of history on the actual performance of the structures (Sorathiya, 2019). The latter concern can be applied to PMC systems too.

“If the growth rate is greater than the education, then the risk of people not using it correctly increases” Williams Munoz – Nordic Structures

The lack of awareness is also present among many Building Officials and Authorities Having Jurisdiction (AHJ's). The mass timber industry in Canada has obtained the necessary certifications and testing to enable building code changes. However, even with the upcoming changes to the code regulatory bodies such as AHJ's and fire marshals see it as new and different. Awareness requires education among all stakeholders and should be discussed early on in project planning. Volumetric and panelized projects also suffer from lack of understanding from regulators and city officials. Due to the double floor/roof assemblies required for multi-level modular construction, the building height 'grows' versus traditional platform framing. This can lead modular structures being excluded from areas with restrictive zoning and height regulations.

Modular projects can also face resistance especially when governed by the prefabrication standard of CSA A277. Acceptance varies among the inspectors' experience and understanding of how factory constructed processes link to the building code (Steven Kuan, 2016).

Before widespread adoption and critical mass is achieved, numerous studies have recommended short professional development courses by professional industry bodies and incorporation of offsite construction technology in existing academic curriculum to broaden the knowledge of prefabrication in the interim (Ajayi, 2019).

Transportation and Logistics

Transportation and logistics can be one of the biggest obstacles for offsite construction. Among the more efficient transport systems in offsite construction is “flat packing”. This works especially well for open panel systems, and CLT, as standard freight carriers can ship and stack panels horizontally on flat decks without too many restrictions and at a relatively low cost. For those utilizing ‘flying factories’ (temporary facilities used to manufacture prefabricated components are different from conventional off-site factories in that they only operate for the duration of a project and are then closed down (Designing Buildings Wiki, 2020)), this tends to be less of an issue. However, closed panel systems tend to be shipped vertically and often require specialized carriers and racking frames to be able to ship the panels without damage. As a result of shipping vertically, the panel height will be limited as road restrictions will have height limitations that could present challenges in optimizing the panel system. Modular tends to be the most restrictive of all, as various jurisdictions have different road permitting requirements that may restrict the size of modules (in height, length, and width) from getting to a particular project site. The transportation hurdle for modular can be especially difficult if transporting across provincial or international lines. For example, in the prairies, modules can be up to 7.3m wide along certain routes, whereas in BC there are maximum widths of 4.88m wide.

With all prefabricated systems, it’s important to consider the end location and crane access to position the prefabricated elements in place. Often tower cranes and mobile cranes are used for panels and mass timber systems and the components tend to be more manageable and have less weight than modular systems. Modular systems require special rigging and spreader-bars and are much heavier and typically require more planning in order to position cranes and ensure adequate reach. It’s also important to understand the project site limitations especially if there are overhead power lines and large slope gradients involved.

The important lesson is to evaluate all site access requirements, and transport routes from the factory to the jobsite at the earliest possible stage in design. Any later in the process and the project may face an unfortunate hurdle that can’t be overcome.



Source: Seagate Structures

Transportation and craning are more costly for closed wall and volumetric projects compared to other forms of prefabrication. Shipping cost is based on transport distance, permitting, and the number of loads required to ship from the factory to the project site. Permitting costs can be minimal if the design is optimized with transport as a consideration. If the project has unique elements that push the size into an oversize load category, permitting costs can be very expensive. On a relative transport cost basis, modular is the most expensive of the prefabricated systems due to the volumetric nature of the load and the specialized carriers that are required. Because modular systems are shipping 3D volumes, they have a higher transport cost per square meter of wall area than other systems. Craning too can be extremely cost prohibitive especially if there are heavy loads and large distance and reach requirements that increase the size of the crane. If the craning cost becomes excessive, it may be enough to kill a project.

When handling and managing wood prefabricated systems, attention to weather protection of finished materials is important. The requirements differ slightly among systems, but NLT requires additional protection over other CLT systems due to the high wetting and low drying potential (Wang, 2016). Other finished prefabricated systems of one side closed panelized and volumetric modular systems require special handling during erection to mitigate moisture penetration. For all systems, joints between panels, interconnections between modules, and interfaces between site components require more detailing than what is traditionally expected in site construction. In addition, timing issues between site construction elements and prefabricated elements will sometimes mean that storage and weatherproofing of the offsite elements will need to be considered. Lack of consistent guidelines and lack of best practices for inexperienced project teams has resulted in poor execution and hence unfavorable experiences among owners and project teams. More education and standard process work in this area is required to mitigate any future concerns.

Contracts and Procurement

The construction industry continues to use a very linear approach to construction contracts as Design-Bid-Build (DBB) contracts are the industry norm. This contract method results in contractors and designers being siloed until the construction begins. In this model, the designs are only 'tested' for constructability when project teams are onsite and where it's also the most costly and disruptive to remedy mistakes (KPMG, 2016).

As a result, the DBB model does not work well for prefabrication. This sentiment was echoed numerous times during stakeholder interviews. Prefabrication requires early input from manufacturers and builders to optimize for prefabrication. Therefore, Integrated Project Delivery (IPD), P3, or Design-Build procurement models can work very well as they involve tremendous amounts of collaboration. "Construction Management at Risk (CM) contracts can work well too if the project team of owners, design, and CM entity are forward thinking, otherwise the process from the offsite contractor's point of view can be seen as still being similar to a DBB" (Taylor, *Industrialized Construction: Business Practices and Relationships in Off-site Construction*, 2020). Joe Geluch, President at Naikoon Contracting utilizes this approach on his non-residential projects and finds it successful as they can offer a lot of value under a preconstruction agreement.

Under a traditional DBB model, owners will spend money for design and rely on an architect or cost consultant to provide budgetary pricing prior to bidding so that they can develop project budgets. Often, owners will turn to a prefabrication option after this stage is reached in the hope that turning to prefabrication will save them money. Unfortunately, the time to consider prefabrication had long passed, as the project will have to be redesigned to accommodate prefabrication. This lack of understanding of how prefabrication works is more about the process and less about the actual form of construction. Prefabrication will continue to lag unless more owners and architects understand the process of where to bring the option of prefabrication into the discussion. Effective communication processes, and an understanding from design teams of a Design for Manufacture and Assembly (DfMA) approach can reduce the likelihood of cost escalations (M. Aris, 2016)

A commitment by an owner to move forward with an offsite project typically means they will not obtain their fixed price until a buildable design is locked down. It is why a pre-construction or IPD contract that brings the owner, design team, contractor(s), and prefabrication manufacturer to the table early in the design process is the more successful way to build an offsite project.

However, across all forms of prefabrication, there is not enough experience to determine what type of contract model works best. Many contracts for mass timber buildings result in subcontract supply agreements with a trade contractor agreement for erection of the structure, but the industry is accepting of all models of contracts which does lead to uncertainty of which model is best.

Owners wanting to procure innovative methods often find the lack of supply chain and proven examples as hurdles. Many owners interviewed don't want to be "bleeding edge" and don't want to undertake an offsite project when there are very few options available to them. Those procuring offsite methods want to feel confident in the supply chain and that there is competition and depth available in the market. One of the largest universities in Canada looking to undertake a large student housing project found the lack of supply chain in the panel industry a risk and decided to kill the project. The City of Toronto found this when seeking expressions of interest for modular providers for providing permanent



Source: City of Toronto (Blog TO)

affordable housing. The desire of the City was to find one company to handle the entire project. Of 36 firms who responded, 3 were prequalified and only 1 was able to meet the requirements of the tender.

Unfortunately, the fragmented nature of Canada's geography leads to lack of manufacturing options in many markets. In addition, lack of standards for product performance has been identified as a hurdle since individual modular and panel manufacturers tend to fabricate differently which leads to details that may not be the same from company to company (Steven Kuan, 2016).

Costs

Using hard construction costs to evaluate traditional projects versus offsite prefabrication projects will result in offsite construction struggling to gain traction if evaluated purely on this basis. The construction industry is so entrenched in hard construction costs and 'dollars per square foot' that offsite construction will struggle to obtain more market share until such time that the other benefits of offsite can be quantified. Better evaluation and comparative analysis of systems from the early schematic design stage right through to commissioning and turnover are required to properly evaluate offsite systems. This means further quantitative and comparative evaluation of real project examples are required. Evaluation can be divided into the following categories (Helen Goodland A. L., 2019):

- Soft Costs – Such as project financing, design fees and bidding costs
- Offsite construction costs such as prefabrication costs (plant overhead, labour materials), transportation, and installation
- On-site construction costs such as owners' business costs, general requirements, material/labour differences due to prefabrication, assembly, and handover costs.

A more detailed list below outlines these ancillary cost considerations that ideally should be considered:

- Additional design time required and early project team integration
- Time savings for quicker turnover which equates to:
 - lower GC General Requirements
 - Lower construction financing costs (less any costs associated with the unique cashflow curve required for offsite projects)
- Weather related impact costs
- Worker safety costs
- Less re-work, higher quality and smaller turnover punchlists
- Earlier revenue generation if a revenue producing asset
- Social and neighbourhood impact
- Reduction in waste
- LCA cost
- Insurance / bonding costs

A study into prefabrication processes in the health care sector aimed to calculate the benefits from offsite construction. In the study using bathroom pods, exterior wall panels, MEP racks and patient headwalls, there was a 6% cost premium paid for prefabrication, but a 10% schedule savings and 150,000 hours diverted which led to a value-based benefit to cost ratio of 1.14 (Eric Antillon, 2014). It's these types of studies that show direct cost savings are not considered to be the main benefit of prefab, but the ancillary benefits which can be significant when quantified.

A recent study in BC compared the hypothetical cost of stick-building a wood frame 50 unit building versus panelized and modular. Panelized and modular were 4.6% and 14% more expensive respectively than conventional construction with time savings of 10% and 26% (Taylor, Industrialized Construction: Light Wood-Frame Construction Costing Comparison - Site-Built vs Closed Panelized vs Modular, 2020). In future, being able to quantify the benefits of prefabrication will make the decisions on construction methods easier to compare.

For those manufacturers using automated processes, dimensional stability of the resource is important for maximum construction efficiency. As a result, most automated manufacturers use premium-grade lumber for wall framing, and those using CNC processing lines, there is now a growing trend toward engineered lumber (Li, 2020). ACQBuilt in Edmonton is one such company that has moved to engineered lumber for this reason. Since panelized and modular also increase the amount of the resource required relative to traditional LWF site construction by an estimated 5% and 15% respectively, the argument is that the increased quality and labour savings outweighs any incremental costs.

There are also specific trades and equipment required for offsite construction that have potential cost impacts. These include specialized transport equipment especially for transporting wall panels vertically, and for modular construction. Also, the larger the prefabrication elements the larger the crane which increases costs. These logistic elements are not present in traditional construction and add incremental costs to the project. Due to the early adoption phase of prefabrication, there tend to be fewer trade contractors with the knowledge that can erect the structural elements of offsite

construction. As result of the specialized nature, these companies tend to have higher charge out rates than their traditional construction labour counterparts.

It's the immaturity of the prefabrication industry in North America that can also be seen among site trades integrating their work into finished assemblies. If site trades are not engaged early and scope of work delineations are not undertaken, MEP contractors tend to put risk dollars against their work due to the unfamiliarity. These layered on costs have resulted in projects being cancelled or projects being re-engineered for site construction.

Finally, little understood by those outside of the prefabrication industry is why prefabrication is more expensive than site-built construction. The prefabrication industry has done a poor job of explaining the operating cost and capital cost requirements that need to be captured from running a manufacturing facility. Offsite prefabrication is a capital-intensive business with higher overheads than the general contracting business. There is considerable land and facility capital costs that construction companies don't have in their business models. Depending on the levels of automation, or subcontracting of the work, many of the labour components can be similar to those of onsite construction, but the indirect costs supporting the business may be higher. Offsite manufacturers must convey to the unfamiliar that it's project backlog and efficiency of production that leads to a successful company. If backlog or efficiency, and even both are lacking, the capital required to support the factory overhead will spell disaster for the company.

Financing and Insurance

The cashflow model for offsite construction is unique and can create confusion and uncertainty for many who are new to using prefabrication. The requirements for prefabrication's higher up front cash outlays required to purchase the offsite building components in advance of construction and the inflexibility and lack of understanding of banking institutions on how to tie the offsite components to the land for collateral creates resistance.

Currently, there is much less resistance from owners and contractors in procuring structural wood components in advance of construction, as the concept and understanding among the construction community is similar to that of other structural systems (i.e. structural steel for example). However, as the amount of multi-trade finishing in the offsite system is increased, the dollar value increases, and ultimately so too does the resistance for the providing large capital outlays prior to delivery. Many factories will want advance payments to book production times and procure long lead materials – this is foreign to many lenders and owners. For those new to prefabrication, this usually takes some education and even tailored finance terms to come up with a workable solution. But without standard and uniform expectations across the industry, the adoption will continue to face resistance.

Insurance can create issues for many of those wanting to utilize wood systems. Understanding of fire ratings and the properties of mass timber requires education for the insurance industry. And while the industry has come a long way in addressing those issues with product testing and acceptance from code officials, there are still companies that put increased insurance premiums on these systems. In a study of participants using mass timber, "misconceptions about mass timber with respect to fire and

longevity” and “high uncertain insurance premium” were among the largest barriers to adoption in Canada (Syed, 2020). Interviews with owners echoed the same hurdles.

Water penetration and ingress during construction can also play havoc with those who are erecting a prefabrication project. Protection of finishes is paramount to the success of the project and avoidance of re-work and insurance claims. Unfortunately, the lack of consistent industry standards on addressing water mitigation during construction for each of the prefab systems adds risk, potential costs, and ultimately another barrier to adoption.

THREATS FACING CANADA’S PREFABRICATION INDUSTRY

Demand for Talent

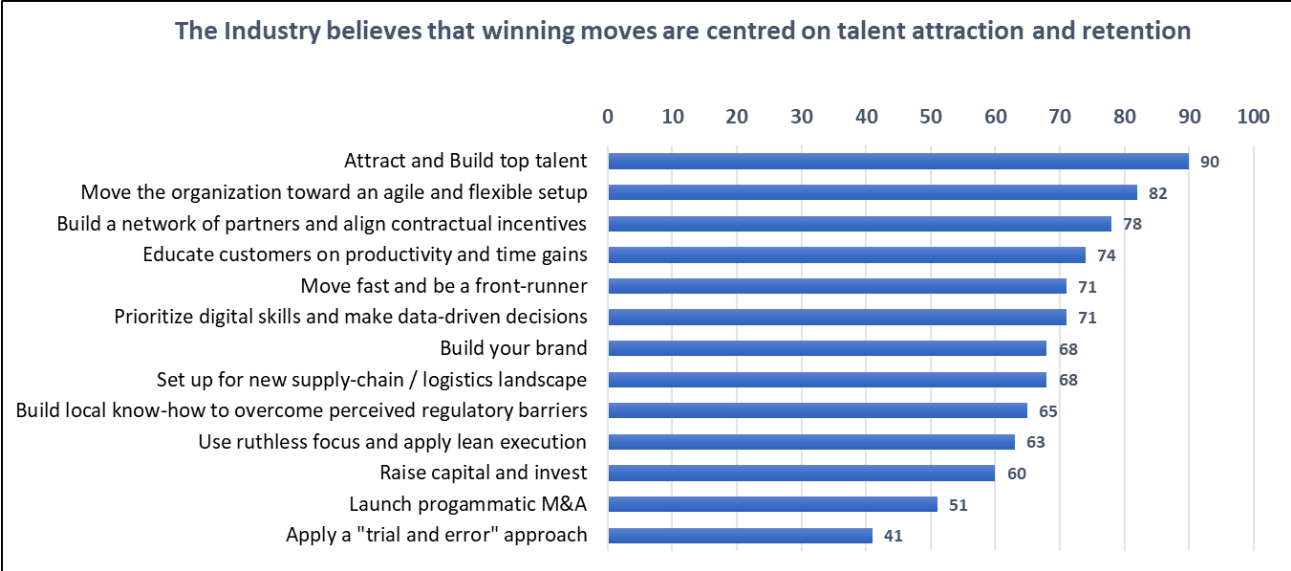
Over the last decade, Canada has cemented itself on the world stage with having a renowned wood science and mass timber ecosystem. However, with the increasing demand for mass timber buildings in North America, like the construction industry it too has developed a skills shortage. With the industry still in its infancy, the labour and knowledge pool of those qualified in mass timber engineering, design, and construction is relatively small. A recent study reported that an “Inadequate Skilled workforce” and inadequate specialized contractors were rated as “very challenging” (Syed, 2020). This was also a common sentiment among many interviewees that there are currently very few available engineers and designers available.

Unfortunately, there are very few mass timber training programs in Canada. It wasn’t up until 2017 that the first training program was developed. Across Canada, there are only a handful of post secondary institutions offering training. As with most institutions, courses will only be offered when there is a critical mass for demand. BCIT is offering their first intake of students for the Associate Certificate program for mass timber installers in January 2022. Up until now, the school has relied on partnerships with industry to offer short form courses or webinars addressing specific aspects of Mass Timber.

Knowledge Drain

One must only look south of our border to see the potential growth that is coming to the Mass Timber Industry. Already, many of the existing US projects dwarf those that we see in Canada. In the next five years, there is expected to be four new mass timber plants coming on stream. With the adoption of 18 storey mass timber buildings in the US, the demand for top talent experience in the form of engineers, designers, and contractors with mass timber experience will also multiply.

For US employers, the Canadian to US exchange rate will be advantageous to companies looking to secure Canadian workers, and with the proven ability to work remotely US companies will look to import the skills necessary to feed that growth. Thus, the threat of draining the existing and future Canadian talent should be on every Canadian Mass Timber company’s radar.



Source: Data from McKinsey and Co, 2020

Many Canadian mass timber companies’ personnel are already being exposed to the US market through export work. Lack of expertise in the early mass timber market in the US has created opportunities for some Canadian companies in the way of providing training for the US workforce. For the new Google mass timber head offices Structurlam of Penticton provided the mass timber for the project with Kinsol Timber of Vancouver Island providing the construction and erection expertise. As commented by Robert Malczyk at Timber Engineering, “the California market is suffering from lack of coordination and needs to change”.

The rest of the offsite industry is not immune to the demand for top talent. Domestically, there are very few senior people with the expertise in prefabricated systems. Even those who are being trained in industrialization and automation are being lured away by other technology companies. A discussion with University of Alberta’s Dr. Mohamed Al-Hussein at the Hule School of Engineering revealed that five of his last year’s class obtained jobs with Tesla.

In summary, it will be critical to the industry to develop talent and retain it. It’s important the market begin developing a healthy, innovative, and supportive ecosystem here in Canada that showcases our ingenuity and expertise and that will encourage people to stay.

Failures of Prefabrication

In North America, there have been a history of high-profile offsite construction businesses and project failures that have caused tremors throughout the industry. Of course, the largest, and most recent business failure was Kattera – the mass timber and panelized company that tried to take a “one size fits all” approach to disrupting construction. A 2018 CLT project failure occurred at Oregon State University, whereby 100 CLT panels had to be replaced at the Peavy Hall project when two layers of a 30-foot panel crashed to the floor due to an adhesive and curing issue with the CLT panels.

Here in Canada, the bigger failures have occurred within the modular construction business. Over the past 20 years there have been many regional modular business failures, that have created pockets of reluctance from stakeholders and owners to try modular again after having seen their projects left unfinished or tied up in bankruptcy proceedings. A BC university recently completed two modular projects by two different manufacturers within a year only to see both companies unable to complete their warranty period due to bankruptcy.

Within BC, there have been three modular business closures and bankruptcies in the past 5 years. The common theme among many of them is poor management, lack of backlog, inadequate financing, and a high-cost manufacturing environment. It's the latter that many prefab manufacturers struggle with here in Canada. It is very difficult for prefab companies to survive in locations of high land costs, and locations with pressure on labour rates. It is why many prefab companies worldwide tend to be outside metropolitan areas.

One of the other differences between Canada and Europe, is the predictability of the offsite process. An interview with Dr. Mohamed Al-Hussein described it perfectly. Here in Canada "virtually all manufacturers don't know how long it takes to design a building, and don't know how long it takes to construct a building". In working with ACQBuilt, he and the owners were able to build a predictable prefabrication model that gives certainty to the process, and ultimately gives certainty to the customer. As Rhys Kane from NRB remarked, "the modular industry is confused in its identity...are we manufacturing or are we construction. Until it becomes manufacturing, it will remain a skills-based industry".

At the project level, PMC has struggled to showcase successful examples of projects. Interviews with stakeholders were critical in this regard with many projects struggling to control costs, each manufacturer having their own proprietary manufacturing method, and ultimately not being able to live up to the advantages that were sold. Ryan Smith refers to the "Three C's" of evaluating modular companies prior to undertaking projects; those being Capacity, Capability, and Competence. PMC companies also need to understand their own shortcomings and not take on projects for the sake of winning the work.

However, PMC has thus far been able to carry on and grow. Many modular companies have learned the hard way that selling a project to a new adopter of modular comes with higher expectations placed on successful execution. Anything short of a positive outcome has left many newcomers asking whether the expended effort was worth it. To safeguard against project expectations, it's equally important to prequalify the owner as much as it is the building. Understanding the drivers by the owner, will help companies deliver a much more successful experience for everyone involved.



Source: RDH / BC Housing – Modular Moisture Management

One of the biggest risks in offsite construction is water penetration during erection. No matter what project type nor type of offsite construction is the need and requirement for a water mitigation plan during storage and execution. Water ingress during project assembly can eliminate any of the potential schedule gains and associated benefits offered by offsite. Unfortunately, there have been some poorly executed projects by both experienced and newcomers to offsite construction. At the root of the problem is the fact there are no industry standards on erection and waterproofing of offsite projects.

“You have to build a water management plan as though it is going to rain every day” Brent Olund, Urban One Builders

Every project team appears to have developed their own methodology and water mitigation plan. A set of industry standards on preventing water penetration and a standard moisture mitigation plan for all forms of prefabrication would greatly assist the industry.

Stakeholders and Regulatory Bodies

One only must look to the UK and the Grenfell Tower fire in 2017 to see the effects that one incident can have on an industry. In 2020, England announced that it intends to reduce the maximum height allowance of wood-framed buildings from six stories to three or four stories to reduce the fire risk of combustible buildings. Those close to the research realize it's a 'kneejerk' reaction not founded on science, but perception.

Offsite construction is still in its infancy in Canada and as such is subject to a higher level of scrutiny among those on the outside looking in. Critical to the success of offsite in Canada is education and proof

of concept. This means successful examples, case studies and education of offsite methods to building officials, lenders, insurers, owners, and other key stakeholders.

A recent study into the needs assessment of influencers in mass timber identified some of the following considerations, and can be applied to other forms of offsite (Scius Advisory, 2020):

- Stakeholders rely on the professional judgement of registered architects and engineers, and on testing certificates
- Contingencies are added for the fear factor of the unknowns
- A reluctance to use mass timber if local codes don't easily accommodate it

Ultimately, it is important for project teams to be proactive, and manage and address perceived risks early in the process if offsite is to satisfy regulatory bodies and become mainstream.

LESSONS FROM THE FIELD

Through the numerous stakeholder interviews and the supporting research from across the prefabrication industries of mass timber, panels and volumetric modular are a number resonating messages that, if acted upon, will enable the future success of these industries.

How Best to Utilize Prefabrication

Successful prefabrication is all about the process. Too many offsite projects begin in the same manner as traditional construction projects and immediately are unable to realize the benefits of what offsite construction offers. Sadly, the offsite industry suffers from a need for a “best practices” process that allows those new to prefabrication can easily adopt. As a result, many owners and prefab companies alike, undertake projects that have been poorly qualified and won't lend themselves to the benefits of prefabrication. The resulting lack of project success leads to dissatisfaction, lack of future commitment, a tendency to resort back to traditional site-built construction, and an opportunity at conversion lost. When the offsite process is executed correctly or results in even marginal success, experience has shown that owners see the potential opportunity to leverage the experience to optimize the process further on the next project.

Critical to the success of every offsite project is the requirement for collaboration among all those involved in the construction process. For those new to prefabrication, it's very important to have experienced members of offsite construction at the table. If a project team new to offsite construction decides to undertake their first project without the aid of experienced offsite professionals as part of the team, the project will invariably lead to failure. A number of interviews talked about the need to manage expectations for those new to offsite construction. Successful projects require early input from those most experienced in the execution of offsite construction – the offsite engineers, designers, manufacturers, and contractors – those who understand the offsite process. “It's the Rule of 3”, as Ryan

Smith from the University of Washington State likes to say. It usually takes three projects for a project owner and project team to begin to realize the true benefits from offsite construction.

With Mass Timber, the manufacturer's input early in the design process allows CLT manufacturers to optimize the design for their manufacturing facilities and their CLT presses. This benefits both the manufacturer and the project team as it not only increases output, but also lowers costs. This is also important when CNC machines are used. Since CNC machines are often the bottleneck in production facilities, optimizing the design and flow through of the plant is important. Several comments from those involved in mass timber projects stressed the need to have the manufacturer and engineers at the design table early to push for more standardized connections rather than having custom fabrications.

Modular requires extensive collaboration due to the number of upfront decisions that must be made which involve mechanical, electrical, and plumbing consultants and trades. In addition, all architectural finishes require decisions prior to going into construction as manufacturers only begin work when all required materials are in the factory. A guide for architects was developed by AIA to assist teams during the design process (The American Institute of Architects (AIA)). It provides an overview of what's important in the modular approach at different stages of design and is a great document for those project teams who may be new to modular.

Culture and Contracts

Offsite construction success comes from the iterative design process and requires a high level of information flow among team members. The culture of teamwork and collaboration to ensure that all parties are talking and problem solving through the design process is what results in an effective offsite project.

In general, the collaborative design process results in delivery models that are better suited to prefabrication than others. Design-Bid-Build should not be used with offsite construction, as the owner and project team develop a design in isolation from the contractors and manufacturers until the bid process. It's at this juncture that the design team may be unwilling or even unable to make changes to optimize for the offsite process. This often results in a poorly optimized offsite project, and some manufacturers may be unable to build what has been designed. Unfortunately, many public sector procurement entities have long used Design-Bid-Build and are unwilling to change their process. This contractual method is often based on lowest price and the structure typically results in poor communication among parties, a longer construction schedule, and a commonly leads to a combative project environment.

Project delivery models that work well are Integrated Project Delivery (IPD), Design-Build, and Construction Management (CM) with early collaborative pre-construction. IPD is new to North America, and thus far has really only been seen on larger scale projects. However, the IPD collaborative approach can be utilized in a Design-Build model as all parties can flesh out the details during the design development process, with the offsite manufacturer at the table ensuring any manufacturing constraints are embedded into the design. The advantage of this process means firm construction budgets can be developed ahead of construction, and many typical site construction project risks can be removed.

Overcoming the Finance and Insurance Hurdles

Prefabrication projects vary in the degree to which the amount of the structure is constructed offsite. The higher the percentage of the project being constructed offsite results in challenges with financing for owners as the value of the unsecured product increases. Manufacturers will want funds to secure materials prior to production and will often require funds to secure production space. This initial amount (sometimes up to 25% of the total value of the offsite components) can result in large capital outlays for the owner with little security. Lenders too see this as a challenge, as they typically disperse funds based on progress at the construction site as it can be considered as secured real estate.

Overcoming this hurdle with prefabrication requires owners to engage lenders early in the construction process. Through early engagement at the schematic design phase, a process can be implemented well ahead of production whereby lenders will have oversight into the production process and even take a security interest for the materials involved in the construction. Lenders will often request financial information from the manufacturer to determine the level of risk in advance of starting construction. Once lenders are educated on the process and understand the risks, many lenders then see offsite construction as a potential stream of business. Since offsite construction costs are fixed prior to going into production, the educated lender sees offsite as less risky than on-site construction due to the minimal change orders and certainty around production and erection schedules.

Insurance costs can also be mitigated with early communication. It is advisable to have a fire safety engineer as part of the project team. Unfortunately, the insurance industry hasn't yet understood the true benefits from offsite construction by the premiums being charged as there are variable insurance risks associated with the different forms of prefabrication.

For the mass timber industry, much of the effort to date has been about debunking myths about wood and the effects of fire. Insurance premiums for post occupancy insurance and strata insurance on mass timber midrise projects are not yet seeing the savings versus light wood frame even though the building is considered safer. In addition, Course of Construction insurance premiums for low and mid-rise mass timber under construction haven't yet seen the savings versus light wood frame even though there is less risk of fire during construction. This was commonly brought up in conversations with those involved in mass timber. Therefore, further education of the insurance industry is required with more case studies and examples to showcase. The changes coming forth in the updated national model code will help legitimize the use of mass timber and provide certainty for insurance providers.

For all forms of prefabrication, water is the enemy during erection when the building is open to the elements. There certainly have been numerous instances of water ingress during the erection period for all types of prefabrication which has resulted in delays to the project and subsequently large insurance claims to repair and replace finishes damaged by moisture. Because modular involves completely finished spaces, the risks of water ingress behind envelopes and in cavities during the erection process can lead to on site remediation and drying out to stem potential mold issues. Panelization also has this issue, but is less of a concern in one side closed panels, as materials can be dried out. Mass timber can also be susceptible to moisture, so attention must be paid to the horizontal and end surfaces and any water must be removed by sweeping or squeegeeing to reduce the risk of absorption.

The one common element among all forms of prefabrication is it's critical to have a water mitigation or moisture protection plan for the project during erection and prior to the topping off. To minimize premiums, insurance companies will often want to see this from the project along with transport and storage plans. For all forms of prefabrication, it is essential to determine the type of covering material being used to protect the surfaces during storage and transport, and at the end of each work day to protect from moisture as the project progresses.

Education and Retention

Despite a long history of wood use here in Canada, prefabrication is very much in its early stages. Thus, the ecosystem for prefabrication is not as developed as many other areas in the world. The pool of knowledge and experience in prefabrication here in Canada is very small with many having come from nations well versed in offsite construction. As the demand for prefabrication expands, it has put workforce pressures on companies needing to find experienced people, and in some cases is limiting their growth.

Studies have identified particular professional and vocational skills required in prefabrication that are different than those in on-site construction. These include skills in (Buddhini Ginigaddara, 2019):

- Designing and manufacturing
- Advanced factory production and logistics, materials handling
- Knowledge in DfMA
- BIM and technology driven advanced ERP Systems
- Process management, design for lean production
- Whole life costing for offsite processes
- Production engineering and process efficiency, purchasing, planning and project integration
- Hoisting, assembly and erection of components, sequencing, crane work, finishing trades

Since these skills are specific to prefabrication, the pool of skilled labour that possess these skills is extremely small.

The most common constraint across all forms of prefabrication is lack of experienced designers, and many companies are lacking the technical experience required in mass timber and modular. A number of interviews identified this concern as a barrier to growth for the industry. At present, many mass timber and modular companies must offset this deficiency with attempting to hire their own in-house engineers, architectural technologists, and technical support staff.

This concern isn't just a Canadian issue. A recent study among US manufacturers and installers identified the lack of work experience in timber construction as the most challenging factor in the US industry with 29% of the respondents concluded that companies and field crews have much less experience with mass timber than they do with other forms of traditional construction (Shafayet Ahmed, 2020). A recent interview with Nate Bergen at BC's Kinsol Timber, discussed this very issue while he was working on the new Google Mass Timber head office project in San Jose. It's the future

growth outside of the Pacific Northwest that will draw expertise from Canada and other markets using mass timber.

As demand for mass timber continues to grow, many universities and technical colleges have been lagging to develop curriculums and programs that support the industry. Since there must be a critical mass of demand requested by industry to support a field of study, it is only recently that institutions have begun to offer studies in prefabrication and mass timber. It has only been 5 years since the first mass timber program was offered in Canada, and in 2022 it will mark the first time a technical mass timber program is offered at BCIT.

However, there are difficulties in offering programs when an industry is still in its infancy. UNBC has had difficulty in attracting students to fill its master's program in Integrated Wood Design but will be continuing to venture forth and collaborate with University of Victoria to begin offering a prefabrication course in the future. At the Hole School of Construction Engineering at University of Alberta several recent co-op graduates all trained in industrialized construction were lured by work outside the industry. It's important to recognize that we are now living in a new economy where digitization and automation are important drivers in many industries outside prefabrication. Therefore, it should be expected that those trained in prefabrication and industrialization will be enticed to work in other markets.

As a relatively small player in the world of prefabrication, Canada should be paying very close attention to what is going on in the U.S. and its growing appetite for experienced people in wood engineering and prefabrication. It wasn't long ago that former U.S. based Katerra acquired BC firms, Equilibrium and Michael Green Architecture. With an attractive exchange rate and the U.S.'s enormous projected growth in modular and mass timber over the next decade, Canadian companies should be highly focused on employee retention if they are to preserve their best people.

The Role of Government

There are many good examples from other jurisdictions around the world where government support in offsite construction has allowed the industry to flourish. We will look at the input from the three levels of government here in Canada and where further support is required.

Federal

A number of countries have recognized the importance of prefabrication and the future possibilities it holds in addressing the productivity and skilled labour issues of traditional construction.

In the UK, the journey began with a report in 1998 by Sir John Egan titled "Rethinking Construction". It was the first in a line of reports that began to bring awareness the existing construction model in the UK was broken and a new line of thinking was required. Recently, there have been subsequent reports addressing the need for offsite construction to be used more extensively. This included a 2017 housing white paper, and in 2018, a House of Lords report recommended development of a framework to assist government toward advancing the role of offsite construction to address the inherent issues in site-built

construction (Lords, 2018). A follow-up to this report and another white paper into the use of MMC for housing was published in 2019 and provided an update to industry on the traction of MMC.

There were several key recommendations from these reports that can be utilized here in Canada if we are serious about growing the adoption of prefabrication.

Some of the recommendations in the report include:

- A “presumption” in favour of MMC, supporting the pipeline for manufacturers, and strengthening the supply chain
- Focusing in on those sectors where MMC contributes to quality and speed of construction with emphasis on affordable housing and build-to-rent
- Access to finance for existing builders and for new entrants into the market, and a focus on capital for Research and Development
- Establishment of an MMC Working Group to address barriers in insurance, finance, and assurance and develop a standardized definition and framework
- Collection of datasets from project builds to better support the industry
- Support for affordable housing through partnerships to delivery over 40,000 units of affordable housing each year.

The last item is particularly important, as the UK government has come to the realization it can’t develop housing without external partnerships

In 2019, Japan’s biggest housebuilder, Sekisui, entered a venture with the UK government expected to result in thousands of modular homes across the country. In addition, in June 2019, the Worthing council gave permission to Ikea to build modular homes on the south coast in a joint venture with the construction firm Skanska. Later this same year, the housing minister announced a USD \$37 million investment in Ilke Homes’ modular housing factory to boost production to 5,000 homes a year within five years. Further calls for government support have come forward mandating the use of offsite construction for all projects over a certain size (Mike De'Ath, 2020)

In Singapore, the government has stipulated the use of volumetric modular construction in up to 65% of certain land parcels and has established a policy system that gives offsite construction a competitive advantage over traditional construction (Yanhui Sun, 2020).

Even to the south, two US states have begun partnering and investing with modular companies to deliver affordable housing. Indie Dwell has recently announced a partnership with the State of Virginia to assist in the supply of affordable housing. Virginia invested \$2M for Indie Dwell to establish a new operation in that region.

Despite some small funding investments to industry here in Canada (i.e. Structurlam’s \$5.7m investment from provincial and federal governments), we have yet to come forth with any specific funding program or policy referencing or mandating the use of Offsite Construction. Over the past decade, the federal government has indirectly funded programs focusing on wood use with programs such as GCWood, Forest Innovation Program, Investments in Forest Industry Transformation and the Expanding Market Opportunities Program. These programs have supported mass timber research and development, and product and building demonstrations.

Likewise, federally funded organizations such as the National Research Council, FPInnovations, and the Canadian Wood Council (CWC), along with academia, have helped to advance the research and development, demonstration and deployment of mass timber, panelized, and modular systems – all with the goal of ensuring industry success.

Thus far, the only initiative that has definitively spelled out a requirement for offsite construction has been through Canada Mortgage and Housing Corporation (CMHC) Rapid Housing Initiative. With recognition that there continues to be a shortfall in the construction of housing, the federal government in October 2020, through CMHC, issued the \$1B Rapid Housing Initiative to rehabilitate existing housing and utilize prefabrication in delivering new housing under the Cities Stream for municipalities and Projects Stream for development agencies. Due to the overwhelming demand and a four-fold

“Our conclusion is clear: housing construction has not kept up with the demand and, when looking at international comparisons, the shortage of supply is even more sharply evident.” Jean-Francois Perrault – Scotiabank Report on Housing 2021

oversubscription of applications for the funding in the first round, in 2021, CMHC extended the program funding to previous applicants under a Phase 2 worth \$1.5B.

Over the past 7 years, the construction and development industry has not been able to keep up with the demand for housing in Canada. Taking lessons from other countries where offsite construction is established and growing, Canada’s federal government must employ new strategies to take a long-term view and procure the next decade of housing now by utilizing offsite construction if it is to have any hope of meeting its new housing targets. By doing so will provide long-term certainty of pipeline, spawn investment into technology and innovation, and increase future productivity of construction.

Provincial

Within several provinces, there have been both direct and indirect initiatives supporting offsite construction. A few jurisdictions have seen the advantages of modular and mass timber systems when it comes to speed and low carbon construction alternatives, and as a result have released further funding programs directed at these sectors.

A listing of provincially funded programs and initiatives directly supporting mass timber and modular is below:

| JURISDICTION | PROGRAM / INITIATIVE | DESCRIPTION |
|--------------|--|--|
| BC | Wood First | 2009 – mandating consideration of wood for provincially funded public projects |
| BC | BC Housing Modular Rapid Response to Homelessness | \$291M investment to build 2,000 modular supportive housing units. |
| BC | Mass Timber Demonstration Program | Provides funding for incremental costs in the design and construction of mass timber buildings |
| BC, AB, ON | Adoption of Provision for Encapsulated Mass Timber Construction 12 storeys | Additions to the provincial building codes ahead of release of the 2020 NBC |
| ON | Mass Timber Program | Funding for research, development, training, partnering with post secondary institutions, profiling technology and subsidizing costs with projects |
| ON | Accelerated Build Pilot Program | 2020-2025 - \$1.75B toward long term care facilities using offsite construction |
| QUE | Wood Charter | 2013 – Wood use mandated for provincially funded projects. |

Midway through 2020, the Ontario government announced the Accelerated Build pilot program investing \$1.75 billion over the next five years to create more urgently needed long term care beds through rapid procurement and modular construction. It’s the province’s first publicly funded program geared to offsite construction.

Also, within the modular field, BC Housing (the crown corporation reporting to the Ministry of Housing) has long been a supporter of innovative housing delivery. However, it’s only been in the past 7 years that the province has embarked on a modular build program for shelters and transitional housing. Early in 2015, BC Housing prequalified several modular builders and direct awarded over 2000 units of housing to the industry using a Design-Build contract method. Considered a success by many as it delivered the required energy efficient housing within the requested time frames, many manufacturers struggled with the Design-Build delivery model. The manufacturers struggled in the role as prime contractor under a Design-Build delivery model due to lack of site and development experience, and lack of capacity. A better model for the program would have been for manufacturers to team with general contractors who had experience with this delivery method. Lessons learned from this exercise is that industry and government need to communicate and collaborate in advance of releasing initiatives to build capacity and ensure success.

BC Housing continues to utilize modular construction within their regional portfolios but have recently expanded their interest in prefabrication by exploring mass timber and panels with a number of projects currently in design.

The driver for mass timber funding has been primarily in the non-residential sector with provincial governments push toward the adoption of low carbon construction alternatives.

With the BC Wood First Act that came in 2009 and Quebec's 2013 Wood Charter, both initiatives mandated wood use as the primary material for all provincially funded projects. This preference for wood created capacity in the market and led to private development of the first CLT production lines and eventually some of the earliest Tall Wood structures in the world. Of all the completed projects in Canada to date, more than half have been constructed in BC which has led to the most developed mass timber ecosystem in the country.

Groups such BC Council of Forest Industries (COFI) and Woodworks BC (the provincial chapter of the Canadian Wood Council), as well as private not-for-profit groups such as FPInnovations are all critical to providing support to the fledgling industry in research and development activities, in supporting code changes, data collection for projects, and providing lessons learned and project histories for industry. Support from government in the funding programs of Forestry Innovation Investment (FII) and the establishment of the Office of Mass Timber Implementation (OMTI) are key to supporting the ecosystem. It's because of collaboration between industry and government that the Mass Timber ecosystem has flourished, and it's the collective effort from which other forms of prefabrication can learn.

Municipal

There is a cry from the offsite industry worldwide for cities to improve and provide certainty around permitting timelines. It's only then that owners can really take advantage of the true benefits of the speed of offsite construction. In McKinsey's Reinventing Construction from 2017, among the recommendations is a broader call to "reshape regulation and to streamline permitting and approvals processes if we are going to improve productivity across the entire development and construction process" (McKinsey Global Institute, 2017).

The process of permitting for development and construction is an antiquated process and like the construction industry, suffers from lack of adequate resources to process the permits. In many cases the pandemic has improved the processing procedure in many Canadian cities as planning departments have finally moved to digital processes in lieu of paper processes to keep permits moving. However, it's the uncertain and unpredictable nature of permit schedules that creates uncertainty for manufacturing and offsite construction operations. Without visibility on timelines for permits, it makes planning for manufacturing very difficult. Owners and contractors are reluctant to release a contract to a manufacturer without an issued permit. If a manufacturer is backlogged with orders, offsite construction schedule savings may be eroded as the onsite work may in fact be complete and 'waiting' for the offsite components to arrive. This may force owners and contractors to re-think their decision of committing to offsite construction if speed is among the drivers.

To leverage the true benefits of prefabrication, municipalities must begin developing and adopting an accelerated permitting and approval process for projects specific to offsite construction *and* providing certainty around those timelines. There are a few examples of cities that have begun to create new processes for specific offsite building typologies. In Germany, building ministers of the sixteen federal states in 2019 adopted a rule to incorporate "type" approvals (those buildings that are standardized) into their building regulations. Type approvals can speed up procedures for granting planning permits because owners no longer need to apply for a permit for each individual house if building several the

same typology. It is now enough for permission to be obtained for one type of house or apartment within a development area (Germany, 2021).

In Los Angeles, to address the lack of affordable housing, the city has pre-approved a set of designs of Accessory Dwelling Units (ADU's) appropriate for backyards. As a result, the city is "shaving weeks off the permitting process" and providing property owners with more than a dozen "off the shelf" modular and panel friendly designs for backyard units (Ionescu, 2021).

Vancouver and Toronto have set a precedence for accelerated permitting for modular construction through the former's accelerated rezoning "SHORT" program and the latter's "Concept to Keys" whereby modular affordable housing projects have priority in processing. However, the accelerated process in Vancouver has on average taken up to 2 years to get rezoning and development approval for a project with the best case having been 9 months. Despite the entitlement timelines, the modular housing program has seen great strides in seeing accelerated building permit (BP) application approvals. Now that over 600 units of temporary modular affordable housing have been delivered in the City, the BP processing has now seen permits issued in as little as four days due to the repetitive nature of the plans being submitted and planning staff having issued prior approvals. This is a great example of how processing gains can be made when standardization takes hold.

Among the biggest hurdles for the offsite industry resides with the general lack of education and understanding of offsite construction methods and certifications within AHJ's. Municipal officials that are unfamiliar with offsite projects have difficulty recognizing where their responsibility lies between onsite and offsite components. Typical site construction requires inspections from AHJ officials at different stages during the building process (i.e. framing, plumbing and electrical rough-in inspections). For modular and panel systems, AHJ's do not have authority over inspections in the facility if the facilities are licenced under CSA A277 (procedure for factory certification of prefabricated buildings, modules, and panels) or CSA Z240 (manufactured homes). The CSA standards take precedence for offsite constructed components that may be enclosed and not visible for inspection. The AHJ's therefore only have jurisdiction for the onsite components incorporated into the work and the connections from the offsite to the onsite components. It's this delegation of authority that is often misunderstood among AHJ's who may be seeing an offsite project for the first time.

It's advised that project teams and owners engage the AHJ early in the design process to confirm understanding and to provide documentation (i.e., manufacturer's "License to Mark" certifications) and ensure a smooth process through permitting and construction. In the future, the offsite industry must work with Codes Canada to improve and update CSA A277 since there are a number of variations that are in use among provinces which result in uneven interpretations.

It should be stated that Mass Timber manufacturing standards have little to do with getting these products approved within buildings. Both Glulam and CLT are to be manufactured to CSA O177, Qualification Code for Manufacturers of Structural Glued-Laminated Timber and ANSI/APA PRG 320, Standard for Performance-Rated Cross-Laminated Timber, which is recognized in the US and Canada. Ahead of the 2020 release of the National Building Code in which 12 storey encapsulated mass timber will be included, several jurisdictions have approved early adoption within their provincial codes. This will allow those AHJ's to become knowledgeable with the new standard before release of the 2020 NBC.

Another offsite construction standard is currently in the works and is addressing current gaps in knowledge regarding high rise modular construction. Even though there haven't been any high rise modular buildings constructed in Canada, CSA Z250 is currently being developed in advance of adoption to address potential issues such as roles and responsibilities, chain of custody, fire rated assemblies and fire protection, acoustics, building transport and assembly, waterproofing, and safety during construction of high rise modular buildings (CSA, 2020). With many countries around the world undertaking high rise modular buildings, CSA is working to establish standards ahead of any large-scale building construction. This will be crucial as it's possible the first high rise modular building in Canada will consist of modules from overseas, which will be subject to meeting Canadian codes for construction. As this standard gets developed, it's important to note that the CSA Z250 standard should supplement the process for construction and inspections from consultants and AHJ's and not add to the regulatory burden.

As offsite construction grows in Canada, it has become apparent there is a need of standardized language and uniform testing for assemblies for fire protection and acoustics, as well as standardized processes for waterproofing, storage, and transportation too. The US has already started down this path with an International Code Council working group to develop two new ANSI standards for offsite construction.

- ANSI 1200 - Standard for Off-Site Construction: Planning, Design, Fabrication and Assembly
- ANSI 1205 - Standard for Off-Site Construction: Inspection and Regulatory Compliance

These standards are intended to be for "adoption by government agencies and organizations for use in conjunction with model codes to achieve uniformity in the inspection and regulatory compliance of offsite construction" (MBI). In addition, as high-performance buildings become the norm, and assemblies become more difficult to construct in the field, having standardized language to create uniform messaging to all AHJ's across the country will be necessary if the industry is to reduce barriers to adoption.

RECOMMENDATIONS AND AREAS FOR FURTHER STUDY

If Canada is to embrace offsite prefabrication and the industry is to succeed, there are several actions that are needed to move offsite prefabrication from the “early adoption” stage to an industry that is embraced by the greater majority. This is not something that will happen in five years or even 10 years, but the importance of applying lessons learned from other areas of the world and to adopt recommendations from Canada’s offsite construction thought leaders and industry stakeholders will begin solving our issues related to construction productivity, sustainability, and affordable housing.

Reframe Mass Timber and Panels as a Single Industry for Market Development

There are tremendous synergies that exist between the panel industry and mass timber. Surveys have shown acceptance of open panels among general contractors for multi-family construction and projects involving mass timber have been using panels for interior walls and exterior applications. With the changes in building code upon us, the move toward high-performance buildings has begun to push project teams to seek out prefabricated panel solutions for project construction.

The panel industry is poorly represented and fragmented, while mass timber has developed into a well-structured industry and has benefited from government and stakeholder support. It’s mass timber’s developed framework which can be leveraged to foster greater acceptance and growth of closed panel systems if there is a coordinated effort toward market development between the two sectors.

It’s recommended the mass timber industry structure a working group to engage panel providers for input on developing a joint market development framework.

Several Canadian mass timber companies currently belong to APA-The Engineered Wood Association while panel suppliers are represented by regional truss associations and one national association (The Canadian Wood Truss Association). The move toward a made in Canada advocacy group will enable supporters of both industries to be better represented and have a more cohesive approach to market development.

The modular construction industry has long been represented by associations in Canada – recently the CMHC Modular Construction Council for residential modular construction, and the Modular Building Institute – Canadian Council for commercial modular construction. Both have recognized the need for industry specific advocacy and education across Canada. The joint mass timber/panel approach to market development could eventually lead to the formation of a trade association which would further cement the messaging across both markets.

Upon formation of a mass timber/panel working group, one of the recommended first tasks will be to update CAN/CSA A277-16 the “Procedure for factory certification of prefabricated buildings, modules, and panels” to modernize and improve the standard to accommodate mass timber and closed panel systems. By doing so will provide further assurance of quality control measures, add legitimacy to the panel industry, and will ease permitting regulations.

Best Practices Guides for All Forms of Prefabrication

The lack of standardized “best practices” information across all forms of prefabrication is contributing to the lack of uptake. Those owners, architects and contractors who are new to offsite construction have difficulty employing prefabrication due to a lack of knowledge around the process of prefabrication, which creates unnecessary hurdles and missteps. In addition, construction and erection teams need to know and understand processes for transportation, storage, connections, safety, and water and fire protection during construction.

It will be in the best interest for each form of prefabrication – mass timber, closed panels, and modular – to develop their own industry led “Best Practices” guide **from early engagement through to erection and turnover**. It’s imperative for all forms of prefabrication to standardize nomenclature and pattern language and develop clear guidelines and recommendations. In the US, the AIA developed a guideline for modular construction to assist architects when designing a modular project (The American Institute of Architects (AIA)). A similar guide for modular, panels and mass timber with additional information on construction execution best practices developed by industry stakeholders would benefit the industry and enable further growth and adoption.

Standardize and Develop Specific Contract Language for Prefabrication

The offsite construction industry is expected to conform and utilize existing Canadian Construction Association (CCA) contracts, Canadian Construction Documents Committee (CCDC) contracts, or owner and general contractor developed terms and conditions. Unfortunately, the language employed within these contracts are detrimental to offsite companies as they have specific language that is to the benefit of the contracting party.

The prefabrication industry will benefit from developing the following in response to contracts that don’t consider offsite construction:

- Standardization of Terms and Conditions for each form of prefabrication including payment terms and process for approving payments
- Revised contract language and definitions within CCA and CCDC to reflect offsite construction nomenclature and terminology consistent with offsite construction
- Develop industry specific standardized Supplementary General Conditions that can be added to any existing CCA or CCDC contract.

Change Public Sector Procurement Practices for Prefabrication

The public sector is currently the largest procurer of modular and mass timber in Canada, but only represents a small percentage of overall public procurement construction dollars. The capital projects and construction procurement models are well ingrained in the public sector, but unfortunately those models don’t work for offsite construction. If offsite construction is to succeed in Canada, Design-Bid-Build methods must be removed from public procurement for any capital project considering prefabrication.

By using more integrated contract models such as IPD, Design-Build, or collaborative Construction Management contracts, it will lead to greater success and will encourage greater adoption by private industry. In addition, public entities should begin to utilize Life Cycle Costing (LCC) as a method to evaluate competitive bids. By doing so will move the focus away from lowest cost to highest value by incorporating not only the hard construction costs of a project, but also the costs over the building life - namely operations, maintenance, and end of life costs.

It's also recommended the industry work with public sector owners to:

- develop language to support offsite construction procurement
- develop financial procurement models and payment terms in contracts that enable long term industry growth
- work together to educate procurement departments and capital planners by utilizing an industry developed "best practices" guide.

Mass Timber Talent Attraction and Retention

As the interest of mass timber construction grows in North America, demand for top talent and the resulting knowledge drain to companies south of the border will be among the highest risks to a Canadian mass timber industry still in its infancy.

This is particularly concerning for the BC mass timber ecosystem. The knowledge base and experienced practitioners operating in BC will be in demand as the projected growth of mass timber in the US will eventually dwarf that here in Canada.

The opportunity to cement and establish BC as a mass timber leader and continue the development of a knowledge cluster here in Canada can be secured by continuing the culture of innovation, education and leadership. Talent will be more interested in staying in Canada if they feel part of an industry ecosystem that is collaborative, aligned, has vision, and is supported by educators, government and industry stakeholders.

One only has to look at other successful industry growth models here in Canada that could be applied to the mass timber industry. The Passive House and green building community in BC has developed over the past decade from a grass roots organization into a robust ecosystem by creating a culture of innovation and collaboration. Showcasing proven European experiences to ensure Canadian adoption allowed the local culture to become comfortable with the outcome. Further support and creation of a central voice with the formation of Passive House Canada assisted in that collective cohesion.

It is recommended to undertake a needs-analysis with educators, government, and stakeholders to identify gaps to support the developing ecosystem.

Government Support for Offsite Construction

Canada is at a critical juncture in its affordable housing crisis. Existing government policies have been ineffective at increasing the supply of housing in this country, and it's this lack of supply that has increased the average home price in almost every urban market in Canada. In Indigenous communities, the situation is dire. A 2017 government report on funding for on-reserve housing in indigenous communities, concluded that "programming initiatives led by INAC as far back as the 1960's, and culminating in the current approach that has been implemented since 1996 have proven ineffective" (Canada, 2017). Offsite construction has the opportunity to deliver housing efficiently, cost effectively, and of high quality for Indigenous communities.

Prefabrication can solve the deficiency in affordable housing by providing a fast, sustainable solution despite the ongoing construction skilled labour shortage. However, government at all levels must be prepared to work directly with industry if they are to enact change.

It is proposed that government take a leadership role at all levels to:

- Develop language in public sector procurement that supports offsite construction, and mandate offsite construction be delivered for certain building typologies
- Work with industry to develop a pipeline of demand and strategic procurement that provides long term commitments and certainty for the industry
- Support the industry through preferential financing arrangements to reduce the burden on operating capital for offsite SME's. By doing so will allow industry to invest in Research and Development, technology, and allow the industry to further invest in people without having to worry about backlog
- Develop networks and relationships with other nations who have policies in place that support and embrace offsite construction, and to share learnings and open up the possibility of supply partnerships.
- Develop collaborative partnerships between Indigenous Services Canada (ISC), the offsite industry, and Indigenous groups across Canada to identify long term opportunities for standardized, energy efficient housing that can be delivered quickly. Begin with Prefabrication Pilot Projects across Canada which will lead to successful case studies and lessons learned. This will result in a reduction of nations' administrative burdens in delivery of housing by creating standardized programs while growing and scaling capacity within Nations.
- Develop and implement building bylaw changes that accommodate and specifically call for sustainable prefabricated construction methods *and* create new municipal processes that facilitate fast tracking of permits with well defined processing timelines.

These initiatives will allow housing to be delivered faster than conventional construction, create schedule certainty for owners, minimize project risk, enable the prefabrication industry to pre-plan which will add certainty to pipeline, and ultimately increase industry investment.

Emphasis on Collecting and Standardizing Data

Offsite construction holds much promise by offering tremendous benefits associated with sustainability, time savings, and quality. Unfortunately, the construction industry remains heavily focused on lowest cost to deliver projects. Studies and stakeholder interviews have identified the higher upfront cost of offsite solutions will be a barrier to uptake unless quantifying the value and the benefit of offsite is understood.

There are opportunities to utilize data to grow confidence to those in the lending community, the insurance industry, and to owners and stakeholders looking to procure offsite construction. These opportunities are:

- Development of a consistent and standardized cost-benefit measurement system using Whole Building Life Cycle Cost Assessment (LCCA) that will enable those outside the prefabrication industry to move away from a capital cost decision and look at whole building life costing. It will also move the offsite industry away from using subjective language in describing benefits offered.
- Standardized and consistent project data, including project KPI's. Project data for every offsite project (of a predetermined size) to be logged and shared along with consistent KPI's which include capturing owners' perceptions and outcomes. Other information to be captured include a database of industry people and companies involved (including imported prefabrication) in each of the catalogued projects. This will enable those new to offsite construction to select experienced project team members which will increase the likelihood of early success and lead to greater long-term adoption of those new to offsite construction.

Digital Technology and Offsite Construction

Digitization and Building Information Modelling (BIM) will be a cornerstone in the growth of prefabrication. However, the offsite construction community must identify and develop BIM standards that are aligned with the greater construction industry. This will assist in offsite's evolution and adoption since unfamiliarity of systems and lack of standards adds to project risk and higher costs. A recent BC Housing report identified BIM's ability to "reduce reliance on potentially wasteful, manual/slow or ad hoc decision making on site" (BC Housing, 2019). This technology can assist in the early decision making required by prefabrication, as all design decisions must be coordinated prior to manufacturing. Furthermore, the visual elements of being able to model connections and review scope of work details reduces the risk for on-site trades, and allows for greater certainty in schedule, cost, and quality.

The offsite community doesn't have to wait for this evolution of BIM standards to happen. It's recommended the various associations and prefabrication industries collaborate with Government and CanBIM to identify the standards and begin to employ the accepted standards on large scale public offsite projects.

Technical Research Recommendations

From a number of interviews with stakeholders and thought leaders, there were several recurring technical research requests that came to the forefront. Much of the technical research itemized below can be undertaken by industry, academics, and non-governmental organizations. Many of the requested themes of research come as a result of suggestions from interviews around issues which have created barriers to adoption or have created uncertainty among decision makers or influencers.

The technical research recommendations are:

- a) Long Term Project Monitoring to create confidence among users and decision makers
- b) Standardize Panel Connections for closed panel systems, especially in high-performance envelopes
- c) Develop standardized seismic systems and connections for multi-storey modular as many structural engineers new to modular are unfamiliar with systems that work well in this environment
- d) Develop opportunities to reduce vertical assembly height for multi-storey modular as doubled up floor/roof assemblies create issues with bylaw height restrictions
- e) Further acoustic testing of wall and floor systems for Mass Timber and Modular
- f) Fire testing of various construction methods for party-walls and floor/roof systems for modular as there is currently too much uncertainty with AHJ's
- g) Standardize fire blocking details between modules in multi-storey modular projects to enable AHJ's and fire protection specialists to have confidence in approach.

APPENDIX A

Methodology

The project consisted of a broad-based literary review through desktop research examining both Canadian and International academic studies, industry papers, and government reports on mass timber, panels and volumetric modular construction.

Main themes of study involved research across the three forms of prefabrication which included investigation and keyword searches around such topics as: advantages, barriers, drivers, opportunities, perceptions, threats, challenges, technology, and government.

The project also solicited information from in-depth long-form interviews conducted with key stakeholders and thought leaders of people in North America who are utilizing prefabrication, have been involved in prefabrication in some capacity and who have enough familiarity with at least one of the three forms of prefabrication being studied. Interviews were conducted both in-person and online. It was imperative the interviews considered a broad cross section of the key stakeholders involved in prefabrication. Interviews included Owners, Contractors, Architects, Academics, Consultants, Associations, Government, and senior level people from mass timber, panel, and volumetric modular companies. A total of 41 interviews were conducted in this study. A list of those who participated is included in Acknowledgements.

APPENDIX B

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