WOOD TECHNOLOGY SOLUTIONS – REPORT FOR QUESNEL

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This report is commissioned by the City of Quesnel and examines the upcoming changes, potential challenges, and some creative solutions arising out of the BC Step Code, this affects the Wood Construction Industry and related fields, such as the Engineered Wood Products industry.

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1. Introduction

The forest industry, as well as the construction industry of British Columbia, is facing novel and unique challenges. This report is focused on upcoming tasks triggered by new building code standards, environmental impacts, and the changing economy while concentrating specifically on where these two industries intersect.

The forest industry is currently facing a reduced Allowable Annual Cut (AAC) and likely further reductions over the next few years. After years of drastically increased AAC, due to beetle infestations, the logical reduction back to levels of before the outbreak or lower, are put into place and expecting further reductions due to large losses through forest fires and other factors. This combined, is leading to a significantly reduced availability of saw logs and potentially to a reduction in revenue if no new strategies, products and solutions are introduced. There were several reasons why BC's forest product industry was only peripherally engaged in Engineered Wood Products (EWP) in the past, but now there is a growing necessity to increase value rather than volume.

The construction industry is directly facing two challenges, resulting in a third.
The first challenge is the 2017 introduced **BC Energy Step Code**, requesting higher levels of energy efficiency by implementing a road map which leads to the highest defined step being implemented in 2032. To achieve higher energy efficiency, one of the core requirements is the increase of thermal performance which is usually achieved through the application of more insulation. This will result in thicker and heavier envelope components with the risk of increased construction costs.
The second challenge is, because of the new **Building Code 2020**, the allowed building height for wood buildings will be increased up to 12 floors and potentially beyond. Stick framing on site is not advisable for taller buildings and not permitted beyond six floors.
The solution for both problems can be found in taking a different approach to building buildings. It can be argued that these two mentioned challenges result in a third, **Prefabrication** (prefab). Prefabrication, the construction of building components off-site and the assembly of such components on-site, is highly advisable for more energy efficient buildings and a precondition for tall wood buildings. By implementing more efficient processes in constructing buildings, including prefabrication, energy efficient and taller buildings can be produced cost efficiently as the productivity of the process can be improved radically.

The upcoming changes in the processes of construction may potentially change the required types of materials used. Prefabrication is theoretically possible with dimensional lumber *(see attachment)* however, to fully utilize the advantages of prefabrication and introducing a certain level of automation, dimensionally stable and accurate products are needed. For the past several decades, in countries where prefabrication is the standard for wooden buildings, EWP are the most common choice. Engineered Wood Products are dimensionally stable, accurate, and generally structurally stronger than dimensional lumber or heavy timber. In BC there are very few EWP currently produced. However, the demand will most likely increase significantly over the next few years as the shift towards off-site construction will be implemented, indirectly triggered by the new building code.

The shift towards prefabrication and EWP presents new opportunities, specifically for those areas, such as in Quesnel, were the traditional forest industry struggles because of reduced AAC and other factors. In identified communities, a shift, from **volume to value**, could be implemented by establishing EWP manufacturers and prefabrication companies. In highly developed, densely populated and very competitive prefabrication markets, we have seen that shipping distances of up to 1000km are financially viable, which suggests that the potential shipping distances for the Canadian market can be significantly larger. This may enable rural communities to turn the perceived disadvantages of a declining forest industry to their advantage, as direct access to wood, a motivated labor force plus low real-estate costs are potentially available.

A strong home market for EWP and off-site construction can eventually lead to international competitiveness and exports of EWP and prefabricated components. The different types of prefabrication are elaborated on in section 2, the most flexible and logical first step would be panelized prefabrication. Modular prefabrication has several limitations and will be mostly beneficial in a particular segment of the market where a large number of identical units is requested. Panelization is particularly favorable for prefab companies located outside the main markets, as lower shipping costs will occur due to a better value to volume ratio.

2. Review of state of the art production technologies (equipment capabilities) for prefabrication [locally and globally]

2.1. Current status of wood construction in BC

Traditionally the vast majority of residential construction in BC was built using wood as the main structural material. The former building code was accepting 6-floor tall construction utilizing "stick frame", which triggered a shift in the market from predominately small size single-family homes or duplexes to larger multi-unit residential buildings (MURB). This opened a new segment in the market for wood construction. With the increase of the allowable height to 12 floors (new building code) for mass timber construction a new chapter has opened.

Wood, as a construction material, represents a large percentage of the total construction activity in BC, although the market share seems to have decreased in recent years. A large portion of residential construction takes place in the lower mainland, and therefore is partly responsible for this shift. Although, concrete buildings still outperform large wooden residential buildings by volume by far. The increased allowable height for wood construction has influenced the total numbers, but the market share of wood buildings over six floors is still miniscule. There are several reasons for this; the requirements for fire safety and acoustic performance are challenging, but the biggest obstacle seems to be, the cost efficiency of tall wooden buildings. This is due to the needed improvements in the processing and manufacturing of these buildings.

Today, the vast majority of low to midrise wooden buildings are built on-site using predominantly "stick frame" as the method of choice. To some degree, the use of so-called "framing packages" and nailing trusses *(see attachment)*, are implemented and occasionally some heavy timber components are used. The construction activity is mainly on-site, and therefore the resulting duration of construction work, including the impact triggered by noise, delivery traffic, and blocking of parts of the public arena, are still similar to what we have experienced over the last few decades.

There is a growing market share of prefabricated systems (level 2 and up, see 2.4.1.). These systems would start to fully utilize the advantages of wood construction, by applying a higher level of prefabrication, resulting in much shorter construction time on-site. Consequently, resulting in less infringement on the daily lives in our cities while simultaneously offering a higher level of quality.

2.2. On-site construction

On-site construction is currently the most common way of building structures in BC, where the building process is happening entirely on the construction site. All materials are shipped to the construction site, then cut and assembled by various tradespersons. The most common exception to on-site construction are roof-trusses. Trusses are normally prefabricated at a truss plant, then shipped to site where they are spaced, and the rest of the roof structure assembled.

Tools used in on-site construction are common trades tools. These include power tools like skill-saws, table-saws, and miter-saws. Some trades may employ more specialized equipment, but regardless all work is done on-site and with primarily handheld tools. Other equipment required in conventional construction are trucks with on-board cranes or small forklifts to unload construction materials like framing lumber, sheathing, drywall, and insulation, to name a few. The above mentioned prefabricated trusses or framing packages are generally unloaded and directly positioned by crane off the delivery truck. Over the past 150 years this method of construction has remained virtually unchanged. Small details like the implementation of nailing guns, plywood and OSB sheathing, and power tools, have slightly accelerated the process. The report from the world economic forum “Shaping the Future of Construction; A Breakthrough in Mindset and Technology”, published in May 2016, identifies the lack of, or slow adaptation of new technologies as a major reason why construction labor productivity dropped by 19% over the last 50 years in the United States of America. Due to the overall similarity of the markets, it is fair to assume that a similar lack of productivity exists in BC.

Traditional on-site construction (Photo: City of Surrey)

On-site construction does have a few advantages over off-site construction as less accurate planning is needed, and no costs are incurred for a prefabrication facility and larger cranes on-site. There is however, a long list of disadvantages when compared to off-site construction, such as:

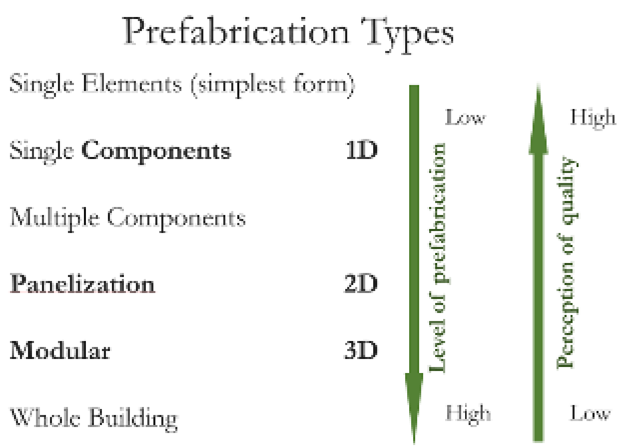
- Potential exposure to rain, cold, or snow affecting the construction material and workers
- Potential exposure to extremes temperatures, affecting construction material and workers
- Lack of ergonomic optimization for workers
- Potential exposure to dust and noise for workers
- Reduced accuracy
- Reduced productivity
- Increased construction waste
- Increased infringement on surrounding neighbors (noise, dust, traffic interruption)
- Increased traffic by shipments and workers to construction site
- Increased time losses of labour driving to site

2.3. Off-site construction

Although the prefabrication of wooden buildings is over 100 years old and is dominating the wood construction market in other countries, it is still in its infancy across BC. Traditionally, only so-called "trailer homes" or lodgings for remote camps utilize prefabrication. The reputation of the quality of these buildings is exceedingly poor and has led to the generally negative reputation of prefabrication. This is an important factor since prefabrication can, and should, lead to a higher quality standard, but the common perception in BC is that these buildings are sub-standard. Prefabrication classifications will be discussed in a later chapter. Modular, or 3-dimensional, prefabrication has in many countries been applied for decades and developed to a very high quality level. But experience in BC paints a rather incoherent picture, presenting a wide range of quality due to occasionally rather inefficient construction processes.

Typical Modular construction in Canada (Photo: Sean Eckford)

Off-site construction, as the name implies, happens primarily away from the construction site or off-site, ideally in a controlled environment, i.e. a large facility. Major components are manufactured and shipped to site for final assembly. The topic of off-site construction or prefabrication is vast, and various ways of breaking down the complexity are to be considered. One consideration lies with the complexity itself, ranging from single prefabricated components to fully prefabricated structures. This report will consider the following categories as levels of complexity or types of prefabrication.



As the graphic shows, with the increase of level of prefabrication the perceived quality of the finished product diminishes. The scope of this report, is prefabrication and its integrities. It will also focus on the level or complexity of prefabrication and its various ways maneuvering within these levels, herein referred to as levels of automation.

Quality perception of prefabrication in Canada (Graphic: M.Gehloff)

2.4. Categorization of prefabrication

Prefabrication can be categorized in several ways, for example, levels of prefabrication have been defined and published in the past, one of the more recent attempts was in the report “Cost Implications of Accelerated Construction Schedules” by Forestry Products Innovation (FPI), or by using dimensions: 1D, 2D, 3D.

2.4.1. Levels of prefabrication

We took the general definitions as used in the FPI report “Cost Implications of Accelerated Construction Schedules” and refined or clarified them where we deemed it is necessary to better reflect the industry:

2.4.1.1. Level 1: Prefabricated components that are manufactured in a factory

The production of these components or elements typically involves only one trade contractor or supplier. The manufactured components may, more efficiently, lend themselves to mass-production and can involve a high degree of advanced processing and/or specialized installation expertise and equipment. Examples include; precut or machined glued laminated timber (glulam), roof trusses, light frame wall panels that only comprise the structural system or mass timber elements (CLT, NLT, LVL panels, etc.). For clarification, this stage would be typically called precut, but not prefabricated, in other countries.

2.4.1.2. Level 2a: One side closed prefabricated panels

In this category, assembly involves several trades (i.e. carpenters, insulators, window installers, etc.) and additional expertise in the form of building science, transportation and installation. The prefabrication company may play a more central role in the design and construction process through the preparation of shop drawings, coordination of sequencing, provision of specialized equipment, etc. Examples include "one side closed" exterior wall panels that include cladding, insulation, vapour/air barrier, glazing, etc. The installation of mechanical and electrical systems are normally done on-site, after the wall, roof, and floor panels are installed. This is globally understood as prefabrication.

2.4.1.3. Level 2b: Both sides closed prefabricated panels

This category involves a wider range of trades (e.g. carpenters, insulators, window installers and electricians, plumbers, installers of mechanical systems, etc.) and in addition to level 2a the design has to be further optimized to allow for easy connections between all panels and their included services on-site. The prefabrication company plays a vital role in the design and construction of the project and in addition to the multiple trades, an interdisciplinary design team is included. On-site all components will be fitted together, structurally connected, and all services will be connected. Only minor finishing work such as the transition from panel to panel is to be done on-site.

2.4.1.4. Level 3: Volumetric pre-assembled pods

Three-dimensional elements have been fabricated by multiple trades and are shipped fully finished from a factory to a project site for integration into a permanent or semi-permanent building, or to a prefabrication plant to be integrated into larger modular elements. The specialized company works with the project team to customize, assemble, transport and install the units. Examples include fully equipped mechanical rooms, most common are bathroom and/or kitchen “pods”. On site these pods are then typically connected to either prefabricated panels according to level 2a or 2b or to modules as described in level 4.

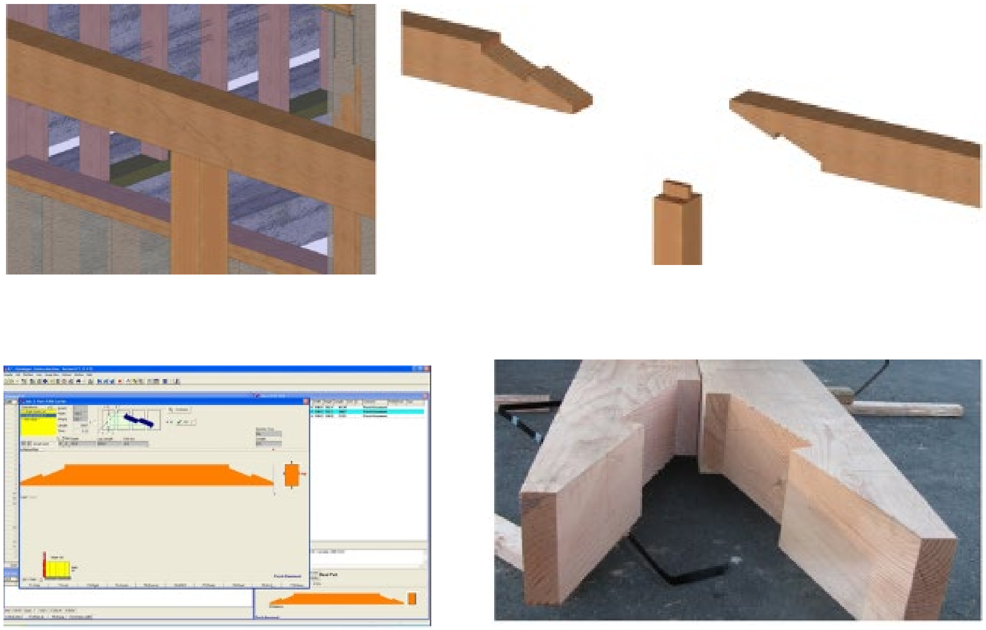
2.4.1.5. Level 4: Volumetric prefabricated modules

Three-dimensional elements are fabricated by multiple trades and shipped fully finished from the factory to the project site, to then be integrated into a permanent or semi-permanent building. The prefabrication company works with the project team to customize, assemble, transport, and install the units. Examples include fully finished residential modules, office spaces, or hotel rooms, and can include fully equipped mechanical rooms, a bathroom and/or kitchen “pods”, hospital rooms, as was described in level 3. These modules are fully finished including final surface of walls, ceiling and floor and built-in furniture is installed as well. Ideally, to be more architecturally appealing, the level of prefabrication should not be obvious once the building is finished. The installation on-site becomes crucial to allow for the full benefits of this “plug and play” approach.

2.4.2. Prefabrication categorization by dimensions: 1D, 2D, 3D

2.4.2.1. 1D

The first level of prefabrication, 1D prefabrication, deals with prefabricated individual elements or components. The most common and traditional form of 1D prefabrication is Log-Building. Log-Builders shape each individual log to be fitted in one particular location of the building. Another, more current, form of 1D prefabrication is the art of timber-framing. Each post, beam, rafter etc. is produced in a shop and the finished timber-frame assembled on site.



Design and processing phases of a timber connection (Graphics: M. Gehloff)

Both timber-framing and log-building offer opportunities for automation. There are companies in British Columbia that scan trees and program computer numerical controlled (CNC) machines or robots to shape these individual elements, while others rely solely on the skilled hands of log-builders or timber- framers to complete the task using common hand-power tools. Timber-framing lends itself to more automation as it uses rectangular cross-sections that are consistent in shape. Timber-framers usually use industry leading, single-beam processing, CNC machines (i.e. Hundegger SC3 / K2, Krusi, Creno, etc.).

With natural logs the selections slims and comes down to highly customized scanners and industrial robots like the KUKA and ABB. When machined logs (i.e. lathed poles, D-shaped machined logs, etc.) are used the CNC machines commonly used by timber-framing companies are well equipped to do the job.

CNC machine, Hundegger Speed Cut 3 (Photo: G. Wimmers)

1D preparation is very beneficial for "stick framing", as each and every post can be precut to perfect length, each piece can be labeled, bottom plates can be notched to allow for quick assembly. Furthermore, waste is reduced as the computer calculates the ideal cutting and extra pieces can be efficiently cut into shorter parts.

2.4.2.2. 2D

The next level of prefabrication is considered 2D, as it primarily utilizes panels or surface-like assemblies which consists of more than one component. One example of 2D prefabrication that is commonly used in North America are roof trusses. The category of 2D prefabrication is vast and can not only be further distinguished by the level of automation used, but can also be further divided into stages of finishing.

One finishing stage in the 2D prefabrication category is referred to in North America as "Engineered Wood Products" and includes common nail-plate trusses as well as open panels, which are usually comprised only of the 2x framing members and the exterior sheathing.

Pre-framed wall panels and trusses (Photos: G. Wimmers, Kingdon Truss)

Beyond what's known as "Engineered Wood Products" the 2D prefabrication category can be further divided into open panels, where insulation and potentially some services are pre-installed but the panel is not finished (prefabrication level 2a, as described in section 2.4) with its final (usually interior) sheathing, and drywall. A step up is offering closed panels (level 2b) that house all services and interior as well as exterior sheathing. Usually the only step left to do on-site, is connecting the panels and services as well as finishing the panel seams. The levels of automation for the 2D category can have intermittent steps, allowing companies to grow in their market and capabilities. The pre-cutting of components can be done either completely by common power tools or using a CNC machine, similar to the 1D method. Beyond the pre-cutting of the components, a simple layout table would complete the list of the base requirements for the equipment.

Prefabricated wall closed on both sides (Photos: Schnorr)

Furthermore, these tables can offer manual or hydraulic clamps to secure the work- piece and to ensure a perfectly rectangular component. The equipment list can then further be supplemented by a butter-fly table, which flip the panel over, enabling ergonomic working conditions for finishing both sides.

The highest level of automation would utilize CNC cutting machines, automated pick and place machines (robots), as well as automated nailing bridges, and framing lines.

Generally, 2D prefabricated building components, and ideally finished on both sides (level 2b), are extremely flexible, and can be applied to different kinds of residential and commercial buildings. A combination with pods (level 3) is advisable, for example, in large residential buildings. Optimization of design and dimensions becomes necessary, but 2D is far less limited compared to 3D structures, and the more efficient shipping allows for longer shipping distances while still remaining competitive. In highly developed, densely populated and competitive markets, it is noted that shipping distances up to 1000 km can be economical, suggesting that in less competitive, less populated and less developed markets, the viable shipping distance could potentially increase.

Manufacturing tables from different manufacturers, with clamps in Sweden (Photos: G. Wimmers)

Table with hydraulic clamps (Photo: Weinmann)

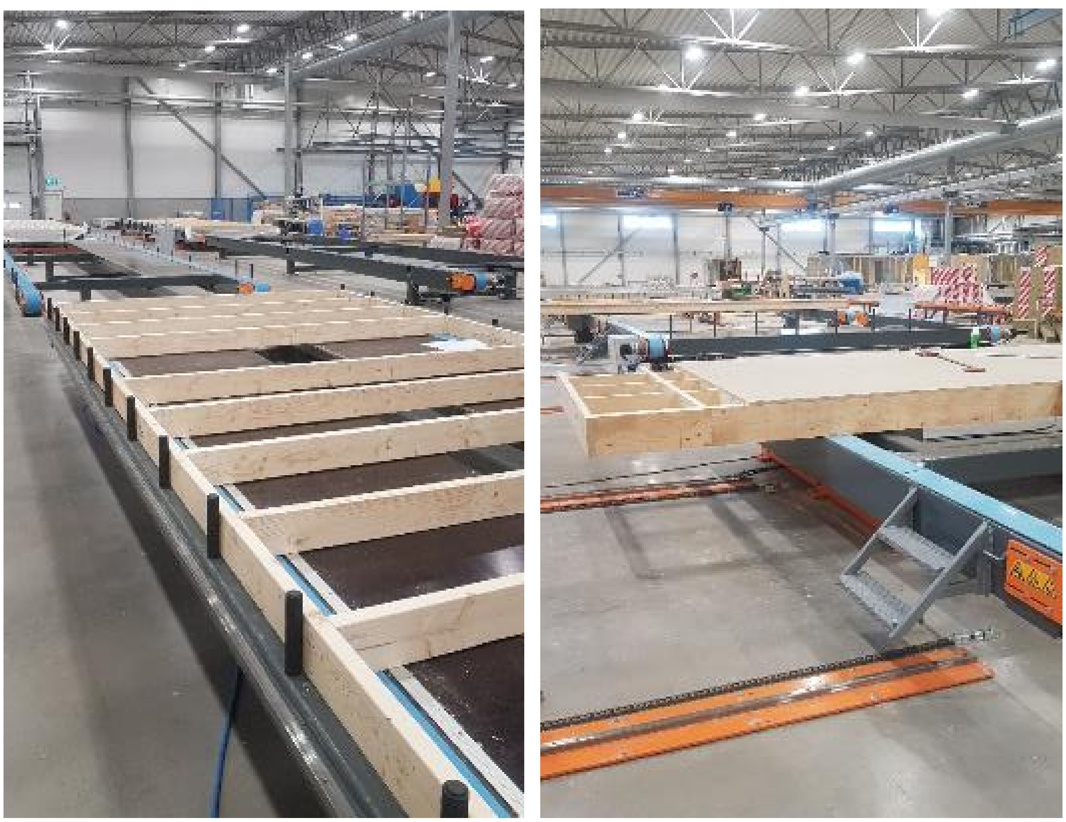


Table system, adjustable in height and non-continuous table allowing easier access to component by worker in Sweden (Photos: G. Wimmers)

Prefabrication line with large tables and no automation in Austria (Photo: G. Wimmers)

Butterfly table to flip over component allowing the finishing of both sides in Sweden (Photo: G. Wimmers)

Nailing bridge and modular construction in the background in Sweden (Photo: G. Wimmers)

2.4.2.3. 3D

The final level of prefabrication or level of prefabrication complexity is 3D, where modules or modular structures are delivered to site completely assembled. There are several variations of this process possible, as categorized earlier on, identified level 3 and level 4.

A common usage for 3D prefabrication are for bathroom pods, kitchens, mechanical rooms, or other pods such as these, in this report referred to as level 3. Using pods is logical when a smaller volumetric space can be easily finished with all services and finishes and be installed as a structurally rigid single unit. This allows for brittle finishes like tiles to be preinstalled, but does require extra consideration for structural rigidity during transportation, so that the brittle finishes do not get damaged. The latter is the most common reason to keep such 3D pods sizable (small) to avoid additional costs associated with reinforcing larger pods or whole components and assemblies for shipping. Bathroom pods are typically built using a steel structure due to the high requirements for stiffness during transportation and lifting. The pods are pre-manufactured and then either shipped to a prefabrication plant for modular construction and integrated in their process or directly shipped on-site to be installed.

Bathroom Pods premanufactured by specialized company (Photo: Euro Components)

Bathroom pods integrated into module and hooked up to electrical and mechanical services in Sweden (Photos: G. Wimmers)

Bathroom Pod lifted into place on building site (Photo: Element Europe)

The highest level of 3D construction are modular whole buildings, in this report categorized as level 4. This level is perceived as the highest quality in the European market due to the high level of accuracy required. In North America, this is rather perceived as of lower value due to quality shortcomings in the past. The process of quality improvement is currently ongoing with varying success.

Although being the highest level of prefabrication, and besides the perceived lack of value in North America, 3D dimensional prefabrication has a few disadvantages. The advantages of fast assembly bring disadvantages in shipping. The transportation of such structures is not as efficient as shipping panelized structures. When large, empty, 3-dimensional structures are shipped there is, consequently, a lot of “air” being shipped. When skilled labor for assembly and final finishes is scarce or cost prohibitive, 3D prefabrication is ideal as in most cases very limited assembly is required on site. The economic argument for modular construction can be made by identifying a lack of skilled labor required on-site, a large number of repetitive modules required, or extreme time constraints on-site, and the shortest possible interruption for the surrounding area of the construction site as possible. Typical examples for this method are office buildings, social housing buildings, hotels, or schools. In addition, the shipping distance plays a significant role, depending on the market, and other above mentioned factors. The viable shipping distance depends largely on the economic factors involved but could be up to 1000km and in extreme cases even beyond.

The levels of automation and use of advanced technologies for 3D prefabrication is essentially the same as for 2D prefabrication, as ideally all optimization in 2D is utilized first, before venturing into 3D production.

2.4.3. Differences between European and Canadian prefabrication

Although we observed crucial differences in the application and the processes of prefabrication technology in different European markets, there are general differences between the European market and the Canadian. On the European market, each panel of a module is generally finished to the highest level possible (typically level 2b) to benefit from the full range of prefabrication advantages and then either shipped to site or assembled to a 3D structure if this is logical. Historically, prefabrication companies had decades of experience with panelized 2D prefabrication before venturing into 3D modular prefabrication. 3D is only applied if there is sufficient repetition of the same modules to justify the disadvantages of higher transportation and lifting costs. This can be, for example, in the case of larger hotels, social housing projects, or student homes where many similar components can be shipped over a relatively short distances and time at the construction site is extremely valuable.

In Canada, we observed that the assembly of the 2D panels into 3D modules happens frequently at the very beginning of the process (typically level 1). Assembling to a 3D structure as soon as possible, automatically eliminates some of the advantages of prefabrication. Not all advantages of working ergonomically optimized at a table can be utilized and in many cases, the finishing of an upright structure or even over-head components are more time consuming and similar to on-site construction. Furthermore, we observed that in Canada the modular prefabrication companies do not necessarily have experience with panelized prefabrication. Currently, we do see the risk developing as companies might directly enter the 3D market without gathering sufficient experience with finished 2D systems first. This would increase the risk of reduced quality and accuracy in the process.

Prefabricated modules showing finished wall and interior connector wall to next module in Sweden (Photo: G. Wimmers)

Prefabricated modules in Canada (Photo: Freeport Industry)

Prefabricated modules featuring completely unfinished walls in Canada (Photo: G. Wimmers)

Prefinished walls are mounted on a prefinished floor system during modular construction in Sweden (Photo: G. Wimmers)

Preinstalled electrical and mechanical systems in module, including the kitchen, heater, warm water and heat recovery ventilation (HRV) in Sweden (Photo: G. Wimmers)

2.4.4. CAD and CAM systems and BIM

When it comes to prefabrication technology, the process starts with 3D design software. Prefabrication requires the creation of a 3D model, often referred to as the digital twin, of the entire structure which includes all services like plumbing and electrical. The use of 3D Computer Aided Design (CAD) software is required to program the various CNC machines or robots involved in the manufacturing process. The software permits accurate material take-offs, scheduling, and martial optimization. These in turn, create opportunities for savings through cost certainty, allow extremely precise financial equations, change orders become virtually non-existent and this takes a crucial step towards the Building Information Modelling (BIM). Since the early 1990s, the European prefabrication industry applied BIM and architects utilized the first available BIM tool, ArchiCad on a large scale. Later, in the early 2000s, Revit arrived on the market. Since then many other tools have become available.

Some industry specific examples for processing software are Cadwork, Dietrichs and HSB. Although many others exist in the European market, these are the most commonly ones used in Timber-Framing and Log-Building in North America.

Once the structure is modelled in the CAD software it is passed onto a Computer Aided Manufacturing (CAM) system, where machine-specific details related to tooling and machine capabilities, are added and the machine code is generated for machine cutting. The above listed software packages are combined CAD/CAM systems specifically design for wood construction, both stick-framing, and mass timber. This is an efficient way of generating manufacturing data. The CAD component of the project can be done in various software programs, like Autodesk Revit, ArchiCAD etc. This is often the case for larger projects when the design is carried out by an Architect.

The implementation of BIM is not absolutely mandatory but considered essential and is highly recommended for level 2b and higher levels of automation. The prefabrication process, after modeling and creation of machine data through the CAD/CAM system, happens with various levels of automation but generally follows a similar sequence.

For conventional stick-framing as well as timber-framing, and log-building, the first step is to pre-cut the individual components. Cutting of the components can be done using common hand-held power tools like circular-saws, miter-saws and, in the case of log building, chainsaws. The cutting however can also be automated using CNC machines. At this stage in the process or the 1D prefabrication, generally the cutting is done using beam processors such as the Hundegger SC3 / K2, Krusi, or Essetere. For larger components like large curved glulam beams, the cutting is usually done on portal machines such as Hundegger PBA, Creno, Uniteam or other brands. While the latest trend is the utilization of robots for cutting and shaping rather than the 'pick and feed' applications robots were limited to in the past.

Hundegger PBA is a gantry style cutting machine for solid wood panels (Photo: Hundegger)

For the case of 1D prefabrication i.e. timber-framing, the process is essentially complete here and the components are shipped to the site for installation.

For 2D and 3D prefabrication the process continues by arranging the pre-cut components into 2D elements. The simplest form is the nail plate truss where the components are arranged and nail plates pressed into them to complete the trusses that are now ready for shipping to the site. For floor, wall, and roof elements, the components are placed, fastened and sheathed in plywood or OSB with the various openings cut out for windows and doors. Again, the level of automation can vary from homemade framing tables, where the components are nailed together by hand and the openings cut with hand-held routers, to the highest level where a framing station automatically places and fastens each component, including sheathing, and cuts the openings with a CNC controlled router.

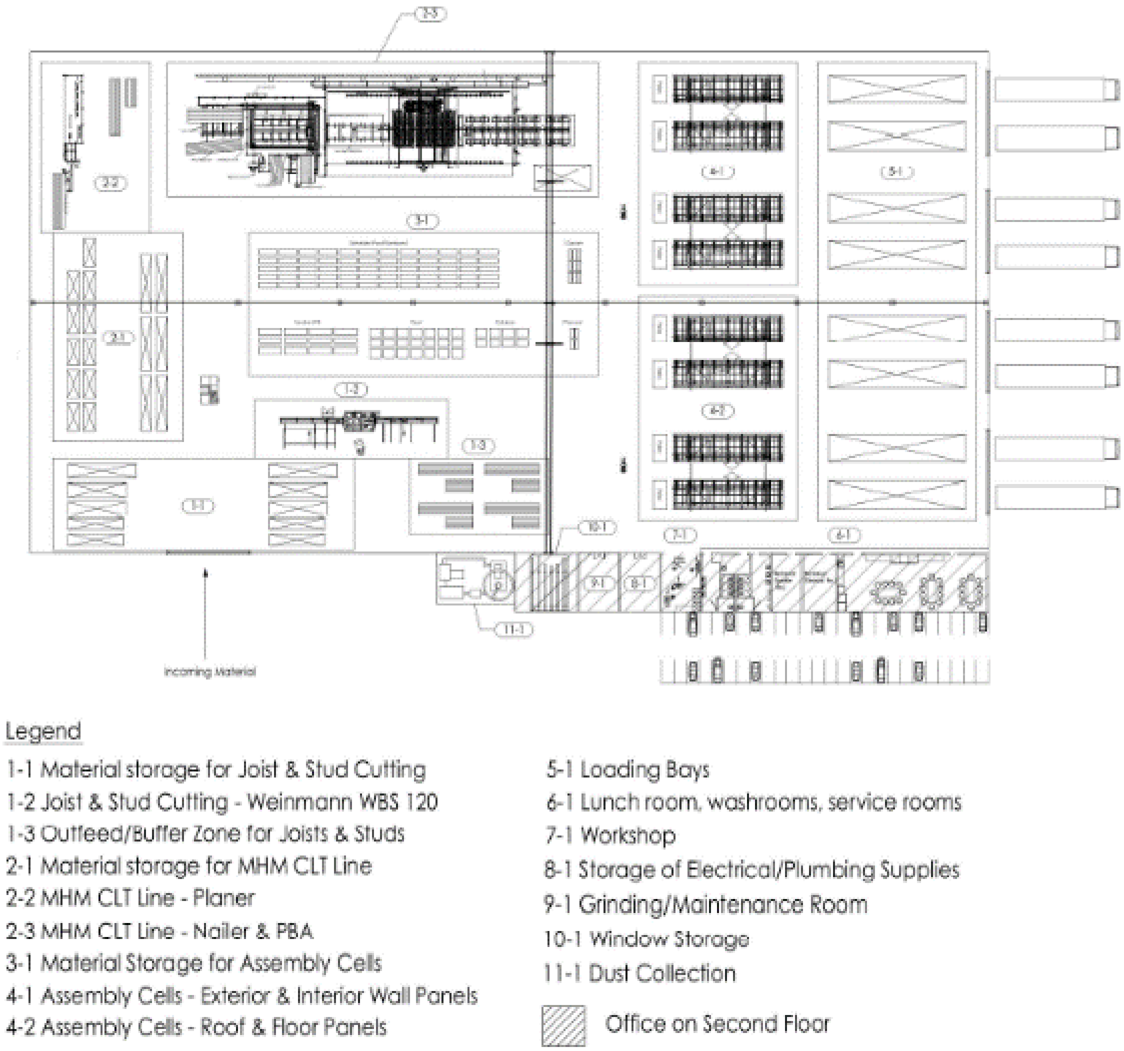
The simplest form of 2D prefabrication is now complete, but none of the two sides is finished. Non-insulated wall/roof/floor panels are ready to be shipped to the site. In North America these open, non-insulated panels, as well as the trusses are commonly referred to as Engineered Wood Products.

For higher levels of prefabrication, the process continues by flipping the panels with either, cranes or butterfly tables, insulating the cavity of the walls, and adding the vapor barrier. The still one side open panels are now ready for the construction site.

To further improve upon the process, the next step would be to install services like electrical and mechanical in the wall prior to adding the vapor barrier. Windows and doors can be added and the interior drywall mounted before the exterior is finished with strapping, rain screen, and even siding. This step can be done on tables but is usually done upright so both sides of the panel are accessible. The finished wall panel is now ready to join the others, either on-site to complete the structure, or in the factory to be assembled into a 3D or modular prefabricated components that are then ready to be shipped.

The process above is laid out for stick-framing, but prefabricated timber framing or mass-timber prefabrication differs little from it. When either CLT, DLT, NLT, or LVL panels are brought to the factory as blanks and then pre-cut with hand tools or portal CNC machines like the aforementioned Hundegger PBA, Creno, Uniteam or others. The blanks are cut to size, window and door openings cut out and the service channels are routed into the surface for mechanical and electrical services to be installed. From this point onward the finishing of the panels and modules is basically the same as it is for stick-framed panels.

Layouts for potential prefabrication plants are given below, and are for reference only. The actual plant layout is highly dependent on the product produced (i.e. small homes, large-scale housing projects, commercial projects, etc.) as well as the available space, either in an existing building or lot size for a new building.



Sample prefabrication plant layout (Graphic: M.Gehloff)

3. Background information to Building Code changes in BC

The BC Building Code (BCBC) influences two key factors in the decision of BC's industry to start transitioning towards prefabrication. The first one, is the energy efficiency defined in the BC Energy Step Code, as this code influences the thickness of the building envelope of each and every building and the second is the allowable height increase of wooden buildings to up to 12 floors.

3.1. BC Energy Step Code roadmap to 2032

The main changes the construction industry will encounter over the next 10 – 12 years will be the energy efficiency criteria of the buildings and their components as well as the optimization of the process in design and construction. Upcoming code changes will certainly influence other construction materials, but the wood construction industry is facing a significantly larger challenge ahead of them, as the process of production will be changed much more significantly than steel or concrete construction.

3.1.1. General changes in and to the design and process of construction:

In the design phase, energy efficiency, influenced by compactness, orientation, thermal performance, and airtightness of the envelope, often plays a minor role. Decisions on design and components are mainly influenced by emotions rather than science. Stating that construction costs play a significant role is ambivalent, as overall cost optimization is not the basis for many design decisions and construction methods. The majority of new construction, no matter if part 9 (small residential up to 4 units and 600m²) or part 3 (large residential and commercial buildings) (BCBC), is not optimized for compactness. This easily results in increased wall areas of 10 to 20% compared to a rather compact shape, triggering a large number of complicated details and specifically for part 9 buildings also a larger number of roofing areas. It is safe to say that a more compact design would save significant amounts in construction costs. These savings could be used to increase the energy efficiency of the building. There have been several studies explaining the increased construction costs on the different levels of the Step Code, but the majority assume the same design of the buildings instead of increasing the compactness and therefore significantly reducing the costs. To fulfill higher energy efficiency requirements, the most efficient first step is to optimize the compactness and, if possible, the orientation of the building. In the majority of buildings this alone would compensate for the additional investment into an improved envelope.

Most buildings built today are not prefabricated but built on-site. No matter if the entire framing is done on-site or with framing packages, the inefficiencies in this process are comparably large. As long as the walls remain relatively thin and the additional requirements for airtightness are low, the production of a building on-site is competitive, as large expenses for a facility and equipment are unnecessary.
We estimate that only a few percent of the annual construction volume for part 9 buildings are currently prefabricated. For part 3 buildings, the market share for off-site construction is certainly higher but still smaller than on-site construction.

We will generally see a shift from the currently dominating on-site construction to off-site construction. That does not mean that on-site construction will disappear but the market will develop in favor of off-site construction. There are several reasons to expect this transformation:

- **Step Code is requesting thermally better performing envelopes**
- **Envelope Components are getting heavier**
- **Envelope segments are getting bulkier**
- **Airtightness requirements are getting more stringent**
- **Labor intensity increases due to added steps**
- **Overall quality**
- **Speed of construction**

The total duration of a project is not dissimilar compared to building on-site, but the various stages are structured differently. The planning and design phase will potentially take a little bit longer as the final product will have to be designed to higher standards than are currently required, and if prefabrication is applied, change orders are generally not possible. Prefabrication in a controlled environment is faster than traditional methods, especially if a higher level of prefabrication is applied with electrical and mechanical lines and equipment preinstalled. The higher the level of prefabrication, the higher the cost efficiency and the faster the projects total timeframe. The time needed on-site is the obvious and largest overall saving. The equivalent size of a single family house can be installed in less than one day. The disruption of traffic or annoyance to neighbours is greatly reduced. The expensive operations of an on-site crew, including cranes, and the costs for shipping, are reduced to a minimum.

3.1.2. Costs of construction

Overall, cost of construction is the most delicate topic to broach, but by looking at other countries where more stringent codes have been in place for numerous years, we can with some confidence, predict that construction costs will not necessarily increase, or if they do, it will only be by a few percent. The base for this assumption is that labour efficiency in the construction sector actually decreased by almost 20% over the last 50 years. Simply put, you get 20% less out of one labourer compared to 50 years ago. In comparison, the labour production index in all other industries went up by around 150% and for farming even significantly higher than that over the same period of time. This shows that how we build is not efficient, or at minimum not remotely comparable to the efficiency in other industries. These numbers are based on the US construction industry. The Canadian construction industry shows a strong resemblance. European wood construction industry does not. Several European countries also demand much higher energy performance in their codes. These two are closely intertwined. If heavier components, thicker insulation, better airtightness, is required, the process has to be optimized to keep the final product affordable. Optimizing processes by introducing off-site construction. This demands a relatively high investment into a larger production facility and additional equipment. These investments will be paid by increased productivity and sales. In practice, we see that entry level prefabrication starts at an equivalent volume of around 50 single-family houses per year. Larger companies produce several hundred buildings per year. Once this market is established and processes optimized, the actual construction costs (not the sales price!) are not significantly higher than what we currently experiencing in BC, but the quality is probably at a significantly higher level. Workers have a safer, more comfortable work environment, independent from weather, and a production line can be run in several shifts. The optimization of the construction process, located mainly off-site, can save significant amounts of labor costs due to higher efficiency, potential introduction of automation, and addition material costs can be reduced as materials can be further optimized and waste minimized. Only the prefinished components will be shipped to the final location of the building and installed in a very short period of time. Finishing work on-site can be completed in a few days.

3.1.3. Changes trigger by the highest step

What does the highest step (4 for part 3 buildings and 5 for part 9 buildings) actually mean for designers and engineers, as well as for the construction industry, and eventually the owner, and user? First we want to clarify what those steps do not mean.

Clarification:

The highest step does not equal a “net zero energy building”.

To reach the theoretical equilibrium of “net zero energy” a building would have to have renewable energy systems installed to generate on-site (or near site) the energy consumed. This can be done with virtually any building, but the investment into energy generating systems will depend on the energy used.

The highest step does not equal a “Passive House”.

A Passive House, following the international standard is a building which offers a stable interior climate, in summer and winter with very minimal active components. The defined energy performance requirements show some similarity with those in the BC Energy Step Code, but the methods of simulation and calculation are different in detail. A part 9 building with a Thermal Energy Demand Intensity (TEDI) of 15 kWh/m² can still have a significantly higher energy consumption then a Passive House as the methods of calculation are not identical. But the gap between a code compliant building in 2032 and a Passive House will be much smaller than it is today. The construction industry will be building better performing buildings by then, so the hurdle to build a Passive House will be much smaller than it is today.

For Architects and Engineers:

For the architect and engineer it means that the building will have to be designed with more emphasis on the aspects which influence the energy efficiency, namely orientation and compactness, better insulation, and reduction of thermal bridges, optimization of glazing and windows, good airtightness, and proper ventilation with heat recovery. In reality this means that earlier in the process, slightly more efforts have to be made to achieve higher energy efficiency targets. Details have to be designed thoroughly, always keeping airtightness and thermal bridges in mind. By optimizing the shape, orientation and the compactness of a building, construction costs can be influenced significantly.

If prefabrication in applied, design processes can be further optimized. The design must be completed before production begins.

For Builders, Trades and Contractors:

The professionals involved in the construction of a building will have to implement new details and strategies, and will have to put more emphasis on workmanship in regards to airtightness and thermal bridging. These changes are relatively easy to implement in the construction process.

The increase of the thermal performance of the envelope might be different in the sense that we will most likely see a fundamental shift in processing.

Mainly depending on your climate zone and size of the building, the thermal envelope for the highest step will feature an increase of wall thickness of up to 87-100% compared to the current code. This implies, depending on the construction method, also an increase of weight between 42 and 77%. The builder, in conjunction with the architect and engineers will find new methods to make this leap affordable. Besides the compactness, the process of construction, namely prefabrication, can develop significant savings. This is not an unsurmountable task, many countries have shown us already how it can be done, nonetheless, it will probably be the largest challenge, and opportunity, the industry has seen for a long time.

When changing your average wall thickness from around 16.5cm to eventually around 31cm, changes to the process are inevitable. Framing crews can easily nail a 2x4 or 2x6 wall on-site together and with the force of a few workers put it up and into position. The same might be still possible with a 2x8 wall but probably not with a 2x10 and certainly not with a 2x12. These walls will simply be too heavy. But the increased thermal performance values do not necessarily trigger larger framing dimensions, they can be accomplished with thicker continuous layers of insulation on the outside. With this method, weight is not the limiting factor, but the volume of insulation is, and the additional labor steps will make production on-site rather inefficient and trigger a lack of competitiveness.

Thick wall assemblies will more likely be pre-manufactured in a controlled environment. The level of prefabrication will most likely far exceed the so called framing packages, as entire walls and other envelope components can be pre-manufactured, even up the point that electrical and plumbing services are included. This becomes even easier if modular systems are chosen, as the number of connections on-site decreases.

For the Owner of the Building:

For the owner the highest step means that your building has an acceptable energy efficiency, as is required in other countries already. It means that your building should perform much better than a building built to fulfill the lower steps, following that your energy bill and environmental impact will be lower, plus your thermal comfort and well-being will be higher. The initial investment for buildings fulfilling the higher energy efficiency requirements might be slightly higher as more materials and also better performing components have to be purchased and installed. Three factors will help to offset those potentially higher initial investments.

a) As industry gets more used to designing and building better performing buildings, the associated soft cost and the extra costs, usually charged for the unknown risks, are going to diminish.
b) With the consequential increase of the volume in customized mass production and accuracy, prefabrication will start to show its potential and through significantly higher efficiencies in the manufacturing process, the increased costs of materials can be balanced to some degree with an increase in efficiency of production.
c) As the Passive House Standard has already proven these past several decades, the monthly or annual costs of ownership (including financing) are usually cheaper for a highly energy efficient building than for a mediocre performing building. Affordability is one of the key goals of the Passive House Standard. As already pointed out earlier, the highest step in the BC Step Code does not necessarily equal that of the level of a Passive House, but at least the gap to actual cost efficiency in terms of monthly costs of ownership is much smaller than ever before.

3.2. Increased allowable building height

The second major influence on the wood construction industry is the already implemented or potentially upcoming changes regarding the maximum allowable height of wooden buildings in BC and other markets.

This will not only increase the market for engineered wood products since the utilization of those products is advised above three floors and necessary above six floors, but building larger buildings in wood also demands a different type of production. Taller buildings above 6 floors cannot be cost efficiently and safely built without EWP and a fairly high level of prefabrication. BCBC has now allowed 12 floor wood buildings and are mandating EWP requiring prefabrication. For prefabrication the use of dimensionally stable engineered products is advisable and when automation is used, necessary. The market share of medium or even high-rises will almost certainly grow and this will most likely trigger a shift to more prefabrication and the use of more engineered wood products. The construction volume of large residential buildings is already more than 50% of the total residential market in BC and small residential buildings will most likely continue to decrease across the province in the future.

3.3. Summary of the BC Energy Step Code:

Older versions of the BCBC had some performance criteria for specific components of a building, for example the thermal performance of the windows was regulated as was the minimum insulation for opaque envelope components, but older versions of the code did not require a certain level of energy efficiency for the entire building. The first step of the BC Energy Step code, implemented in 2018, does not really change that, only additional performance parameters are introduced (e.g. airtightness) but there is no specific performance required. Currently, for both building categories specified by the code, part 3 and part 9, no overall performance is required. This will change with step 2 and all following steps. For the first time in BC, the energy efficiency of a building has to be calculated and simulated before it is built. Energy efficiency becomes a design requirement. Currently it is not clear when and where the intermediate steps will be implemented but it is planned that the highest step will be implemented in 2032. In the following sections we will focus mainly on the highest step, because this will have to be achieved in a relatively short timeframe anyway and all intermediate steps are incremental steps and follow the same rational as the highest.

"The BC Energy Step Code is a provincial regulation that local governments may use, if they wish, to incentivize or require a level of energy efficiency in new construction that goes above and beyond the requirements of the *BC Building Code*. It consists of a series of steps, representing increasing levels of energy-efficiency performance. By gradually adopting one or more steps of the standard, local governments can increase building performance requirements in their communities. The Province of British Columbia has set a goal that all new buildings must reach a net-zero energy ready level of efficiency by 2032; the BC Energy Step Code serves as the policy pathway to reach that goal."

BC Energy Step Code Brand Handbook Volume 2, version 1 Jan 2018

The Energy Step Code is focused on the BCBC part 3 (commercial and large residential) and part 9 (small residential) buildings and defines energy efficiency targets for a large variety of buildings. First published in 2017 it defines 4 performance steps for part 3 buildings and 5 performance steps for part 9 buildings.

Steps for part 9 buildings

Steps for part 3 buildings (Source: RDH/ BC Housing)

3.3.1. Step Code metrics

For both types of buildings, small residential (part 9) as well as large residential or commercial (part 3), the metrics are defined by using the different performance indicators. The performance steps are defined by using airtightness, the Mechanical Energy Use Intensity (MEUI) for part 9 and the Total Energy Use Intensity (TEUI) for part 3 and the definition of the performance of the building enclosure defined by the Thermal Energy Demand Intensity (TEDI). The unit for energy used is kWh/m²year, dividing the consumed energy by the conditioned floor area, resulting in energy intensity.

Building Type	Airtightness	Equipment and Systems	Building Enclosure
Part 9		% < REF OR MEUI	TEDI
Part 3		TEUI	TEDI

(Source: RDH/ BC Housing)

For part 9 buildings, the lower four steps alternatively allow the MEUI as a reference case scenario but since this option is only a temporary alternative and cannot be used for the mandatory highest step put in place at the latest in 2032 we will not focus on this option further.

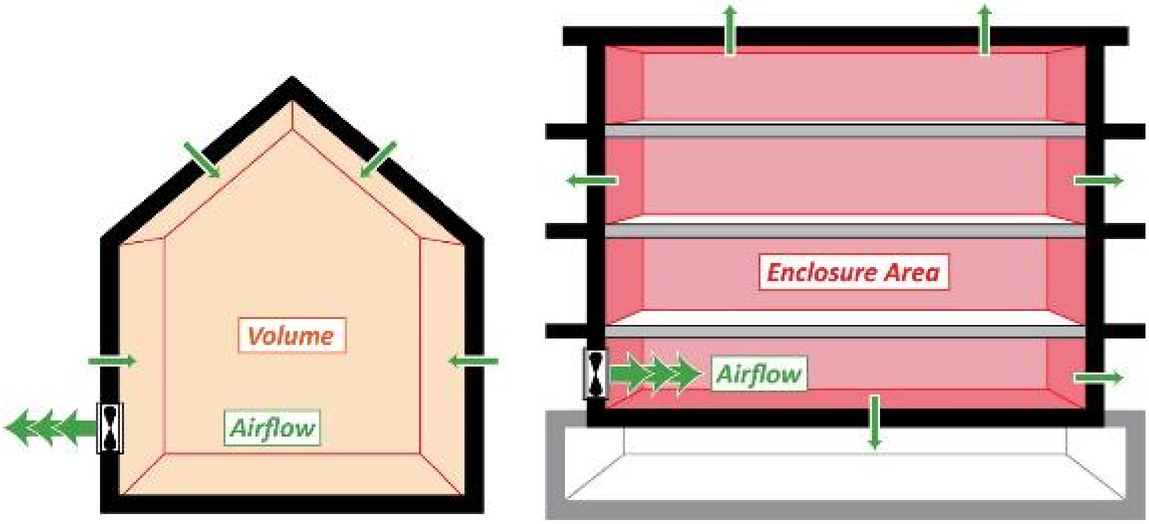
3.3.2. Airtightness

Airtightness of buildings is measured by pressurizing or depressurizing the interior volume by utilizing a fan. Air flow in or out of the building is then measured at the fan to evaluate how much air in- or ex-filtrates through leakages in the envelope. This is an important quality control for various reasons, the most important ones are safeguarding the insulation layers (if air flows through insulation, performance would be reduced drastically) and preventing condensation in envelope components due to warm humid air flowing over cold surfaces.

The requirements for airtightness are homogeneous throughout the province and increase slightly with each step. Unofficially the average airtightness of new construction in Vancouver in the years 2010 to 2013 was around 5 air changes per hour at a pressure difference of 50 Pascal. This shows that airtightness will be one of the larger challenges for the construction industry as in a few years an airtightness of 1.5 or even 1.0 ach/h@50Pa are required.

Design details will become more accurate and an airtightness strategy must be developed for each project. The implementation of these details becomes crucial and all trades on site, including electricians and plumbers, have to be aware of not penetrating the air barrier in an uncontrolled matter. Experience has shown that spray foam, besides having some serious environmental concerns, might not be capable of fulfilling higher airtightness requirements, functional strategies with air tight layers will have to be introduced.

Although airtightness might be one of the larger hurdles to master for the construction industry, it is certainly possible. For almost 30 years the International Passive House Standard requires an airtightness of 0.6 ach/h@50Pa with a very large array of buildings built in many countries over various climate zones. UNBC's Wood Innovation Research Laboratory built in 2017/18 in Prince George by local builders is currently (Feb. 2020) North America's most airtight building with an airtightness of 0.07 ach/h@50Pa.

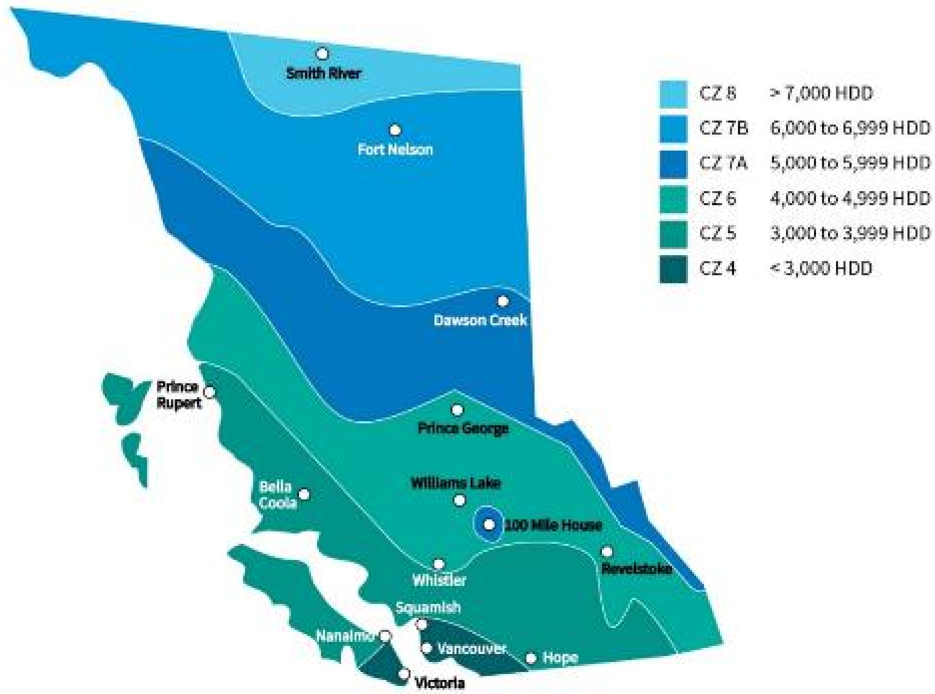


Concept of airtightness test (Source: RDH/ BC Housing)

$$\text{Step Code Metrics} = \frac{\text{Annual Energy Consumption}}{\text{Area of Conditioned Space}} = \frac{\text{kWh}}{\text{m}^2 \cdot \text{year}}$$

3.3.3. Climate

BC features several different climate zones and MEUI and YEDI requirements are dependent on these climate zone. This allows buildings in the colder climate zone to consume more energy than those in milder climate zones. The climate zones are defined with Heating Degree Days (HDD) based on 18°C. For each day on average lower than 18 degrees the temperature difference is added on an annual base. Quesnel is located in the center of climate zone 6, therefore all further explanations are based on this climate zone.



The highest step for part 9, climate zone 6 (Source: RDH/ BC Housing)

Depending on the climate zone, the requirements for the highest step differ, in the lower mainland a TEDI of 15kWh/m² is required, in climate zone 6 only 25kWh/m²is required. This means that a building in climate zone 6 is allowed to use more energy than if it were in a milder climate zone.

For both categories, part 3 and part 9, the highest step (step 4 and step 5) is occasionally also referred to as “net zero ready”.

“Net-zero energy buildings produce as much clean energy as they consume. They are up to 80 percent more energy efficient than a typical new building, and use on-site (or near-site) renewable energy systems to produce the remaining energy they need. A net-zero energy ready building is one that has been designed and built to a level of performance such that it could, with the addition of solar panels or other renewable energy technologies, achieve net-zero energy performance.” (BC Energy Step Code Brand Handbook Volume 2, Version 1 Jan 2018)

This definition is rather vague since only the equilibrium of consumption and generation is described, not the energy efficiency itself. Almost every building could theoretically be net zero, it only depends on the size and investment into renewable energy systems installed on site. Key factors such as time frame and grid losses are not factored in.

But the step code gives a more precise definition by using the Airtightness, the MEUI and TEDI to describe the performance to be met in the highest step.

	Airtightness	Equipment & Systems			Building Enclosure
	Air changes per hour at 50 Pa pressure differential	% < REF	OR	MEUI	TEDI (kWh/(m²·year))
STEP 1		0%			
STEP 2	≤ 3.0	10%	OR	see below	60
STEP 3	≤ 2.5	20%	OR	see below	50
STEP 4*	≤ 1.5	40%	OR	see below	40
STEP 5*	≤ 1.0			see below	25

Performance requirements in climate zone 6 (Source: RDH/ BC Housing)

3.3.4. TEDI

The Thermal Energy Demand Intensity describes the annual thermal losses of the entire envelope of the building, all six surfaces, if the building would be a cube. The energy losses of each component, such as walls, roof, floors, windows and doors are calculated according to their U or R values and simulated in the respective climate, resulting in the total thermal losses. This amount of energy will be needed to maintain a comfortable interior climate and is divided by the conditioned floor area to be expressed as energy density in kWh/m²year

3.3.5. MEUI

The Mechanical Energy Use Intensity is the calculated energy consumption of the mechanical systems installed in a building, such as ventilation or warm water systems, excluding light and plug loads. This energy consumption is then divided by the conditioned floor area resulting in the energy density expressed in kWh/m²year. Source or primary energy are not factored into this equation. In step 5, climate zone 6 a very small building with a floor space below 50 m² is allowed to consume up to 80 kWh/m²year while a large building with over 210 m² would only be allowed to consume a maximum of 45 kWh/m²year. If a cooling system is installed the allowable values are increased.

MEUI Targets per Building Size and Whether the Building is Designed and Constructed with or without a Cooling System (kWh/(m²·year))

	≤ 50 m² (538 ft²)	≤ 75 m² (807 ft²)	≤ 120 m² (1292 ft²)	≤ 165 m² (1776 ft²)	≤ 210 m² (2357 ft²)	> 210 m² (2357 ft²)
Buildings Designed and Constructed with No Cooling System						
STEP 2	160	145	115	100	90	85
STEP 3	145	125	100	87.5	77.5	75
STEP 4*	105	95	75	62.5	55	55
STEP 5*	80	70	55	45	40	40
Buildings Designed and Constructed with Cooling System						
STEP 2	195	172.5	132.5	110	97.5	90
STEP 3	180	152.5	117.5	97.5	85	80
STEP 4*	140	122.5	92.5	72.5	62.5	60
STEP 5*	115	97.5	72.5	55	47.5	45

MEUI requirements in ratio to conditioned floor area (Source: RDH/ BC Housing)

3.3.6. The highest step for part 3 buildings

For large residential and commercial buildings (part 3) the requirements are a bit simpler, not dependent on size and not dependent on location or climate. The 4 performance steps are defined by two factors, the Total Energy Use Intensity and the Thermal Energy Demand Intensity, both measured in kWh/m²year.

TEUI represents the entire operational energy consumption of a building, divided by its floor space. Primary or source energy is not factored into the equation.

TEDI describes all thermal losses of a building projected on the floor space. TEDI is identical to the calculation of part 3 buildings and expresses the total thermal energy losses of the building divided by the conditioned floor space.

	Equipment & Systems TEUI (kWh/(m²·year))	Building Enclosure TEDI (kWh/(m²·year))
STEP 1	Conform to Part 8 of the NECB	
STEP 2	130	45
STEP 3	120	30
STEP 4*	100	15

Part 3 TEUI and TEDI requirements (Source: RDH/ BC Housing)

3.3.7. Timeline

The BC Energy Step Code was introduced in 2017 and currently step 1 is binding across BC. In the coming years, the BCBC will make steps in the BC Energy Step Code mandatory, potentially even skipping steps to keep the clearly defined goal of having all new construction following the highest step by 2032. The implementation of steps beyond the code requirements is up to the discretion of each municipality. Since the time span from today (2020) to the latest possible date when the highest step will be put in place (2032) is only 12 years, the main focus is on the highest steps. The intermediate steps logically increase with each discussed challenge in incremental step.

Realistically, part 9 buildings have a timeline of around two years from the preliminary planning stage to completion, and part 3 buildings usually take three to five years. This shows there is only a small number of generations to be built in order to gain the necessary experience towards successfully fulfilling the highest code step, 12 years from now.

4. Summary

The already implemented or upcoming changes of the BCBC, in terms of energy efficiency and allowable height of buildings has the potential to significantly influence the wood construction industry and therefore indirectly also the forest product industry. By observing other countries who went through similar code changes in the past, it seems reasonable to assume that similar changes in industry will occur in BC. A major change is the general transition from on-site construction to off-site construction. With this change the demand for materials will potentially change and influence the forest and forest products industry.

Even though those changes might seem daunting at a first glance, it is important to emphasise that they include significant opportunities, specifically for municipalities outside of the lower mainland. The manufacturing of engineered wood products or the prefabrication of buildings is economically viable in areas with easy access to construction material, workers and lower real estate prices, as larger facilities are required. As long as those municipalities are connected via rail or highway to larger markets, the above listed advantages most likely outperform the disadvantages of larger shipping distances.

Given the history and setting of Quesnel, it can be assumed that the coming years bring a number of opportunities to extend the range of forestry products, EWP or prefabricated construction components to the benefit of the entire community.

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