A Comparative Feasibility Study for Encapsulated Mass Timber Construction

BC Energy Step Code Compliant 7 to 12 Storey Buildings

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Definitions Used in This Report

Air Leakage: The measure of unwanted air changes through the building envelope is a measure of the airtightness of the building. The options provided for the user are “Code” and percent better than Code. Code is set based on national building energy standards code while percent better is achieved by improving the air barrier system above Code. Reaching improvements in the air infiltration can greatly reduce the heating load in buildings and requires planning, coordination, and process changes during construction.

Biogenic Carbon: The carbon that is stored in biological materials, such as plants or soil. Carbon accumulates in plants through the process of photosynthesis.

Carbon footprint: The amount of carbon dioxide and other carbon compounds emitted due to the consumption of fossil fuels by a particular person, group, product system, building, etc.

Cooling Energy Demand Intensity (CEDI): The measure of annual cooling load in kWh/m^2/year of the building (how much cooling energy the cooling equipment must deliver to maintain space temperatures).

Circular economy: refers to a closed-loop model of an economy where waste is eliminated. All waste products are either sold, consumed, collected and then reused, remade into new products, returned as nutrients to the environment or incorporated into global energy flows.

Climate Zone: A building will perform differently when situated in different regions in B.C. Each region is modelled based on a single representative city using its Canadian Weather year for Energy Calculation (CWEC). Climate zone 4 weather is based on Vancouver CWEC (4), climate zone 5 Kamloops CWEC, climate zone 6 Prince George CWEC, and climate zone 7a Fort St John CWEC.

CLT-suitable lumber: Lumber that meets CLT wood species, dimension, grade, and manufacturing specifications.

Construction waste: refers to wastes that are derived from the process of constructing new buildings or retrofitting existing buildings, but excluding large civil and public infrastructure projects (dams, bridges, etc.), marine pilings, telephone infrastructure, rail infrastructure, land clearing, etc.

Cross-laminated timber (CLT): A large-scale, prefabricated, engineered wood panel. A CLT panel is made up of several layers (typically three, five, or seven) of dimension lumber stacked in alternating directions, bonded with structural adhesives, and pressed to form a solid, rectangular panel.

Cyclical Renewal Cost: During the life of a building certain items need to be replaced for the building to continue to be used to it’s full potential. Allowances for these renewals based on the current level of design would be split into more details as the design develops.

Design for Disassembly: Describes how a building is “designed with the end in mind” so that it can then be cost-effectively and rapidly taken apart at the end of life and components can be reused and/or recycled. The design team creates a disassembly plan that sets out the method of disassembly of major systems during renovations and end of life, and the properties of major materials and components.

Dimensional lumber: A type of lumber that is cut to specified industry-standard dimensions (e.g. 2 x 4, 2 x 6).

Dowel-laminated timber (DLT): A mass timber panel which can be used for floor, wall, and roof structures. In many ways, it is similar to Nail Laminated Timber (NLT) but utilizes dowels rather than nails to join successive boards together, making it a 100% wood product.

Economic impact: The effect of an event on the economy in a specified area, ranging from a single neighborhood to the entire globe. It usually is measured by changes in business revenue, business profits, personal wages, and/or jobs.

Electricity Energy Use Intensity (EEUI): The total electricity use in kW/m^2/year of the building per square meter of gross floor building area. See also EUI

Embodied carbon emissions in construction: Commonly referred to as “embodied carbon” refers to the GHG emissions associated with the manufacturing, maintenance, and decommissioning of a building product.

Energy Use Intensity (EUI): The total energy use in kW/m^2/year of the building per square meter of gross floor building area.

Engineered wood products: Also called composite wood, man-made wood, or manufactured board, these products are manufactured by binding or fixing the strands, particles, fibres, or veneers or boards of wood, together with adhesives, or other methods of fixation to form composite materials.

Glue-laminated timber (GLT): Glued laminated timber, also called glulam, is a type of structural engineered wood product comprising of several layers of dimensional lumber bonded together with durable, moisture-resistant structural adhesives. In North America, the material providing the laminations is termed laminating stock or lamstock.

Greenhouse gases (GHG): Are gases that trap heat in the Earth’s atmosphere. Commonly these are carbon dioxide, methane, nitrous oxide, and fluorinated gases (such as CFCs, HCFCs, HFCs etc. found in refrigerants).

Greenhouse gases intensity (GHGI): The total greenhouse gas emissions, expressed as kgCO2e per m^2 per year, associated with the energy used by the building’s systems. See also EUI

Labor income: All forms of employment income, including employee compensation (wages and benefits) and proprietor income.

Life cycle assessment (LCA): Compilation and evaluation of the inputs, outputs, and the potential environmental impacts of a product system throughout its life cycle.

Machine grading: A system used to determine relative strength and stiffness of lumber using mechanical tests.

Machine stress rated lumber: Lumber that is evaluated using machine stress rating equipment.

NECB Electricity Energy Use Intensity: For each archetype a comparable building was created which adheres to the National Energy Code of Canada for Buildings (NECB) Code building was created and modelled. The NECB Reference Building uses a natural gas boiler plant to supply hydronic terminal space heating systems. This number provides the electricity use intensity of that comparable building.

Net Zero: A net zero building, also known as a zero net energy (ZNE) building, net-zero energy building (NZEB), or zero-energy building, is "an energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy."

Net-zero-energy-ready or "zero energy ready": A net-zero-energy-ready building is a high-performance building which is so energy efficient, that a renewable energy system can offset all or most of its annual energy consumption. It is inferred that the renewable energy system itself is not included in the building, but the owner could add it at some future time and the building would then become a net zero building.

Operating emissions: In buildings refers to the GHG emissions that are generated from the supply and consumption of energy used to heat, cool and power a building during its service life.

Salvage Credit: Adjusted costs when structural components in a takedown may be used to rebuild the structure, or may be returned to stock for future use or in the case of steel components that are sold for scrap or salvage by the company or EMTC components that are re-utilized.

Thermal Energy Demand Intensity (TEDI): This metric represents the amount of heating a building needs to offset building envelope losses and temper ventilation air, prior to any mechanical interventions (with the exception of ventilation heat recovery equipment). The intent of this metric is to maximize passive or near passive systems before looking at heating delivery methods and technology.

Wall or Roof RSI Value: The thermal resistance value of a wall or roof assembly is indicated by its RSI value. The higher the RSI value the lower the heat loss through the surface. To convert between RSI and commonly found R-value, use 1 K·m^2/W = 5.678 (hr·ft^2·°F)/Btu. An RSI of approximately 2.28 is approximately R13, while an RSI of 4.89 is approximately R28. The value entered here should be the overall system value, not the nominal value of the insulation layer in the wall assembly. The system value accounts for thermal bridging effects from studs, shelf-angles, window-to-wall transitions, etc.

Vertical Wall to Floor Area Ratio: A building's vertical exposed surface area to floor area ratio (VFAR) is a significant influential factor on the heating energy use of a building, especially when the TEDI target is normalized for floor area. This metric is similar to a more common metric of surface area to volume ratio. However, for high-rise MURBs, the majority of heat loss occurs in the vertical surface areas due to the relative high percentage surface area compared to total exposed surfaces and due to the difficulty of effectively insulating vertical assemblies. Therefore, VFAR has a more direct relationship with TEDI than surface area to volume ratio and is commonly used as a primary building shape metric.

Window to Wall Ratio: The Window to Wall Ratio parameter is the percent of the total, above grade exposed wall area that is made up of windows. Windows will have greater heat loss than walls hence, the more windows a greater overall heat loss. However, windows also admit solar radiation offsetting heating loads, so a balance is necessary.

List of Acronyms & Abbreviations

AEC Architectural, Engineering, Construction

AHJ Authority Having Jurisdiction

BCBC British Columbia Building Code

BCFC British Columbia Fire Code

BETBG Building Envelope Thermal Bridging Guide

CFM Cubic Feet per Minute

CLT Cross-laminated Timber

DHW Domestic Hot Water

DLT Dowel-laminated Timber

EMTC Encapsulated Mass Timber Construction

FRR Fire-Resistance Rating

GC/CM General Contractor/ Construction Manager

GFA Gross Floor Area

GHG Greenhouse Gas

HRV Heat Recovery Ventilator

HSS Hollow Steel Section

HVAC Heating, Ventilation, and Air Conditioning

IBC International Building Code

KD Kiln-dried

MSR Machine stress rated lumber

MURB Multi-unit Residential Building

NAFS North American Fenestration Standards

NBC National Building Code of Canada

ROI Return on investment

SHGC Solar Heat Gain Co-efficient

SPF Spruce-Pine-Fir

VBBL Vancouver Building Bylaw

VFAR Vertical Wall to Floor Area Ratio

WWR Window-to-Wall ratio

Elemental Cost Descriptions

GENERAL CONDITIONS AND REQUIREMENTS	Management (project managers/coordinators, superintendents, etc.), field office (trailers, furniture, office supplies, services, equipment, etc.), field operations support (labor, storage, equipment, tools, fencing, clean-up, etc.), job-site requirements (security, roads, toilets, signage, etc.), project safety requirements (audits, safety equipment, safety supplies, fire protection, etc.), waste management, temporary power, water, heating, etc., scaffolding, hoisting, etc. and excludes insurance and bonding, surveying, warranty, training, legal, and taxes
STRUCTURE	Above grade steel, concrete, mass timber, slabs and columns for floors and roof, rough carpentry, cast in place concrete cores, lateral restraint system
ENCLOSURE	Cladding, fenestration, shading devices, exterior doors, roofing and roof deck waterproofing, roofing, and roof deck assemblies (including insulation), balcony waterproofing, balcony and integrated guardrails, damp-proofing and waterproofing on below grade walls.
INTERIORS	Steel studs for interior walls, acoustic insulation (if any), gypsum wallboard (GWB), flooring and paint, mill work (kitchen cabinetry, bathroom vanities, entrance lobby fixtures, etc.), finish carpentry (windowsills and casing, baseboards, etc.), washroom accessories, interior doors
MECHANICAL	Heating, Ventilation and Air conditioning (HVAC) system, plumbing system, building automation system, fire protection system
ELECTRICAL	Electrical distribution system, lighting, fire alarm system
FOUNDATION	Concrete footings, below-grade walls, suspended slabs and slab-on-grade, elevator shafts, concrete block walls, structural steel, and miscellaneous metals
CONTINGENCY/ OTHER	Design & Pricing Allowance, escalation allowance, construction allowance

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Executive Summary

Addressing greenhouse gas (GHG) emissions from buildings and infrastructure is critical to protect our planet from climate change. One potential strategy can be found in the methods and materials used to construct buildings, especially tall residential and commercial structures.

There have been recent changes in Canada's National Building Code to include encapsulated mass timber construction (EMTC) and a lot of interest in encapsulated mass timber construction. For these reasons, this study was commissioned to develop comprehensive 7- to 12-storey archetypes for comparison of the potential methods and a means of construction in B.C. The goal was to examine the scope of activities involved during the production, distribution and installation of building components and systems, and the construction planning process of affordable, high performance multi-unit housing. There was also a focus on the financial viability of EMTC as a solution to address carbon emissions and energy use. Furthermore, the report explored GHG emissions in compliance with the requirements of the BC Energy Step Code and BC's Zero Carbon Step Code.

The three building archetypes designed in this study were based on three unique bylaw and climatic regions. This enabled a reasonable comparison of costs between concrete, steel and EMTC. These regions included the cities of Vancouver, Coquitlam and Kamloops. The archetypes were developed to be compliant with the Vancouver Building By-Law, BC Building Code, and the BC Energy Step Code 3 and 4 as a minimum standard where applicable. Many of the design strategies developed in the three regional EMTC archetypes are specific solutions for improving building performance and durability. These solutions enable the best potential use of biogenic carbon as part of a complete carbon removal strategy.

The EMTC archetypes encompass embodied carbon reductions, thermal performance considerations that reduce energy use and applicable GHG emissions, and avoided emissions through durability and the long-term storage of biogenic carbon. This approach avoids a singular focus on operational carbon emissions reductions and includes both embodied carbon and avoided emissions as part of the comparison of the Global Warming Potential of each unique building structure, massing, and location.

As well, an online tool, Mass Timber Navigator, was developed in parallel to this study. This tool allows researchers to assess both EMTC feasibility and energy code compliance. Data generated by the Navigator can also be used by developers to produce real estate proformas.

When assessing the potential economic advantages of EMTC, researchers found the following three key processes that reduce project costs for EMTC when compared to conventional steel and concrete construction.

- Increased speed of construction,
- An integration of mass timber structures and facades
- Optimization of mechanical and electrical systems.

Furthermore, the life cycle cost advantages offered the best opportunity for EMTC projects to produce the highest return on investment (ROI).

This study is for developers, builders, engineers, design professionals, building product manufacturers and suppliers, government officials and others involved in zero-carbon buildings and infrastructure. It presents practical approaches to using EMTC structural components and building concepts that are tested, certified and practice-oriented standard solutions. This study shares what was learned about energy efficiency, cost, schedule and code implications. However, since every building project and market is unique, the report makes no claims concerning specific cost or time frame. Instead, it provides comparative feasibility data that is necessary for a comprehensive real estate study.

With regards to building for a sustainable future across all archetypes and achieving the Canada Green Building Council's Net Zero Carbon Performance Standard, further recommendations include:

- Adoption of low-carbon energy systems, electrification and low-carbon grids to reduce greenhouse gas intensity.
- Adoption of offsite construction and digital twin technologies to improve building performance, lower costs and productivity in the mass timber industry.

These initiatives are fundamentally integrated into EMTC construction and only help to strengthen the compelling business case for EMTC as a solution for 7- to 12-storey buildings.

Finally, this report encourages related industries and professionals to embrace the unique systematic performance design process of EMTC. This would help to achieve the advantages in embodied carbon, resilience and cost that were demonstrated in the study.

Background

The idea of carbon neutrality in buildings has typically focused on operational carbon. This means that a building would be carbon-neutral if it could meet its annual operational energy demands with 100% carbon-free energy (i.e., energy produced without fossil fuels). Examples could include an all-electric building with a photovoltaic system offsetting its annual energy demand or a natural gas-heated building whose owner purchases enough carbon offsets to outweigh its gas use. But in focusing only on operational carbon, developers fail to account for the energy and carbon expended during the extraction, manufacture, transportation and installation of all building components.

In the future, the goal is that most carbon emissions from buildings will be embodied and locked in at the time of building occupation. Increasingly, EMTC buildings are becoming a focus for further embodied carbon reductions due to biogenic carbon removal and for providing a solution to the complexity and cost of high-performance concrete or steel structure buildings that comply with the BC Energy Step Code and Carbon Step Code.

Résumé

La lutte contre les émissions de gaz à effet de serre (GES) provenant des bâtiments et des infrastructures est essentielle pour protéger notre planète contre les changements climatiques. Les méthodes et les matériaux utilisés pour construire les bâtiments, en particulier les immeubles résidentiels et commerciaux de grande hauteur, offrent une stratégie potentielle.

Le Code national du bâtiment du Canada a été modifié récemment afin d'inclure la construction en bois d'œuvre massif encapsulé (CBOME), qui suscite beaucoup d'intérêt. La présente étude a été commandée pour élaborer des archétypes complets d'immeubles de 7 à 12 étages. Elle vise à comparer les méthodes de construction potentielles aux moyens de construction actuels en Colombie-Britannique. Plus précisément, l'objectif est d'examiner la portée des activités nécessaires pendant la production, la distribution et l'installation des composants et des systèmes du bâtiment, et pendant le processus de planification de la construction de logements collectifs abordables et à haut rendement. On met aussi l'accent sur la viabilité financière de la CBOME comme solution pour réduire les émissions de carbone et la consommation d'énergie. De plus, le rapport traite des émissions de GES en tenant compte des exigences du BC Energy Step Code et du BC Carbon Step Code.

Les trois archétypes de bâtiments conçus dans le cadre de cette étude sont fondés sur trois régions aux conditions climatiques et réglementaires particulières. Ils ont permis une comparaison raisonnable des coûts entre le béton, l'acier et la CBOME. Les régions étudiées étaient les villes de Vancouver, de Coquitlam et de Kamloops. Les archétypes ont été élaborés conformément au règlement sur le bâtiment de Vancouver et aux codes de construction 3 et 4 du BC Energy Step Code en tant que norme minimale, le cas échéant. Bon nombre des stratégies de conception associées aux trois archétypes de CBOME régionaux sont des solutions précises pour améliorer le rendement et la durabilité des bâtiments. Ces solutions permettent de faire la meilleure utilisation potentielle du carbone biogénique dans le cadre d'une stratégie complète d'élimination des émissions de carbone.

Les archétypes de CBOME englobent la réduction des émissions de carbone intrinsèque, les facteurs de rendement thermique qui réduisent la consommation d'énergie et les émissions de GES applicables, ainsi que les émissions évitées grâce à la durabilité et au stockage à long terme de carbone biogénique. Cette approche évite de mettre uniquement l'accent sur la réduction des émissions de carbone opérationnelles. Elle tient compte des émissions de carbone intrinsèque et des émissions évitées dans le cadre de la comparaison du potentiel de réchauffement climatique de la structure, de la masse et de l'emplacement propres à chaque bâtiment.

Un outil en ligne, Mass Timber Navigator (en anglais seulement) a aussi été élaboré en parallèle avec cette étude. Il permet aux chercheurs d'évaluer la faisabilité de la CBOME et la conformité au code de l'énergie. Les promoteurs peuvent aussi utiliser les données générées par cet outil pour produire des rapports pro forma immobiliers.

En évaluant les avantages économiques potentiels de la CBOME, les chercheurs ont constaté que les trois processus clés suivants réduisent les coûts d'un ensemble résidentiel construit selon la CBOME par rapport à ceux de la construction traditionnelle en acier et en béton :

- Construction plus rapide
- Intégration de structures et de façades en bois massif
- Optimisation des systèmes mécaniques et électriques

De plus, ce sont les avantages en matière de coûts du cycle de vie qui représentaient la meilleure occasion pour les ensembles de logements construits selon la CBOME de produire le rendement du capital investi le plus élevé.

Cette étude s'adresse aux promoteurs, aux constructeurs, aux ingénieurs, aux professionnels de la conception, aux fabricants et fournisseurs de produits de construction, aux représentants du gouvernement et aux autres personnes qui participent à la construction de bâtiments et d'infrastructures à carbone zéro. Elle présente des approches pratiques pour l'utilisation des composants structuraux et des concepts de la CBOME qui sont des solutions testées, certifiées et normalisées axées sur la pratique. Cette étude présente ce que nous avons appris concernant les répercussions sur l'efficacité énergétique, les coûts, l'échéancier et les codes.

Contexte

L'idée de la carboneutralité dans les bâtiments s'est généralement concentrée sur les émissions de carbone opérationnelles. Autrement dit, un bâtiment serait neutre en carbone s'il pouvait répondre à sa demande opérationnelle annuelle avec une énergie entièrement exempte de carbone (c'est-à-dire une énergie produite sans combustibles fossiles). Pensons par exemple à un immeuble entièrement électrique doté d'un système photovoltaïque qui compense sa demande annuelle d'énergie ou à un immeuble chauffé au gaz naturel dont le propriétaire achète suffisamment de compensations de carbone pour compenser son utilisation du gaz. Cependant, en mettant l'accent uniquement sur les émissions de carbone opérationnelles, les promoteurs ne rendent pas compte de l'énergie consommée et du carbone émis pendant l'extraction, la fabrication, le transport et l'installation de tous les composants du bâtiment.

À l'avenir, l'objectif est que la plupart des émissions de carbone provenant des bâtiments englobent les émissions de carbone intrinsèque et les émissions futures au moment de l'occupation des bâtiments. Deux figures de cas font que les bâtiments construits selon la CBOME retiennent de plus en plus l'attention : 1) ils permettent de réduire encore plus les émissions de carbone intrinsèque, grâce au stockage biogénique; et 2) ils constituent une solution de rechange aux bâtiments en béton ou en acier à haut rendement conformes au BC Energy Step Code et au Carbon Step Code, qui impliquent des processus complexes et des coûts importants.

Cependant, comme chaque projet de construction et chaque marché sont uniques, le rapport ne fait aucune affirmation concernant des coûts ou échéanciers particuliers. Il fournit plutôt les données comparatives de faisabilité nécessaires à une étude immobilière complète.

En ce qui concerne la construction d'un avenir durable pour tous les archétypes et l'atteinte de la norme du bâtiment à carbone zéro - Performance du Conseil du bâtiment durable du Canada, d'autres recommandations ont été formulées :

- Adoption de systèmes énergétiques à faibles émissions de carbone, d'électrification et de réseaux à faibles émissions de carbone pour réduire l'intensité des GES.
- Adoption de technologies de construction hors site et de technologies numériques jumelées pour améliorer le rendement des bâtiments et la productivité dans le secteur du bois d'œuvre massif, et pour réduire les coûts.

Ces initiatives sont fondamentalement intégrées à la CBOME. Elles ne font que renforcer l'analyse de rentabilisation convaincante de la CBOME en tant que solution pour les immeubles de 7 à 12 étages.

Enfin, le rapport encourage les secteurs d'activité connexes et leurs professionnels à adopter le pro-cessus unique et systématique de conception du rendement de la CBOME. En l'adoptant, ils tireraient parti des avantages en matière de carbone intrinsèque, de résilience et de coûts démontrés dans l'étude.

Key Findings: Embodied Carbon, Life Cycle Cost and Comparative Costs

The project team worked collaboratively as design professionals, construction specialists, and quantity surveyors to develop the scope and content of this report. Base-case data was developed through the practice of systematic design as though the archetypes presented were real projects. The value of the data stemming from the systematic approach is imperative to inform an "industry" challenged with the combination of requirements for achieving BC Step Code Energy compliant encapsulated mass timber construction (EMTC) buildings of 7 – 12 storeys for residential occupancies.

The report provides financial indicators based on the archetype design considerations and calculations based on anticipated models and timelines for comparing project capital cost between the structural typologies. Therefore, the rough order of magnitude cost comparisons can be utilized for comprehensive real estate feasibility analysis, either at a high-level feasibility, static feasibility or at its most developed a cash flow feasibility to highlight impacts of labour, carbon credits, and salvage credit inputs.

Overall, the EMTC archetype designs meet the applicable construction requirements and acceptable solutions for encapsulated mass timber construction, however during this study several variations were identified and included in the archetypes that have the potential to benefit constructability, improve performance, schedule and cost. Applying these variations do not meet the prescribed acceptable solutions, therefore these variations would each require an alternative solution approach acceptable to the authority having jurisdiction:

- Exposed mass timber ceiling in residential suite in Vancouver to address the Vancouver Building Bylaw.
- Encapsulation at topside of mass timber floors using a mineral wool and magnesium oxide board assembly.
- Mass timber panel in exterior wall in the absence of meeting CAN/ULC-S134 or minimum 96mm thickness.
- Combustible window sashes and frames to address the use of hybrid wood and aluminum window frame.
- Manufacturing of components offsite in a controlled environment under optimum conditions provides a better product than fully site-built structures.

The overall simplicity of the design of the study building typologies is pragmatic and a key factor for the affordability, safety, and efficient construction of the buildings in either EMTC, concrete, steel, or variations created by hybrid designs.

Composite steel and concrete buildings, such as the representative steel buildings, use a unique configuration of steel and concrete components with high strength-to-weight ratios that allow for long spans, rigidity, and fire performance meeting the requirements of noncombustible construction. Advantages for this type of composite system are also present in composite steel and EMTC buildings which were not explicitly included in this study. These advantages include:

- Faster speed of construction than conventional concrete
- Manufacturing of components offsite in a controlled environment under optimum conditions provides a better product than fully site-built structures.
- Lower carbon when steel components are made from recycled steel
- Flexibility in design providing long floor spans
- Pre-punched holes for electrical and plumbing service rough ins through steel stud walls.

In addition, it should be mentioned that steel hybrid buildings offer a few advantages that EMTC must overcome. These include:

- Wide selection of assemblies with listings for fire resistance rating and sound transmission.
- Builders risk insurance reduced for noncombustible construction.
- Moisture resistant product with the use of galvanized and pre-primed steel components.
- Building owners realize long term benefits of reduced insurance rates with noncombustible construction.
- Further optimization of a specific building project will result from an informed hybridization of various construction types to maximize the inherent benefits of each element and the design of the study buildings highlights improvements of EMTC within hybrid building types.

Photo of CLT Production (Kalesnikoff)

Uniquely, the design team evaluated the extensive costing tool dataset of the Mass Timber Navigator, procured by The Office of Mass Timber Implementation (OMTI) and explored the potential trends which would indicate the best Return on Investment (ROI) for a developer. Cost reduction for building performance improvement was a clear trend across the various climate zones in B.C. was counterintuitive to market expectation. The large dataset showed that the trend was representative of key indicators which could be summarized in energy performance mapping. Clear evidence of a tipping point for EMTC building cost competitiveness compared to concrete and steel structures relates to simplification of achieving net zero readiness which will shift from an aspirational target to a code mandate by 2030 (Figure 1.9). In addition, cost competitiveness is attributable to the means and method advantages inherent to EMTC implementation. We've identified those three means and methods as follows:

1. The integration of mass timber structure and facade
2. The speed of construction
3. The optimization of Mechanical & Electric energy efficient systems integrated into the design

Illustrated by the trend arrow in the scatter chart (Figure 1), the total estimated capital cost of a EMTC projects dropped in relation to improved Thermal Energy Demand Intensity (TEDI) which is a key metric for BC Energy Step Code compliance. This is due in part to the inherent efficiency required to deliver EMTC projects.

The BC Energy Step Code provides the pathway for local governments in B.C. to raise the bar with respect to the construction of energy efficient, high-performance buildings in British Columbia. The emergence of new methods of construction including mass timber provides a solution to meet that challenge. Traditionally, mid-rise buildings, typically 7-12 storeys in height, have used concrete and steel as structural systems that limit the rest of the building's performance design. The advancements in engineered wood products, as well as increased concerns for environmental impacts, such as carbon emissions, are driving the interest in utilizing mass timber as the primary structure and façade system for mid-rise residential projects in British Columbia. Demonstration projects like UBC Brock Commons Tallwood Building have showcased the feasibility and opportunities of mass timber systems.

To undertake the energy and costing study, we utilized the Energy + Mass Timber Design Costing Tool as an early forecaster of structural efficiency and high-performance building envelope. The costing tool provides an Industry resource to improve the base level of literacy for energy compliance in the context of the capital cost of mid-rise mass timber building implementation between 7-12 storeys in height. Therefore, the project team was enabled to efficiently develop order of magnitude (or class D) proforma estimates when comparing the potential base case buildings against a baseline archetypal building utilizing the key features of the tool:

- Navigate quickly and optimize the building design, given a set of boundary parameters, which are set using parallel coordinates sliders.
- Perform baseline comparisons for incremental changes in design, indicating both the performance percent difference and the cost premium involved for a desired outcome.
- Select between various concept building design specifications and compare best match scenarios for performance metrics, such as TEDI, Step Code compliance, GHGI, construction cost, and utility costs.

The correlation of capital cost and TEDI is indicative of low thermal bridging in the EMTC building facades which is leveraged to reduce materials needed for thermal performance. Subsequently, improving the opportunity for EMTC means and methods.

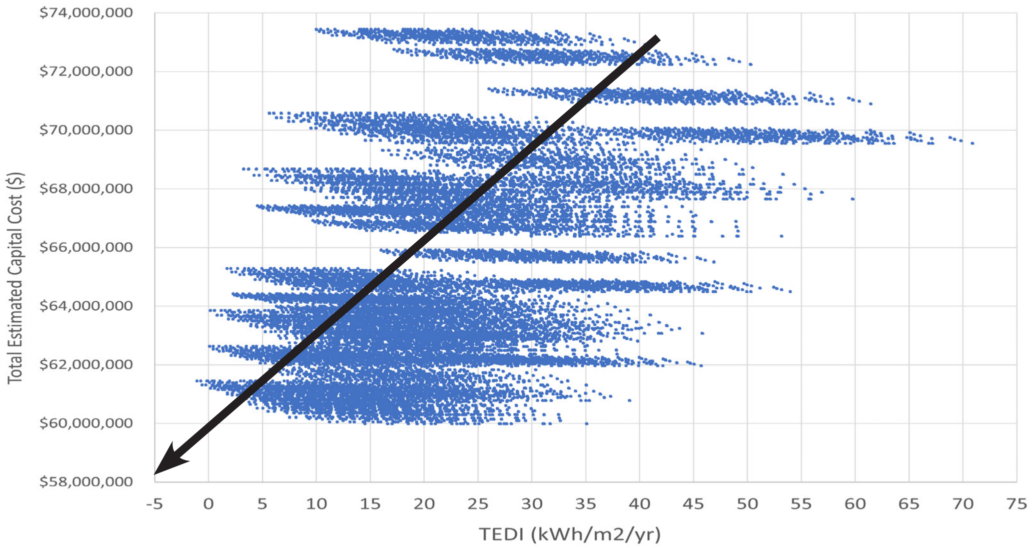


Figure 1: Scatter Chart showing concentrations of results from 100,000 Energy + EMTC Design Costing Tool scenarios.

Given the indicators identified in the energy performance mapping, our goal was then set to assess the viability of EMTC for the high-rise residential housing type in British Columbia through detailed design and digital twin modeling. The three atypical means and methods of mass timber implementation identify a need for a significant shift in construction methodology when constructing EMTC buildings. The construction methodology that best suits EMTC is a systematic approach to design and implementation. A systematic EMTC approach can be defined as a performance-based design approach for combining mass timber systems including facades and structures having a single-sourced implementation. The single sourced system capability could enable additive manufacturing supply channels to leverage automation efficiently and predictably. Given enough EMTC project volume, the resulting offsite prefabrication supply chain could become the most capable, and best able to absorb the cost of construction technology innovation necessary to build new high-performance buildings as a manufacturing industry.

Energy efficiency, cost, schedule, and code implications noted in the study took place over a period of time when lumber and steel prices – two of the principal materials – experienced high volatility in supply and record increases in price. Since every building project and market is unique, the report makes no claims concerning specific cost or time frame.

Rather, it identifies conclusions to consider in creating a reliable framework for optimizing costs and schedules while meeting code requirements when building residential high-rise EMTC buildings:

- Reducing WWR has nominal impact on EUI
- Maximize WWR where possible, balanced with TEDI
- More work to be done to lower EUI to meet net-zero energy goals
- Allowance for incentives to address residential building EUI beyond Step 4 is the next logical step for B.C.

Photo of CLT CNC Fabrication. (Kalesnikoff)

Matrix of Building Structure Advantages / Disadvantages

Steel stud, Cast-in-Place Concrete

Steel stud, Steel Web Joists, and Concrete

EMTC, Facade, Point-supported CLT, and Concrete

Steel stud, Cast-in-Place Concrete	Steel stud, Steel Web Joists, and Concrete	EMTC, Façade, Point supported CLT, and Concrete	
✓	✓	✓	Flexibility in floorplan design
✓	✓	✓	Reduced requirements for costly and time-consuming bulkheads
✓	✓	✓	Pre-punched holes for electrical and plumbing services
✓	✓	✓	Shrinkage and warping of structures are minimized
✗	✓	✓	Prefabricated uniform, straight, flat and dimensionally accurate walls and floors
✗	✗	✓	Reduced thermal bridging transmittances at the exterior wall interfaces
✗	✓	✓	Prefabricated structure and exterior wall system
✗	✗	✓	Low Global Warming Potential (GWP)
✗	✗	✓	Increased daylighting due to allowable glazing area
✗	✓	✓	Digital twin fabrication modelling utilized during design for implementation
✗	✓	✓	Structural elements are made from recycled materials
✓	✓	✗	Improved fire and sound ratings are cost effective with long-term benefits of reduced insurance rates
✓	✓	✗	Long-term benefits of reduced insurance rates
✓	✓	✗	Termite, insect and vermin proof
✓	✓	✗	Moisture-resistant structure with the use of galvanized and pre-primed materials
✓	✓	✗	Exterior assemblies minimally affected by adverse weather conditions
✓	✓	✗	Builders Risk Insurance reduced

EMTC disadvantages are consistent with emerging technologies where continual adoption will lead to cost reduction and improved insurance conditions. A hybrid building type can take advantage of each building material's strengths.

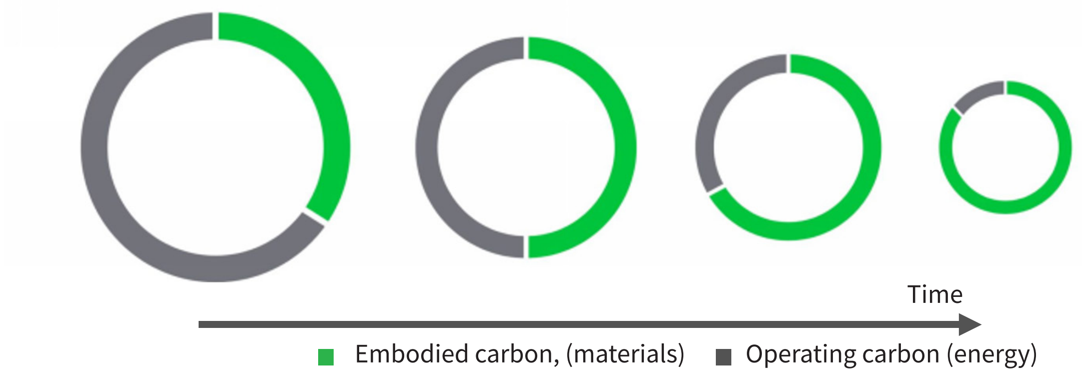
Addressing greenhouse gas (GHG) emissions from buildings and infrastructure is a key component of the global fight against climate change. The idea of carbon neutrality has typically been focused only on operational carbon, meaning that a building could be carbon neutral if it could meet its annual operational energy demands with 100% carbon-free energy (operational energy produced without fossil fuels). Therefore, an all-electric building of any structure type with an on-site photovoltaic system offsetting its annual energy demand, a natural gas building that purchases enough offsets to outweigh its gas use, or a portfolio that combines onsite renewable with offsite renewable energy procurement to target 100% carbon free energy could be rationalized. However, when focusing on operational carbon only, developers fail to account for the energy and carbon expended during the extraction, manufacture, transportation, and installation of all the building's components. As grids electrify and decarbonize, most of the carbon emissions from buildings will be embodied and locked in at the time of building occupation.

> *"Developers need to understand and capture all the carbon associated with their projects in order to move toward individual buildings and a construction industry that is truly carbon neutral."*

Increasingly, EMTC buildings are becoming a focus for further embodied carbon reductions due to their low embodied carbon emissions in comparison to concrete and steel as well as their potential for carbon storage in long lasting bio-based products. Unfortunately, a common misconception in the industry is that the biogenic carbon stored in the engineered elements of EMTC buildings offsets the emissions associated with the materials in the building, as well as operational emissions. Often, biogenic carbon stored in bio-based materials is insufficient to counteract all the embodied and operational emissions and the majority of the biogenic carbon would be re-released into the atmosphere at the end of the building's life, unless all bio-based materials are reused.

Many of the design strategies developed in the EMTC archetypes, are specific solutions for improving building performance and durability enabling the best potential outcome for carbon removal.

> *"A carbon neutral building with engineered timber elements fundamentally shall ensure thermal and energy efficiency, durability, material sourcing, and transportation carbon impacts are accounted for."*



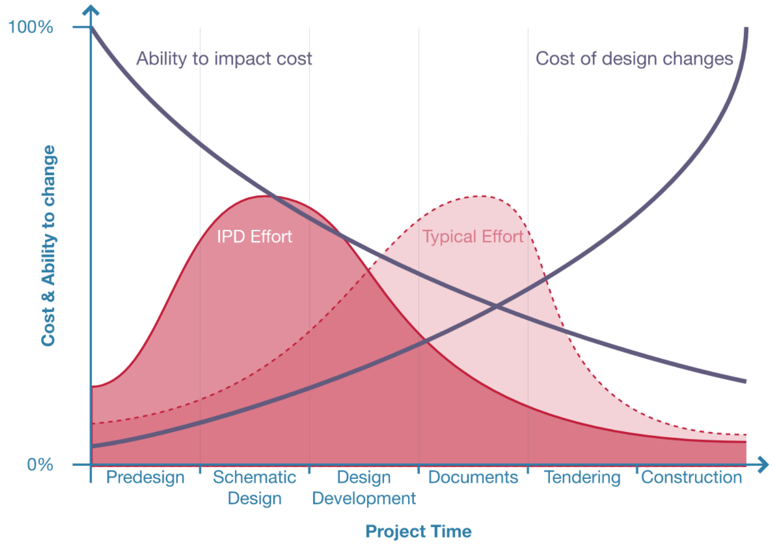
Source: LETI Embodied Carbon Review, 2018

Comprehensive 7 to 12 storey archetypes were developed for comparison of construction methods and means to explore and examine the complex scope of activities involved during the production, distribution, and consumption of goods and services undertaken in affordable multi-unit housing project design and implementation. To provide a reasonable cost comparison between concrete, steel, and EMTC the archetype designs of the 7-12 storey buildings were based in three unique bylaw and climate areas and developed to be compliant with the BC Energy Step Code 3 and 4 as a minimum standard. This is a reasonable industry benchmark for current development compliance in B.C. and tests the carbon neutrality of each archetype encompassing embodied carbon, durability, and thermal performance considerations without a singular focus on just the operational carbon emissions reductions of complex mechanical and electrical systems that make up for conventionally poor performance of building envelopes.

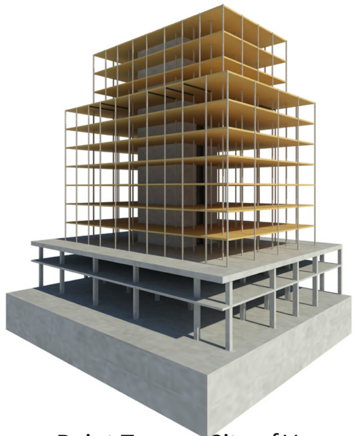
> *"A complete biogenic carbon removal strategy only exists over a long period of time, greater than a 100-year building life span."*

In our assessment of the potential economic advantages of EMTC, the life cycle cost spectrum when including embodied carbon was the singular largest and best opportunity. Essentially, a very qualified reason to pay more for the cost of mass timber elements while reducing the overall cost of construction and the cost of ownership and/ or management of the buildings.

Where life cycle assessments are not inclusive of embodied carbon, EMTC projects benefit greatly from the integration of mass timber structure and facade, increased speed of construction, and the optimization of Mechanical & Electric energy systems. These factors serve to reduce the risk in a project while increasing overall quality. Successful EMTC projects require an integrated approach where effort shifts to pre-construction planning and off site fabrication which greatly reduce the time and associated risk of active construction and increase the value of all efforts to the project stakeholders.

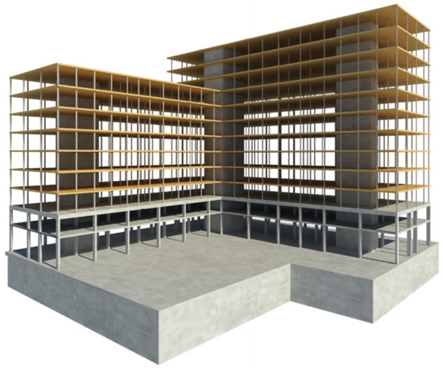


Macleamy Curve Daniel Davis, 2013

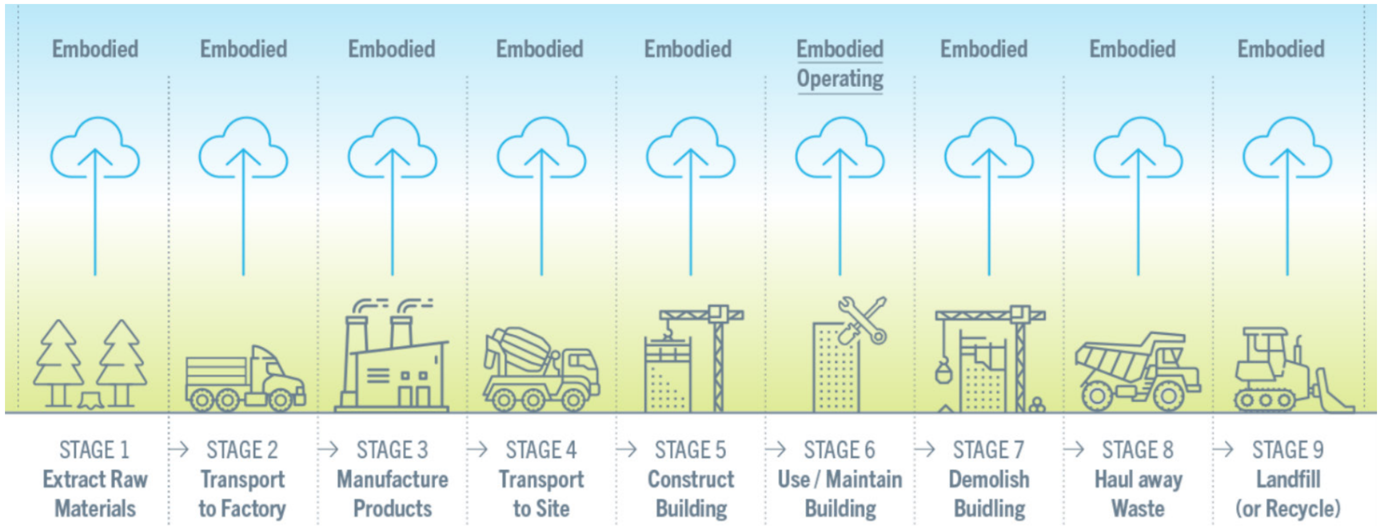


Point Tower - City of Vancouver

Slab Tower - City of Kamloops



L Tower - City of Coquitlam



Source: Embodied Carbon of Buildings and Infrastructure: International Policy Review (BCFII 2017)

This report illustrates how operating and embodied carbon emissions fit in to a building's life cycle in the graphic above. For EMTC, the potential advantages and opportunities are considerable, including:

Stages 1 to 5 – Performance-based design of systematic EMTC buildings significantly reduces embodied carbon and provides a lasting legacy of energy efficiency and reduced carbon emissions, through building envelope and structure durability, structural resiliency, and enabling the long storage of biogenic carbon and thermal efficiency as a carbon removal strategy with limited need for repair and replacement. The use of clean wood has an advantage over other structures including light wood framing which is comprised of dirty wood.

Stage 6 – With a minimum threshold as a 100 year building, the purpose-built nature of mass timber maintains a clean wood waste stream within a durable carbon sink. An occupied and operational EMTC building could be a model for long term biogenic carbon storage. As net zero energy performance is a value proposition in the construction costs, an EMTC building requries limited envelope and building system renewals which can focus on interior and exterior aesthetics and programming.

Stage 7 to 9 – Thinking forward to future covenants regarding end-use through design for disassembly enables a circular economy of potentially certified building materials and engineered timber elements as part of an EMTC building could be a certified carbon removal system when available.

By reusing and recycling engineered timber elements, future carbon emissions are reduced by re-directing materials from traditional high carbon end of life pathways. With an innovative Municipal end-use strategy that includes technologies like biochar production from clean wood residuals that remove carbon from the atmosphere and store it for a very long-time frame. Such solutions could also become part of a negative emissions technology (NET). NET are systems that permanently remove carbon or greenhouse gases (GHG) from the atmosphere.

Each building erection method constitutes a unique challenge. Upon review of even high-level planning aspects, it is easy to demonstrate the complexity of technology and how this compounds the associated coordinated building tasks: beginning with the interests of the client and the ideas of the architect, to the demands of statics and design, to questions of building services, and overall sustainable utilization including ecology and recycling. With the answers to these and more questions, every building project evolves into a very special solution, comparable to a prototype.

The examination of the advantages and challenges for EMTC standardization and implementation from a cost and ROI standpoint pointed to a necessity to investigate current building codes and develop innovative EMTC archetypes for comparison with conventional construction archetypes to reduce the impacts of "prototype" design and construction.

The study identifies opportunities for new investment to address current limitations for the adoption of mass timber technologies among developers and affordable housing providers. The most convincing strategy that resulted from the study was the discovery of the benefits of a systematic approach to EMTC. The work we've undertaken as described in the following results of Figures 2 to 10, could enable developers to better predict early systematic EMTC project buyout costs despite three key gaps in information technology that are present in the Industry and Development market:

1. Lack of historical systematic EMTC project costing data
2. Complex and expensive process for Energy + Carbon analytics for compliance/ business case
3. Inability to capture and compare as-built data from systematic EMTC projects for future project development.

Discount Rate: *3.0%* **Period of Study:** *20 years* **Base Year:** *2022*

	Capital Costs	Operations & Maintenance Costs	Energy Costs	Cyclical Renewal Costs	Salvage Credits	Total Cost (Present Value)
A Mass Timber construction	$43,560,500	$43,452,400	$5,084,030	$762,690	($592,940)	**$92,266,680**
B Concrete Construction	$44,368,500	$42,330,020	$6,745,130	$762,690	($592,940)	**$93,613,400**
C Hybrid Concrete and Structural Steel Cons	$45,268,700	$42,971,380	$6,745,130	$762,690	($592,940)	**$95,154,960**

Figure 2: Point Tower – City of Vancouver Comparison Life Cycle Cost Analysis Summary ($)

Discount Rate: *3.0%* **Period of Study:** *20 years* **Base Year:** *2022*

	Capital Costs	Operations & Maintenance Costs	Energy Costs	Cyclical Renewal Costs	Salvage Credits	Total Cost (Present Value)
A Mass Timber construction	$59,767,700	$58,047,690	$5,798,870	$878,410	($681,920)	**$123,810,750**
B Concrete Construction	$60,910,800	$56,548,170	$8,002,770	$878,410	($681,920)	**$125,658,230**
C Hybrid Concrete and Structural Steel Cons	$61,480,200	$57,404,960	$8,002,770	$878,410	($681,920)	**$127,084,420**

Figure 3: Slab Tower – City of Kamloops Comparison Life Cycle Cost Analysis Summary ($)

Discount Rate: *3.0%* **Period of Study:** *20 years* **Base Year:** *2022*

	Capital Costs	Operations & Maintenance Costs	Energy Costs	Cyclical Renewal Costs	Salvage Credits	Total Cost (Present Value)
A Mass Timber construction	$84,154,600	$85,574,370	$7,147,080	$1,534,140	($1,161,600)	**$177,248,590**
B Concrete Construction	$84,650,600	$83,364,150	$10,374,690	$1,534,140	($1,161,600)	**$178,761,980**
C Hybrid Concrete and Structural Steel Cons	$85,476,800	$84,627,130	$10,374,690	$1,534,140	($1,161,600)	**$180,851,160**

Figure 4: L Tower – City of Coquitlam Comparison Life Cycle Cost Analysis Summary ($)

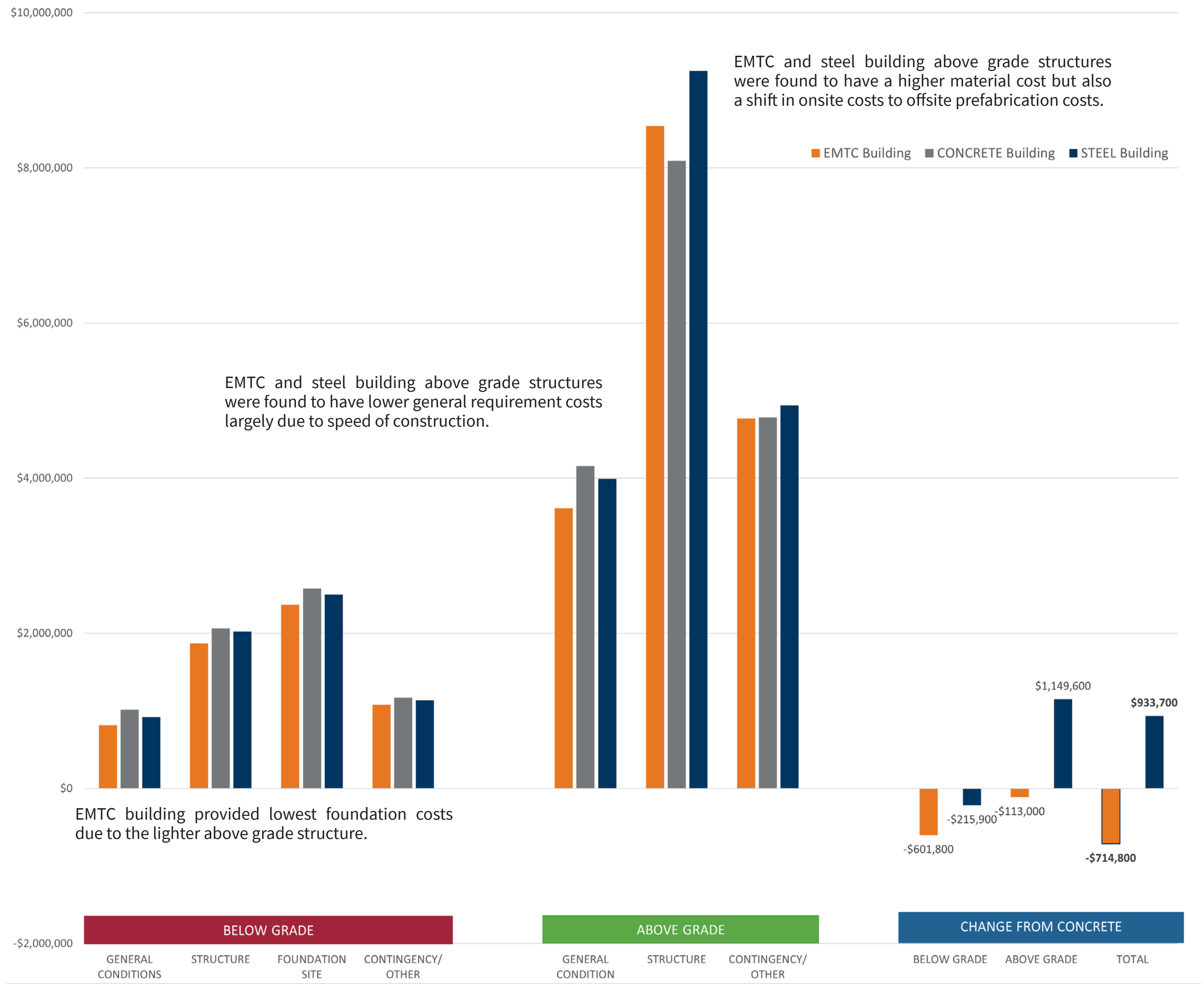
This Life Cycle Cost summary in Figure 2, 3 and 4, considers all significant costs of ownership over the economic life of each option and expresses these costs in equivalent dollars using present value analysis. Ownership costs include construction costs as well as operations, maintenance, energy costs, cyclic renewal costs and salvage credits. As each option will present different costs incurred at different times during the life cycle study, the use of present value analysis is necessary to bring all of these diverse and time sensitive expenditures to a common basis for comparison and to account for the time value of money.

Understanding the time value of money begins with the recognition that money invested earns interest. For this reason, a sum of money invested today will earn interest and will therefore be worth more than the same sum at a later date. For example, $100 invested for a year at 7% interest would be worth $107 a year from now. Accordingly, $100 today is worth more than $100 a year from now. Using this principle, present value analysis 'discounts' future sums of money to present value and shows the results as 'equivalent dollars' for comparison.

Where revenue is being considered in a commercial model, the economic life of most buildings before a major renewal or retrofit is typically 20 years. The economics of residential properties usually demand that the interior and exterior finishes are renewed long before the general lifespan of a structure (anticipated to be at least 35-40 years). When sustainability is prioritized at the onset, future energy efficiency upgrade costs can be reduced along with a reduced carbon tax burden and limited renewals of envelope and building systems.

The 3% discount rate used is the most common conservative rate applied broadly in the industry and it is the most recommended in our experience for the archetype comparisons. Lower discount rates raise the end Net Present Value and higher rates flatten the Net Present Value down to current costs depending on the term applied.

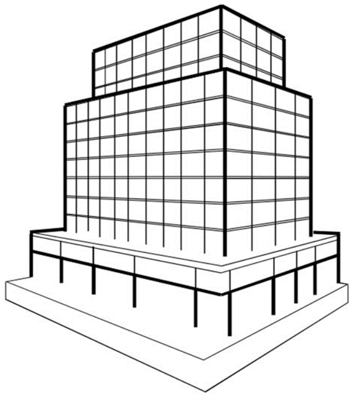
Capital costs in the Life Cycle Cost summaries are expressed net of General Contractor's General Conditions and Fee. Further, the comparative costs summarized in the following figures 5 through 10 represent costs including the general conditions and fee.


EMTC and steel building above grade structures were found to have a higher material cost but also a shift in onsite costs to offsite prefabrication costs.

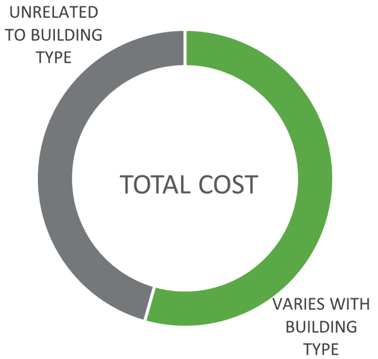
EMTC and steel building above grade structures were found to have lower general requirement costs largely due to speed of construction.

EMTC building provided lowest foundation costs due to the lighter above grade structure.

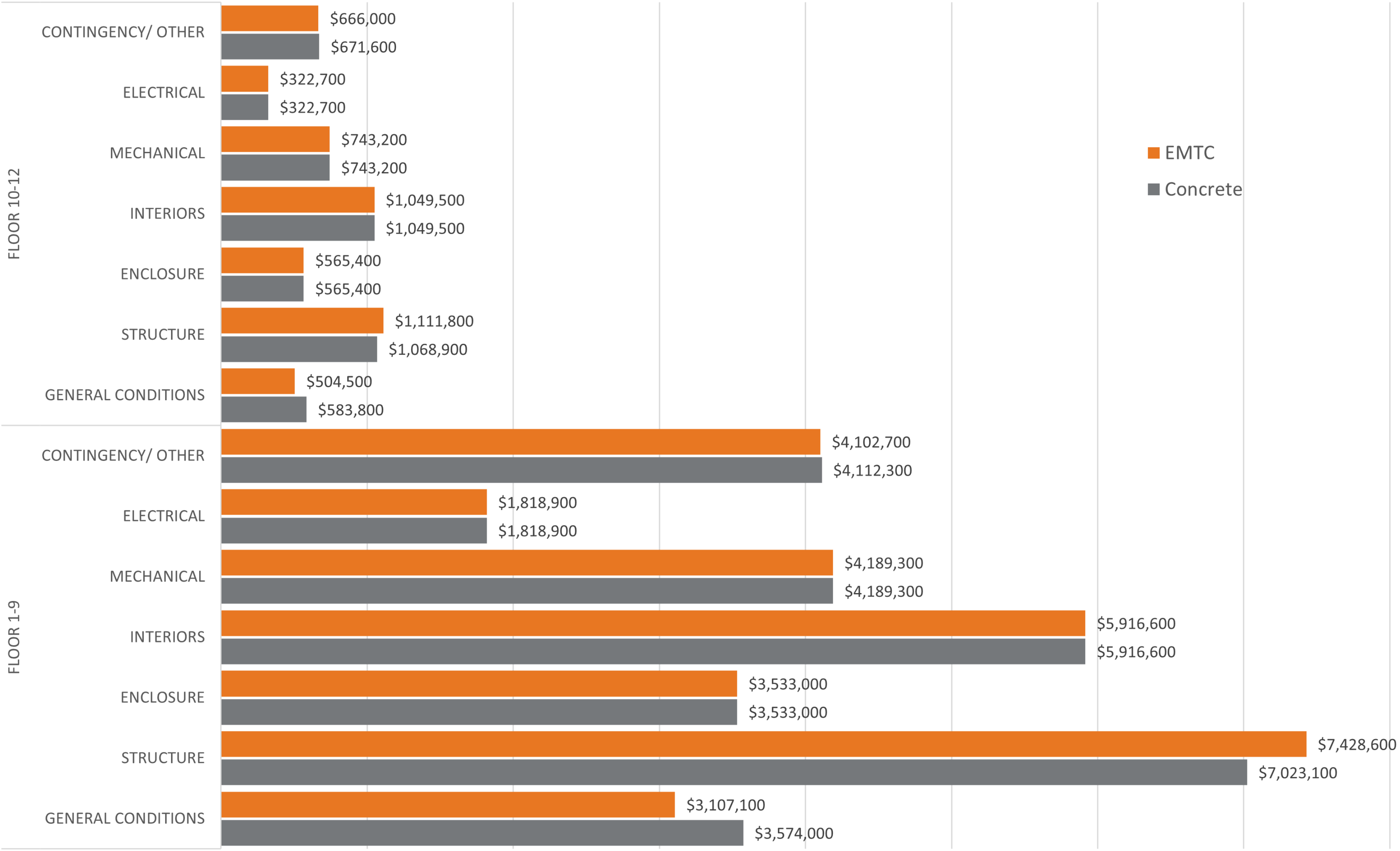
Figure 5: Point Tower – City of Vancouver Comparison of Above Grade vs Below Grade Cost ($)



Point Tower - City of Vancouver



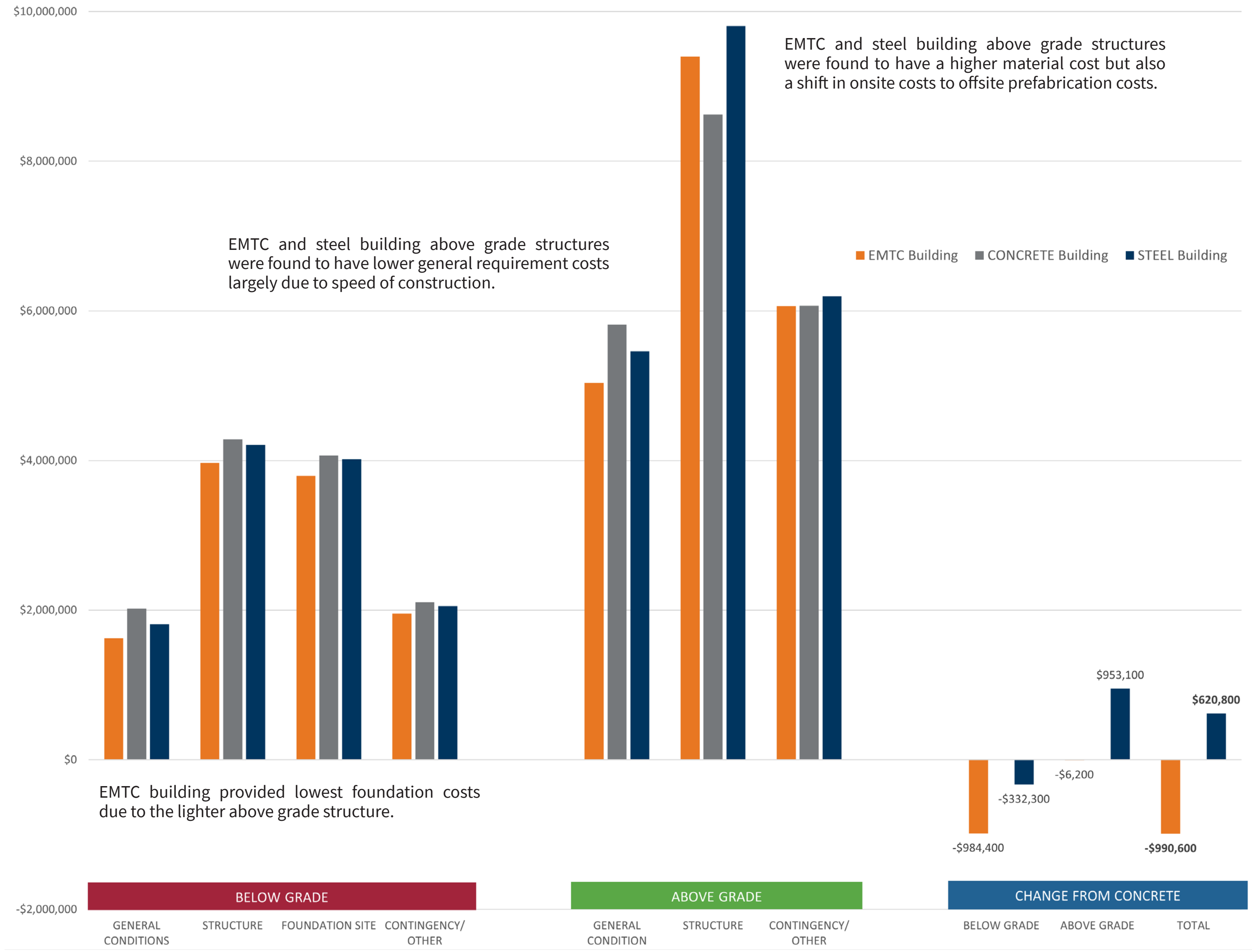
Cost of enclosures, interiors, mechanical, and electrical were equivalent in this dataset across all project types and were excluded from the graph. These costs represent around 46% of the total project costs whereas building type comprises the other 54%. The required virtual design and construction of an offsite prefabricated building type such as Steel or EMTC can lead to additional cost reductions in these categories through general efficiency and integrated delivery but was outside of the scope of this study. This virtual integrated approach can be used with concrete buildings as well though they benefit from fewer value propositions from the upfront cost of virtual construction.



Fgure 6: Point Tower – City of Vancouver Comparison of Above Grade Floors 1-9 vs 10-12 Cost ($)

EMTC building above grade structures were found to have a higher material cost but also a shift in onsite costs to offsite prefabrication costs.

A reduction in general requirements cost due to speed of prefabricated EMTC can provide an overall advantage when compared to the Concrete building baseline.

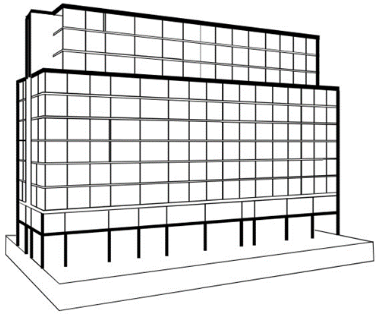


EMTC and steel building above grade structures were found to have a higher material cost but also a shift in onsite costs to offsite prefabrication costs.

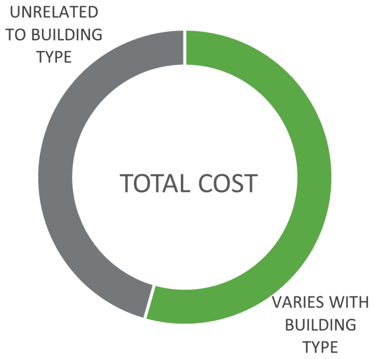
EMTC and steel building above grade structures were found to have lower general requirement costs largely due to speed of construction.

EMTC building provided lowest foundation costs due to the lighter above grade structure.

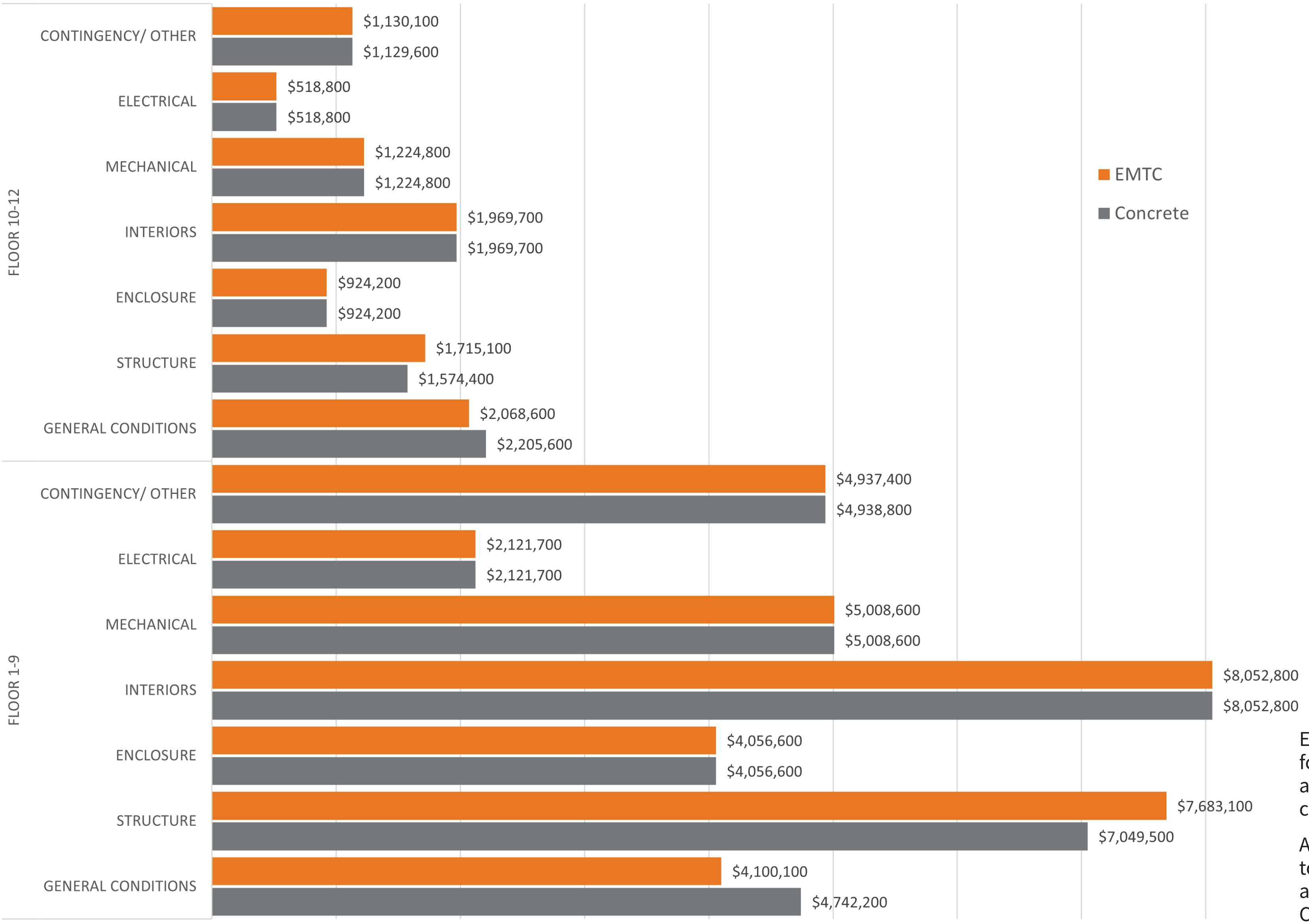
Figure 7: Slab Tower – City of Kamloops Comparison of Above Grade vs Below Grade Cost ($)



Slab Tower - City of Kamloops



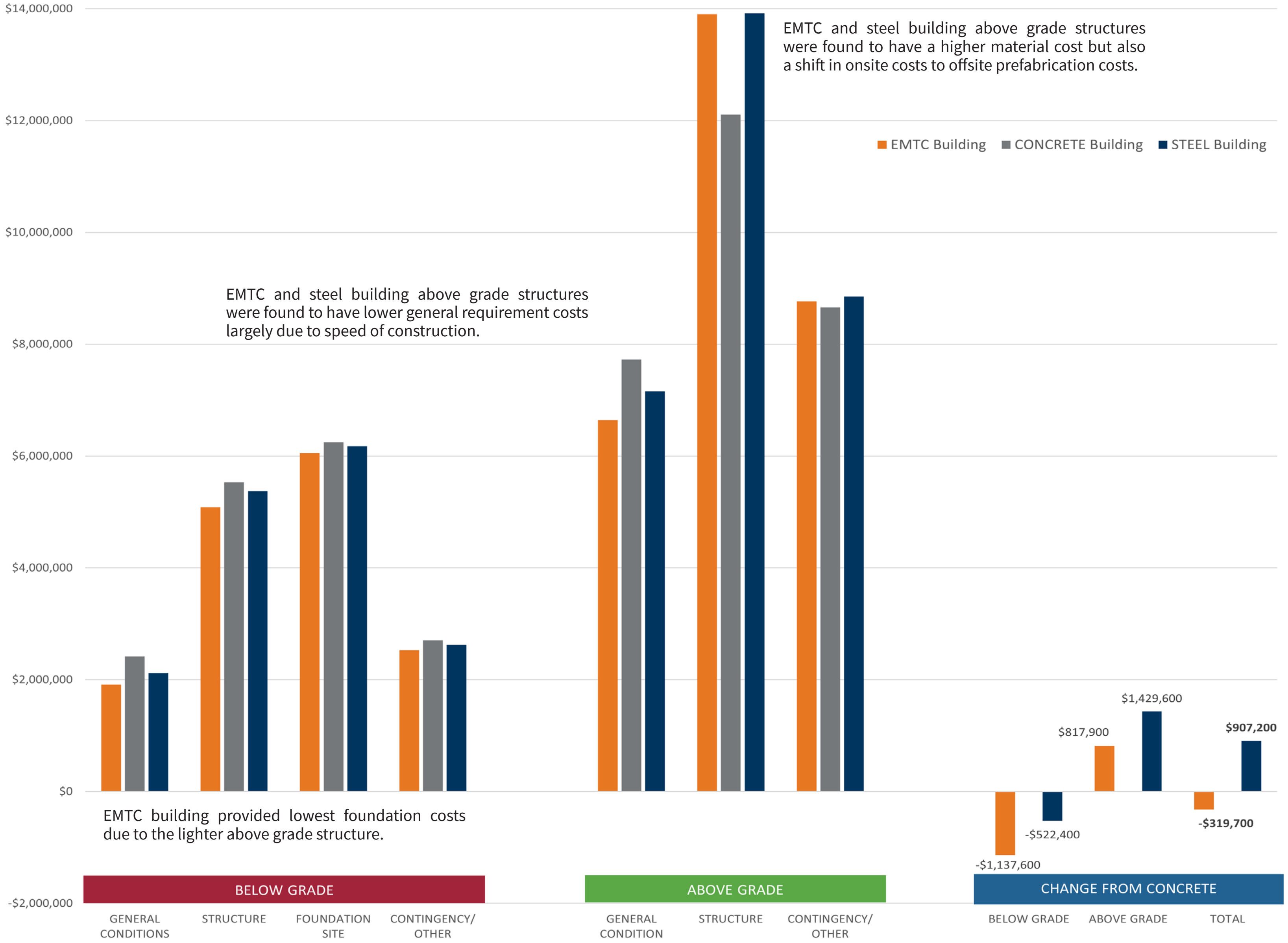
Cost of enclosures, interiors, mechanical, and electrical were equivalent in this dataset across all project types and were excluded from the graph. These costs represent around 47% of the total project costs whereas building type comprises the other 53%. The required virtual design and construction of an offsite prefabricated building type such as Steel or EMTC can lead to additional cost reductions in these categories through general efficiency and integrated delivery but was outside of the scope of this study. This virtual integrated approach can be used with concrete buildings as well though they benefit from fewer value propositions from the upfront cost of virtual construction.



EMTC building above grade structures were found to have a higher material cost but also a shift in onsite costs to offsite prefabrication costs.

A reduction in general requirements cost due to speed of prefabricated EMTC can provide an overall advantage when compared to the Concrete building baseline.

Figure 8: Slab Tower – City of Kamloops Comparison of Above Grade Floors 1-9 vs 10-12 Cost ($)

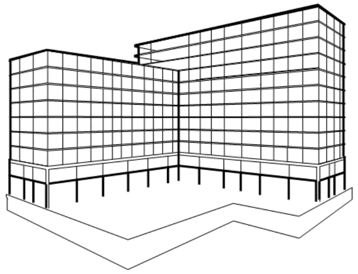


EMTC and steel building above grade structures were found to have a higher material cost but also a shift in onsite costs to offsite prefabrication costs.

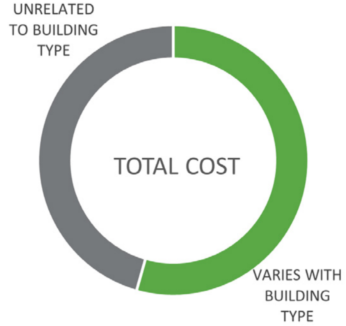
EMTC and steel building above grade structures were found to have lower general requirement costs largely due to speed of construction.

EMTC building provided lowest foundation costs due to the lighter above grade structure.

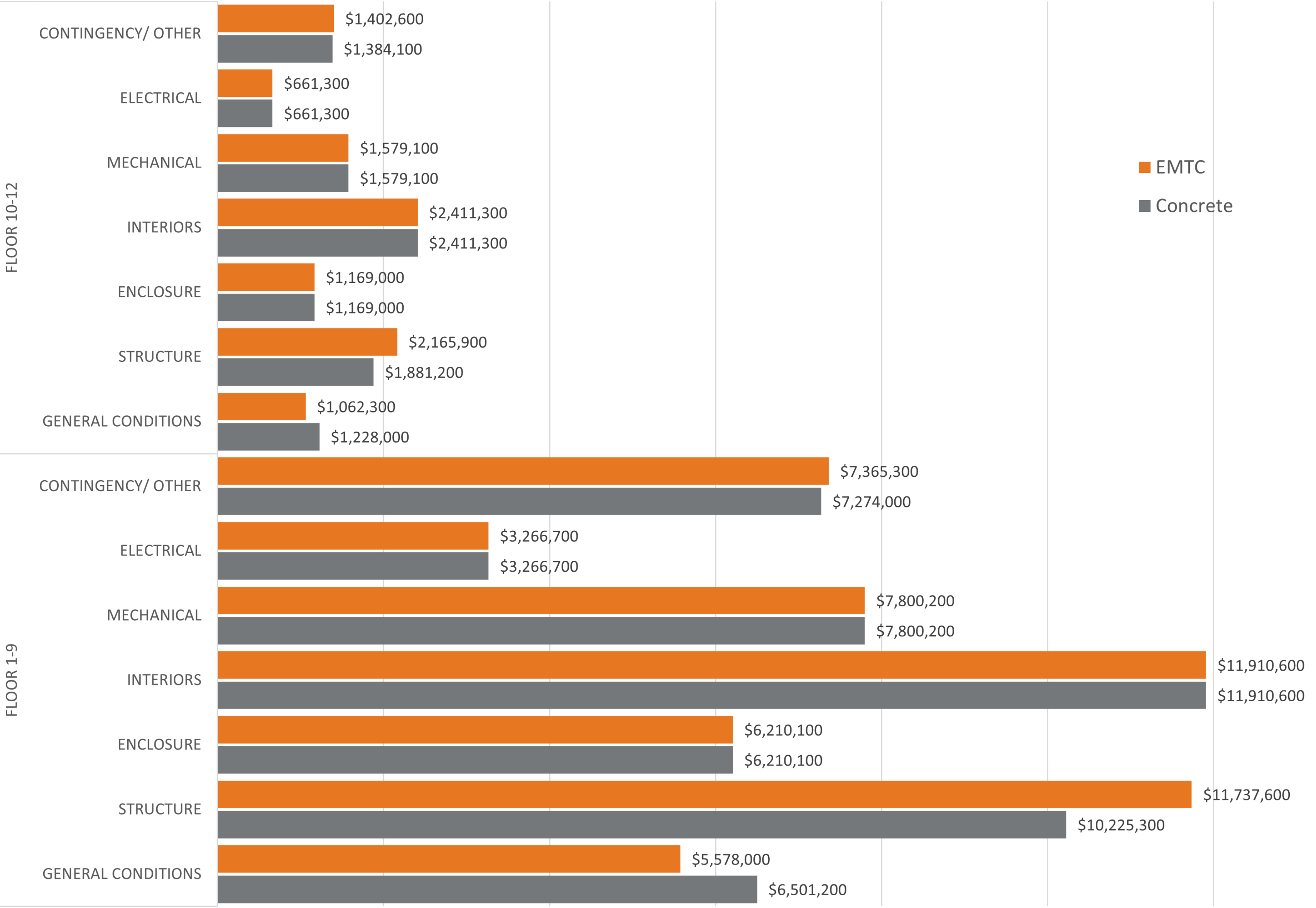
Figure 9: L Tower – City of Coquitlam Comparison of Above Grade vs Below Grade Cost ($)



L Tower - City of Coquitlam



Cost of enclosures, interiors, mechanical, and electrical were equivalent in this dataset across all project types and were excluded from the graph. These costs represent around 46% of the total project costs whereas building type comprises the other 54%. The required virtual design and construction of an offsite prefabricated building type such as Steel or EMTC can lead to additional cost reductions in these categories through general efficiency and integrated delivery but was outside of the scope of this study. This virtual integrated approach can be used with concrete buildings as well though they benefit from fewer value propositions from the upfront cost of virtual construction.



EMTC building above grade structures were found to have a higher material cost but also a shift in onsite costs to offsite prefabrication costs.

A reduction in general requirements cost due to speed of prefabricated EMTC can provide an overall advantage when compared to the Concrete building baseline.

Figure 10: L Tower – City of Coquitlam Comparison of Above Grade Floors 1-9 vs 10-12 Cost ($)

Who is This Study For?

This report is of interest for jurisdictions that have a responsibility for the development, procurement, and construction of EMTC buildings. This report may also be of interest to businesses, design professionals, building product manufacturers and suppliers, non-governmental organizations and other stakeholders that are involved in the design and construction of zero-carbon buildings and infrastructure. Research results demonstrate EMTC archetypes that offer a compelling strategy for the systematic design and construction approach of combining facades and structures that use mass timber elements.

The technical team combined EMTC studies using digital twin modelling analytics. The analytics were strategic for correlating all system details and material information to form the basis for cost comparison of EMTC with steel and concrete construction. Technical cost information for 7- to 12-storey EMTC buildings has long been sought after and is a gap identified in several quantitative and qualitative studies completed previously. Therefore, this study is also intended as an in-depth technical analysis of systematically designed, point-supported, 7-ply CLT structures and engineered timber facades to provide a comparative feasibility of cost and performance to achieve the BC Energy Step Code requirements.

Photo of 7-ply CLT in Production. (Kalesnikoff)

Industry Q&A Regarding Comparison of Encapsulated Mass Timber with Other Building Structures

1. EUI targets need to be addressed for low operational energy (i.e., 'net-zero ready' or Step 5 of the BC Energy Step Code). For Part 3 buildings, Step Code 4 is the highest current step for compliance. If the regulatory focus is more on reducing operational carbon through enabling regulation, what else should be considered if Step 5 is a reality in the future?

   Answer: The research study points to diminishing results for investment in building envelopes once a project's EUI begins to drop below 100. At this point, the building and building envelope have been optimized within a range of potential renewable systems to offset the remaining energy use. Therefore, investment value is best focused on multiple energy trade-off scenarios between renewable systems in combination with non-envelope measures such as energy efficient household appliances and plug loads, efficient and smart lighting designs, heat pump based corridor makeup air and domestic hot water systems, and/or drain water heat recovery systems, to name a few.

2. Can prefabricated construction also be utilized with steel and in some cases also with volumetric modular construction?

   Answer: This study has developed concrete slab and prefabricated steel stud archetypes for comparison with encapsulated mass timber construction. Volumetric modular construction would be a variable of the prefabricated steel stud or wood buildings. Prefabricated steel stud closely resembles some of the key offsite construction advantages shared by encapsulated mass timber. However, negative performance impacts of the higher conducting structure and building envelope assemblies are considerable and generally require reductions of natural daylighting to meet thermal and energy performance requirements. The solutions to the performance impacts typically led to higher estimated costs of construction. Volumetric modular would have similar thermal and energy performance as the steel stud systems and may also include higher site construction install costs. The conclusion is that volumetric modular systems for 7- to 12-storey structures would not provide performance or cost advantages, like the steel stud archetype.

3. Municipal approvals can lead to alterations in design and, therefore, delay when orders can be placed for prefabricated components, which could undermine the time benefits of prefabricated construction. When can a builder be comfortable enough to place an order for prefabricated components?

Answer: The permit approval conflict experienced by prefabrication projects is a common result of traditional project design phasing, which is likely precipitated by public procurement strategies that were not developed for prefabricated projects. Digital approval processes that are coupled with digital design phasing and new procurement methods that allow for the execution of division 13 master specifications would provide for greater design flexibility at rezoning and building permit stages. Unique to encapsulated mass timber, the level of comprehensive data that can be developed in an appropriate mass timber project workflow reduces the number of potential design gaps and lowers the risks of unplanned alternative solutions and engineering judgements since they can be vetted early at concept level of the project rather than at the building permit stage. Project design development and the confirmation of costing through the systems buyout approach are demonstrated in the study. The risk of re-design can also be greatly reduced by the amount of repeatability shared between Step Code-compliant EMTC designs compared to more typical construction.

4. Are building officials confident that the prefabricated elements or assemblies conform with the B.C. Building Code, as they are built offsite?

   Answer: Offsite construction inherently means a much more comprehensive QA/QC process by the entire AEC team involved in the project. CSA Standard A277 "Procedure for certification of prefabricated buildings, modules and panels," increases due diligence and does not relieve an engineer/architect of their professional responsibility for field reviews including upfront performance mock-up testing. Digital fabrication also provides a practice-before-build workfow that enables AHJ, building officials and coordinating professionals to review the project during early design with assurance that construction can be carried out as it is largely pre-planned. This is unlike the conventional delegated design process for most projects, where review of construction in progress can be intensive. Intensive coordination is achieved during early design phases of prefabricated projects through the appropriate development of division 13 master specifications. These specs are key to ensuring compliance with relevant requirements. Specifications are developed to provide much more testing and verification resulting in rigorous verification of performance. Again, appropriate design phasing and procurement are crucial to enabling the low-risk approach to approvals that offsite prefabrication can provide.

5. Designs for encapsulated mass timber often include maximizing the size of the CLT panels. Is there a trade-off with the transportation costs of moving the panels from the factory to the site? Will larger panels be more difficult and costly to move?

   Answer: The logistics of larger CLT panels was vetted in the study by Seagate Mass Timber, and material and fabrication efficiency trade-offs were utilized to develop a buyout cost for comparison. A disciplined overall design layout led to a reduced need for additional materials. This also contributed to a reduction in the methods and means of construction and offered cost offsets worth capitalizing on by using larger CLT panels.

6. Are the operation/maintenance costs for encapsulated mass timber higher than for concrete and hybrid approaches?

   Answer: Operation and maintenance costs are generally higher for EMTC buildings primarily due to anticipated higher insurance premiums. In the absence of documented losses involving EMTC buildings that are substantiated by historical real building data, higher insurance rates should be expected.

7. Encapsulated mass timber buildings can have improved exterior wall performance over conventionally built concrete and steel buildings. Is this because CLT/wood is naturally more insulating or is additional insulation needed to achieve the energy performance?

   Answer: The study provides a comparison table on page 14 that shows the typical mass timber exterior wall that potentially can be used across all three building types and regions of B.C. The two steel and concrete exterior wall assemblies represent typical exterior wall assemblies commonly used in compliant projects that can meet at least the minimum threshold for Step Code 3. For the steel and concrete option with 7 inches of exterior insulation, it shows the difference in the amount of thermal bridging common in steel and concrete buildings that must be overcome to reach Step Code 4. This demonstrates the amount of re-design required to utilize the same steel stud wall structure for either concrete or steel stud systems, which would be further challenged if the building was built in a colder climate zone. In comparison, the same timber exterior wall with minimal design changes has considerably less thermal bridging to overcome and, therefore, can meet Step 3 and 4 in all climate zones with less insulation and, in some cases, larger glazing areas.

Photo of 7-ply CLT in Production. (Kalesnikoff)

Key Design Aspects Informing a Municipal Understanding of EMTC

It has been demonstrated that tall timber is a viable option for mid-rise housing with precedent projects such as Brock Commons Tallwood at UBC. However, the latest advancements in engineered wood products, and research, as well as industry-wide acceptance of encapsulation assemblies and construction sequencing, have accelerated tall timber as a cost-competitive solution.

A concrete flat-slab system remains the most common in mid- to tall-rise construction due to its availability and the number of experienced concrete builders in British Columbia. The flat-slab nature also allows for unobstructed and flexible architectural spaces. Still, supporting concrete columns are large and not easily masked aesthetically. Concrete flat slabs also require curing time, which slows down the construction schedule.

An open-web steel joist on steel stud bearing wall system offers opportunity for columns to be hidden within walls. It is a fair cost and scheduling alternative to the concrete flat slab, but still poses challenges in providing architectural layout flexibility and scheduling as it requires many structural elements to be installed per floor and a concrete composite metal deck.

A point-supported CLT system for EMTC combines the benefits of both a concrete flat slab and an open-web steel joist on steel stud bearing wall systems while offering further benefits in construction schedule and lower embodied carbon emissions. EMTC projects are not common in most jurisdictions. This may present an initial challenge in acceptance by the municipality of the point-supported CLT timber structural system suggested in the study. The following summary of the findings of this study intends to assist the understanding of repeatable and standardized design aspects for EMTC of 7 to 12 storeys for residential occupancies.

1.1. STRUCTURAL WEIGHT

Use of mass timber floors, especially with use of a non-concrete flooring system, makes for a light-weight structure in comparison to its steel and concrete counterparts. A lighter structure leads to smaller podium and foundation substructures, smaller or fewer gravity structural elements, lower demand on the lateral resisting system and thus less reinforcing steel and concrete, and faster construction time.

TRANSFER AT LEVEL 3

Levels above L3 intended to contain residential only. Ground level through L2 to contain commercial and residential - amenity spaces where applicable.

Transfer slab at level L3 required to shift column/bearing supports from residential suites to commercial/amenity space below.

TRANSFER AT GROUND LEVEL

Columns below ground level at parkade are controlled by parking layouts.

Transfer slab at ground level required to allow shift in columns from parkade to ground level commercial/amenity space.

KEY TAKEAWAYS

+ Transfer levels add complexity and additional material.

+ Consider continuation of column layout from foundation through commercial/amenity space at ground floor to limit transfer slabs.

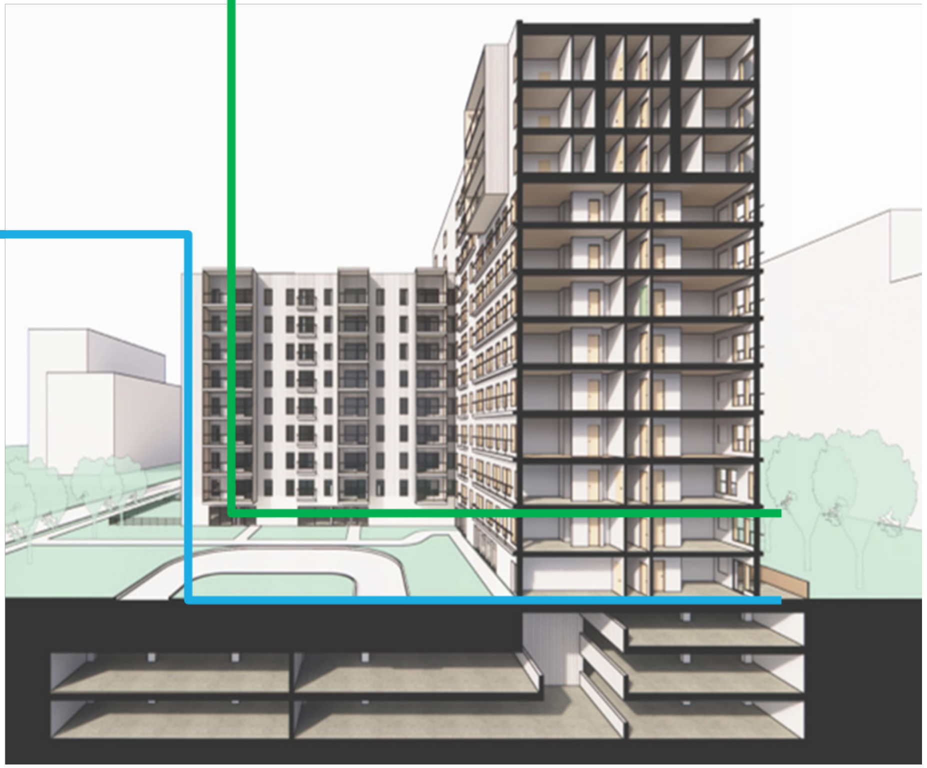


Figure 11: Typical Section Through Slab Tower Floor Levels

1.2. PODIUM COLUMN SPACING

Three types of occupancies within one building are applicable to the reviewed archetypes developed: residential, commercial, and parking. This results in three different floor plate layouts and column grids and leads to two levels of structural transfers. The noticeable costs savings can be achieved by aligning columns between parking and commercial floors to eliminate a structural transfer system between these two floors as shown in the Figure 11.

1.3. CLT PANEL DIMENSIONS

Maximizing dimension efficiencies of CLT panels used is the key strategy in achieving the most cost-effective mass timber solution. Panels are chosen to have maximum possible dimensions satisfying structural requirements, fire protection requirements, and minimizing production waste. Consistency of panel sizes used on a given project is prioritized whenever possible.

1.4. FIRE PROTECTION

Where required, a 2-hr fire-resistance rating is achieved with a combination of Type X gypsum board layers and CLT charring. The gypsum board layers must be fastened to the CLT as per CSA O86:19 Annex B.8.2 to allow for 60 min fire-resistance contribution from the gypsum board only. This gives the most efficient application of the CLT panels. For HSS columns, a higher M/D ratio can be applied for the columns placed within encapsulated walls, which results in less HSS column overall weight and leads to cost savings. Virtually all listed ULC designs specify a minimum column size. The term "minimum" is defined as a minimum M/D ratio, where M= mass per meter of length of the steel member (kg/m), and D= heated perimeter, visualized as the inside surface of the protective covering in square metres per metre of length of the steel member (m2/m).

1.5. CLT PANEL THICKNESS

Both 5-ply and 7-ply CLT panels can be used. 7-ply panels result in a higher volume of timber but provide benefits of eliminating concrete topping and achieving wider column spacing. 7-ply panels lead to faster construction and a lighter weight of the structure, overall, when paired with a non-concrete flooring system.

1.6. CONSTRUCTABILITY

CLT panel system allows for a shorter construction period and for a less construction site waste in comparison to a concrete flat slab and an open web steel joist on steel stud bearing wall systems. This can be enforced with the following strategies: using simple column-to-panel connections; enforcing consistent panel sizing; maximizing panel sizing which leads to reduced crane time usage; and lastly, by using 7-ply panels and eliminating concrete topping. Further reduction of the construction period can be achieved by utilizing steel brace bays instead of concrete shear walls for the lateral system.

1.7. EMTC AND GLOBAL WARMING POTENTIAL

Reducing carbon emissions from construction materials and the construction process, commonly referred to as upfront embodied carbon emissions, is a priority of many jurisdictions in B.C. including the provincial government. Cities are starting to introduce reductions like the City of Vancouver which requires embodied carbon emissions be reported through a life cycle assessment (LCA) for all new large (Part 3) buildings starting in mid-2023 with further reductions required starting in 2025. The Province of British Columbia is also considering adding embodied carbon emissions as part of the BC Energy Step Code in the future.

EMTC plays an important role in reducing embodied carbon emissions from buildings since timber has lower upfront carbon emissions, represented as the Global Warming Potential (GWP), measured in kg of CO2 equivalence, than other traditional construction materials like concrete and steel. This reduction comes from less carbon emissions associated with extraction and processing of wood into lumber compared to more energy intensive processing and extraction associated with metals and cement. Further reductions may be achieved when considering carbon sequestration of lumber, also known as biogenic carbon, which may be considered in future LCA models.

As shown in the LCA comparisons in this report and other studies, such as the Embodied Carbon Pathfinder tool, EMTC buildings are able to achieve much lower GWP than conventional buildings, in some cases by as much as 70%. This will enable many project teams to meet aggressive embodied carbon reduction targets and help many jurisdictions meet their climate/carbon neutral goals:

- EMTC buildings had lowest Global Warming Potential (GWP). Notably, the majority of GWP savings were from the structures.
- Minimizing concrete use is high priority to reduce GWP
- GWP values may change with greater detail, but trends should be similar
- GWP values did not factor in transportation/location, but likely have a minor impact if materials were sourced locally.

1.8. NOTABLE EMBODIED CARBON POLICIES WITHIN THE PROVINCE OF B.C.

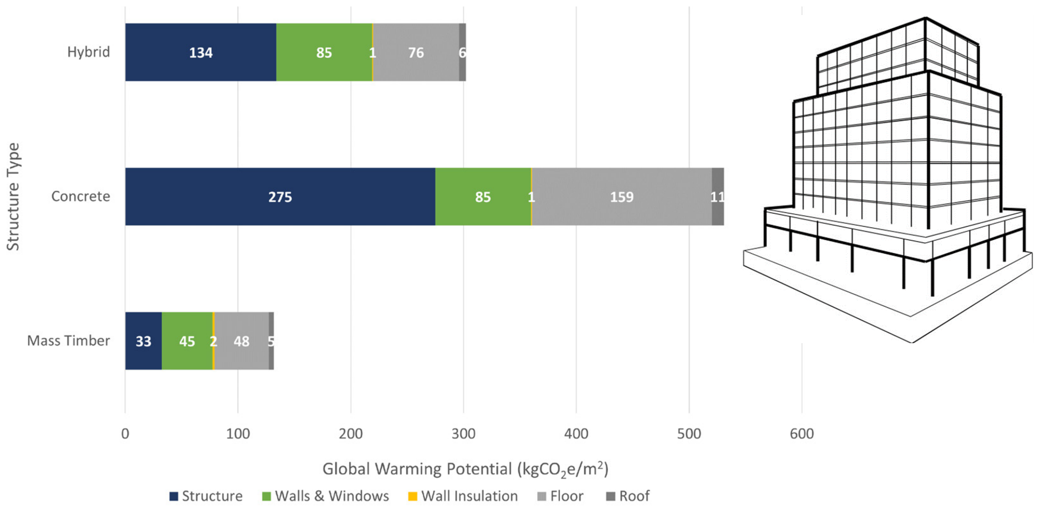
2023 VBBL

- Projects calculate and report LCA results compared to new standardize baseline
- GWP < 100% above baseline

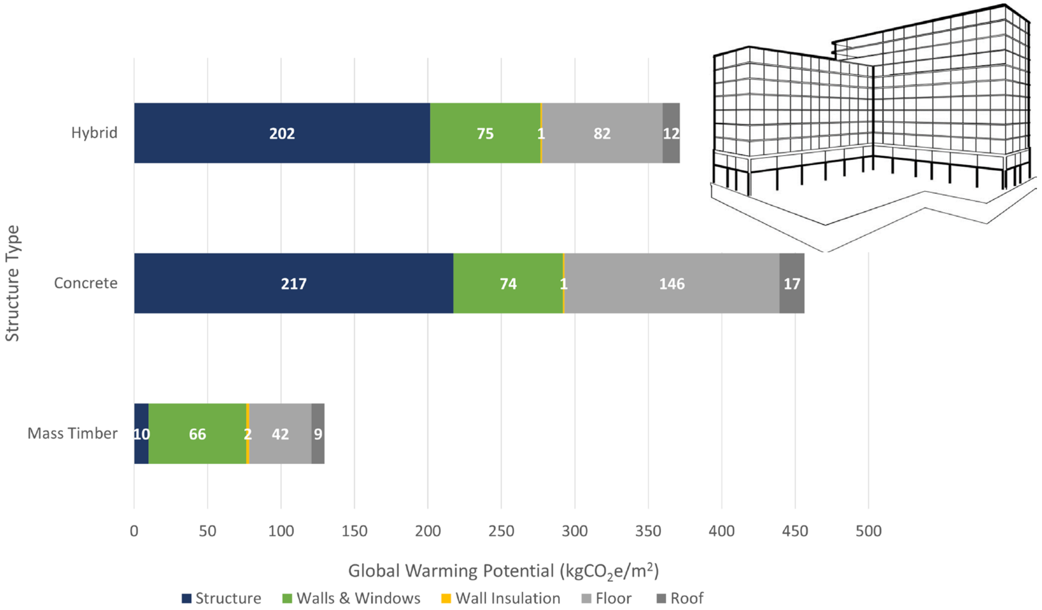
2025 VBBL

- 10% GWP reduction for 7+ storey Part 3 buildings + 1 responsible materials option
- 20% GWP reduction for 1-6 storey Part 3 wood and EMTC
- Compared to concrete baseline

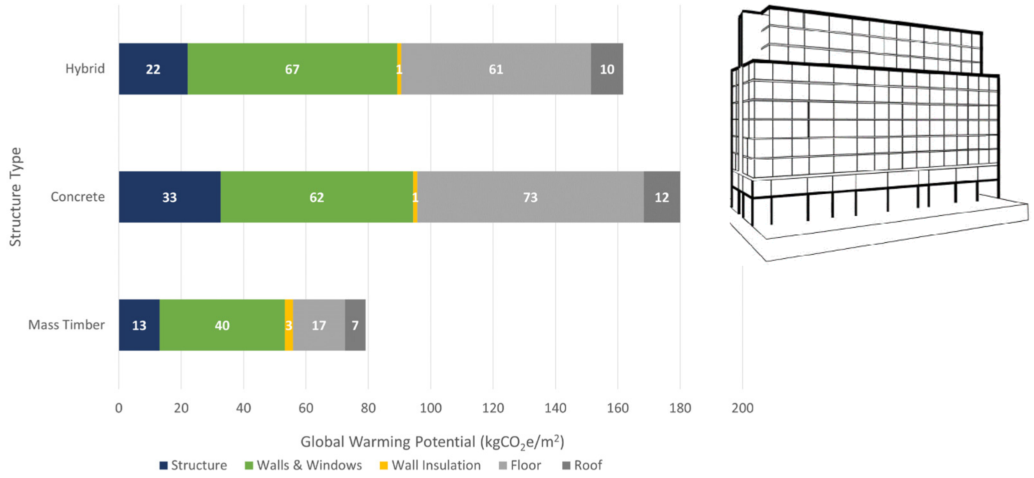
1.9 COMPARISON OF GLOBAL WARMING POTENTIAL



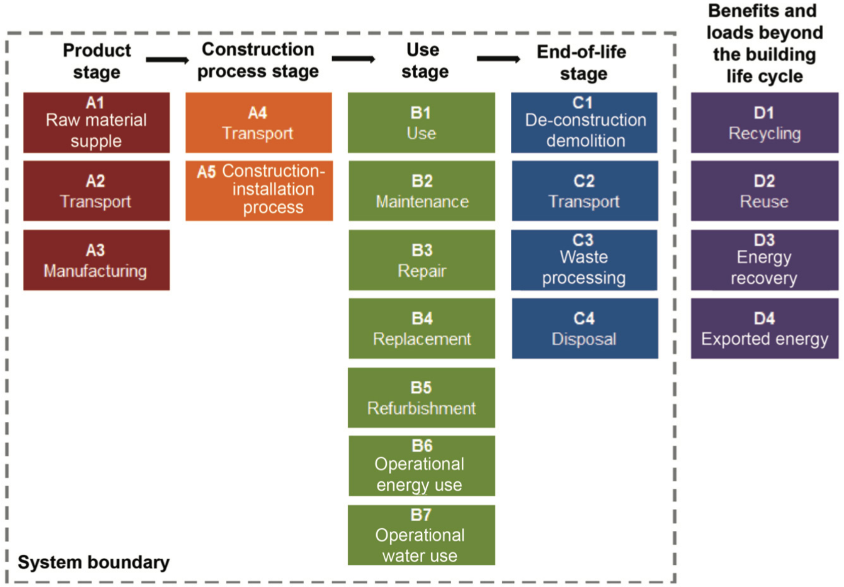
Point Tower – City of Vancouver



L Tower – City of Coquitlam



Slab Tower – City of Kamloops



INCLUDED:

MAIN STRUCTURE	**EXTERIOR BUILDING ENVELOPE**
Beams, columns, floors	Exterior walls, insulation, cladding, roofing membrane, vapour and air air barriers, windows and doors (glazing and frame)

1.10. EMTC ARCHETYPES CONSTRUCTION REQUIREMENTS

Building Classification and Construction Requirements

Based on a building's occupancy classification, Subsection 3.2.2. of the Building Code establishes construction requirements such as the permitted building size, construction type, sprinkler protection and minimum fire separation and fire resistance ratings of floor, mezzanine, and roof assemblies. Currently the Building Code provides only one set of construction requirements under Article 3.2.2.48EMTC "Group C, up to 12 storeys, Sprinklered" which is applicable to the EMTC archetypes of this study.

The proposed EMTC archetypes are classified as Group C and meet the construction requirements of Article 3.2.2.48EMTC and Subsection 3.2.2. as follows:

Major Occupancy: The primary major occupancy for each archetype is residential. Other permitted major occupancies (Group A, Division 2, Group E and Group F, Division 3 storage garage) in different configurations for each archetype are included in conformance with Article 3.2.2.48EMTC.

Construction Type: Each archetype uses a combination of noncombustible construction and encapsulated mass timber construction.

Building Area: The building area of archetypes is Point Tower 764m^2, Slab Tower 1067m^2 and L tower 1718m^2. Each building area is well below the maximum permitted 6000m^2.

Building Height: Each archetype is less than the maximum permitted building height of 42m measured between the floor the first storey and the upper most floor level.

Sprinkler Protection: As required each archetype will be sprinkler protected in conformance with NFPA 13.

Floor Assemblies: Each archetype includes floor assemblies constructed as fire separations using a 7 ply CLT slab sized to provide the minimum required 2h fire-resistance rating (FRR) if exposed or encapsulated.

Supporting Construction: Floor assemblies are supported by HSS columns encapsulated with gypsum board to the minimum required 2h FRR required for supporting construction. A glulam transfer beam system is provided at level 10 to account for level 10, 11 and 12 setbacks. These beams will be exposed on 2-sides and will be sized to provide the minimum required 2h FRR.

Exterior Balconies: Exterior balconies will be noncombustible metal deck with CLT sidewall finishes at least 96mm thick, meeting the minimum requirements for unencapsulated mass timber balconies.

Streets: As required each archetype faces at least one street for fire department access.

Mass Timber and Combustible Materials

Traditionally the Building Code has prescribed provisions based on a building being of combustible construction or of noncombustible construction or a combination of both. The development of EMTC requirements was based on the principle of providing the same performance level as a noncombustible building.

Therefore, the types of materials used in EMTC buildings must meet the minimum requirements of Subsection 3.1.5. This subsection regulates combustible materials permitted in buildings required to be of noncombustible construction (unless modified by specific provisions of Subsection 3.1.18 that specifically provide the minimum requirements for EMTC).

However, based on material and assembly choices for the archetypes only a few minor provisions of Subsection 3.1.5. apply, as most of the provisions are repeated or modified in Subsection 3.1.18. for EMTC. The following describes key types of materials used in the archetypes and how conformance with the Building Code is provided:

Structural Mass Timber Elements: Mass timber floor assemblies, roof assemblies and mass timber transfer beams (at level 10 in the point and Slab Tower archetypes) are proposed. The proposed structural mass timber elements meet the minimum prescribed dimensional criteria, except for the exterior wall timber panels.

Exposed Underside of Mass Timber Floors: Exposed mass timber ceilings using SPF or Douglas Fir 7 ply CLT floor slabs are proposed and will meet the 75 flame spread and up to 25% exposed limit. Exposed mass timber is not permitted by the Vancouver Building Bylaw in residential suites. One option is to demonstrate compliance for the Point Tower archetype by providing an alternative solution.

Encapsulation Materials: All mass timber elements are encapsulated as required. The exception is that the topside of floor assemblies should be encapsulated with a layer of mineral wool covered by 2 layers of 12.7 mm thick Magnesium Oxide (MgO) board for better acoustic performance and impact resistance. This encapsulation system has not been tested to CAN/ULC-S146 and the use of MgO board is a variation from the acceptable solution that deems 38 mm concrete toping or 2 layers 12.7mm thick Type X gypsum board to provide a minimum 50 minute encapsulation rating. Therefore, the topside encapsulation system will require an approved alternative solution.

Combustible Components in Exterior Walls: The exterior façade system includes 64mm thick glulam mass timber panel. The panel thickness does not meet the minimum 96mm thickness required as an encapsulated mass timber element. The thinner panel was selected by the team since it provides enhanced energy performance. The exterior wall assembly does not meet one of the generic options of Appendix D Section D-6. The remaining compliance option is for the exterior wall assembly to pass fire testing in conformance with CAN/ULC-S135 and the criteria of BCBC (Clause 3.1.5.5.(1)(b)). However such fire testing can be costly ($100K+), therefore an alternative solution may be desired to address the exterior wall glulam panel.

Combustible Window Sashes and Frames: Hybrid aluminum and wood frame windows are proposed in prefabricated nonloadbearing façade panel systems that include two layers of 12.7 mm thick gypsum board on glulam panels with outbound noncombustible insulation and cladding. Glulam wood frames are also integrated on the interior side of the timber panels, and conventional aluminum frames on the exterior side. However, the thickness of the glulam panel varies and at several points does not meet the minimum 96mm thick requirement of the Building Code. An alternative solution is required to demonstrate that the performance level (in terms for fire and life safety) afforded by the panel design is as least the same as the acceptable solution of the Building Code.

High Building Measures: As each of the archetypes are 12 storeys in building height (which will be more than 18m in height) the measures for high buildings under Subsection 3.2.6 are applicable. These provisions apply to EMTC buildings no differently than a conventional steel and concrete building. The EMTC archetypes are required to incorporate all high building measures including limits to smoke movement, firefighters elevator, venting to aid firefighting, a central alarm and control facility, voice communication system for buildings subject to VBBL only, protected electrical conductors for specific systems, and 2 hour duration of emergency power for building services, including for high building features.

1.11. CONVENTIONAL ARCHETYPES

The conventional archetypes included in this study consist of a noncombustible steel and concrete 12-storey residential buildings. These include pre-formed steel exit stair cores and elevator core modules and steel stud with gypsum exterior walls. As the noncombustible archetype is classified as a Group C major occupancy and 12 storeys in building height, it can only be classified under Article 3.2.2.47. "Group C, Any Height, Any Area, Sprinklered". As the title of Article 3.2.2.47. notes, building area and height are not limited and the building must be sprinkler protected in conformance with NFPA 13. The proposed noncombustible archetype is required to meet the relevant construction requirements of Article 3.2.2.47. and Subsection 3.2.2. as follows:

Major Occupancy: The primary major occupancy for the noncombustible archetype is residential. Other major occupancies in the building require the application of and conformance with Subsection 3.2.2. construction requirements for any size and any area, which are generically the same among other occupancies.

Construction Type: Structural assemblies and elements of the building, including fire separations, require noncombustible construction and the use of noncombustible materials.

Floor Assemblies: Floor assemblies constructed as fire separations using a composite concrete on steel deck on open web steel joist floor system. This is protected with a listed suspended ceiling system (ex. cUL Design Numbers G229, G524, G561) to provide the minimum required 2h FRR.

Supporting Construction: Floor assemblies are supported by HSS box beams and columns. All supporting construction requires a minimum 2h FRR.

Exterior Balconies: Exterior balconies are required to be of noncombustible construction.

Streets: The noncombstible archetype is required to face at least one street for fire department access. Subsection 3.1.5 regarding combustible materials permitted in a building of noncombustible construction and Subsection 3.2.6. regarding high building measures also apply to the conventional archetype.

1.12. SITE SPECIFIC BUILDING CODE REQUIREMENTS

As the archetypes are conceptual designs without specific sites identified, they cannot capture all fire protection and occupant safety requirements of the Building Code that are site specific. This includes site design features suh as spatial separation, fire department access, and connections with streets. The following points are provided to draw attention to variables that may impact building design and construction of the archetypes on specific sites.

Spatial Separation: To limit fire exposure and spread between buildings the Building Code requires noncombustible exterior wall construction when the permitted area of openings (windows, doors, louvers, etc.) in an exterior wall is 10% or less of the exterior wall area. When locating one of the EMTC archetypes on a site, sufficient distance will be required to permit the exterior wall assemblies of EMTC or to include combustible components.

Fire Department Access: In general, the Building Code requires a fire department access route meeting specific design criteria (width, load capacity, overhead clearance, turning radii, surface finish, etc.) to be provided so that the distance from the curb of the access route to the principal entrance (used by firefighters) is not more than 15m. Additionally, a fire hydrant is required to be within 45m of a fire department connection. For buildings under the VBBL, the fire department connection is required to be within a 5m horizontal distance from the principal entrance of a building. The location of each archetype on a site needs to take into account the distance of the fire department access route from the building, as well as location of fire hydrants and fire department connections.

Access to Public Thoroughfare: Based on the Building Code definition of an exit, the exit discharge locations at the exterior are required to give the ability for an occupant to move a safe distance away from the building (3m is typically deemed a safe distance) and have access to an open public thoroughfare (a street). Occupants limited to a back yard or gated/fenced parking lot without access to a street does not meet the definition of exit, unless sufficient open area is available at a safe distance from the building. The location of each archetype on a site needs to take into account access to a street from exterior exit discharges.

Site Grading: Unusual grade conditions such a sloping site or a drop-off can impact building height (number of storeys and height limit based on the definition of grade), fire department access and response, exit discharge, etc. It will need to be considered early in the design stage.

Water Supply (Fireflow): Part 3 of the Building Code requires an adequate water supply for firefighting be provided for every building. The Building Code acknowledges that sprinkler protection of a building achieves compliance with this requirement. However, prior to the Building Permit stage of a project many municipalities in B.C. have pre-existing bylaws that require properties to be provided with fireflows that could be in excess of existing water supply infrastructure. Further, these bylaws may not have been updated to capture the unique fire safety provisions that apply to EMTC buildings. While this does not influence building design, there is potential this can impact project development costs and schedule which in turn can impact construction schedule. An experienced civil engineer or fire protection engineer can help to assess fireflow requirements and identify options that could reduce cost and schedule impact early in a project.

Wildland Urban Interface Fires: There may be additional requirements of the authority having jurisdiction with respect to building design or construction to address fire risks associated with the interface between the urban site and adjacent wildlands. The FireSmart program in B.C. contains additional requirements, and another example is the National Guide for Wildland-urban Interface Fires recently published by NRC. These types of exterior building finishes and features may need to be considered to address building resiliency and protection from the effect of fire.

Construction Fire Safety Requirements: Construction fire safety requirements under Part 8 of the Building Code reference Section 5.6. of the Fire Code. Construction of a EMTC archetype will need to consider measures that may be needed such as construction methods or temporary barriers in order to satisfy the authority having jurisdiction that risks of fire spread to adjacent buildings are appropriately addressed during construction.

1.13. CONSTRUCTION FIRE SAFETY REQUIREMENTS

Part 8 of the BCBC and VBBL prescribe safety measures at construction and demolition sites. The scope of this Part requires that fire safety at construction sites conform with Division B Section 5.6. of the BCFC / VFBL. This applies to all building construction types, noncombustible, combustible or EMTC. Additional fire safety measures at construction sites may also be imposed by municipalities via bylaws, bulletins, or conditions of a building permit.

Fire safety is an implicit aspect of every design consideration and needs to be factored particularly when new construction processes and methods are applied on site. Designing and constructing a EMTC building must address multiple fire safety considerations. Here is a summary of key fire safety requirements of the Fire Code:

Protection of Adjacent Property: All buildings (EMTC and conventional) are required to provide protection of adjacent buildings during construction. Sufficient protection must be provided at construction sites to limit the probability of a fire from the site spreading to adjacent buildings during the time required for emergency responders to perform their duties. Most municipalities require the submission of a report prepared by an experienced fire protection engineer to identify the fire risk of a proposed construction project to adjacent buildings and protection options to be implemented to reduce the risks. Typically, protection options include passive or active systems such as spatial separation, installing water curtains, using construction methods and materials that include gypsum sheathing, or erecting a temporary fire barrier.

For the EMTC archetypes a feasible approach to address protection of adjacent properties is by enclosing the perimeter of the building from the bottom up as each storey progresses, using the pre-fabricated exterior wall panels that are finished with gypsum board on the interior side, and a noncombustible cladding and insulation at the exterior side. This will limit the radiant heat transmission of a fire to areas beyond the exterior wall. Protection of the exterior wall panel connection points should be in place for this approach to be effective.

Encapsulation During Construction: This requirement addresses the protection of adjacent buildings as mass timber is expected to burn for a longer duration and at heights above 6 storeys which poses firefighting operational challenges. Construction sequencing for the EMTC archetypes of this study can be managed by including encapsulation measures combined with facade installation that is no more than 4 floors below the uppermost timber floor without imposing significant additional construction costs. However, addressing the encapsulation requirements on an alternative solution basis is another possibility. Where it is desired to have more than 4 exposed floors during construction, an alternative solution can typically be based on additional compensating measures, when considering mitigating conditions. The following is required for encapsulation during construction:

- Not more than the four uppermost contiguous storeys are permitted to have fully exposed mass timber at any one time of construction; this means sequencing of construction must encapsulate a minimum 80% of the underside of the first storey floor assembly before constructing the fifth storey.
- The encapsulation material or assembly of materials must provide an encapsulation rating of 25 min, e.g., 1 layer of 12.7mm thick Type X gypsum board.

Exit Stairways During Construction: A minimum of two exit stairs are required to be provided as each floor is installed and must be enclosed with construction providing a minimum 30min FRR for EMTC buildings under construction. Additional exit stairs features include:

- A minimum stair width of 900mm.
- Stair treads and risers complying with the dimensional requirements of the Building Code.
- At least one handrail complying with the Building Code.
- At least 920mm high guards along the sides of stairs and at least 1070mm high guards around landings.
- All stair doorways are provided with 45mm thick solid core wood doors, hollow metal doors, or doors constructed of 12.7mm thick plywood with 12.7mm thick gypsum board mechanically fastened to the floor area side, or any door assembly having a fire protection rating not less than 20min.
- Stair doors swing on the vertical axis and are equipped with latches and a means to close automatically.
- For EMTC archetypes it is planned to provide concrete formed stairs ahead of floor installation to meet this requirement.

Standpipe Installation: A permanent or temporary standpipe system is required to be progressively installed during construction and must always be in an operable condition when it is not being actively worked on. Key requirements for a standpipe system in buildings under construction are:

- The standpipe can be wet or dry.
- For each new level that hose valves are installed for the standpipe system they must be pneumatic pressure tested for wet systems and air pressure tested for dry systems.

- For wet standpipe systems freeze protection is required.
- A fire department connection that is readily accessible must be provided.
- Signage indicating the type of standpipe systems is required at the fire department connection.
- Pressure gauges with manual relief valves at required at the fire department connection.
- Standpipe system installation during construction is a common practice and is not expected to pose challenges for the archetypes.

1.14. ARCHETYPE PODIUM STRUCTURE

All building archetypes and their various schemes are supported by a concrete podium structure at Level 3. This ensures maximum column-to-column spans at the ground level, allowing for larger commercial and amenity spaces. It also allows for any additional change to the column layout at the parkade level, which requires columns to occur efficiently between every second or third parking stall, maximizing the number of parking spaces.

Only the Point Tower would allow for columns at the commercial/amenity levels on L1-L2 to continue down through the parkade levels below grade, given the architectural layouts. This makes for a very efficient podium structure that requires fewer transfer levels than for a commercial/amenity layout. The latter requires a different column grid configuration to that of a parkade. Thus, it would be recommended to adopt a similar approach for the concrete podiums at the Slab and L Towers. Understandably, the efficiency in parking stall layout or in commercial space above the ground level may diminish due to the structural efficiency of column grid layout on all podium levels.

Section through the Point Tower with the podium structure:

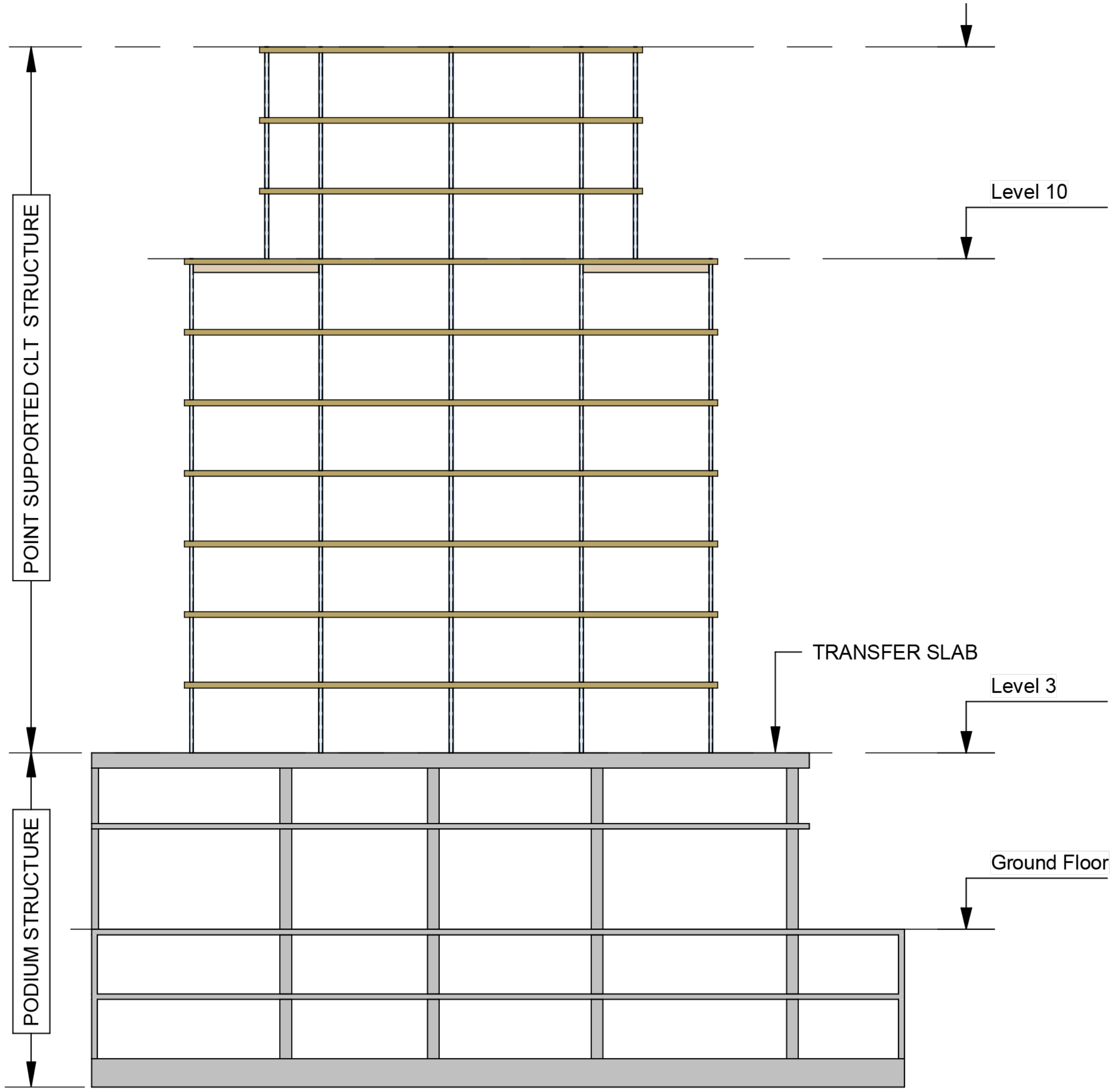


Figure 12: Section Through Point Tower with Podium Structure

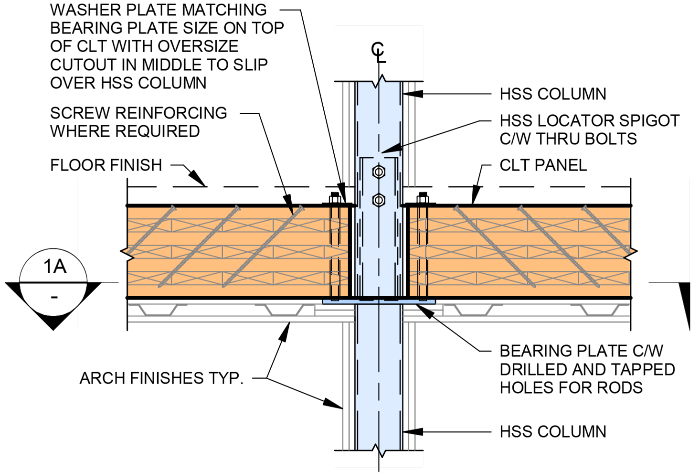
1.15. SCHEME 1: CLT POINT-SUPPORTED SYSTEM FOR EMTC

The CLT point-supported system used for each of the building archetypes consists of two-way spanning CLT panels supported by hollow structural steel (HSS) columns. The column-to-panel connection comprises of a flat bearing plate that supports the CLT floor and receives the column for the floor above. This results in a connection that eliminates perpendicular-to-grain bearing issues which might otherwise limit the CLT capacity. The connection is also easy to install in the field and thus accelerates the construction schedule (see Figure 6 Typical HSS column to panel connection for a CLT Point-Supported System). Column supports occur along each CLT panel joint and there is no need for beams to support the panels, making for unobstructive head roof and maximizing floor-to-floor heights. Beams only occur to transfer shifting column layouts at Level 10, where the building offsets.

Shrinkage is a common issue in wood and EMTC buildings, specifically in wood bearing wall and post-and-beam configurations. However, using a column-to-column detail as shown below and in a point-supported system, which eliminates bearing of the column above on the CLT floor panel, effects of shrinkage are limited. By using steel columns everywhere, any axial shortening that might be expected in wood columns due to axial load as well as shrinkage is avoided. Note that with shrinkage, and effectively any differential deflection is an important consideration if wood and steel columns are desired to be used in conjunction on any given floor level.

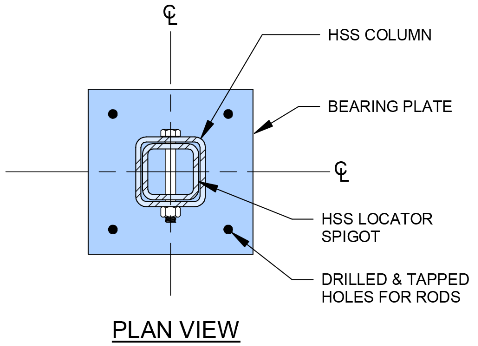
CLT panels contain multiple cross layers of machine stress-rated (MSR) or visually graded lumber that can provide bending resistance and stiffness in two directions. To maximize bending resistance and stiffness, and thus the spacing of supporting columns, MSR grade lumber is considered for the strong direction. MSR grade lumber can also be considered in the weak direction. However, given that the weak direction is limited by panel width, manufacturing constraints, and contains one less layer than that of the strong direction for all typical panel supplied in North America, use of MSR grade lumber in the weak direction does not provide maximum benefit for its cost. Therefore, a maximum No.1/No. 2 visually graded lumber is considered in the weak direction.

Under a point-supported system, as opposed to a post-and-beam supported system where panels are line-supported, rolling shear at the column supports is a main consideration, similar to punching shear in a concrete flat slab system. CLT laminations are considered to “roll over” each other under shear stresses perpendicular to grain. While it is understood that the concentrated forces at the point supports provide added restraint against rolling shear, lack of code guidance and resulting conservative codified values given for rolling shear often result in rolling shear being a controlling factor. To reinforce against rolling shear, strategies like those used for punching shear design in a concrete flat slab are available, if required. These include the use of inclined fully-threaded screws into the CLT, similar to stud rails in a concrete slab, in a starburst pattern at column locations. Another option is thickening the CLT panel to provide additional shear resisting area. In general, however, reinforcing is avoided, as added reinforcement to resist punching shear can be costly. Where change in building layout occurs above level L10 for the Point and the Slab Towers, glulam beams spanning north-south between HSS columns transfer HSS column loads from above at level L10 only. This avoids landing HSS columns in the open suite layouts at all floors from the podium to level L10. No transfer beams are required in the L Tower, since the change in layout above level L10 only consists of the south bar topping out as roof at level L10 and the layout of the north bar continuing above the level L13 roof.



1 - TYPICAL STEEL COLUMN TO CLT SLAB

N.T.S.

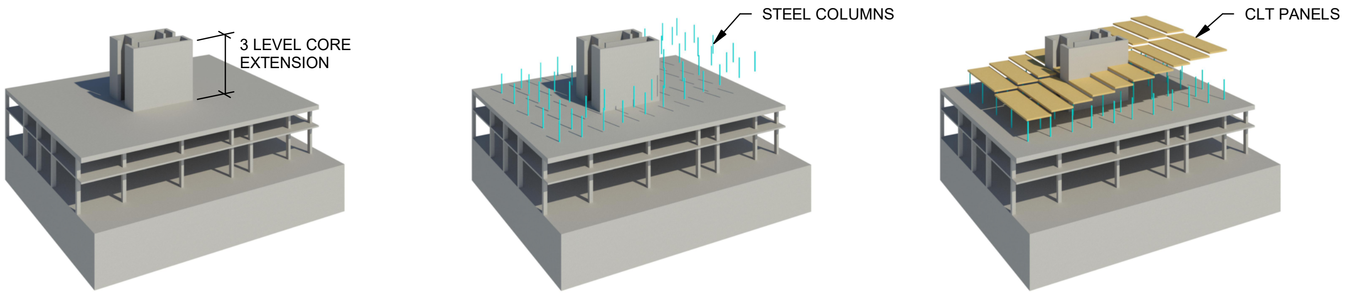


1A - TYP. COLUMN - COLUMN CONNECTION

N.T.S.

Figure 13: Typical HSS Column to Panel Connection for a CLT Point Supported System

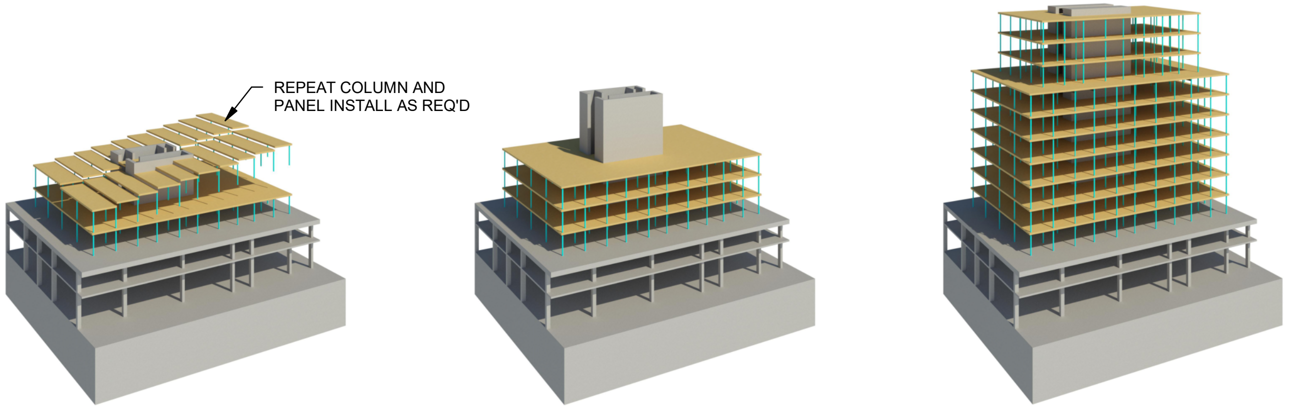
Figure 14 below shows a point-supported CLT system over a concrete podium using the Point Tower archetype. The top row of images show the completion of the concrete podium and at least 3 levels of concrete core before the first level of HSS columns at L3 are installed. The second row of images particularly highlights the construction sequencing of panel installation per floor following HSS column erection:



CONCRETE PODIUM W/ TRANSFER SLAB

COLUMN INSTALL ON TRANSFER SLAB

CLT PANEL INSTALL ON STEEL COLUMNS



FLOOR LEVEL INSTALL

3 LEVELS COMPLETED

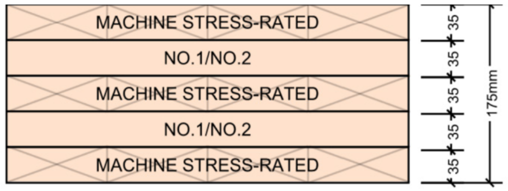
COMPLETED STRUCTURE

Figure 14: Sequence of EMTC Floor by Floor

1.16. 5 PLY CLT

To date, a 5 ply, 175mm thick CLT layup has been typically used and is the most efficient layup materially and economically. A 5 ply CLT layup, maximized for efficient column layout, consists of three 1950f-1.7E MSR grade, spruce pine fir (SPF) species laminations in the strong direction, and two No.1/No. 2 grade, SPF species laminations in the weak direction. Using this layup, the average column grid spacing in the strong direction of the panel ranges from 3.5 metres to 4.5 metres, depending on architectural layout. Spans that are closer to this upper limit may be governed by rolling shear, due to higher concentrated loads at the column supports. Because screw reinforcement to resist excess rolling shear in the CLT panels can be costly, it is more economical to balance column grid spacing to avoid reinforcing. This layup and these spans assume a 38mm – 50mm concrete topping that is often added for durability, footfall vibration, acoustics, and for fire safety.

The following image shows a layup for a 5 ply CLT using MSR lumber in the strong-direction:

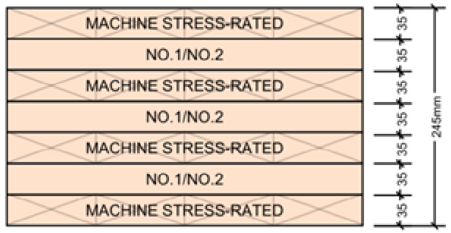


5 PLY CLT

While a 5 ply CLT layup is typically used and code compliant for tall timber, a 7 ply CLT panel is considered for this economic study. For this study, the 7 ply, 245mm thick, CLT layup consists of four 1950fb-1.8E MSR grade, SPF species laminations in the strong direction, and three No.1/No. 2 grade, SPF species laminations in the weak direction.

While a 7 ply system results in a 40% increase in wood fibre, a 7 ply CLT layup is chosen for specific added benefits. These include minimizing effects of rolling shear, maximize spans in the strong direction, and more importantly, providing the opportunity to use of a non-concrete flooring system. This demonstrates the required performance by way of Alternative Solution, since Division B of BCBC 2018 requires a concrete topping for encapsulation of the top side of CLT.

The following image shows a layup for a 7 ply CLT using MSR lumber in the strong-direction:



7 PLY CLT

The additional lamination in the strong direction allows for column grid spacing to push beyond the limits of the 5 ply system. For a 7 ply panel, using the grades mentioned above (and with a comparable concrete topping and encapsulation as to that being used on a 5 ply system) spans are increased by 20%. This maximum span, however, like in the 5 ply system, is balanced against the rolling shear effects at the column supports, and more significantly, by char due to fire. Under the BCBC 2018, this encapsulated mass timber building is required to have floor assemblies and load-bearing structure that provide a 2-hour fire resistance rating on all sides (determined by testing in accordance with CAN/ULC-S101 or BCBC Division B, Appendix D). Resistance to fire for this duration is primarily achieved by providing encapsulation with Type X gypsum layers, and by allowing the CLT to char. However, given the allowance for a small percentage of the ceiling to remain as exposed CLT, there are portions of the CLT slabs, specifically where bending is low along column lines, where only char at the underside of the CLT meets the fire resistance rating. According to the Encapsulation of Mass Timber Construction (EMTC) Guidelines, 2 layers of 12.7 mm thick Type X gypsum board applied to the underside of the CLT plus a 38mm concrete topping can provide a 50-minute encapsulation rating on the underside and full encapsulation on the top side. The CLT, therefore, needs to be designed for a 70-minute char depth on the bottom side for a result of a 120-minute (2-hour) assembly.

However, bending and char analysis indicates that a minimum 60-minute encapsulation rating is required for a more cost-efficient CLT panel (ie. one that does not require a high bending strength in the strong direction.) CSA O86:19 Annex B, allows for 2 layers of 12.7 mm thick Type X gypsum board, screw fastened directly to the CLT in a prescriptive manner, to provide 60-minutes of encapsulation rating. For encapsulation on the top side, this study explores a new flooring system (non-concrete topping) that offers better acoustic properties the opportunity for modular installation of in-suite finishes. It avoids a wet system against the timber. The new flooring system, in lieu of a concrete topping, is made up of 2 layers of 15.9 mm thick Type X gypsum board and rock wool insulation on the top side. This provides a 60-minute encapsulation rating. Therefore, for both the bottom and the top sides, a 7 ply CLT is required to resist a minimum of 60 minutes of char.

If the 2 layers of gypsum are directly applied to the CLT per CSA O86:19 Annex B, on the top and the bottom sides, the CLT is then only required to be designed for a 60-minute char depth on each side. This means that a 1950fb-1.8E MSR, E-rated panel is feasible. However, if the 2 layers are not fastened to the CLT per CSA O86 Appendix B, then the encapsulation rating of a 2-layer gypsum assembly is only 50 minutes. Thus, a stronger 2150fb-1.8E MSR E-rated panel must be utilized to resist loads under this fire condition. In general, a lower-strength E-rated MSR panel is more cost-effective than a higher strength panel.

Despite this limitation the added depth of the 7 ply CLT layup, in most cases, results in the elimination of an additional column line that would be required for a 5 ply CLT layup with a concrete topping, It also minimizes rolling shear stresses at the column supports. The elimination of a concrete topping also makes for a lighter overall structure, which reduces material in the HSS columns, reinforcing bars in the concrete elements, and overall volume of concrete. Eliminating a concrete topping to provide full encapsulation against fire at the top side of a panel is possible with use of a 7 ply CLT layup. A 5 ply CLT layup is not capable of providing a reduced section under a fire load case, if the top side is required to char at any depth.

Figure 15 shows a comparison of a 7 ply layup with a 5 ply layup, assuming that a concrete topping is eliminated for the 7 ply CLT layup only. The column layout is the same between the two CLT layup options, due to the fact that the 7 ply CLT layup with no concrete topping must char on the top and the bottom side to resist a full 2 hour fire duration:

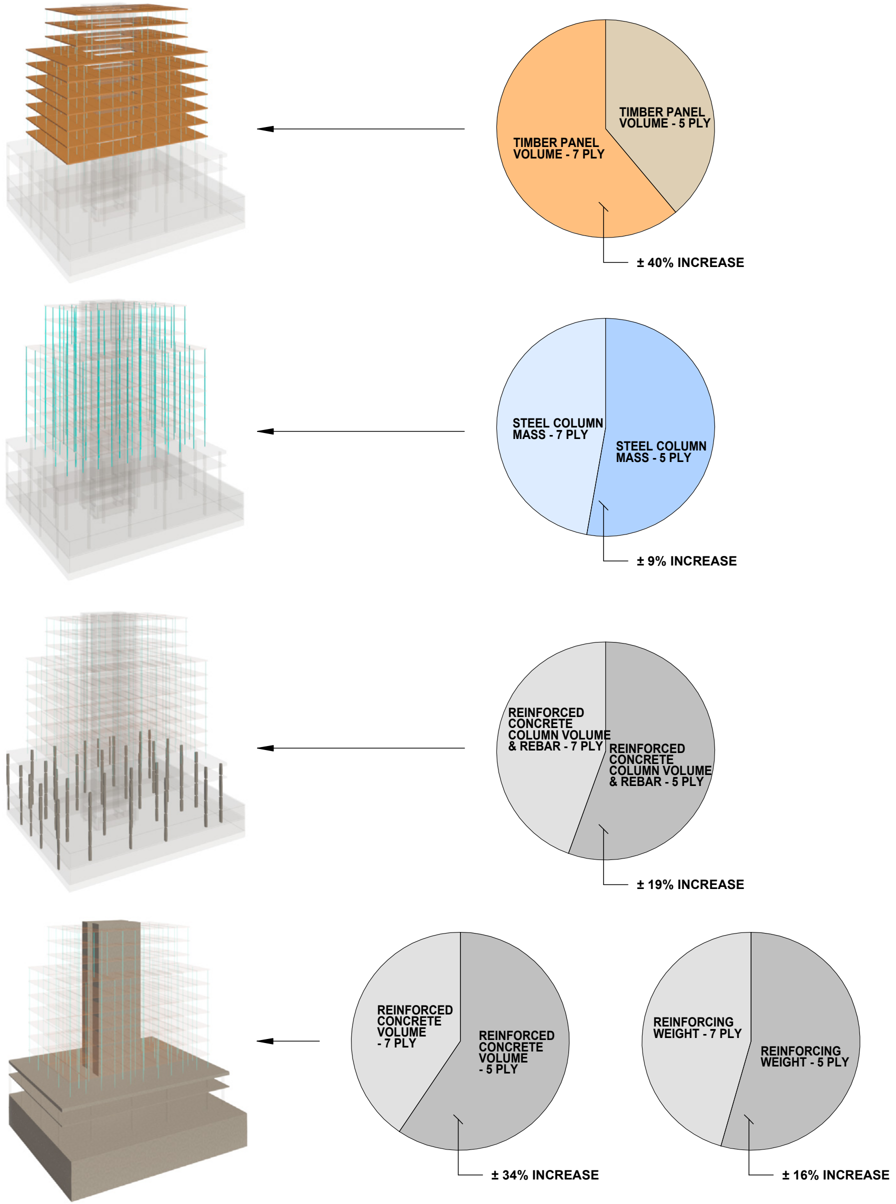


Figure 15: Comparison of a 7-ply layup vs a 5-ply layup

1.17. 7 PLY CLT PANEL DIMENSIONS

Historically, CLT panel widths came in 8’-0” (2.5m) and 10’-0” (3.05m) due to CLT presses that were available to manufacturers in North America. While European manufacturers could produce wider panels, shipping wider formats greater than 3.05 metres wide was not logical or economical. Panels are also available in widths smaller than the typical widths; however, cutting to any width without consideration of efficiency can be wasteful. For example, if project calls for a 6’-6” (2.0m) panel, manufacturers press an 8’-0” panel and cut it down to size. The remaining 1’-6” panel width may not be functional elsewhere in the project and is thus considered waste.

With the availability of high-frequency presses to the newest North American manufacturing plants, wider formats up to 11’-6” are available without the same shipping constraints that come with European-produced panels. Additionally, narrower panel widths can be cut to size more accurately without the waste created by cutting a standard panel width to size. However, panel lengths are still limited by trucking and shipping container sizes at 39’-6” maximum, which may further limit panel layout efficiencies.

Three main panel widths are used throughout the building archetypes: a maximum 3.5m, a 3.2m (10’-6”), and a 2.9m (9’-6”) wide panel. Architecturally, the varying panel dimensions can be used within a suite, such that the panel joints and column supports land mostly within partition walls. In some cases, as seen in the studio suites in the Slab Tower, panel orientation is turned by 90 degrees to allow for larger open spaces within the suites. However, by limiting the number of panel widths, panel efficiency is maintained such that the press can cut multiple panels quickly before having to reset for another width dimension. This also helps with crane pick times on site during installation as shown in the example of the CLT Panel layout for the Slab Tower (Figure 16):

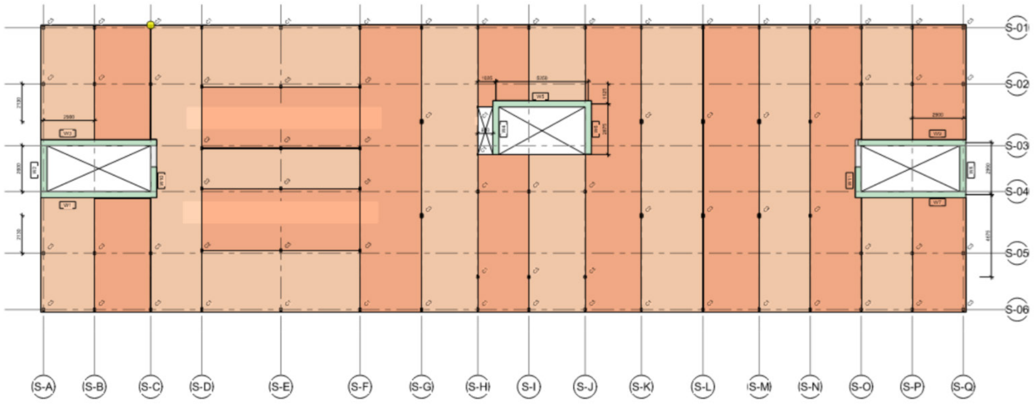


Figure 16: CLT Panel Layout Plan

1.18. CLT PANEL BALCONIES

Balcony structures were carefully considered for the EMTC scheme in order to maximize thermal performance and constructability. A double knife plate solution was developed, as seen in the figure below, using the gravity columns already in place for the structure. The first connection to the building allows a connection point to be available before installation of the façade. The double knife plate configurations provides a thermal bridge reduction when compared with a continuous cantilevered slab from the exterior condition to interior condition without the use of expensive thermal break systems that do not provide much construction tolerance. Lastly, the second connection point on the exterior of the façade then allows for the installation of the balcony decks well after completion of the façade installation, maximizing construction sequence efficiencies. Ultimately, this balcony scheme is one of many ways to support an exterior balcony to a point-supported EMTC building. It utilizes a vertical CLT panel as both gravity support and as an architectural feature.

Support of a variation of this balcony type might warrant a very different connection detail. A more structurally efficient connection, which would include an Armatherm thermal break with a bolted end splice connection, as is traditionally seen, might be more expensive and difficult to install on site. A detail like this would typically require heavy coordination with the project architect and building contractor to suit site and project needs.

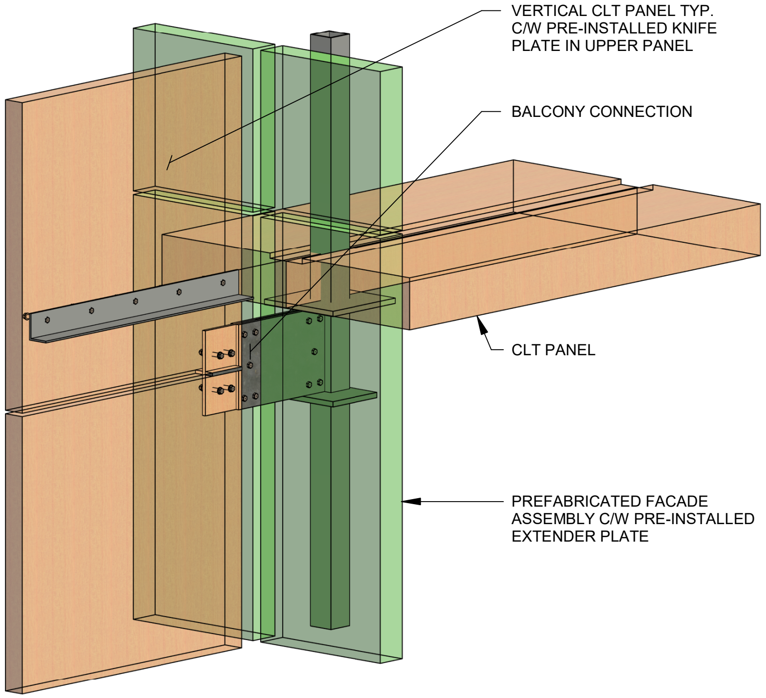


Figure 17: Structural Connection at a Column - EMTC Balconies

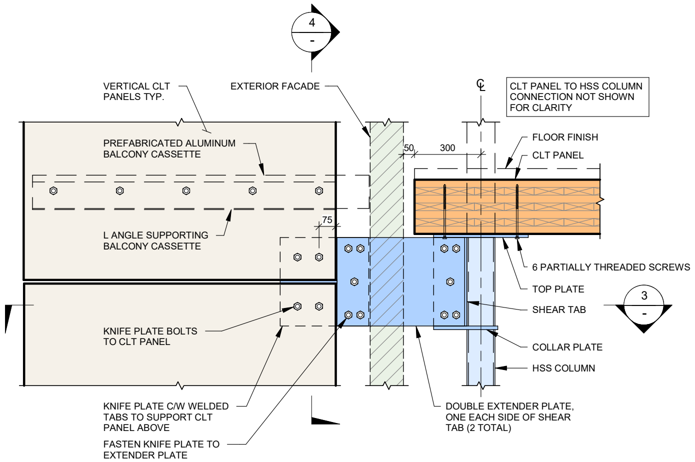


Figure 18: Structural Section at a Column – EMTC Balconies Connection

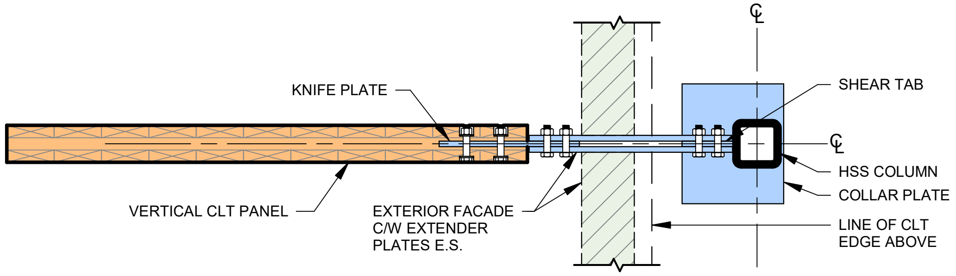


Figure 19: Structural Section Balcony – CLT Balcony Exterior Wall Connection

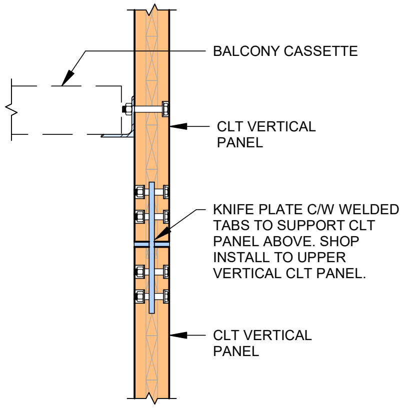


Figure 20: Structural Section at a Column – EMTC Balconies Connection

1.19. SCHEME 2: CAST-IN-PLACE (CIP) CONCRETE SLAB SYSTEM

The cast-in-place (CIP) concrete slab system for each of the building archetypes utilizes a two-way spanning concrete flat slab at 230mm (9”) thick supported by square concrete columns. Typical spans in each direction are approximately 5.5 metres to 6.5 metres, varying in order to avoid columns in the middle of open suite layouts where possible. Concrete columns range from 300mm by 300mm in plan dimension to a maximum of 500mm by 500mm plan dimension, with larger columns occurring in the bottom levels from levels L1 – L2. The smallest columns in plan dimension occur at the top 3 levels of the tower.

The (CIP) concrete slab is designed for bending in both plan directions, and punching shear is considered at each column locations, particularly due to high concentrated loads experienced at these areas. Given the shallow thickness of the slab, punching shear can be a controlling factor for larger spans. To reinforce against excess punching shear, welded stud rails are used at column locations within the concrete slab depth.

Use of a (CIP) concrete slab allows for unobstructive head room between floors, and helps maintain compact floor-to-floor dimensions and limiting large penetrations for services in major structural elements. The shallow concrete slab thickness further allows for compact floor-to-floor dimensions without sacrificing head room. Large column-to-column spans also allow for unobstructive in-suite layouts, which is architecturally ideal.

The transfers required for the Point and the Slab Towers above level L10 are resisted by a thickened slab at level L10. This means that the column layout can shift form level L9 to L10 without the use of transfer beams. According to BCBC Appendix B fire resistance for a concrete structure is provided by the inherent thickness of concrete and minimum clear cover provided for the reinforcing. Size of structural elements are governed by structural loading and durability criteria, which easily meet minimum requirements for fire resistance ratings.

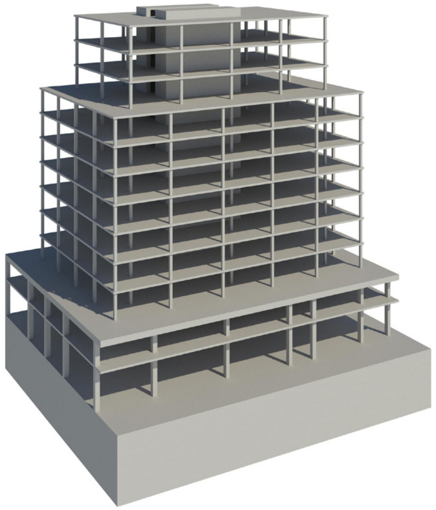


Figure 21: The Point Tower as a full concrete scheme

1.20. SCHEME 3: STEEL STUD AND CONCRETE SYSTEM

The steel system makes use of all major walls as bearing lines that are already architecturally required to create the individual spaces by utilizing them as structural bearing walls. The result is a light-weight structural system that emulates the simplicity of conventional low-rise framing and still provides strength and stability required for 12-storeys. In each of the building archetypes, floors are comprised of 38mm concrete topping over a 64mm deep metal deck spanning over open web steel joists (OWSJ) at 1.2m (4'-0") on centre spacing, supported by cold-formed steel—or light-gauge metal—stud-framed walls at corridor, exterior, demising and major in-suite partition walls. Joist depths range from 200mm deep in the corridors to 350mm deep at the longest spans within suites. All bearing walls utilize 150mm (6") deep light-gauge metal studs at 300mm (12") on centre spacing with the thickest studs occurring at the bottom level L3 of the superstructure.

Steel header beams are used to limit spans for the OWSJ's, which help to maintain depths to 350mm maximum. Any increase in depth beyond that impacts ceiling and window header elevations. Where header beam lengths are for typical door and window widths—or 1.2m (4'-0") maximum in width dimension—king stud posts at the ends of adjacent stud walls are considered. However, where longer steel header beams above and beyond that typical dimension are required, steel beams are supported by HSS columns that continue down to the podium structure.

Above level L10, for all building archetypes, where a shift in architectural layout occurs, OWSJ's at level L10 are aligned with exterior walls above to support bearing wall loads. Most primary bearing walls above level L10 in the north south direction align or nearly align with bearing walls below; multiple OWSJ's in the perpendicular direction are considered to transfer bearing wall loads above level L10 are within 300mm (1'-0") of adjacent bearing walls below. In the Slab Tower, steel beams are required to maintain typical OWSJ spans at levels L10-L12 and the supporting HSS columns are carried down to the concrete podium structure at L3. A similar condition occurs at the L Tower at levels L10-L12; however, because supporting HSS columns would then land within an open suite layout in the floors below, a steel transfer beam system at level L10 is only implemented to transfer these HSS point loads.

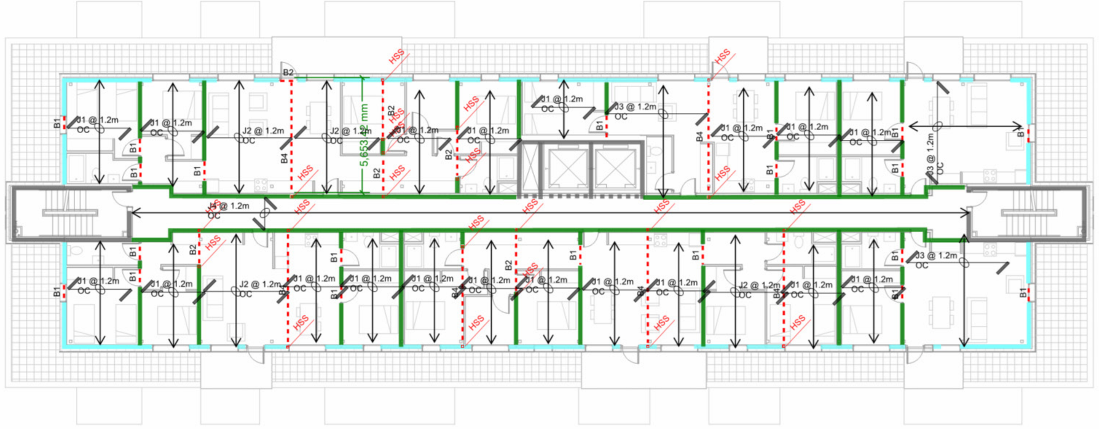


Figure 22: Top 3 levels at the Slab Tower using a steel stud and concrete scheme.

Like in the Scheme 1 EMTC system, fire resistance for the structure is achieved by using Type X gypsum board layers to encapsulate the steel stud walls and the steel joists. Fire resistance over top of the floor assemblies is achieved in the inherent concrete topping thickness and clear cover provided over the reinforcing.

1.21. LATERAL SYSTEM DESIGN - CONCRETE SHEAR WALL

For all building archetypes and schemes, a lateral resisting concrete shear wall system is considered. The ductility for the system varies depending on building archetype, its representative location within B.C., and its corresponding climatic data. A ductile concrete shear wall system is used for the Point and the L Towers, since they are intended to occur within the lower Mainland, and where seismic accelerations warrant the use of this ductility to minimize base shear. For the Slab Tower, a moderately ductile concrete shear wall system is used, as seismic accelerations in the Northern and Interior regions, where the Slab Tower is considered to occur, are well below that of the Lower Mainland and Vancouver Island regions.

Concrete shear wall thicknesses are designed in accordance with BCBC 2018 for loads and per CSA A23.3 for Concrete Structures. Each scheme has its own seismic weight attributed to it. The EMTC scheme, Scheme 1, has the lightest seismic weight of 2.4kPa plus snow load. The concrete flat slab scheme, Scheme 2, has the heaviest seismic weight of 6.6kPa plus snow load. The greater the seismic weight of the scheme, the harder the lateral resisting system must work to resist lateral forces due to inertial forces. The result of heavier buildings is often more reinforcing within shear walls and thicker wall dimensions.

To ease constructability constraints of a concrete shear wall system, a Prefabricated Form system was considered as a permanent wall form. Like a metal decking system for concrete slabs, the Prefabricated Form system is a permanent steel-frame with corrugated metal infill form for concrete walls. This would eliminate the need for a jump-form system and would allow upper storey walls to be poured prior to the curing of the lower-level walls. It also would allow for a construction stair to be erected shortly after concrete wall installation (before full cure time for the walls is complete). Ultimately, the concrete wall thickness is the permanent lateral resisting system, with no help from the steel framing and is not part of the detailed design for this economic study.

1.22. LATERAL SYSTEM DESIGN – STEEL BRACED FRAME SYSTEM

As an alternative to a concrete lateral resisting system, concentrically steel braced frames for lateral resistance was considered for each building archetype. However, this lateral resisting system can only be applied to Schemes 1 and 2; it is not feasible for Scheme 3, the concrete flat slab system. This is mainly because the building seismic weight is not compatible with a steel braced frame.

For Schemes 1 and 2, a moderately ductile concentrically steel braced frame system is considered for the Slab Tower, which is representative of a residential building outside of the Lower Mainland and Vancouver Island regions. For the other two building archetypes, which would occur in Vancouver and its surrounding areas, a ductile steel concentrically braced frame system is considered, due to higher seismic climatic data that is typical of these areas.

A steel braced frame lateral resisting system has benefits over a concrete lateral resisting core, particularly in terms of the construction schedule. A steel frame can be completely erected from concrete foundations to the roof before any floors need to be installed. This avoids trade overlap, crane sharing and accelerates construction efficiency.

Additionally, with structural optimizations, mutli-level parts of the steel frame can be prefabricated and lifted as one piece, which further limits crane work and time on site. Also, a steel braced frame lateral resisting system can allow for thinner wall assemblies and easier service distribution from cores around which the lateral resisting frames would be located. This system is specifically beneficial to a CLT point-supported system (Scheme 1), especially if a non-concrete flooring system is implement. It would eliminate the use of any concrete above the podium levels. In turn, one less material and trade is needed on site during construction of the main tower.

Because a steel braced frame for lateral resistance is not compatible with a concrete flat slab system (Scheme 3), it was not included in the detailed design of this economic study.

1.23. EVALUATING EMTC FOR RESIDENTIAL HOUSING – STRUCTURAL OPTIMIZATION

While there are many options for mid-rise housing, the use of mass timber offers key benefits. There are specific challenges to using mass timber, particularly for a point-supported CLT system. However, the results can outweigh the advantages of the other schemes that are often considered for mid-rise housing. The point-supported CLT system is most comparable to the concrete flat slab system. Depending on architectural constraints and the spans desired to meet those constraints, the thickness of the slab can be designed to suit. However, detail challenges with providing the required fire resistance ratings and panel width availability does limit the tall timber scheme.

Even so, in comparison to a concrete flat Slab Tower, steel column supports for a CLT system, while more numerous than a concrete flat slab scheme due to span limitations, are smaller in plan and are more easily contained with typical partition walls. Stand-alone steel columns, where they must occur within a mass timber scheme, will also have a smaller impact on an open suite-layout in comparison to a concrete column. In order to meet similar sizes in a concrete scheme, slab thickness can be made thinner to suit. However practical slab thicknesses are limited to 150mm to 200mm, which may mean that slabs are thicker than the span and loading require. Stand-alone steel columns, for the CLT system, where they must occur within a mass timber scheme, will also have a smaller impact on an open suite-layout in comparison to a concrete column.

A point-supported CLT system is also more structurally efficient than a steel stud bearing wall system. In order to minimize depths of OWSJ floor systems, more bearing walls must be utilized. Therefore, particularly at upper storeys where there is minimal compression accumulation from floors above, steel stud bearing walls are often over designed for their use. Otherwise, a more efficient joist on bearing wall system would require that every unique span be designed for a unique depth, which can slow the construction installation. Additionally, stud walls in nature are redundant structures, utilizing repeating elements at specific spacings along their lengths.

Comparing a perspective view of a point-supported CLT system (bottom); a steel system (middle); and a reinforced concrete system (top)

Steel stud, Cast-in-Place Concrete

Steel stud, Steel Web Joists, and Concrete

EMTC Facade, Point-supported CLT, and Concrete

1.24. EVALUATING EMTC FOR RESIDENTIAL BUILDINGS – EMTC PRELIMINARY SEQUENCE SCHEDULE

In general, a CLT panel system and its simple column-to-panel connections can be installed faster than a concrete flat slab system, which decreases its construction cost considerably. Maximization of panel sizes, such as using wide format panels and the longest lengths feasible, further optimize the construction schedule, due to less crane time and picks when larger and fewer panels are used. Since CLT panels do not require curing time, a CLT floor does not require supporting temporary shoring to stay in place until a minimum compressive strength is developed within the slab. More so, if supplementary cementitious materials (SCM's) are used within the concrete mix to decrease environmental impact. Preparation for floor install is also minimized with CLT, as no reinforcing bars are required to be tied on site, and any screw reinforcing that may be required is typically done within the manufacturing shop.

Steel stud bearing wall systems are also limited in construction schedule due to the floor build-up. While bearing walls can be prefabricated in distinct lengths on ground or in the shop, the OWSJ's must be installed piece by piece or as assembled cassettes. The concrete on metal decking must also cure before the next floor is erected. However, if paired with a steel concentrically braced frame lateral resisting system, speed of construction may be increased when compared to a concrete shear wall lateral resisting system.

EMTC projects benefit from the practice of a digital twin fabrication process during the shop drawing phase. Therefore, an effective construction schedule can be established prior to project tender which includes the sequence of activities and associated durations and resources needed to complete the tasks, especially when there is a high level of sequencing overlap with both structure and facade. Overall project schedule requirements (dates of completion) are typically established by the building owner and then managed by the GC/CM. The specialty subcontractors then use the master schedule to determine their schedule requirements. A project schedule is a collaborative effort between the GM/CM and specialty contractors which reinforces the need for early procurement. Creating a comprehensive schedule and maintaining communication between all parties is vital for EMTC project success. The mass timber subcontractor or self-performing GC/ CM needs to identify all required activities, key milestones and constraints, and to communicate clearly with the owner and/ or consultants to ensure alignment with other aspects of the project.

Using mass timber requires extensive decision making during the preconstruction process to avoid delays on site. Shifting the preplanning, coordination and decision making to an earlier stage in the project does not necessarily increase the fees associated with design and preconstruction; it just shifts the timing of the fees within the overall project schedule. When properly executed, the delivery of the mass timber superstructure is accelerated and allows for compression of subsequent follow-on activities further decreasing the critical path of the schedule. These are advantages owners and developers can leverage. Having a clear plan of the full project spectrum prior to complete tender of the rest of the building/ project can reduce risk of scope creep, change orders for incomplete design or coordination, cost escalation. It can also limit mitigation costs whether they are derived from financing or insurance requirements.

Construction scheduling requires allocating adequate time for shop drawing creation, review and approvals. During the shop drawing phase, dimensional errors and constructability issues are often discovered within the digital twin through clash detection processes with other BIM workflows, prompting additional collaboration between stakeholders. It is more cost effective to resolve these issues before construction than to discover them in the field. The GC/CM, mass timber fabricator, mass timber installer and specialty subcontractors establish and coordinate sequencing installation of the buildings structural frame and prefabricated facade. To provide an accurate and meaningful schedule, it is important to have all the necessary information and data coordinated with the digital twin model and planning. If information and data are missing, misunderstood or incomplete, the schedule and sequencing will require later revisions, which may adversely affect the mass timber installation.

Construction sequence planning has been studied for the three regional EMTC buildings and a Method Statement of Work description is provided for the context. It is important that municipal authorities are aware of the potential sequencing schedule and performance on the project site while mass timber is installed. This will allow them to understand the risks for fire and egress planning and the logistics for emergency vehicles, traffic, public transit, and pedestrians.

Erection of Timber start: L2 Columns for Slab and L Towers, L3 columns for the Point Tower:

Preparation

- Receive offset gridlines at L2 slab provided by others
- Receive confirmation that pedestals anchor bolts are in the correct locations, correct orientation and are square
- Receive benchmark elevation for underside of L2 column pedestal
- Receive columns pedestals at L2 slab c/w packing slip to identify correct locations
- Receive bundle wrapped columns at L2 slab

Execution

- Install leveling nuts to receive column pedestals under supervision of surveyor
- Install column pedestals and secure in place ready to receive grout
- Grout is installed
- Install glulam columns to tops of column pedestals using tower crane
- Sequence of installation is from pre-determined starting corner, installing panels to lock in at concrete cores first
- Make up column bundles for prescribed locations as per proposed column installation sequence plan
- Plumb and line columns using offset gridlines, vertical line laser and line laser making adjustments as may be necessary to bring back to grid

Safety Procedures

- Provide written site-specific safe work procedures
- Ensure that perimeter guardrails at L2 slab are continuous and secure
- Ensure any openings in L2 slab are covered and secured
- Use Worksafe BC approved rolling ladders to access tops of columns for installation, plumbing and lining. Use fall arrest when on rolling ladders at edge or install upper guardrail
- Use fall arrest if required with anchor points into L2 slab to be determined

Quality Control

- Receive confirmation by others that pedestal anchor bolts are in the right location, orientation and are square
- Using gridlines provided by others double check that they are and if necessary, make adjustments as required to get pedestal bases located to within tolerances allowed
- Receive benchmark provided by others to set underside of column pedestal to required datum. Use surveyor to help set leveling nuts
- Coordinate gridlines provided by others and with the assistance of surveyor use vertical and horizontal line lasers to plumb and line columns
- Provide written documentation that work has been completed per specifications in the form of QA/QC logs as outlined in Project Specifications

<u>Installation of Typical CLT Panels:</u>

Preparation

- Receive typical floor panels on trucks loaded as required to suit installation sequence
- Receive packing list that clearly identifies the individual panels, their location and orientation
- Submit an engineered bracing plan completed by Secondary Structural Engineers
- Submit an engineered stitching plan showing certain splines being progressively installed in conjunction with panel installations in order to provide a laterally stable active deck
- Submit an engineered lifting plan for CLT lifts
- Submit engineering for lifting plates
- Provide a “prior to landing” inspection checklist to ensure bracing requirements are in place

Execution

- Install lifting plate lifting devices to CLT panels at locations provided for
- Crane lift panels using 4 lifting plates and 4 chains rigged so that first touch side is a bit lower than the last touch side
- Install tag lines
- Install D Ring for fall arrest anchor nailed to the top of the perimeter panel
- Receive CLT Panel # 1 at location with 2 workers on rolling step ladders at first touch side and 2 workers at last touch side guiding panel so that it lands in the exact position with the 25mm holes in the CLT panels centred on the 16mm threaded rods at the column caps
- Use extension ladder properly secured top and bottom to allow worker access to Panel # 1 to disconnect chains and remove lifting plates
- Repeat sequence for Panel # 2
- Once Panel # 2 is installed one worker is to begin installation of SDS screws to Core L’s
- Repeat sequence for Panel # 3
- Once Panel # 3 is in place and secured to core stair access to active floor is possible and one more worker to join first worker on top to assist with lining up and landing the CLT panels, disconnecting the chains, removing, and cycling down the lifting plates
- Sequence is repeated until all panels are in place with 2 workers on top, 4 workers below on roiling ladders and 1 below on rolling ladder installing SDS screws at Core steel L angle’s
- Install steel washers and nuts and tighten per specifications

Safety Procedures

- Submit an engineered bracing plan
- Submit an engineered lifting plan
- Submit engineering for lifting plates
- Provide a “prior to landing” inspection checklist
- Provide written site-specific safe work procedures
- Use rolling ladders with a platform at 45” for workers’ use to land CLT panels
- Use D-ring nail in anchors for anchor points for workers above
- Install D ring anchors on perimeter Panels
- Workers above to use fall arrest using retractable lanyards

Quality Control

- Placement of panels is EXTREMLY critical with only 3mm theoretical gaps between panels in both length and width
- Any slight deviation in length or width of panels, out of squareness, swelling or creeping will mean that the panels will not fit without cutting or reaming of the holes
- Maintain extreme accuracy in the plumbing, lining, griding and squaring of the tops of the columns prior to landing the panels
- Cutting of panels will not be done without written authorization from Engineer of Record (EOR)
- Reaming of placement holes may be performed with requiring written authorization from Engineer of Record (EOR)
- Provide written documentation that work has been completed per specifications in the form of QA/QC logs as outlined in Project Specifications

<u>Installation of Splines:</u>

Preparation

- Install perimeter guardrails
- Receive splines provided
- Provide electrical cords, air lines if applicable to active floor for installation of spline fasteners
- Submit an engineered stitching plan showing certain splines being progressively installed in conjunction with panel installations in order to provide a laterally stable active deck

Execution

Install splines using approved fasteners as acceptable to speed up the installations and provide a laterally stable deck as quickly as possible.

Safety Procedures

- Provide written site-specific safe work procedures
- It will be necessary to begin installing splines on Day 1 and in advance of the perimeter guardrails being in place
- Workers will need to use fall arrest or fall restraint using either the D ring nail in anchors on perimeter panels or a horizontal lifeline running the length of the building between gridlines
- Once the perimeter guardrails are in place fall arrest will not be required
- Quality Control
- Follow the Structural drawings regarding spacing of spline fasteners
- Provide written documentation that work has been completed per specifications in the form of QA/QC logs as outlined in Project Specifications

<u>Installation of Drag Struts:</u>

Preparation

- All perimeter guardrails are in place
- Receive Drag Struts c/w packing slips to identify floor and location and bundled according to predetermined weights and locations
- Land column bundles on CLT panels after panels have been secured from below to the core L’s and after splines are in place
- Land bundles on dunnage and at locations as approved per engineered bracing plan

Execution

- Spread drag struts to their positions, fix to core brackets installed
- Install SDS screws to fasten drag struts to CLT panels

Safety Procedures

- Provide written site-specific safe work procedures
- Determine weights of individual pieces and develop means and methods to ensure safety of workers
- Perimeter guardrails are to be in place prior to work beginning

Quality Control

- Install per structural drawings
- Provide written documentation that work has been completed per specifications in the form of QA/QC logs as outlined in Project Specifications

Installation of Perimeter Steel L:

Preparation

- Receive perimeter L's c/w shop drawings and packing list identifying pieces as to their location and bundled according to predetermined weights and locations
- Land steel bundles on CLT panels after panels have been secured from below to the core L's and after splines are in place
- Land bundles on dunnage and at locations as approved per engineered bracing plan
- Receive gridline offsets provided surveyor

Execution

- Remove perimeter guardrails as required and use fall restraint
- Move steel L's into position using specially equipped pallet jacks
- Place in exact positions according to shop drawings provided both in/out and right/left and secure with SDS screws as per Structural drawings
- Reinstall guardrails

Safety Procedures

- Provide written site specific safe work procedures
- Determine weights of individual pieces and develop means and methods to ensure safety of workers
- Use specially equipped pallet jacks to move pieces into position
- When perimeter guardrails are removed use fall restraint.

Quality Control

- Place L's in exact location plus minus 3mm in/out right/left
- Install screws per structural drawings
- Provide written documentation that work has been completed per specifications in the form of QA/QC logs as outlined in Project Specifications

Repeat Erection of Additional Floors:

Preparation

- Receive offset gridlines
- Receive benchmark elevation
- Receive wrapped columns

Execution

- Survey tops of steel tubes at each floor and adjust up to theoretical design elevation (pulled from Architectural drawings) Install steel shims provided to tops of column tubes to achieve required datum.
- Columns and hence CLT slabs will not be set higher to allow for axial shortening
- Install columns – smaller upper column into larger lower column
- Sequence of CLT slab installation is from pre-determined starting corner, installing panels to lock in at concrete cores first
- Coordination with curtain wall contractor to follow sequence of installation in a pre-determined direction/ order around the perimeter of the building
- Make up column bundle and locations per proposed column installation sequence plan
- Install diagonal braces and spreaders per engineer approved bracing plan
- Plumb and line glulam columns using offset gridlines, vertical line laser and line laser adjusting as may be necessary to bring back to grid
- Install bolt and cotter pin to bottom tube connection

Safety Procedures

- Provide written site-specific safe work procedures
- Ensure that perimeter guardrails are continuous and secure
- Ensure any openings in slab are covered and secured
- Use Worksafe BC approved rolling ladders to access tops of columns for installation, plumbing and lining. Use fall arrest when on rolling ladders at edge or install upper guardrail

Quality Control

- Ensure that columns are plumb and/or on grid
- Provide written documentation that work has been completed per specifications in the form of QA/QC logs as outlined in Specification Comparison of Onsite Construction Schedules

Regional Archetype Identification and Comparison

The intent of this study is to underline the advantages and disadvantages for using mass timber in the three building archetypes that are typical of developments in B.C., compared to other construction types. Each building archetype is specific to one of three regions of British Columbia, including the City of Vancouver, City of Coquitlam, or any Metro Vancouver municipality, and the City of Kamloops or any Interior municipality. All building archetypes were considered as high-rise construction of up to 12-storeys with below-grade parking levels. Given each building archetype's unique location, the corresponding lateral systems are also designed to unique climatic data, such as seismic and wind loads, which further help to highlight the economic benefits of mass timber across British Columbia.

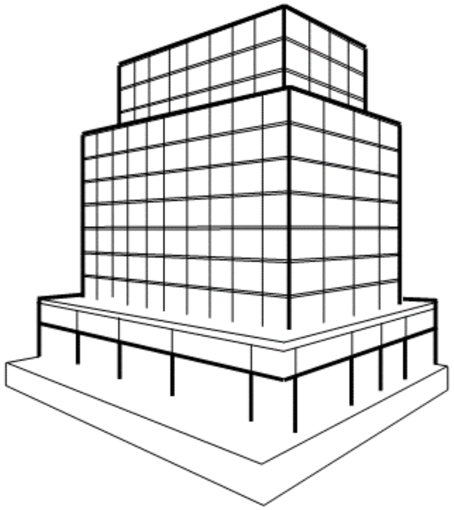
The material commonly used for high-rise construction is concrete and the structure is typically flat slab construction, for its ability to accommodate larger spans and flexible layouts, and to allow unobstructed head room. This all results in compact floor-to-floor dimensions. Concrete construction allows for taller buildings, although construction schedules are limited by the required cure time that is typical for concrete. Obstructive shoring does not shoring does not allow for construction work below the levels that are still curing.

Another system that is gaining popularity amongst mid-rise construction, is the steel stud bearing wall system, which takes advantage of using all demising and in-suite partition walls as bearing support for a steel open web joist floor system. While the full floor system is deeper than a typical concrete flat slab system, the open web steel joists allow for services to pass through, therefore eliminating the need for an added drop ceiling. However, this system does not allow for maximum flexibility in floor layout and change in layout from one floor to the one below or above requires addition of a transfer beam system. This can slow down the construction schedule and adds more pieces to a system that already requires multiple-piece installation.

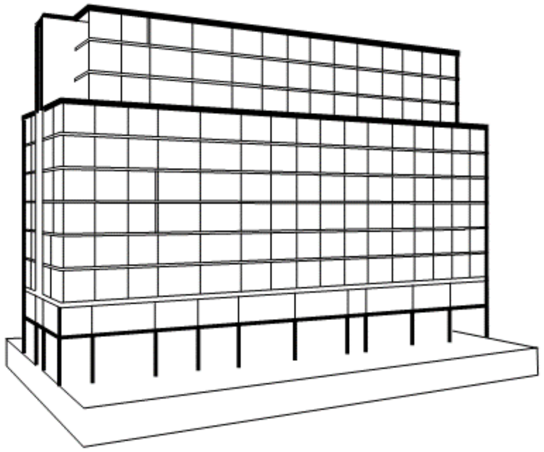
The latest advancements in mass timber technology and landmark projects such as the Brock Commons Tallwood House at the University of British Columbia in Vancouver are making the case for tall mass timber in mid-rise 7- to 12-storey construction, using flat, two-way spanning cross-laminated timber (CLT), point-supported systems. The CLT panels are supported by steel or timber columns with no beams, and this allows for unobstructed head space, minimizing penetrations for service runs through structural members. The panelized configuration, simple column-to-panel connections, and no required curing time also result in an accelerated construction schedule compared to concrete construction.

For each of the three building archetypes being considered, a CLT point-supported system will be compared against a concrete flat slab construction and a steel option that uses a steel stud bearing wall system. All three schemes utilize a concrete shear wall system, using a permanent concrete forming system to ease constructability constraint, such as jump-forming.

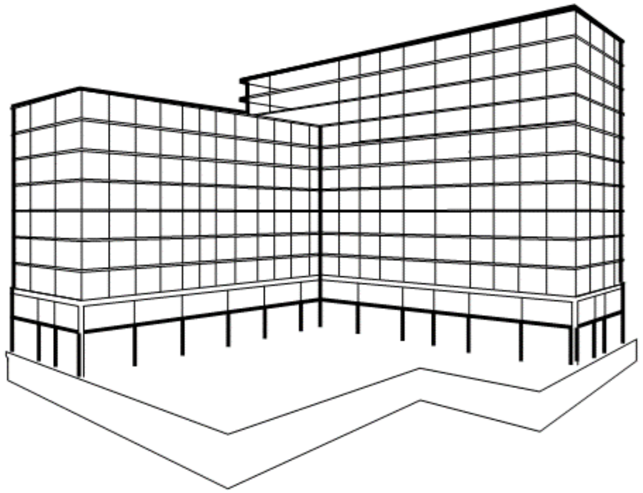
The costing specific to the building enclosure is similar across the three regional buildings. The costing of the three structure types provides an understanding of the potential exterior wall thermal performance advantages and disadvantages at equal cost. Roof and window performance variables were kept constant across all of the scenarios. For exterior walls, the EMTC case is a hung wall structure vs sill bearing wall structures for both the concrete and steel buildings. The cost of various assembly layers applicable to each wall structure type is considerably different but, overall, each wall structure type shares the same cladding and an equal supply and installation budget for comparison with other, more significant attributes discussed in this report.



Point Tower - City of Vancouver

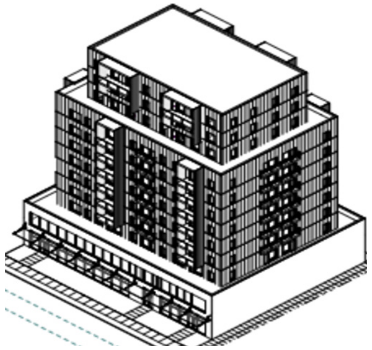


Slab Tower - City of Kamloops



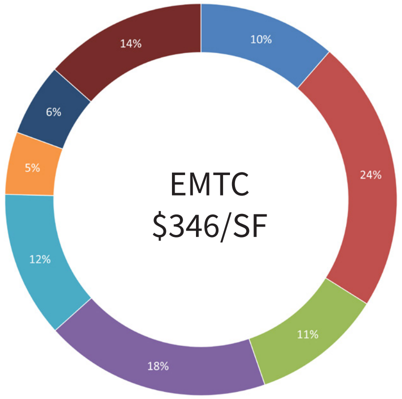
L Tower - City of Coquitlam

1.25. POINT TOWER – CITY OF VANCOUVER GFA AND ELEMENT COST BREAKDOWN (%)

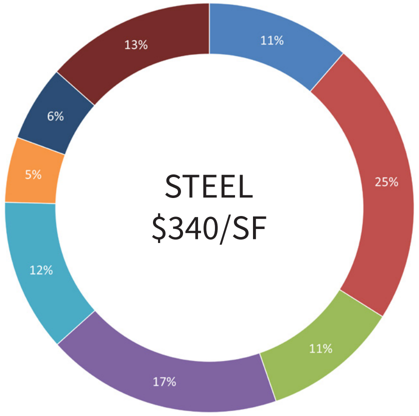


The Point Tower is a typical BC Housing tower that might occur within a dense urban area, such as the City of Vancouver. The Point Tower consists of 12-storeys over 3 levels of a below grade parkade. There are offsets in the building outline at the Level 1 or ground level again at Level 10. In plan, the Point Tower is nearly square in dimension, which is reflective of a compact building site that is commonly seen in dense urban areas. The Point Tower consists of a central lateral-resisting core that serves as vertical circulation for access and services and continues to the lowest level of parkade. The lateral-resisting system is designed as a ductile system, corresponding to the local climatic data. The gravity system then radiates from this central core and will be further evaluated under the sections for each scheme.

	Existing	Proposed
Lot Width	-	130'-0
Lot Depth	-	120'-0
Lot Area	-	15,600 SF
Height	-	12 Storeys
Zoning	RM-4	CD-1
FAR	2.5	6.8
Setback (front)	20'-0	14'-0
Setback (side)	6.8'-0	13'-0
Setback (rear)	33.1'-0	12'-0
Stepback (front)	20'-0 @ 40'-0	24'-0 @ 30'-0
	-	34'-0 @ 70'-0
Stepback (side)		22'-0 @ 30'-0
		30'-0 @ 70'-0
Lot Coverage	n/a	68%



Description	sqft
L1 to L2	24,670
L3 to L9	57,791
L10 to L12	14,628
Gross Floor Area (Point Tower) - Above Grade	97,090
Basement Parking (3 Levels)	28,847
Total Gross Floor Area (Point Tower)	**125,937**



GENERAL CONDITIONS AND REQUIREMENTS
STRUCTURE
ENCLOSURE
INTERIORS
MECHANICAL
ELECTRICAL
FOUNDATION
CONTINGENCY/ OTHER

1.26. EMTC POINT TOWER VS. CONCRETE MARKET COMPARISON COST REFERENCE

ELEMENT				UNDERGROUND PARKADE (2 Levels)						LEVEL 1 - 9 (9 levels + Roof + Site)					
				A. MASS TIMBER		B. CONCRETE		VARIANCE (A-B)		A. MASS TIMBER		B. CONCRETE		VARIANCE (A-B)	
				GFA	2,680 m2	GFA	2,680 m2			GFA	7,661 m2	GFA	7,661 m2		
				Total ($)	($/m2)	Total ($)	($/m2)	Total ($)	Percent	Total ($)	($/m2)	Total ($)	($/m2)	Total ($)	Percent
A	SHELL			4,984,300	1,859.81	5,384,800	2,009.25	(400,500)	-8.04%	10,961,600	1,430.83	10,556,100	1,377.90	405,500	3.70%
A1	SUBSTRUCTURE			2,369,800	884.25	2,576,100	961.23	(206,300)	-8.71%	0	0.00	0	0.00	0	0.00%
	A11 Foundations			782,900	292.13	931,200	347.46	(148,300)	-18.94%	0	0.00	0	0.00	0	0.00%
	A12 Basement Excavation			1,346,900	502.57	1,394,900	520.49	(48,000)	-3.56%	0	0.00	0	0.00	0	0.00%
	A11 Special Conditions			240,000	89.55	250,000	93.28	(10,000)	-4.17%	0	0.00	0	0.00	0	0.00%
A2	STRUCTURE			1,869,500	697.57	2,063,700	770.04	(194,200)	-10.39%	7,428,600	969.66	7,023,100	916.73	405,500	5.46%
	A21 Lowest Floor Construction			79,900	29.81	79,900	29.81	0	0.00%	0	0.00	0	0.00	0	0.00%
	A22 Upper Floor Construction			1,669,400	622.91	1,863,600	695.37	(194,200)	-11.63%	6,267,200	818.07	6,025,600	786.53	241,600	3.85%
	A23 Roof Construction			120,200	44.85	120,200	44.85	0	0.00%	1,161,400	151.60	997,500	130.20	163,900	0.00%
A3	EXTERIOR ENCLOSURE			745,000	277.99	745,000	277.99	0	0.00%	3,533,000	461.17	3,533,000	461.17	0	0.00%
	A31 Walls Below Grade			698,400	260.60	698,400	260.60	0	0.00%	0	0.00	0	0.00	0	0.00%
	A32 Walls Above Grade			0	0.00	0	0.00	0	0.00%	1,816,100	237.06	1,816,100	237.06	0	0.00%
	A33 Windows & Entrances			0	0.00	0	0.00	0	0.00%	582,000	75.97	582,000	75.97	0	0.00%
	A34 Roof Covering			46,600	17.39	46,600	17.39	0	0.00%	345,800	45.14	345,800	45.14	0	0.00%
	A35 Projections			0	0.00	0	0.00	0	0.00%	789,100	103.00	789,100	103.00	0	0.00%
B	INTERIORS			694,600	259.18	694,600	259.18	0	0.00%	5,916,600	772.30	5,916,600	772.30	0	0.00%
B1	PARTITIONS & DOORS			200,000	74.63	200,000	74.63	0	0.00%	2,511,400	327.82	2,511,400	327.82	0	0.00%
	B11 Partitions			172,800	64.48	172,800	64.48	0	0.00%	1,813,800	236.76	1,813,800	236.76	0	0.00%
	B12 Doors			27,200	10.15	27,200	10.15	0	0.00%	697,600	91.06	697,600	91.06	0	0.00%
B2	INTERIOR FINISHES			198,600	74.10	198,600	74.10	0	0.00%	1,589,200	207.44	1,589,200	207.44	0	0.00%
	B21 Floor Finishes			75,900	28.32	75,900	28.32	0	0.00%	567,100	74.02	567,100	74.02	0	0.00%
	B22 Ceiling Finishes			66,400	24.78	66,400	24.78	0	0.00%	477,800	62.37	477,800	62.37	0	0.00%
	B23 Wall Finishes			56,300	21.01	56,300	21.01	0	0.00%	544,300	71.05	544,300	71.05	0	0.00%
B3	FITTINGS & EQUIPMENT			296,000	110.45	296,000	110.45	0	0.00%	1,816,000	237.04	1,816,000	237.04	0	0.00%
	B31 Fittings & Fixtures			86,000	32.09	86,000	32.09	0	0.00%	746,100	97.39	746,100	97.39	0	0.00%
	B32 Equipment			60,000	22.39	60,000	22.39	0	0.00%	390,400	50.96	390,400	50.96	0	0.00%
	B33 Elevators			150,000	55.97	150,000	55.97	0	0.00%	679,500	88.70	679,500	88.70	0	0.00%
C	SERVICES			453,900	169.37	453,900	169.37	0	0.00%	6,008,200	784.26	6,008,200	784.26	0	0.00%
C1	MECHANICAL			295,200	110.15	295,200	110.15	0	0.00%	4,189,300	546.83	4,189,300	546.83	0	0.00%
	C11 Plumbing & Drainage			101,200	37.76	101,200	37.76	0	0.00%	1,158,800	151.26	1,158,800	151.26	0	0.00%
	C12 Fire Protection			85,200	31.79	85,200	31.79	0	0.00%	383,000	49.99	383,000	49.99	0	0.00%
	C13 HVAC			88,400	32.99	88,400	32.99	0	0.00%	2,341,100	305.59	2,341,100	305.59	0	0.00%
	C14 Controls			20,400	7.61	20,400	7.61	0	0.00%	306,400	39.99	306,400	39.99	0	0.00%
C2	ELECTRICAL			158,700	59.22	158,700	59.22	0	0.00%	1,818,900	237.42	1,818,900	237.42	0	0.00%
	C21 Service and Distribution			56,700	21.16	56,700	21.16	0	0.00%	569,800	74.38	569,800	74.38	0	0.00%
	C22 Lighting, Devices and Heating			67,000	25.00	67,000	25.00	0	0.00%	845,900	110.42	845,900	110.42	0	0.00%
	C23 Systems and Ancillaries			35,000	13.06	35,000	13.06	0	0.00%	403,200	52.63	403,200	52.63	0	0.00%
NET BUILDING COST - EXCLUDING SITE				6,132,800	2,288.36	6,533,300	2,437.80	(400,500)	-6.53%	22,886,400	2,987.39	22,480,900	2,934.46	405,500	1.77%
D	SITE & ANCILLARY WORK			0	0.00	0	0.00	0	0.00%	475,600	62.08	475,600	62.08	0	0.00%
D1	SITE WORK			0	0.00	0	0.00	0	0.00%	475,600	62.08	475,600	62.08	0	0.00%
	D11 Site Development			0	0.00	0	0.00	0	0.00%	75,400	9.84	75,400	9.84	0	0.00%
	D12 Mechanical Site Services			0	0.00	0	0.00	0	0.00%	236,000	30.81	236,000	30.81	0	0.00%
	D13 Electrical Site Services			0	0.00	0	0.00	0	0.00%	164,200	21.43	164,200	21.43	0	0.00%
D2	ANCILLARY WORK			0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%
	D21 Demolition			0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%
	D22 Alterations			0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%
NET BUILDING COST - INCLUDING SITE				6,132,800	2,288.36	$6,533,300	2,437.80	(400,500)	-6.53%	23,362,000	3,049.47	$22,956,500	2,996.54	405,500	1.74%
Z	GENERAL REQ'S & ALLOWANCES			1,892,800	706.27	2,187,300	816.16	-294,500	-15.56%	7,209,800	941.10	7,686,300	1,003.30	-476,500	-6.61%
Z1	GENERAL REQUIREMENTS & FEE	M. Timber	Concrete	815,700	304.37	1,017,000	379.48	(201,300)	-24.68%	3,107,100	405.57	3,574,000	466.52	(466,900)	-15.03%
	Z10 Location Factor	0.00%	0.00%	0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%
	Z11 General Requirements	10.00%	12.20%	613,300	228.84	797,100	297.43	(183,800)	-29.97%	2,336,200	304.95	2,801,300	365.66	(465,100)	-19.91%
	Z12 Fee	3.00%	3.00%	202,400	75.52	219,900	82.05	(17,500)	-8.65%	770,900	100.63	772,700	100.86	(1,800)	-0.23%
TOTAL CONSTRUCTION ESTIMATE - EXCLUDING CONTINGENCIES				6,948,500	2,592.72	7,550,300	2,817.28	-601,800	-8.66%	26,469,100	3,455.05	26,530,500	3,463.06	-61,400	-0.23%
Z2	ALLOWANCES			1,077,100	401.90	1,170,300	436.68	(93,200)	-8.65%	4,102,700	535.53	4,112,300	536.78	(9,600)	-0.23%
	Z21 Design & Pricing Allowance	10.00%	10.00%	694,900	259.29	755,000	281.72	(60,100)	-8.65%	2,646,900	345.50	2,653,100	346.31	(6,200)	-0.23%
	Z22 Escalation Allowance	0.00%	0.00%	0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%
	Z23 Construction Allowance	5.00%	5.00%	382,200	142.61	415,300	154.96	(33,100)	-8.66%	1,455,800	190.03	1,459,200	190.47	(3,400)	-0.23%
TOTAL CONSTRUCTION ESTIMATE - INCLUDING CONTINGENCIES				8,025,600	2,994.63	8,720,600	3,253.96	-695,000	-8.66%	30,571,800	3,990.58	30,642,800	3,999.84	-71,000	-0.23%
GOODS & SERVICES TAX				0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
TOTAL CONSTRUCTION ESTIMATE				$8,025,600	2,994.63	$8,720,600	3,253.96	-$695,000	-8.66%	$30,571,800	3,990.58	$30,642,800	3,999.84	-$71,000	-0.23%

LEVEL 10 - 12 (additional 3 levels)						TOTAL (12 levels)						OVERALL CONSTRUCTION COST					
A. MASS TIMBER		B. CONCRETE		VARIANCE (A-B)		A. MASS TIMBER		B. CONCRETE		VARIANCE (A-B)		A. MASS TIMBER		B. CONCRETE		VARIANCE (A-B)	
GFA	1,359 m2	GFA	1,359 m2			GFA	9,020 m2	GFA	9,020 m2			GFA	11,700 m2	GFA	11,700 m2		
Total ($)	($/m2)	Total ($)	($/m2)	Total ($)	Percent	Total ($)	($/m2)	Total ($)	($/m2)	Total ($)	Percent	Total ($)	($/m2)	Total ($)	($/m2)	Total ($)	Percent
1,677,200	1,234.14	1,634,300	1,202.58	42,900	2.56%	12,638,800	1,401.20	12,190,400	1,351.49	448,400	3.55%	17,623,100	1,506.25	17,575,200	1,502.15	47,900	0.27%
0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%	2,369,800	202.55	2,576,100	220.18	(206,300)	-8.71%
0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%	782,900	66.91	931,200	79.59	(148,300)	-18.94%
0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%	1,346,900	115.12	1,394,900	119.22	(48,000)	-3.56%
0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%	240,000	20.51	250,000	21.37	(10,000)	-4.17%
1,111,800	818.10	1,068,900	786.53	42,900	3.86%	8,540,400	946.83	8,092,000	897.12	448,400	5.25%	10,409,900	889.74	10,155,700	868.01	254,200	2.44%
0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%	79,900	6.83	79,900	6.83	0	0.00%
1,111,800	818.10	1,068,900	786.53	42,900	3.86%	7,379,000	818.07	7,094,500	786.53	284,500	3.86%	9,048,400	773.37	8,958,100	765.65	90,300	1.00%
0	0.00	0	0.00	0	0.00%	1,161,400	128.76	997,500	110.59	163,900	14.11%	1,281,600	109.54	1,117,700	95.53	163,900	12.79%
565,400	416.04	565,400	416.04	0	0.00%	4,098,400	454.37	4,098,400	454.37	0	0.00%	4,843,400	413.97	4,843,400	413.97	0	0.00%
0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%	698,400	59.69	698,400	59.69	0	0.00%
322,200	237.09	322,200	237.09	0	0.00%	2,138,300	237.06	2,138,300	237.06	0	0.00%	2,138,300	182.76	2,138,300	182.76	0	0.00%
103,200	75.94	103,200	75.94	0	0.00%	685,200	75.96	685,200	75.96	0	0.00%	685,200	58.56	685,200	58.56	0	0.00%
0	0.00	0	0.00	0	0.00%	345,800	38.34	345,800	38.34	0	0.00%	392,400	33.54	392,400	33.54	0	0.00%
140,000	103.02	140,000	103.02	0	0.00%	929,100	103.00	929,100	103.00	0	0.00%	929,100	79.41	929,100	79.41	0	0.00%
1,049,500	772.26	1,049,500	772.26	0	0.00%	6,966,100	772.29	6,966,100	772.29	0	0.00%	7,660,700	654.76	7,660,700	654.76	0	0.00%
445,500	327.81	445,500	327.81	0	0.00%	2,956,900	327.82	2,956,900	327.82	0	0.00%	3,156,900	269.82	3,156,900	269.82	0	0.00%
321,700	236.72	321,700	236.72	0	0.00%	2,135,500	236.75	2,135,500	236.75	0	0.00%	2,308,300	197.29	2,308,300	197.29	0	0.00%
123,800	91.10	123,800	91.10	0	0.00%	821,400	91.06	821,400	91.06	0	0.00%	848,600	72.53	848,600	72.53	0	0.00%
282,000	207.51	282,000	207.51	0	0.00%	1,871,200	207.45	1,871,200	207.45	0	0.00%	2,069,800	176.91	2,069,800	176.91	0	0.00%
100,600	74.03	100,600	74.03	0	0.00%	667,700	74.02	667,700	74.02	0	0.00%	743,600	63.56	743,600	63.56	0	0.00%
84,800	62.40	84,800	62.40	0	0.00%	562,600	62.37	562,600	62.37	0	0.00%	629,000	53.76	629,000	53.76	0	0.00%
96,600	71.08	96,600	71.08	0	0.00%	640,900	71.05	640,900	71.05	0	0.00%	697,200	59.59	697,200	59.59	0	0.00%
322,000	236.94	322,000	236.94	0	0.00%	2,138,000	237.03	2,138,000	237.03	0	0.00%	2,434,000	208.03	2,434,000	208.03	0	0.00%
132,300	97.35	132,300	97.35	0	0.00%	878,400	97.38	878,400	97.38	0	0.00%	964,400	82.43	964,400	82.43	0	0.00%
69,200	50.92	69,200	50.92	0	0.00%	459,600	50.95	459,600	50.95	0	0.00%	519,600	44.41	519,600	44.41	0	0.00%
120,500	88.67	120,500	88.67	0	0.00%	800,000	88.69	800,000	88.69	0	0.00%	950,000	81.20	950,000	81.20	0	0.00%
1,065,900	784.33	1,065,900	784.33	0	0.00%	7,074,100	784.27	7,074,100	784.27	0	0.00%	7,528,000	643.42	7,528,000	643.42	0	0.00%
743,200	546.87	743,200	546.87	0	0.00%	4,932,500	546.84	4,932,500	546.84	0	0.00%	5,227,700	446.81	5,227,700	446.81	0	0.00%
205,600	151.29	205,600	151.29	0	0.00%	1,364,400	151.26	1,364,400	151.26	0	0.00%	1,465,600	125.26	1,465,600	125.26	0	0.00%
67,900	49.96	67,900	49.96	0	0.00%	450,900	49.99	450,900	49.99	0	0.00%	536,100	45.82	536,100	45.82	0	0.00%
415,300	305.59	415,300	305.59	0	0.00%	2,756,400	305.59	2,756,400	305.59	0	0.00%	2,844,800	243.15	2,844,800	243.15	0	0.00%
54,400	40.03	54,400	40.03	0	0.00%	360,800	40.00	360,800	40.00	0	0.00%	381,200	32.58	381,200	32.58	0	0.00%
322,700	237.45	322,700	237.45	0	0.00%	2,141,600	237.43	2,141,600	237.43	0	0.00%	2,300,300	196.61	2,300,300	196.61	0	0.00%
101,100	74.39	101,100	74.39	0	0.00%	670,900	74.38	670,900	74.38	0	0.00%	727,600	62.19	727,600	62.19	0	0.00%
150,100	110.45	150,100	110.45	0	0.00%	996,000	110.42	996,000	110.42	0	0.00%	1,063,000	90.85	1,063,000	90.85	0	0.00%
71,500	52.61	71,500	52.61	0	0.00%	474,700	52.63	474,700	52.63	0	0.00%	509,700	43.56	509,700	43.56	0	0.00%
3,792,600	2,790.73	3,749,700	2,759.16	42,900	1.13%	26,679,000	2,957.76	26,230,600	2,908.05	448,400	1.68%	32,811,800	2,804.43	32,763,900	2,800.33	47,900	0.15%
0	0.00	0	0.00	0	0.00%	475,600	52.73	475,600	52.73	0	0.00%	475,600	40.65	475,600	40.65	0	0.00%
0	0.00	0	0.00	0	0.00%	475,600	52.73	475,600	52.73	0	0.00%	475,600	40.65	475,600	40.65	0	0.00%
0	0.00	0	0.00	0	0.00%	75,400	8.36	75,400	8.36	0	0.00%	75,400	6.44	75,400	6.44	0	0.00%
0	0.00	0	0.00	0	0.00%	236,000	26.16	236,000	26.16	0	0.00%	236,000	20.17	236,000	20.17	0	0.00%
0	0.00	0	0.00	0	0.00%	164,200	18.20	164,200	18.20	0	0.00%	164,200	14.03	164,200	14.03	0	0.00%
0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%
0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%
0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%
3,792,600	2,790.73	$3,749,700	2,759.16	42,900	1.13%	27,154,600	3,010.49	$26,706,200	2,960.78	448,400	1.65%	33,287,400	2,845.08	$33,239,500	2,840.98	47,900	0.14%
1,170,500	861.30	1,255,400	923.77	-84,900	-7.25%	8,380,300	929.08	8,941,700	991.32	-561,400	-6.70%	10,273,100	878.04	11,129,000	951.20	-855,900	-8.33%
504,500	371.23	583,800	429.58	(79,300)	-15.72%	3,611,600	400.40	4,157,800	460.95	(546,200)	-15.12%	4,427,300	378.40	5,174,800	442.29	(747,500)	-16.88%
0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%
379,300	279.10	457,500	336.64	(78,200)	-20.62%	2,715,500	301.05	3,258,800	361.29	(543,300)	-20.01%	3,328,800	284.51	4,055,900	346.66	(727,100)	-21.84%
125,200	92.13	126,300	92.94	(1,100)	-0.88%	896,100	99.35	899,000	99.67	(2,900)	-0.32%	1,098,500	93.89	1,118,900	95.63	(20,400)	-1.86%
4,297,100	3,161.96	4,333,500	3,188.74	-36,400	-0.85%	30,766,200	3,410.89	30,864,000	3,421.73	-97,800	-0.32%	37,714,700	3,223.48	38,414,300	3,283.27	-699,600	-1.85%
666,000	490.07	671,600	494.19	(5,600)	-0.84%	4,768,700	528.68	4,783,900	530.37	(15,200)	-0.32%	5,845,800	499.64	5,954,200	508.91	(108,400)	-1.85%
429,700	316.19	433,300	318.84	(3,600)	-0.84%	3,076,600	341.09	3,086,400	342.17	(9,800)	-0.32%	3,771,500	322.35	3,841,400	328.32	(69,900)	-1.85%
0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%
236,300	173.88	238,300	175.35	(2,000)	-0.85%	1,692,100	187.59	1,697,500	188.19	(5,400)	-0.32%	2,074,300	177.29	2,112,800	180.58	(38,500)	-1.86%
4,963,100	3,652.02	5,005,100	3,682.93	-42,000	-0.85%	35,534,900	3,939.57	35,647,900	3,952.10	-113,000	-0.32%	43,560,500	3,723.12	44,368,500	3,792.18	-808,000	-1.85%
0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
$4,963,100	3,652.02	$5,005,100	3,682.93	-$42,000	-0.85%	$35,534,900	3,939.57	$35,647,900	3,952.10	-$113,000	-0.32%	$43,560,500	3,723.12	$44,368,500	3,792.18	-$808,000	-1.85%

1.27. EMTC POINT TOWER – CITY OF VANCOUVER ENERGY PERFORMANCE MAP

The energy modelling analysis was based on a fixed massing (VFAR=0.44) per architectural drawings. Likewise, the suite mix (corresponding to ~0.5 L/s/m^2 suite area based on central ventilation systems) and occupant density (~25m^2/person) were applied. Additionally, the minimum performance for fenestration (USI- 1.48; SHGC 0.3) and heat recovery effectiveness of 80% was utilized per the BC Housing Sustainability Guidelines. Other envelope variables included 50% improved air leakage over the typical modeled minimum rate expected to be easily achievable with EMTC and associated detailing, as well as a minimum constructible wall assembly performance of RSI-3.36. A high (45%) WWR was selected to illustrate the extent of what is achievable in residential towers with a modern architectural expression.

Figure 23 shows the energy performance metrics that can be expected. This result illustrates that Step 3 TEDI (30 kWh/m^2/yr) and EUI (120 kWh/m^2/yr) are easily achieved, even without any improvement in code-level airtightness. To achieve Step 4 TEDI (15 kWh/m^2/yr) and EUI (100 kWh/m^2/yr) only require nominal non-envelope improvements over the base design to reduce EUI by ~5 kWh/m^2/yr. For example, low flow DHW fixtures, ENERGY STAR household appliances, lighting savings in common areas, or a heat pump-based heating coil for corridor pressurization can be potential solutions. Some of these improvements have little to no overall cost over current design best practices based on our recent project experience.

1.28. EMTC POINT TOWER – CITY OF VANCOUVER ENERGY MODELLING RESULTS

	Vancouver	
	Step 3	Step 4
	MT	MT
Wall RSI	3.36	3.36
Roof RSI	4.41	4.41
Air Leakage	50% Imp	50% Imp
Window USI/SHGC	1.4/0.3	1.4/0.3
WWR	45%	45%
HRV	80%	80%
DHW	Elec	Elec

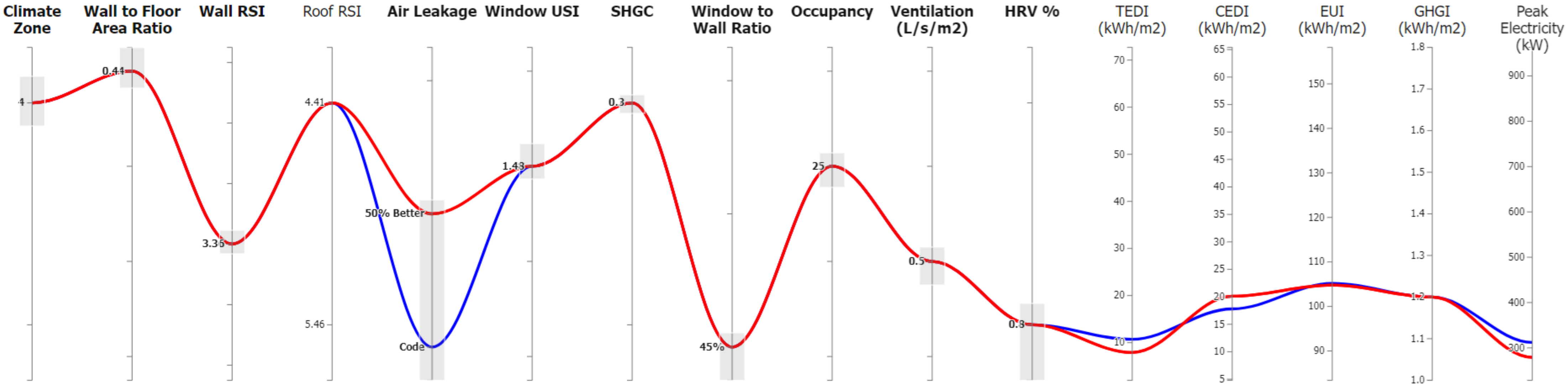


Figure 23: Step 3 and 4 EMTC designs in Vancouver, B.C.

1.29. STEEL AND CONCRETE POINT TOWER – CITY OF VANCOUVER ENERGY PERFORMANCE MAP

A similar methodology was considered for the baseline concrete tower simulation results. However, a lower range of wall RSI was studied given the substantially higher amount of thermal bridging expected in conventional steel stud assemblies and details. Airtightness improvements over baseline code were not claimed given the envelope air barrier and detailing challenges.

Figure 24 illustrates the range of energy performance expected with varying wall performance in this regard. Step 3 is achievable with the lowest wall performance tested (RSI-0.7) largely due to the other optimized envelope design variables (such as window performance, heat recovery effectiveness, and building massing). However, Step 4 solutions require a wall performance of RSI-1.76 to achieve the TEDI threshold, and an additional EUI reduction of ~6 kWh/m^2/yr from mechanical and lighting optimization as discussed for the EMTC scenario.

1.30. STEEL AND CONCRETE POINT TOWER – CITY OF VANCOUVER ENERGY MODELLING RESULTS

	Vancouver	
	Step 3	Step 4
	CS	CS
Wall RSI	0.7	1.6
Roof RSI	4.41	4.41
Air Leakage	50% Imp	50% Imp
Window USI/SHGC	1.4/0.3	1.4/0.3
WWR	45%	45%
HRV	80%	80%
DHW	Elec	Elec

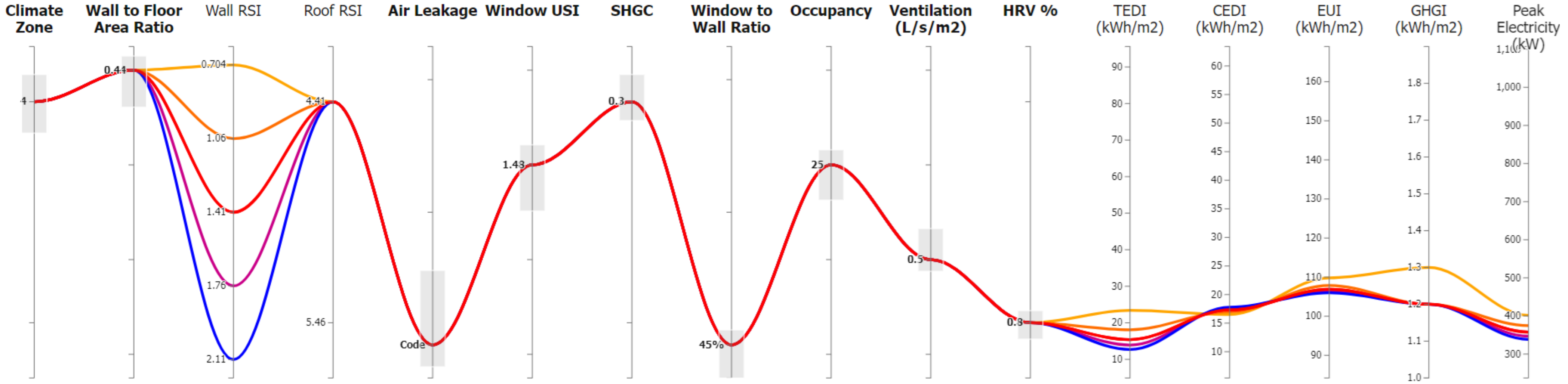
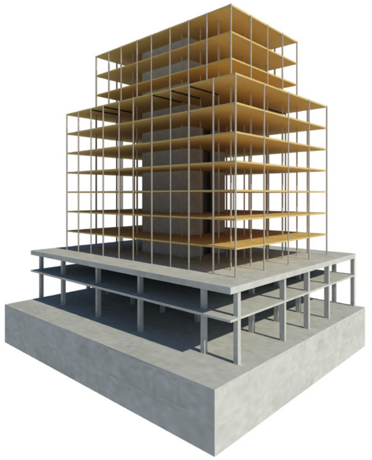


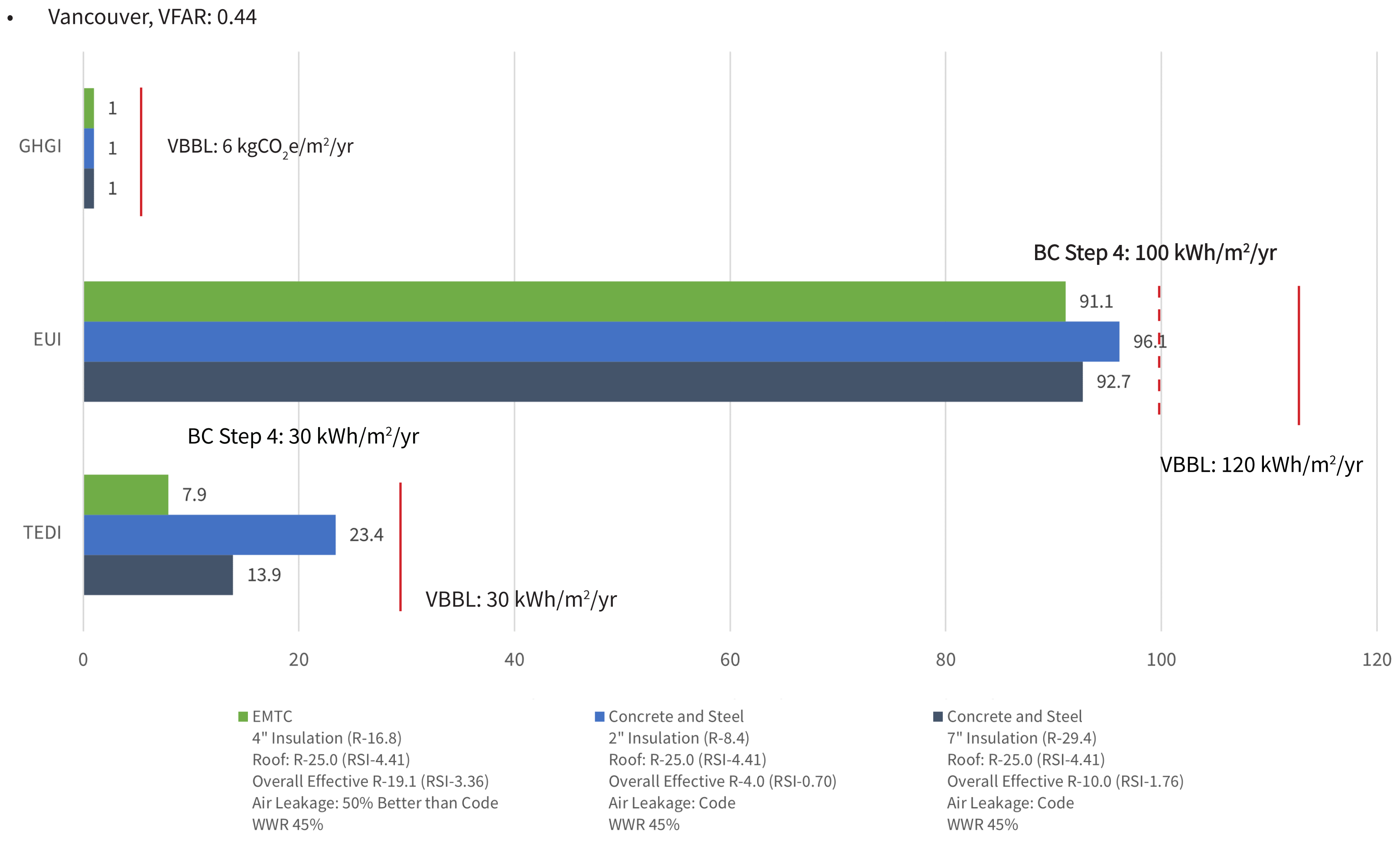
Figure 24: Step 3 and 4 concrete designs in Vancouver, B.C.

1.31. SUMMARY OF POINT TOWER ENERGY PERFORMANCE – CITY OF VANCOUVER

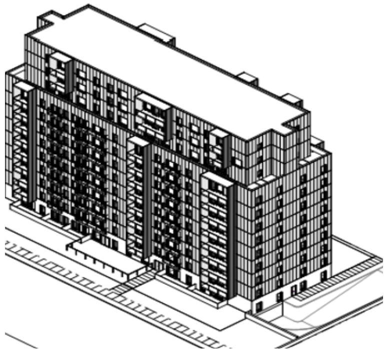
Concrete buildings have more difficulty achieving ‘Step 4’ targets, often requiring WWR to be significantly reduced.

It is possible to achieve lower air leakage rates, but it causes constructibility and detailing challenges.



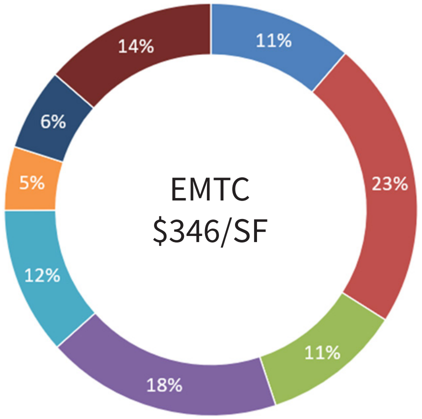


1.32. SLAB TOWER – CITY OF KAMLOOPS GFA AND ELEMENT COST BREAKDOWN (%)

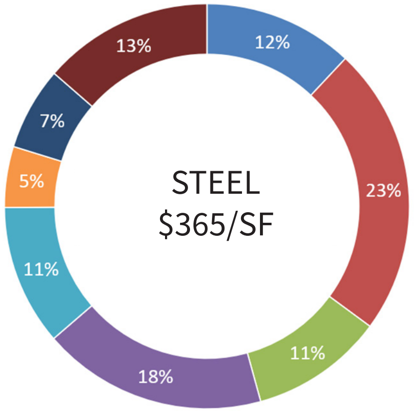


The Slab Tower is representative of a typical BC Housing tower that might occur in a small urban area outside of the greater metro area, like the City of Kamloops. The Slab Tower consists of 12-storeys above grade over 2 levels of below grade parking. Offsets in building perimeter occur at Levels 1 or ground level and again at Level 10. In plan, the Slab Tower is rectangular in plan and reflects a larger building site that is expected in a less densely populated urban area. The Slab Tower consists of three lateral resisting cores, one at the east and west side of the building in plan that also serve as stair access, and one at the center of the building that also serve as service and elevator shafts all continue down to the lowest parkade level. These lateral resisting cores are designed with moderate ductility, which is appropriate for the lower seismic climatic data that is typical of the Northern and Interior regions of B.C. The gravity system extends out from these central cores and will be further evaluated under the sections for each scheme.

	Existing	Proposed
Lot Width	-	250’-0
Lot Depth	-	120’-0
Lot Area	-	30,000 SF
Height	-	12 Storeys
Zoning	RM-3	-
FAR	5.0	3.6
Setback (front)	19.7’-0	9.8’-0
Setback (side)	14.8’-0	19.7’-0
Setback (rear)	19.7’-0	20.8’-0
Stepback (front)	-	27’-0 @ 70’-0
Stepback (side)	-	38’-0 @ 70’-0
Lot Coverage	70%	54%



Description	sqft
L1 to L2	19,805
L3 to L9	69,319
L10 to L12	21,796
Gross Floor Area (Slab Tower) - Above Grade	110,922
Basement Parking (3 Levels)	57,325
Total Gross Floor Area (Slab Tower)	**165,333**



GENERAL CONDITIONS AND REQUIREMENTS
STRUCTURE
ENCLOSURE
INTERIORS
MECHANICAL
ELECTRICAL
FOUNDATION
CONTINGENCY/ OTHER

1.33. EMTC SLAB TOWER VS. CONCRETE MARKET COMPARISON COST

ELEMENT			UNDERGROUND PARKADE (3 Levels)						LEVEL 1 - 9 (9 levels + Roof + Site)					
			A. MASS TIMBER		B. CONCRETE		VARIANCE (A-B)		A. MASS TIMBER		B. CONCRETE		VARIANCE (A-B)	
			GFA	5,325 m2	GFA	5,325 m2			GFA	8,280 m2	GFA	8,280 m2		
			Total ($)	($/m2)	Total ($)	($/m2)	Total ($)	Percent	Total ($)	($/m2)	Total ($)	($/m2)	Total ($)	Percent
A SHELL			**9,223,000**	**1,732.02**	**9,807,300**	**1,841.75**	**(584,300)**	**-6.34%**	**11,739,700**	**1,417.84**	**11,106,100**	**1,341.32**	**633,600**	**5.40%**
A1 SUBSTRUCTURE			**3,794,800**	**712.64**	**4,066,500**	**763.66**	**(271,700)**	**-7.16%**	**0**	**0.00**	**0**	**0.00**	**0**	**0.00%**
A11 Foundations			1,027,600	192.98	1,224,600	229.97	(197,000)	-19.17%	0	0.00	0	0.00	0	0.00%
A12 Basement Excavation			2,467,200	463.32	2,526,900	474.54	(59,700)	-2.42%	0	0.00	0	0.00	0	0.00%
A11 Special Conditions			300,000	56.34	315,000	59.15	(15,000)	-5.00%	0	0.00	0	0.00	0	0.00%
A2 STRUCTURE			**3,968,100**	**745.18**	**4,280,700**	**803.89**	**(312,600)**	**-7.88%**	**7,683,100**	**927.91**	**7,049,500**	**851.39**	**633,600**	**8.25%**
A21 Lowest Floor Construction			106,500	20.00	106,500	20.00	0	0.00%	0	0.00	0	0.00	0	0.00%
A22 Upper Floor Construction			3,230,600	606.69	3,543,200	665.39	(312,600)	-9.68%	7,012,600	846.93	6,437,300	777.45	575,300	8.20%
A23 Roof Construction			631,000	118.50	631,000	118.50	0	0.00%	670,500	80.98	612,200	73.94	58,300	8.70%
A3 EXTERIOR ENCLOSURE			**1,460,100**	**274.20**	**1,460,100**	**274.20**	**0**	**0.00%**	**4,056,600**	**489.93**	**4,056,600**	**489.93**	**0**	**0.00%**
A31 Walls Below Grade			1,224,900	230.03	1,224,900	230.03	0	0.00%	0	0.00	0	0.00	0	0.00%
A32 Walls Above Grade			0	0.00	0	0.00	0	0.00%	1,798,400	217.20	1,798,400	217.20	0	0.00%
A33 Windows & Entrances			30,000	5.63	30,000	5.63	0	0.00%	849,400	102.58	849,400	102.58	0	0.00%
A34 Roof Covering			205,200	38.54	205,200	38.54	0	0.00%	277,600	33.53	277,600	33.53	0	0.00%
A35 Projections			0	0.00	0	0.00	0	0.00%	1,131,200	136.62	1,131,200	136.62	0	0.00%
B INTERIORS			**864,600**	**162.37**	**864,600**	**162.37**	**0**	**0.00%**	**8,052,800**	**972.56**	**8,052,800**	**972.56**	**0**	**0.00%**
B1 PARTITIONS & DOORS			**65,300**	**12.26**	**65,300**	**12.26**	**0**	**0.00%**	**3,627,600**	**438.12**	**3,627,600**	**438.12**	**0**	**0.00%**
B11 Partitions			65,300	12.26	65,300	12.26	0	0.00%	2,697,400	325.77	2,697,400	325.77	0	0.00%
B12 Doors			0	0.00	0	0.00	0	0.00%	930,200	112.34	930,200	112.34	0	0.00%
B2 INTERIOR FINISHES			**358,900**	**67.40**	**358,900**	**67.40**	**0**	**0.00%**	**2,110,100**	**254.84**	**2,110,100**	**254.84**	**0**	**0.00%**
B21 Floor Finishes			147,200	27.64	147,200	27.64	0	0.00%	725,600	87.63	725,600	87.63	0	0.00%
B22 Ceiling Finishes			131,400	24.68	131,400	24.68	0	0.00%	583,300	70.45	583,300	70.45	0	0.00%
B23 Wall Finishes			80,300	15.08	80,300	15.08	0	0.00%	801,200	96.76	801,200	96.76	0	0.00%
B3 FITTINGS & EQUIPMENT			**440,400**	**82.70**	**440,400**	**82.70**	**0**	**0.00%**	**2,315,100**	**279.60**	**2,315,100**	**279.60**	**0**	**0.00%**
B31 Fittings & Fixtures			180,400	33.88	180,400	33.88	0	0.00%	1,041,600	125.80	1,041,600	125.80	0	0.00%
B32 Equipment			60,000	11.27	60,000	11.27	0	0.00%	630,700	76.17	630,700	76.17	0	0.00%
B33 Elevators			200,000	37.56	200,000	37.56	0	0.00%	642,800	77.63	642,800	77.63	0	0.00%
C SERVICES			**892,100**	**167.53**	**892,100**	**167.53**	**0**	**0.00%**	**7,130,300**	**861.15**	**7,130,300**	**861.15**	**0**	**0.00%**
C1 MECHANICAL			**579,800**	**108.88**	**579,800**	**108.88**	**0**	**0.00%**	**5,008,600**	**604.90**	**5,008,600**	**604.90**	**0**	**0.00%**
C11 Plumbing & Drainage			199,200	37.41	199,200	37.41	0	0.00%	1,608,300	194.24	1,608,300	194.24	0	0.00%
C12 Fire Protection			171,900	32.28	171,900	32.28	0	0.00%	399,300	48.22	399,300	48.22	0	0.00%
C13 HVAC			170,400	32.00	170,400	32.00	0	0.00%	2,669,800	322.44	2,669,800	322.44	0	0.00%
C14 Controls			38,300	7.19	38,300	7.19	0	0.00%	331,200	40.00	331,200	40.00	0	0.00%
C2 ELECTRICAL			**312,300**	**58.65**	**312,300**	**58.65**	**0**	**0.00%**	**2,121,700**	**256.24**	**2,121,700**	**256.24**	**0**	**0.00%**
C21 Service and Distribution			109,900	20.64	109,900	20.64	0	0.00%	701,400	84.71	701,400	84.71	0	0.00%
C22 Lighting, Devices and Heating			133,200	25.01	133,200	25.01	0	0.00%	964,300	116.46	964,300	116.46	0	0.00%
C23 Systems and Ancillaries			69,200	13.00	69,200	13.00	0	0.00%	456,000	55.07	456,000	55.07	0	0.00%
NET BUILDING COST - EXCLUDING SITE			**10,979,700**	**2,061.92**	**11,564,000**	**2,171.64**	**(584,300)**	**-5.32%**	**26,922,800**	**3,251.55**	**26,289,200**	**3,175.02**	**633,600**	**2.35%**
D SITE & ANCILLARY WORK			**0**	**0.00**	**0**	**0.00**	**0**	**0.00%**	**831,300**	**100.40**	**831,300**	**100.40**	**0**	**0.00%**
D1 SITE WORK			**0**	**0.00**	**0**	**0.00**	**0**	**0.00%**	**831,300**	**100.40**	**831,300**	**100.40**	**0**	**0.00%**
D11 Site Development			0	0.00	0	0.00	0	0.00%	427,100	51.58	427,100	51.58	0	0.00%
D12 Mechanical Site Services			0	0.00	0	0.00	0	0.00%	236,000	28.50	236,000	28.50	0	0.00%
D13 Electrical Site Services			0	0.00	0	0.00	0	0.00%	168,200	20.31	168,200	20.31	0	0.00%
D2 ANCILLARY WORK			**0**	**0.00**	**0**	**0.00**	**0**	**0.00%**	**0**	**0.00**	**0**	**0.00**	**0**	**0.00%**
D21 Demolition			0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%
D22 Alterations			0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%
NET BUILDING COST - INCLUDING SITE			**10,979,700**	**2,061.92**	**11,564,000**	**2,171.64**	**(584,300)**	**-5.32%**	**$27,754,100**	**3,351.94**	**$27,120,500**	**3,275.42**	**633,600**	**2.28%**
Z GENERAL REQ'S & ALLOWANCES			**3,575,200**	**671.40**	**4,127,800**	**775.17**	**-552,600**	**-15.46%**	**9,037,500**	**1,091.49**	**9,681,000**	**1,169.20**	**-643,500**	**-7.12%**
Z1 GENERAL REQUIREMENTS & FEE	**M. Timber**	**Concrete**	**1,621,900**	**304.58**	**2,022,000**	**379.72**	**(400,100)**	**-24.67%**	**4,100,100**	**495.18**	**4,742,200**	**572.73**	**(642,100)**	**-15.66%**
Z10 Location Factor	1.30%	1.30%	142,700	26.80	150,300	28.23	(7,600)	0.00%	360,800	43.57	352,600	42.58	8,200	0.00%
Z11 General Requirements	10.00%	12.60%	1,112,200	208.86	1,476,000	277.18	(363,800)	-32.71%	2,811,500	339.55	3,461,600	418.07	(650,100)	-23.12%
Z12 Fee	3.00%	3.00%	367,000	68.92	395,700	74.31	(28,700)	-7.82%	927,800	112.05	928,000	112.08	(200)	-0.02%
TOTAL CONSTRUCTION ESTIMATE - EXCLUDING CONTINGENCIES			**12,601,600**	**2,366.50**	**13,586,000**	**2,551.36**	**-984,400**	**-7.81%**	**31,854,200**	**3,847.13**	**31,862,700**	**3,848.15**	**-8,500**	**-0.03%**
Z2 ALLOWANCES			**1,953,300**	**366.82**	**2,105,800**	**395.46**	**(152,500)**	**-7.81%**	**4,937,400**	**596.30**	**4,938,800**	**596.47**	**(1,400)**	**-0.03%**
Z21 Design & Pricing Allowance	10.00%	10.00%	1,260,200	236.66	1,358,600	255.14	(98,400)	-7.81%	3,185,400	384.71	3,186,300	384.82	(900)	-0.03%
Z22 Escalation Allowance	0.00%	0.00%	0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%
Z23 Construction Allowance	5.00%	5.00%	693,100	130.16	747,200	140.32	(54,100)	-7.81%	1,752,000	211.59	1,752,500	211.65	(500)	-0.03%
TOTAL CONSTRUCTION ESTIMATE - INCLUDING CONTINGENCIES			**14,554,900**	**2,733.31**	**15,691,800**	**2,946.82**	**-1,136,900**	**-7.81%**	**36,791,600**	**4,443.43**	**36,801,500**	**4,444.63**	**-9,900**	**-0.03%**
GOODS & SERVICES TAX			0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
TOTAL CONSTRUCTION ESTIMATE			**$14,554,900**	**2,733.31**	**$15,691,800**	**2,946.82**	**-$1,136,900**	**-7.81%**	**$36,791,600**	**4,443.43**	**$36,801,500**	**4,444.63**	**-$9,900**	**-0.03%**

												OVERALL CONSTRUCTION COST					
LEVEL 10 - 12 (additional 3 levels)						TOTAL (12 levels)											
A. MASS TIMBER		B. CONCRETE		VARIANCE (A-B)		A. MASS TIMBER		B. CONCRETE		VARIANCE (A-B)		A. MASS TIMBER		B. CONCRETE		VARIANCE (A-B)	
GFA	2,025 m2	GFA	2,025 m2			GFA	10,305 m2	GFA	10,305 m2			GFA	15,630 m2	GFA	15,630 m2		
Total ($)	($/m2)	Total ($)	($/m2)	Total ($)	Percent	Total ($)	($/m2)	Total ($)	($/m2)	Total ($)	Percent	Total ($)	($/m2)	Total ($)	($/m2)	Total ($)	Percent
2,639,300	1,303.36	2,498,600	1,233.88	140,700	5.33%	14,379,000	1,395.34	13,604,700	1,320.20	774,300	5.38%	23,602,000	1,510.04	23,412,000	1,497.89	190,000	0.81%
0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%	3,794,800	242.79	4,066,500	260.17	(271,700)	-7.16%
0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%	1,027,600	65.75	1,224,600	78.35	(197,000)	-19.17%
0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%	2,467,200	157.85	2,526,900	161.67	(59,700)	-2.42%
0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%	300,000	19.19	315,000	20.15	(15,000)	-5.00%
1,715,100	846.96	1,574,400	777.48	140,700	8.20%	9,398,200	912.00	8,623,900	836.87	774,300	8.24%	13,366,300	855.17	12,904,600	825.63	461,700	3.45%
0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%	106,500	6.81	106,500	6.81	0	0.00%
1,715,100	846.96	1,574,400	777.48	140,700	8.20%	8,727,700	846.94	8,011,700	777.46	716,000	8.20%	11,958,300	765.09	11,554,900	739.28	403,400	3.37%
0	0.00	0	0.00	0	0.00%	670,500	65.07	612,200	59.41	58,300	8.70%	1,301,500	83.27	1,243,200	79.54	58,300	4.48%
924,200	456.40	924,200	456.40	0	0.00%	4,980,800	483.34	4,980,800	483.34	0	0.00%	6,440,900	412.09	6,440,900	412.09	0	0.00%
0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%	1,224,900	78.37	1,224,900	78.37	0	0.00%
439,800	217.19	439,800	217.19	0	0.00%	2,238,200	217.20	2,238,200	217.20	0	0.00%	2,238,200	143.20	2,238,200	143.20	0	0.00%
207,700	102.57	207,700	102.57	0	0.00%	1,057,100	102.58	1,057,100	102.58	0	0.00%	1,087,100	69.55	1,087,100	69.55	0	0.00%
0	0.00	0	0.00	0	0.00%	277,600	26.94	277,600	26.94	0	0.00%	482,800	30.89	482,800	30.89	0	0.00%
276,700	136.64	276,700	136.64	0	0.00%	1,407,900	136.62	1,407,900	136.62	0	0.00%	1,407,900	90.08	1,407,900	90.08	0	0.00%
1,969,700	972.69	1,969,700	972.69	0	0.00%	10,022,500	972.59	10,022,500	972.59	0	0.00%	10,887,100	696.55	10,887,100	696.55	0	0.00%
887,200	438.12	887,200	438.12	0	0.00%	4,514,800	438.12	4,514,800	438.12	0	0.00%	4,580,100	293.03	4,580,100	293.03	0	0.00%
659,700	325.78	659,700	325.78	0	0.00%	3,357,100	325.77	3,357,100	325.77	0	0.00%	3,422,400	218.96	3,422,400	218.96	0	0.00%
227,500	112.35	227,500	112.35	0	0.00%	1,157,700	112.34	1,157,700	112.34	0	0.00%	1,157,700	74.07	1,157,700	74.07	0	0.00%
516,200	254.91	516,200	254.91	0	0.00%	2,626,300	254.86	2,626,300	254.86	0	0.00%	2,985,200	190.99	2,985,200	190.99	0	0.00%
177,500	87.65	177,500	87.65	0	0.00%	903,100	87.64	903,100	87.64	0	0.00%	1,050,300	67.20	1,050,300	67.20	0	0.00%
142,700	70.47	142,700	70.47	0	0.00%	726,000	70.45	726,000	70.45	0	0.00%	857,400	54.86	857,400	54.86	0	0.00%
196,000	96.79	196,000	96.79	0	0.00%	997,200	96.77	997,200	96.77	0	0.00%	1,077,500	68.94	1,077,500	68.94	0	0.00%
566,300	279.65	566,300	279.65	0	0.00%	2,881,400	279.61	2,881,400	279.61	0	0.00%	3,321,800	212.53	3,321,800	212.53	0	0.00%
254,800	125.83	254,800	125.83	0	0.00%	1,296,400	125.80	1,296,400	125.80	0	0.00%	1,476,800	94.48	1,476,800	94.48	0	0.00%
154,300	76.20	154,300	76.20	0	0.00%	785,000	76.18	785,000	76.18	0	0.00%	845,000	54.06	845,000	54.06	0	0.00%
157,200	77.63	157,200	77.63	0	0.00%	800,000	77.63	800,000	77.63	0	0.00%	1,000,000	63.98	1,000,000	63.98	0	0.00%
1,743,600	861.04	1,743,600	861.04	0	0.00%	8,873,900	861.13	8,873,900	861.13	0	0.00%	9,766,000	624.82	9,766,000	624.82	0	0.00%
1,224,800	604.84	1,224,800	604.84	0	0.00%	6,233,400	604.89	6,233,400	604.89	0	0.00%	6,813,200	435.91	6,813,200	435.91	0	0.00%
393,300	194.22	393,300	194.22	0	0.00%	2,001,600	194.24	2,001,600	194.24	0	0.00%	2,200,800	140.81	2,200,800	140.81	0	0.00%
97,600	48.20	97,600	48.20	0	0.00%	496,900	48.22	496,900	48.22	0	0.00%	668,800	42.79	668,800	42.79	0	0.00%
652,900	322.42	652,900	322.42	0	0.00%	3,322,700	322.44	3,322,700	322.44	0	0.00%	3,493,100	223.49	3,493,100	223.49	0	0.00%
81,000	40.00	81,000	40.00	0	0.00%	412,200	40.00	412,200	40.00	0	0.00%	450,500	28.82	450,500	28.82	0	0.00%
518,800	256.20	518,800	256.20	0	0.00%	2,640,500	256.23	2,640,500	256.23	0	0.00%	2,952,800	188.92	2,952,800	188.92	0	0.00%
171,500	84.69	171,500	84.69	0	0.00%	872,900	84.71	872,900	84.71	0	0.00%	982,800	62.88	982,800	62.88	0	0.00%
235,800	116.44	235,800	116.44	0	0.00%	1,200,100	116.46	1,200,100	116.46	0	0.00%	1,333,300	85.30	1,333,300	85.30	0	0.00%
111,500	55.06	111,500	55.06	0	0.00%	567,500	55.07	567,500	55.07	0	0.00%	636,700	40.74	636,700	40.74	0	0.00%
6,352,600	3,137.09	6,211,900	3,067.60	140,700	2.21%	33,275,400	3,229.05	32,501,100	3,153.92	774,300	2.33%	44,255,100	2,831.42	44,065,100	2,819.26	190,000	0.43%
0	0.00	0	0.00	0	0.00%	831,300	80.67	831,300	80.67	0	0.00%	831,300	53.19	831,300	53.19	0	0.00%
0	0.00	0	0.00	0	0.00%	831,300	80.67	831,300	80.67	0	0.00%	831,300	53.19	831,300	53.19	0	0.00%
0	0.00	0	0.00	0	0.00%	427,100	41.45	427,100	41.45	0	0.00%	427,100	27.33	427,100	27.33	0	0.00%
0	0.00	0	0.00	0	0.00%	236,000	22.90	236,000	22.90	0	0.00%	236,000	15.10	236,000	15.10	0	0.00%
0	0.00	0	0.00	0	0.00%	168,200	16.32	168,200	16.32	0	0.00%	168,200	10.76	168,200	10.76	0	0.00%
0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%
0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%
0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%
$6,352,600	3,137.09	$6,211,900	3,067.60	140,700	2.21%	$34,106,700	3,309.72	$33,332,400	3,234.59	774,300	2.27%	45,086,400	2,884.61	$44,896,400	2,872.45	190,000	0.42%
2,068,600	1,021.53	2,205,600	1,089.19	-137,000	-6.62%	11,106,100	1,077.74	11,886,600	1,153.48	-780,500	-7.03%	14,681,300	939.30	16,014,400	1,024.59	-1,333,100	-9.08%
938,500	463.46	1,076,000	531.36	(137,500)	-14.65%	5,038,600	488.95	5,818,200	564.60	(779,600)	-15.47%	6,660,500	426.14	7,840,200	501.61	(1,179,700)	-17.71%
82,600	40.79	80,700	39.85	1,900	0.00%	443,400	43.03	433,300	42.05	10,100	0.00%	586,100	37.50	583,600	37.34	2,500	0.00%
643,500	317.78	783,000	386.67	(139,500)	-21.68%	3,455,000	335.27	4,244,600	411.90	(789,600)	-22.85%	4,567,200	292.21	5,720,600	366.00	(1,153,400)	-25.25%
212,400	104.89	212,300	104.84	100	0.05%	1,140,200	110.65	1,140,300	110.66	(100)	-0.01%	1,507,200	96.43	1,536,000	98.27	(28,800)	-1.91%
7,291,100	3,600.54	7,287,900	3,598.96	3,200	0.04%	39,145,300	3,798.67	39,150,600	3,799.18	-5,300	-0.01%	51,746,900	3,310.74	52,736,600	3,374.06	-989,700	-1.91%
1,130,100	558.07	1,129,600	557.83	500	0.04%	6,067,500	588.79	6,068,400	588.88	(900)	-0.01%	8,020,800	513.17	8,174,200	522.98	(153,400)	-1.91%
729,100	360.05	728,800	359.90	300	0.04%	3,914,500	379.86	3,915,100	379.92	(600)	-0.02%	5,174,700	331.07	5,273,700	337.41	(99,000)	-1.91%
0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%
401,000	198.02	400,800	197.93	200	0.05%	2,153,000	208.93	2,153,300	208.96	(300)	-0.01%	2,846,100	182.09	2,900,500	185.57	(54,400)	-1.91%
8,421,200	4,158.62	8,417,500	4,156.79	3,700	0.04%	45,212,800	4,387.46	45,219,000	4,388.06	-6,200	-0.01%	59,767,700	3,823.91	60,910,800	3,897.04	-1,143,100	-1.91%
0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
$8,421,200	4,158.62	$8,417,500	4,156.79	$3,700	0.04%	$45,212,800	4,387.46	$45,219,000	4,388.06	-$6,200	-0.01%	$59,767,700	3,823.91	$60,910,800	3,897.04	-$1,143,100	-1.91%

1.34. EMTC SLAB TOWER – CITY OF KAMLOOPS ENERGY PERFORMANCE MAP

The Kamloops archetype analysis differs from the Vancouver case mentioned only in its more articulated massing (VFAR=0.54) and more extreme climate.

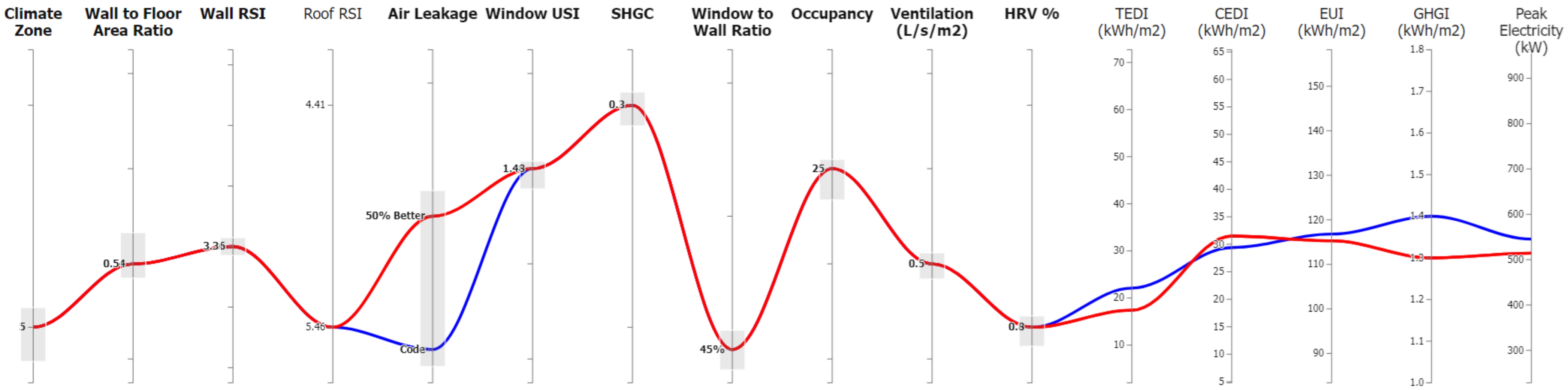


Figure 25: Step 3 and 4 EMTC designs in Kamloops, B.C.

1.35. EMTC SLAB TOWER – CITY OF KAMLOOPS ENERGY MODELLING RESULTS

	Kamloops	
	Step 3	Step 4
	MT	MT
Wall RSI	3.36	3.36
Roof RSI	5.46	5.46
Air Leakage	50% Imp	50% Imp
Window USI/SHGC	1.48/0.3	1.48/0.3
WWR	45%	45%
HRV	80%	80%
DHW	Elec	Elec

1.36. STEEL AND CONCRETE SLAB TOWER – CITY OF KAMLOOPS ENERGY PERFORMANCE MAP

As with the concrete archetype in Vancouver, the range of energy performance and consequently Step 3 or 4 compliance is highly dependent on wall performance.

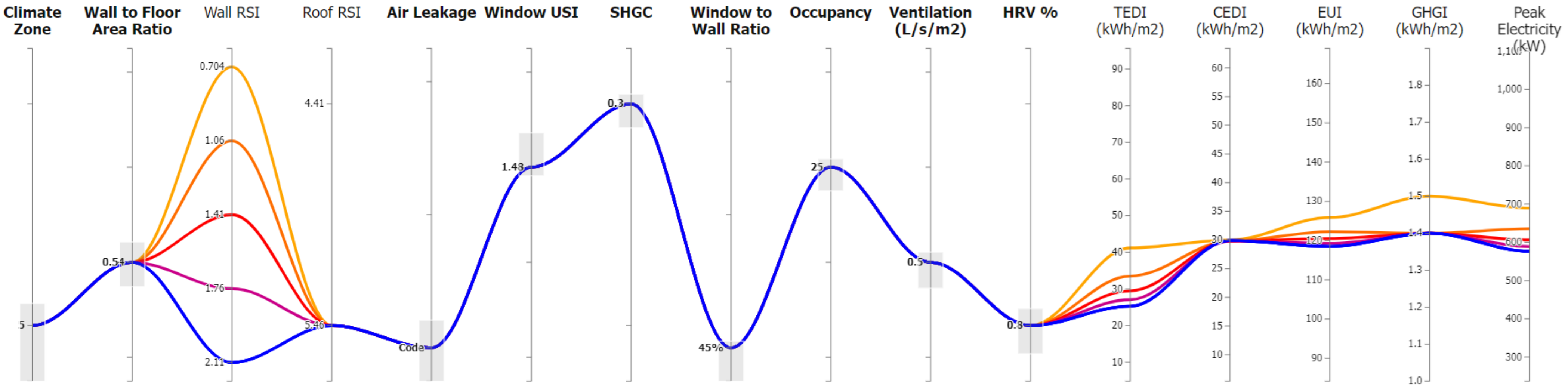


Figure 26: Step 3 concrete designs in Kamloops, B.C.

Interestingly, Figure 26 shows that while Step 3 can be met with RSI-1.06 wall performance and a ~2 kWh/m²/yr reduction in EUI from mechanical or lighting improvements discussed above, the Step 4 TEDI threshold cannot be met with the walls tested.

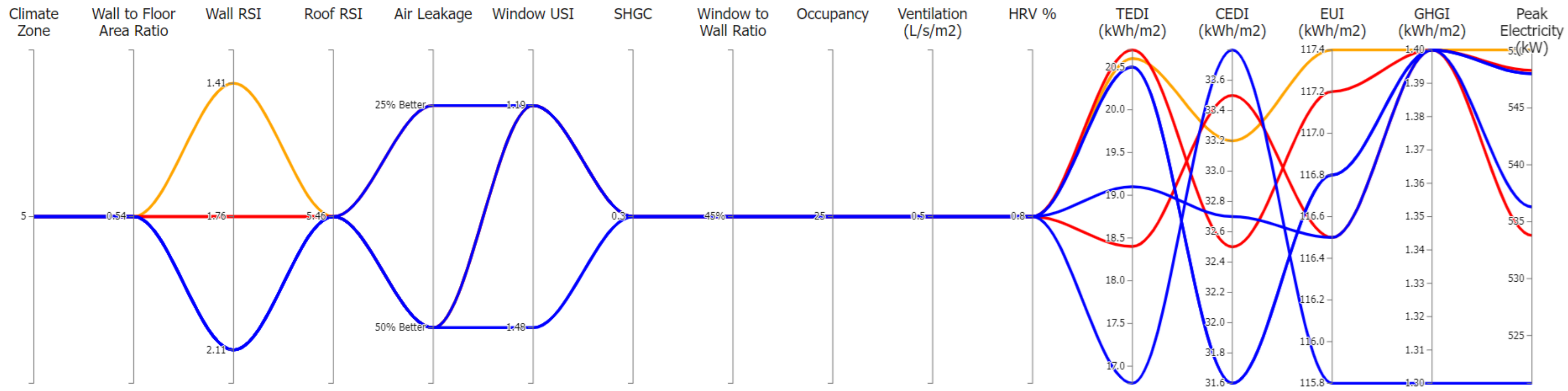


Figure 27: Aggressive Step 4 concrete designs in Kamloops, B.C.

This implies that the design needs to incorporate premium performing windows (USI-1.19) or higher heat recovery effectiveness than was tested in the model, as shown in Figure 27. Alternatively, a better than code airtightness (50%) can also meet the target, or some combination of improved airtightness, improved heat recovery, and improved windows with a good wall assembly. Nonetheless, a Step 4 compliant design in this context is likely to be either expensive or risky from an airtightness perspective.

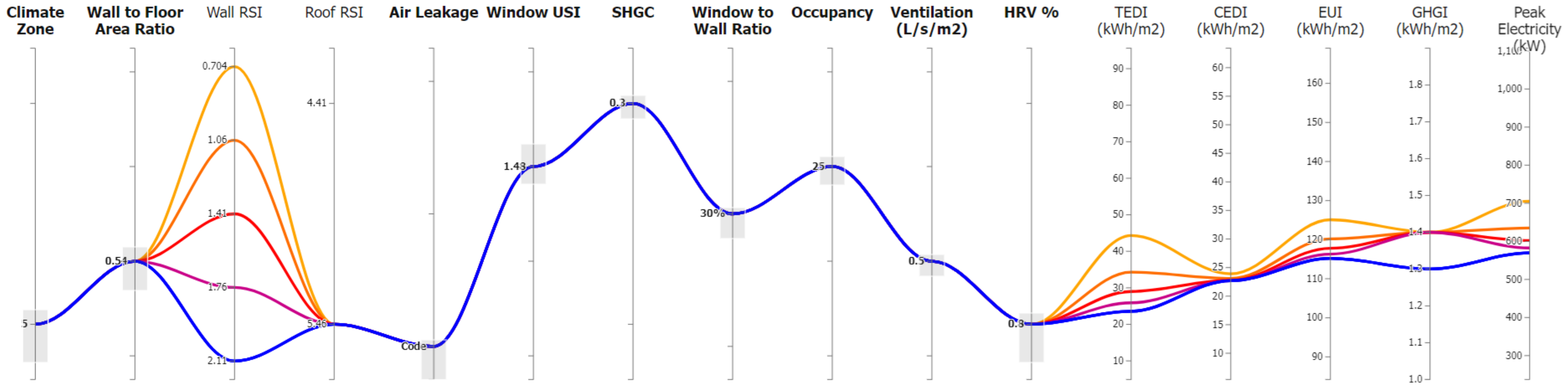


Figure 28: Likely Step 4 concrete design in Kamloops, B.C.

For this reason, a more likely Step 4 design is presented in Figure 28 where the WWR is reduced to 30%. This allows the rest of the design variables to remain manageable from a cost and constructability perspective. Given Step 4 targets are adjusted for climate zone and all other variables are similar to the Vancouver archetype, the greater articulated massing of the Kamloops archetype appears to increase the level of design complexity for the concrete scenario.

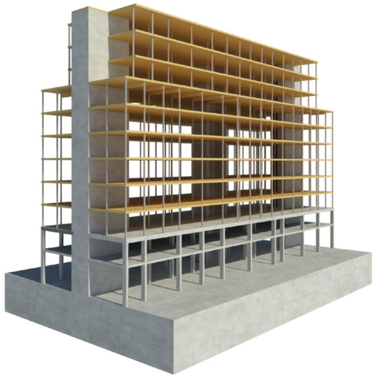
1.37. STEEL AND CONCRETE SLAB TOWER – CITY OF KAMLOOPS ENERGY MODELLING RESULTS

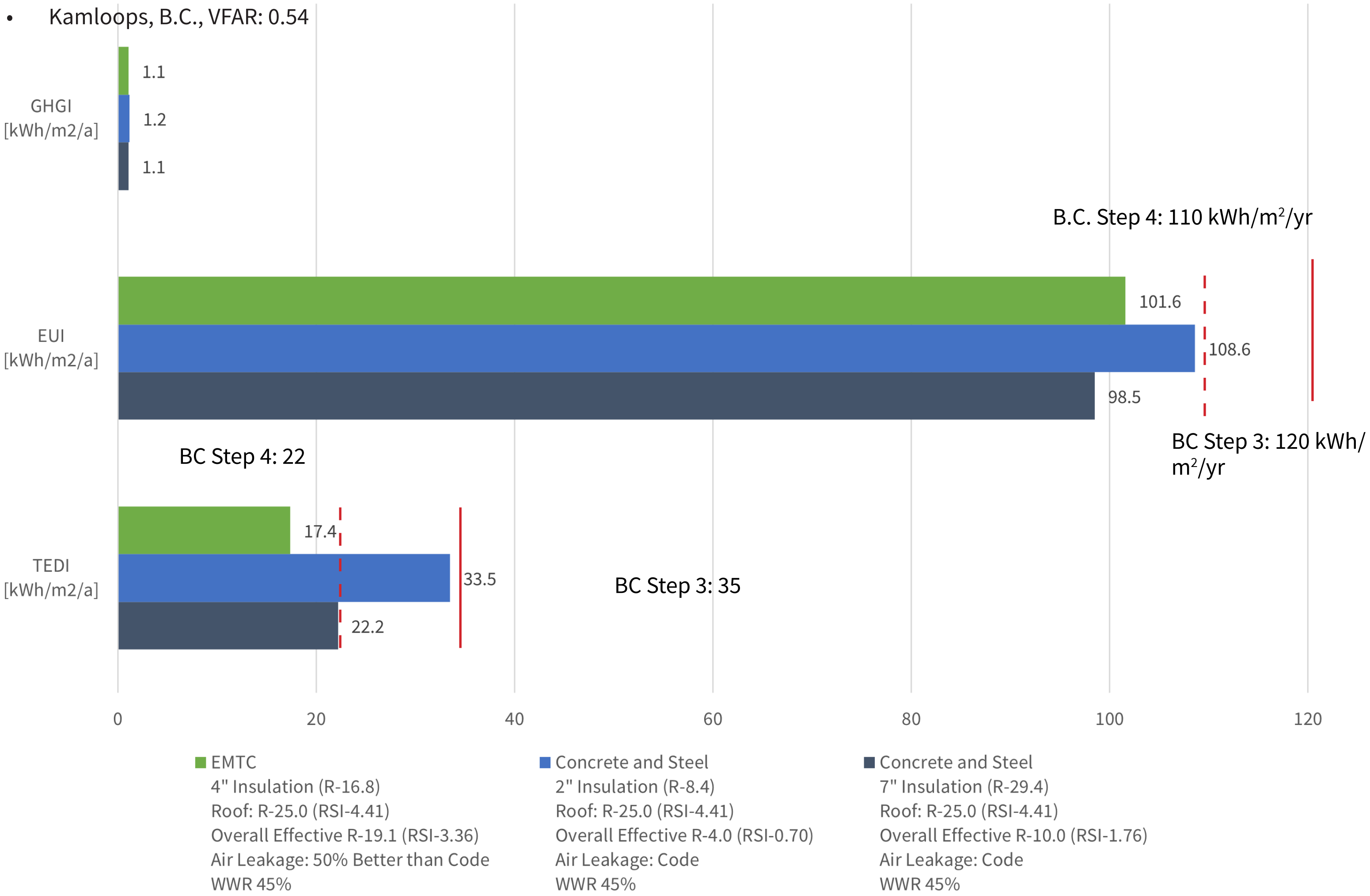
	Vancouver	
	Step 3	Step 4
	CS	CS
Wall RSI	1.06	2.11
Roof RSI	5.46	5.46
Air Leakage	Code	Code
Window USI/SHGC	1.48/0.3	1.48/0.3
WWR	45%	45%
HRV	80%	80%
DHW	Elec	Elec

1.38. SUMMARY OF SLAB TOWER ENERGY PERFORMANCE – CITY OF KAMLOOPS

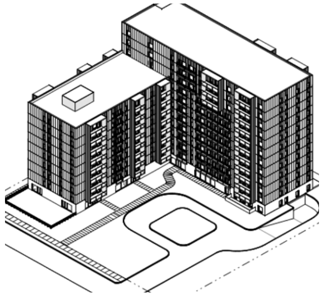
EMTC buildings can easily meet ‘Step 3’ and ‘Step 4’ targets without significant changes to the design.

This could allow for trade-off of good envelope performance (e.g. relaxing window U-value or HRV effectiveness requirements)



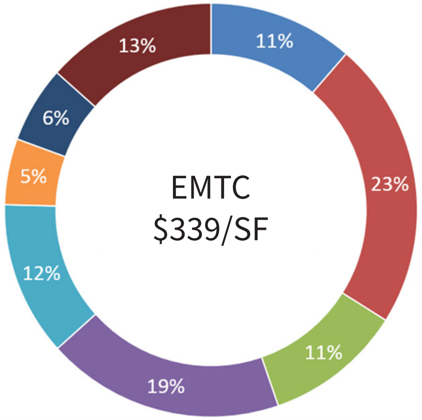


1.39. L TOWER – CITY OF COQUITLAM GFA AND ELEMENT COST BREAKDOWN (%)

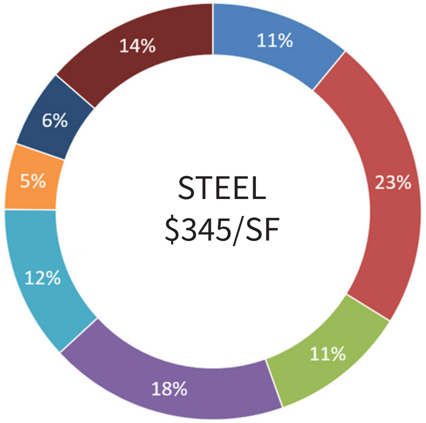


The L Tower is representative of a typical massing that might occur in the Greater Lower Mainland area, such as the City of Coquitlam. The L Tower consists of 12-storeys above grade over 3 levels of below grade parking. Offsets in building perimeter occur at Levels 1 or ground level and again at Level 10. In plan, as the name suggests, the L tower is formed in an L shape with a north bar running east-west in plan and a south bar running north-south in plan. This larger building area is reflective of a larger building site and density demand that is expected in a growing suburb like Coquitlam and the surrounding areas in the Lower Mainland. The L Tower consists of three lateral resisting cores, a stair core at the east side of the north bar, another stair core at the southern end of the south bar, and central elevator and service shaft core at the adjoining "knuckle" of the north and south bars. Like the Point Tower, the lateral resisting cores of the L Tower are also designed with a ductile lateral resisting system, in response to higher seismic climatic data that is typical of the Lower Mainland and Vancouver Island regions than would be expected elsewhere in B.C. The gravity system surrounds each core and will be further evaluated under the sections of each scheme.

	Existing	Proposed
Lot Width	-	225'-0
Lot Depth	-	220'-0
Lot Area	-	49,500 SF
Height	-	12 Storeys
Zoning	RM-6	-
FAR	2.5	3.1
Setback (front)	14.8'-0	14'-0
Setback (side)	14.8'-0	13'-0
Setback (rear)	19.7'-0	12'-0
Stepback (front)	-	95'-0 @ 70'-0
Stepback (side)	-	-
Lot Coverage	90%	37%



Description	sqft
L1 to L2	31,645
L3 to L9	109,253
L10 Stair Roof	344
L10 to L12	28,093
Gross Floor Area (L Tower) - Above Grade	168,907
Basement Parking (3 Levels)	79,114
Total Gross Floor Area (L Tower)	**248,022**



GENERAL CONDITIONS AND REQUIREMENTS
STRUCTURE
ENCLOSURE
INTERIORS
MECHANICAL
ELECTRICAL
FOUNDATION
CONTINGENCY/ OTHER

1.40. EMTC L TOWER VS. CONCRETE MARKET COMPARISON COST

ELEMENT			UNDERGROUND PARKADE (3 Levels)						LEVEL 1 - 9 (9 levels + Roof + Site)					
			A. MASS TIMBER		B. CONCRETE		VARIANCE (A-B)		A. MASS TIMBER		B. CONCRETE		VARIANCE (A-B)	
			GFA	7,350 m2	GFA	7,350 m2			GFA	13,050 m2	GFA	13,050 m2		
			Total ($)	($/m2)	Total ($)	($/m2)	Total ($)	Percent	Total ($)	($/m2)	Total ($)	($/m2)	Total ($)	Percent
A SHELL			11,817,900	1,607.88	12,453,400	1,694.34	(635,500)	-5.38%	17,947,700	1,375.30	16,435,400	1,259.42	1,512,300	8.43%
A1 SUBSTRUCTURE			5,039,900	685.70	5,228,600	711.37	(188,700)	-3.74%	0	0.00	0	0.00	0	0.00%
A11 Foundations			1,407,200	191.46	1,679,300	228.48	(272,100)	-19.34%	0	0.00	0	0.00	0	0.00%
A12 Basement Excavation			3,212,700	437.10	3,289,300	447.52	(76,600)	-2.38%	0	0.00	0	0.00	0	0.00%
A11 Special Conditions			420,000	57.14	260,000	35.37	160,000	38.10%	0	0.00	0	0.00	0	0.00%
A2 STRUCTURE			5,084,900	691.82	5,531,700	752.61	(446,800)	-8.79%	11,737,600	899.43	10,225,300	783.55	1,512,300	12.88%
A21 Lowest Floor Construction			147,100	20.01	147,100	20.01	0	0.00%	0	0.00	0	0.00	0	0.00%
A22 Upper Floor Construction			4,412,100	600.29	4,858,900	661.07	(446,800)	-10.13%	10,698,100	819.78	9,291,900	712.02	1,406,200	13.14%
A23 Roof Construction			525,700	71.52	525,700	71.52	0	0.00%	1,039,500	79.66	933,400	71.52	106,100	10.21%
A3 EXTERIOR ENCLOSURE			1,693,100	230.35	1,693,100	230.35	0	0.00%	6,210,100	475.87	6,210,100	475.87	0	0.00%
A31 Walls Below Grade			1,486,500	202.24	1,486,500	202.24	0	0.00%	0	0.00	0	0.00	0	0.00%
A32 Walls Above Grade			0	0.00	0	0.00	0	0.00%	2,521,200	193.20	2,521,200	193.20	0	0.00%
A33 Windows & Entrances			30,000	4.08	30,000	4.08	0	0.00%	1,299,000	99.54	1,299,000	99.54	0	0.00%
A34 Roof Covering			176,600	24.03	176,600	24.03	0	0.00%	436,100	33.42	436,100	33.42	0	0.00%
A35 Projections			0	0.00	0	0.00	0	0.00%	1,953,800	149.72	1,953,800	149.72	0	0.00%
B INTERIORS			1,361,600	185.25	1,361,600	185.25	0	0.00%	11,910,600	912.69	11,910,600	912.69	0	0.00%
B1 PARTITIONS & DOORS			325,600	44.30	325,600	44.30	0	0.00%	5,522,400	423.17	5,522,400	423.17	0	0.00%
B11 Partitions			296,200	40.30	296,200	40.30	0	0.00%	4,225,400	323.79	4,225,400	323.79	0	0.00%
B12 Doors			29,400	4.00	29,400	4.00	0	0.00%	1,297,000	99.39	1,297,000	99.39	0	0.00%
B2 INTERIOR FINISHES			528,500	71.90	528,500	71.90	0	0.00%	3,226,900	247.27	3,226,900	247.27	0	0.00%
B21 Floor Finishes			215,100	29.27	215,100	29.27	0	0.00%	1,106,500	84.79	1,106,500	84.79	0	0.00%
B22 Ceiling Finishes			182,800	24.87	182,800	24.87	0	0.00%	904,300	69.30	904,300	69.30	0	0.00%
B23 Wall Finishes			130,600	17.77	130,600	17.77	0	0.00%	1,216,100	93.19	1,216,100	93.19	0	0.00%
B3 FITTINGS & EQUIPMENT			507,500	69.05	507,500	69.05	0	0.00%	3,161,300	242.25	3,161,300	242.25	0	0.00%
B31 Fittings & Fixtures			247,500	33.67	247,500	33.67	0	0.00%	1,532,600	117.44	1,532,600	117.44	0	0.00%
B32 Equipment			60,000	8.16	60,000	8.16	0	0.00%	963,400	73.82	963,400	73.82	0	0.00%
B33 Elevators			200,000	27.21	200,000	27.21	0	0.00%	665,300	50.98	665,300	50.98	0	0.00%
C SERVICES			1,201,900	163.52	1,201,900	163.52	0	0.00%	11,066,900	848.04	11,066,900	848.04	0	0.00%
C1 MECHANICAL			783,700	106.63	783,700	106.63	0	0.00%	7,800,200	597.72	7,800,200	597.72	0	0.00%
C11 Plumbing & Drainage			267,700	36.42	267,700	36.42	0	0.00%	2,351,000	180.15	2,351,000	180.15	0	0.00%
C12 Fire Protection			227,900	31.01	227,900	31.01	0	0.00%	573,700	43.96	573,700	43.96	0	0.00%
C13 HVAC			235,200	32.00	235,200	32.00	0	0.00%	4,379,600	335.60	4,379,600	335.60	0	0.00%
C14 Controls			52,900	7.20	52,900	7.20	0	0.00%	495,900	38.00	495,900	38.00	0	0.00%
C2 ELECTRICAL			418,200	56.90	418,200	56.90	0	0.00%	3,266,700	250.32	3,266,700	250.32	0	0.00%
C21 Service and Distribution			143,400	19.51	143,400	19.51	0	0.00%	1,038,800	79.60	1,038,800	79.60	0	0.00%
C22 Lighting, Devices and Heating			183,800	25.01	183,800	25.01	0	0.00%	1,513,500	115.98	1,513,500	115.98	0	0.00%
C23 Systems and Ancillaries			91,000	12.38	91,000	12.38	0	0.00%	714,400	54.74	714,400	54.74	0	0.00%
NET BUILDING COST - EXCLUDING SITE			14,381,400	1,956.65	15,016,900	2,043.12	(635,500)	-4.42%	40,925,200	3,136.03	39,412,900	3,020.15	1,512,300	3.70%
D SITE & ANCILLARY WORK			0	0.00	0	0.00	0	0.00%	1,014,900	77.77	1,014,900	77.77	0	0.00%
D1 SITE WORK			0	0.00	0	0.00	0	0.00%	1,014,900	77.77	1,014,900	77.77	0	0.00%
D11 Site Development			0	0.00	0	0.00	0	0.00%	589,700	45.19	589,700	45.19	0	0.00%
D12 Mechanical Site Services			0	0.00	0	0.00	0	0.00%	236,000	18.08	236,000	18.08	0	0.00%
D13 Electrical Site Services			0	0.00	0	0.00	0	0.00%	189,200	14.50	189,200	14.50	0	0.00%
D2 ANCILLARY WORK			0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%
D21 Demolition			0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%
D22 Alterations			0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%
NET BUILDING COST - INCLUDING SITE			14,381,400	1,956.65	15,016,900	2,043.12	(635,500)	-4.42%	$41,940,100	2,672.71	$40,427,800	2,576.33	1,512,300	3.61%
Z GENERAL REQ'S & ALLOWANCES			4,438,300	603.85	5,116,700	696.15	-678,400	-15.29%	12,943,300	824.83	13,775,200	877.85	-831,900	-6.43%
Z1 GENERAL REQUIREMENTS & FEE	M. Timber	Concrete	1,912,700	260.23	2,414,800	328.54	(502,100)	-26.25%	5,578,000	355.47	6,501,200	414.30	(923,200)	-16.55%
Z10 Location Factor	0.00%	0.00%	0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%
Z11 General Requirements	10.00%	12.70%	1,438,100	195.66	1,907,100	259.47	(469,000)	-32.61%	4,194,000	267.27	5,134,300	327.19	(940,300)	-22.42%
Z12 Fee	3.00%	3.00%	474,600	64.57	507,700	69.07	(33,100)	-6.97%	1,384,000	88.20	1,366,900	87.11	17,100	1.24%
TOTAL CONSTRUCTION ESTIMATE - EXCLUDING CONTINGENCIES			16,294,100	2,216.88	17,431,700	2,371.66	-1,137,600	-6.98%	47,518,100	3,028.17	46,929,000	2,990.63	589,100	1.24%
Z2 ALLOWANCES			2,525,600	343.62	2,701,900	367.61	(176,300)	-6.98%	7,365,300	469.37	7,274,000	463.55	91,300	1.24%
Z21 Design & Pricing Allowance	10.00%	10.00%	1,629,400	221.69	1,743,200	237.17	(113,800)	-6.98%	4,751,800	302.82	4,692,900	299.06	58,900	1.24%
Z22 Escalation Allowance	0.00%	0.00%	0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%
Z23 Construction Allowance	5.00%	5.00%	896,200	121.93	958,700	130.44	(62,500)	-6.97%	2,613,500	166.55	2,581,100	164.49	32,400	1.24%
TOTAL CONSTRUCTION ESTIMATE - INCLUDING CONTINGENCIES			18,819,700	2,560.50	20,133,600	2,739.27	-1,313,900	-6.98%	54,883,400	3,497.54	54,203,000	3,454.18	680,400	1.24%
GOODS & SERVICES TAX			0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
TOTAL CONSTRUCTION ESTIMATE			$18,819,700	2,560.50	$20,133,600	2,739.27	-$1,313,900	-6.98%	$54,883,400	3,497.54	$54,203,000	3,454.18	$680,400	1.24%

												OVERALL CONSTRUCTION COST					
LEVEL 10 - 12 (additional 3 levels)						TOTAL (12 levels)											
A. MASS TIMBER		B. CONCRETE		VARIANCE (A-B)		A. MASS TIMBER		B. CONCRETE		VARIANCE (A-B)		A. MASS TIMBER		B. CONCRETE		VARIANCE (A-B)	
GFA	2,642 m2	GFA	2,642 m2			GFA	15,692 m2	GFA	15,692 m2			GFA	23,042 m2	GFA	23,042 m2		
Total ($)	($/m2)	Total ($)	($/m2)	Total ($)	Percent	Total ($)	($/m2)	Total ($)	($/m2)	Total ($)	Percent	Total ($)	($/m2)	Total ($)	($/m2)	Total ($)	Percent
3,334,900	1,262.26	3,050,200	1,154.50	284,700	8.54%	21,282,600	1,356.27	19,485,600	1,241.75	1,797,000	8.44%	33,100,500	1,436.53	31,939,000	1,386.12	1,161,500	3.51%
0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%	5,039,900	218.73	5,228,600	226.92	(188,700)	-3.74%
0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%	1,407,200	61.07	1,679,300	72.88	(272,100)	-19.34%
0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%	3,212,700	139.43	3,289,300	142.75	(76,600)	-2.38%
0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%	420,000	18.23	260,000	11.28	160,000	38.10%
2,165,900	819.80	1,881,200	712.04	284,700	13.14%	13,903,500	886.02	12,106,500	771.51	1,797,000	12.92%	18,988,400	824.08	17,638,200	765.48	1,350,200	7.11%
0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%	147,100	6.38	147,100	6.38	0	0.00%
2,165,900	819.80	1,881,200	712.04	284,700	13.14%	12,864,000	819.78	11,173,100	712.03	1,690,900	13.14%	17,276,100	749.77	16,032,000	695.77	1,244,100	7.20%
0	0.00	0	0.00	0	0.00%	1,039,500	66.24	933,400	59.48	106,100	10.21%	1,565,200	67.93	1,459,100	63.32	106,100	6.78%
1,169,000	442.47	1,169,000	442.47	0	0.00%	7,379,100	470.25	7,379,100	470.25	0	0.00%	9,072,200	393.72	9,072,200	393.72	0	0.00%
0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%	1,486,500	64.51	1,486,500	64.51	0	0.00%
510,400	193.19	510,400	193.19	0	0.00%	3,031,600	193.19	3,031,600	193.19	0	0.00%	3,031,600	131.57	3,031,600	131.57	0	0.00%
263,000	99.55	263,000	99.55	0	0.00%	1,562,000	99.54	1,562,000	99.54	0	0.00%	1,592,000	69.09	1,592,000	69.09	0	0.00%
0	0.00	0	0.00	0	0.00%	436,100	27.79	436,100	27.79	0	0.00%	612,700	26.59	612,700	26.59	0	0.00%
395,600	149.74	395,600	149.74	0	0.00%	2,349,400	149.72	2,349,400	149.72	0	0.00%	2,349,400	101.96	2,349,400	101.96	0	0.00%
2,411,300	912.68	2,411,300	912.68	0	0.00%	14,321,900	912.69	14,321,900	912.69	0	0.00%	15,683,500	680.65	15,683,500	680.65	0	0.00%
1,118,000	423.16	1,118,000	423.16	0	0.00%	6,640,400	423.17	6,640,400	423.17	0	0.00%	6,966,000	302.32	6,966,000	302.32	0	0.00%
855,400	323.77	855,400	323.77	0	0.00%	5,080,800	323.78	5,080,800	323.78	0	0.00%	5,377,000	233.36	5,377,000	233.36	0	0.00%
262,600	99.39	262,600	99.39	0	0.00%	1,559,600	99.39	1,559,600	99.39	0	0.00%	1,589,000	68.96	1,589,000	68.96	0	0.00%
653,300	247.27	653,300	247.27	0	0.00%	3,880,200	247.27	3,880,200	247.27	0	0.00%	4,408,700	191.33	4,408,700	191.33	0	0.00%
224,000	84.78	224,000	84.78	0	0.00%	1,330,500	84.79	1,330,500	84.79	0	0.00%	1,545,600	67.08	1,545,600	67.08	0	0.00%
183,100	69.30	183,100	69.30	0	0.00%	1,087,400	69.30	1,087,400	69.30	0	0.00%	1,270,200	55.13	1,270,200	55.13	0	0.00%
246,200	93.19	246,200	93.19	0	0.00%	1,462,300	93.19	1,462,300	93.19	0	0.00%	1,592,900	69.13	1,592,900	69.13	0	0.00%
640,000	242.24	640,000	242.24	0	0.00%	3,801,300	242.24	3,801,300	242.24	0	0.00%	4,308,800	187.00	4,308,800	187.00	0	0.00%
310,300	117.45	310,300	117.45	0	0.00%	1,842,900	117.44	1,842,900	117.44	0	0.00%	2,090,400	90.72	2,090,400	90.72	0	0.00%
195,000	73.81	195,000	73.81	0	0.00%	1,158,400	73.82	1,158,400	73.82	0	0.00%	1,218,400	52.88	1,218,400	52.88	0	0.00%
134,700	50.98	134,700	50.98	0	0.00%	800,000	50.98	800,000	50.98	0	0.00%	1,000,000	43.40	1,000,000	43.40	0	0.00%
2,240,400	847.99	2,240,400	847.99	0	0.00%	13,307,300	848.03	13,307,300	848.03	0	0.00%	14,509,200	629.68	14,509,200	629.68	0	0.00%
1,579,100	597.69	1,579,100	597.69	0	0.00%	9,379,300	597.71	9,379,300	597.71	0	0.00%	10,163,000	441.06	10,163,000	441.06	0	0.00%
476,000	180.17	476,000	180.17	0	0.00%	2,827,000	180.16	2,827,000	180.16	0	0.00%	3,094,700	134.31	3,094,700	134.31	0	0.00%
116,100	43.94	116,100	43.94	0	0.00%	689,800	43.96	689,800	43.96	0	0.00%	917,700	39.83	917,700	39.83	0	0.00%
886,600	335.58	886,600	335.58	0	0.00%	5,266,200	335.60	5,266,200	335.60	0	0.00%	5,501,400	238.76	5,501,400	238.76	0	0.00%
100,400	38.00	100,400	38.00	0	0.00%	596,300	38.00	596,300	38.00	0	0.00%	649,200	28.17	649,200	28.17	0	0.00%
661,300	250.30	661,300	250.30	0	0.00%	3,928,000	250.32	3,928,000	250.32	0	0.00%	4,346,200	188.62	4,346,200	188.62	0	0.00%
210,300	79.60	210,300	79.60	0	0.00%	1,249,100	79.60	1,249,100	79.60	0	0.00%	1,392,500	60.43	1,392,500	60.43	0	0.00%
306,400	115.97	306,400	115.97	0	0.00%	1,819,900	115.98	1,819,900	115.98	0	0.00%	2,003,700	86.96	2,003,700	86.96	0	0.00%
144,600	54.73	144,600	54.73	0	0.00%	859,000	54.74	859,000	54.74	0	0.00%	950,000	41.23	950,000	41.23	0	0.00%
7,986,600	3,022.94	7,701,900	2,915.18	284,700	3.56%	48,911,800	3,116.99	47,114,800	3,002.47	1,797,000	3.67%	63,293,200	2,746.86	62,131,700	2,696.45	1,161,500	1.84%
0	0.00	0	0.00	0	0.00%	1,014,900	64.68	1,014,900	64.68	0	0.00%	1,014,900	44.05	1,014,900	44.05	0	0.00%
0	0.00	0	0.00	0	0.00%	1,014,900	64.68	1,014,900	64.68	0	0.00%	1,014,900	44.05	1,014,900	44.05	0	0.00%
0	0.00	0	0.00	0	0.00%	589,700	37.58	589,700	37.58	0	0.00%	589,700	25.59	589,700	25.59	0	0.00%
0	0.00	0	0.00	0	0.00%	236,000	15.04	236,000	15.04	0	0.00%	236,000	10.24	236,000	10.24	0	0.00%
0	0.00	0	0.00	0	0.00%	189,200	12.06	189,200	12.06	0	0.00%	189,200	8.21	189,200	8.21	0	0.00%
0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%
0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%
0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%
$7,986,600	3,022.94	$7,701,900	2,915.18	284,700	3.56%	$49,926,700	3,181.67	$48,129,700	3,067.15	1,797,000	3.60%	64,308,100	2,790.91	$63,146,600	2,740.50	1,161,500	1.81%
2,464,900	932.97	2,612,100	988.68	-147,200	-5.97%	15,408,200	981.91	16,387,300	1,044.31	-979,100	-6.35%	19,846,500	861.32	21,504,000	933.25	-1,657,500	-8.35%
1,062,300	402.08	1,228,000	464.80	(165,700)	-15.60%	6,640,300	423.16	7,729,200	492.56	(1,088,900)	-16.40%	8,553,000	371.19	10,144,000	440.24	(1,591,000)	-18.60%
0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%
798,700	302.31	967,900	366.35	(169,200)	-21.18%	4,992,700	318.17	6,102,200	388.87	(1,109,500)	-22.22%	6,430,800	279.09	8,009,300	347.60	(1,578,500)	-24.55%
263,600	99.77	260,100	98.45	3,500	1.33%	1,647,600	105.00	1,627,000	103.68	20,600	1.25%	2,122,200	92.10	2,134,700	92.64	(12,500)	-0.59%
9,048,900	3,425.02	8,929,900	3,379.98	119,000	1.32%	56,567,000	3,604.83	55,858,900	3,559.71	708,100	1.25%	72,861,100	3,162.10	73,290,600	3,180.74	-429,500	-0.59%
1,402,600	530.89	1,384,100	523.88	18,500	1.32%	8,767,900	558.75	8,658,100	551.75	109,800	1.25%	11,293,500	490.13	11,360,000	493.01	(66,500)	-0.59%
904,900	342.51	893,000	338.00	11,900	1.32%	5,656,700	360.48	5,585,900	355.97	70,800	1.25%	7,286,100	316.21	7,329,100	318.08	(43,000)	-0.59%
0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%	0	0.00	0	0.00	0	0.00%
497,700	188.38	491,100	185.88	6,600	1.33%	3,111,200	198.27	3,072,200	195.78	39,000	1.25%	4,007,400	173.92	4,030,900	174.94	(23,500)	-0.59%
10,451,500	3,955.90	10,314,000	3,903.86	137,500	1.32%	65,334,900	4,163.58	64,517,000	4,111.46	817,900	1.25%	84,154,600	3,652.23	84,650,600	3,673.75	-496,000	-0.59%
0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
$10,451,500	3,955.90	$10,314,000	3,903.86	$137,500	1.32%	$65,334,900	4,163.58	$64,517,000	4,111.46	$817,900	1.25%	$84,154,600	3,652.23	$84,650,600	3,673.75	-$496,000	-0.59%

1.41. EMTC L TOWER – CITY OF COQUITLAM ENERGY PERFORMANCE MAP

Step 3 designs are practically identical to that of the Vancouver archetype. This result is justifiable since the Coquitlam archetype was simulated with the same weather data as the Vancouver archetype and all variables remained the same, except for the nominally more articulated massing (VFAR=0.5).

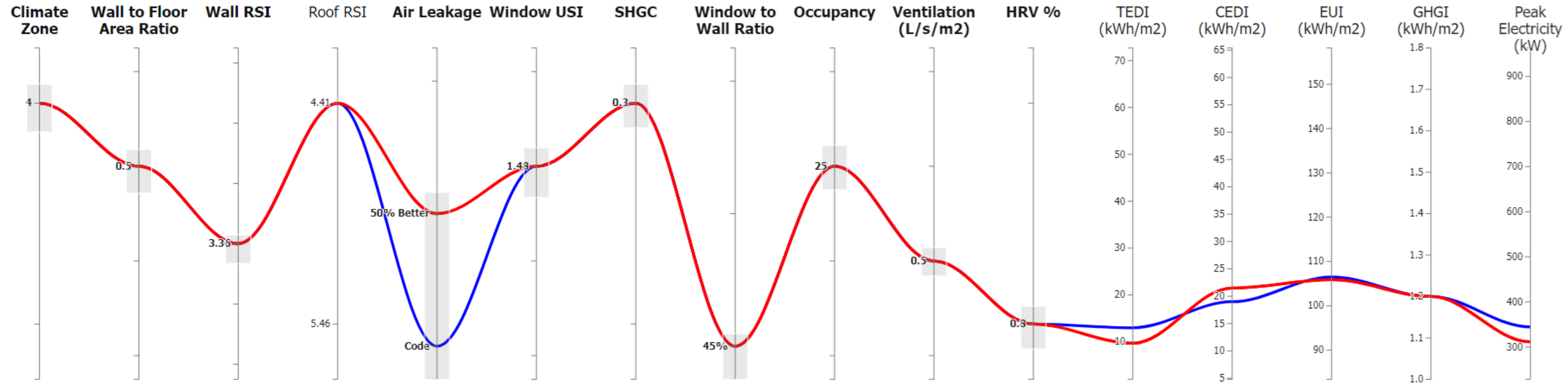


Figure 29: Step 3 and 4 EMTC designs in Coquitlam, B.C.

1.42. EMTC L TOWER – CITY OF COQUITLAM ENERGY MODELLING RESULTS

	Coquitlam	
	Step 3	Step 4
	EMTC	EMTC
Wall RSI	3.36	3.36
Roof RSI	4.41	4.41
Air Leakage	50% Imp	50% Imp
Window USI/SHGC	1.48/0.3	1.48/0.3
WWR	45%	45%
HRV	80%	80%
DHW	Elec	Elec

1.43. STEEL AND CONCRETE L TOWER – CITY OF COQUITLAM ENERGY PERFORMANCE MAP

Step 3 designs are also identical to Vancouver. However, Step 4 designs require a nominally higher R-value and reduced WWR, which follow a similar methodology to that of the Kamloops typology.

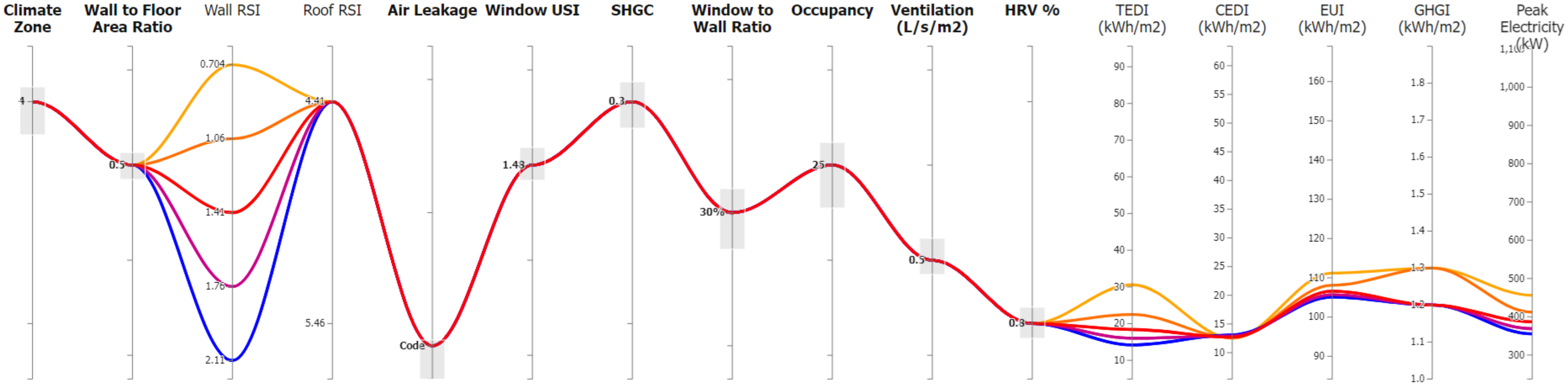


Figure 30: Likely Step 4 concrete design in Coquitlam, B.C.

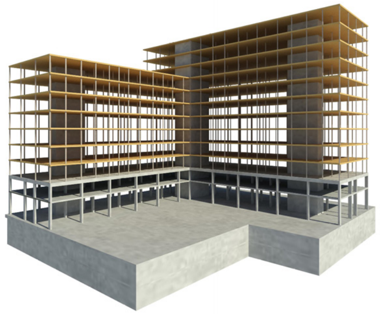
This scenario can be seen in Figure 30, where the TEDI threshold is only achieved with RSI-2.11 walls and 30% WWR. As discussed above, the slightly poorer massing than the Vancouver archetype ultimately explains the slightly different design requirement.

1.44. STEEL AND CONCRETE L TOWER – CITY OF COQUITLAM ENERGY MODELLING RESULTS

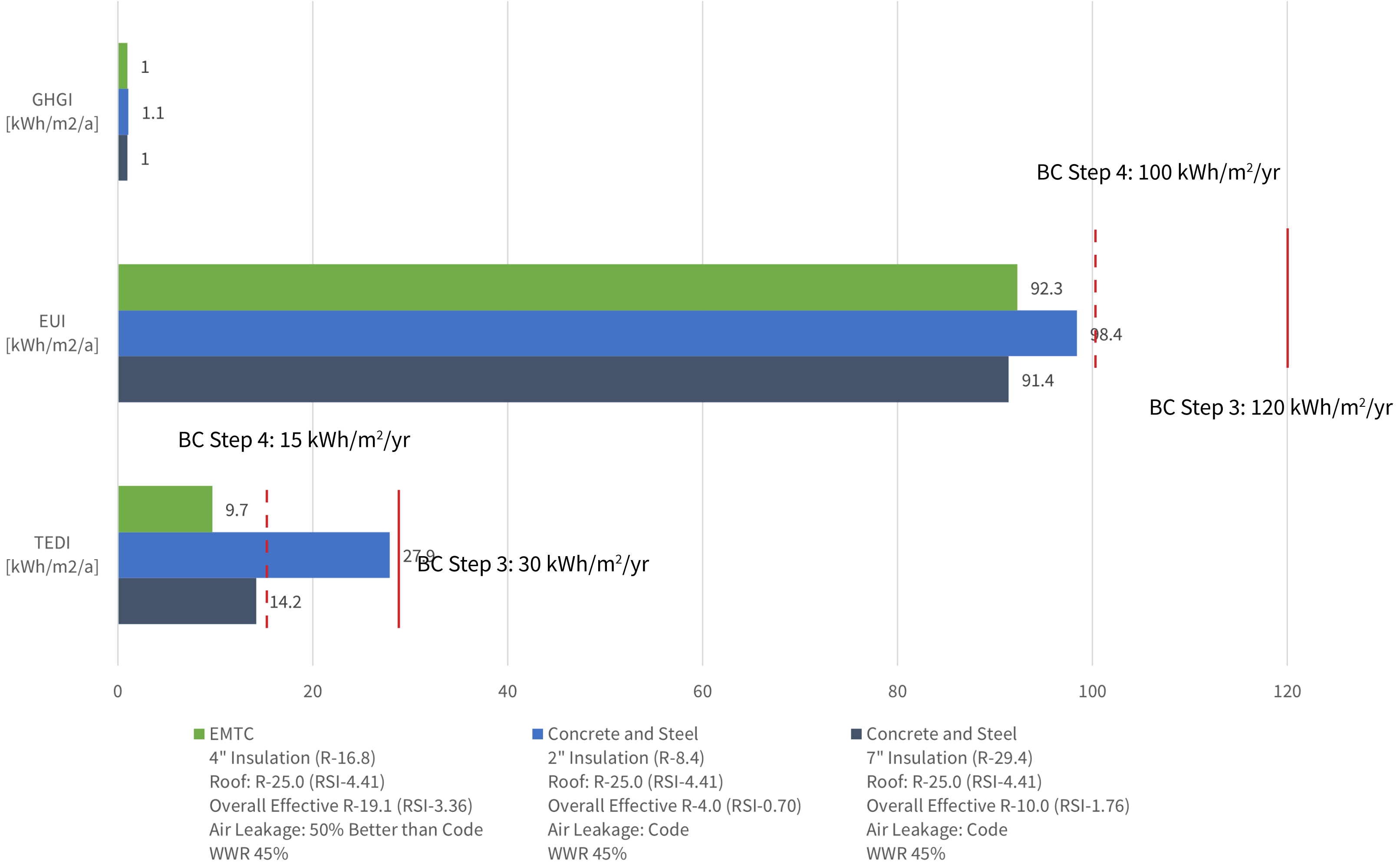
	Coquitlam	
	Step 3	Step 4
	CS	CS
Wall RSI	0.7	2.11
Roof RSI	4.41	4.41
Air Leakage	Code	Code
Window USI/SHGC	1.48/0.3	1.48/0.3
WWR	45%	30%
HRV	80%	80%
DHW	Elec	Elec

1.45. SUMMARY OF L TOWER ENERGY PERFORMANCE – CITY OF COQUITLAM

BC Housing Sustainability Guidelines prescriptive criteria for window and heat recovery performance can already achieve good overall energy performance.



- Coquitlam, B.C., VFAR: 0.50



Mass Timber is a Solution for Energy Performance

Despite a significant amount of well-documented research on the characteristics and performance of mass timber structural systems and products, there has been less done on the cost implications and affordability factors of these buildings above storeys. Even less has been done on meeting the requirements of the BC Energy Step Code. Cost is a major driver and constraint for decisions at every stage of building projects. The lack of information is indicative of market uncertainty and technology gaps. The research for this project includes investigation of supply chain products and services relevant to the widespread adoption of mass timber as a primary building construction material.

Significant savings for each project phase can be realized with digital twins, design automation, analytics-based modelling, and simulation technologies. A digital twin is a virtual representation of a physical, real-world entity at a scale of 1:1. This enables the behaviour of the digital replica to be simulated, analyzed, and optimized in digital form, performing a digital "rehearsal" to fully resolve the building design and optimize its performance before it is built. Although design costs typically amount to only 5-10% of asset costs, the decisions made during this phase are critical for the construction phase and for determining the operating costs of the high-performance building.

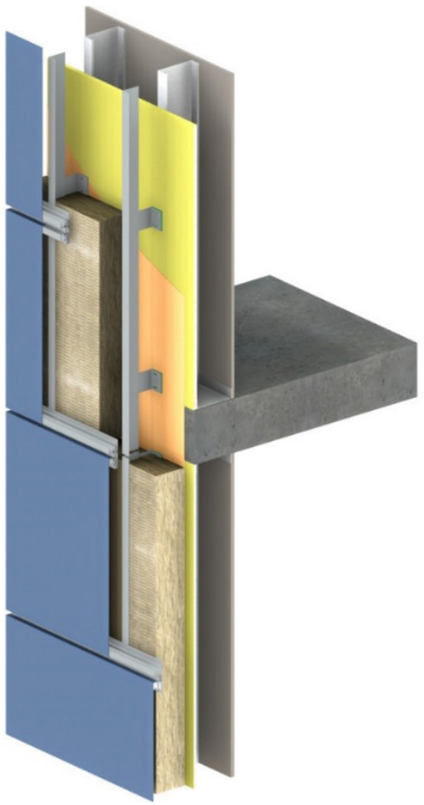
The BC Housing Sustainability Guidelines outline criteria for window and heat recovery performance on projects that, when combined, help achieve energy performance goals. This was especially apparent in Step 3 for both EMTC and steel and concrete construction. High WWR and standard airtightness and standard airtightness were sufficient for compliance with targets; however, Step 4 designs for all typologies are gradually more restrictive for the steel and concrete cases:

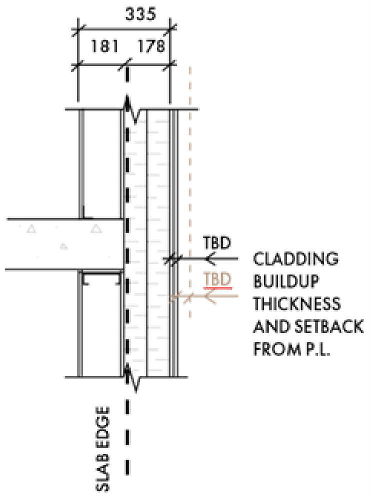
- While the comparative steel and concrete Vancouver Point Tower can comply with a high WWR, its steel stud wall assembly would require a 7" exterior insulated wall assembly.
- With the nominally less optimized massing for the Coquitlam Slab Tower, the steel stud wall assembly instead requires an, 8" exterior insulated wall assembly and a reduced WWR of 30% .
- In Kamloops, the "L" Tower typology building envelope design mimics that of Coquitlam's except that the WWR is further reduced to 15%.

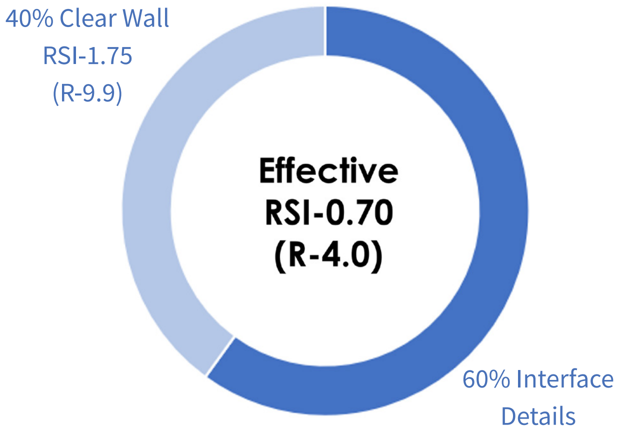
Photo of CLT in Production. (Kalesnikoff)

Building Perspective - Rendering of EMTC “L” Tower – Maple Creek, Coquitlam

1.46. STEEL AND CONCRETE EXTERIOR WALL WITH 45% WINDOW TO WALL RATIO (WWR) IN VANCOUVER, B.C.

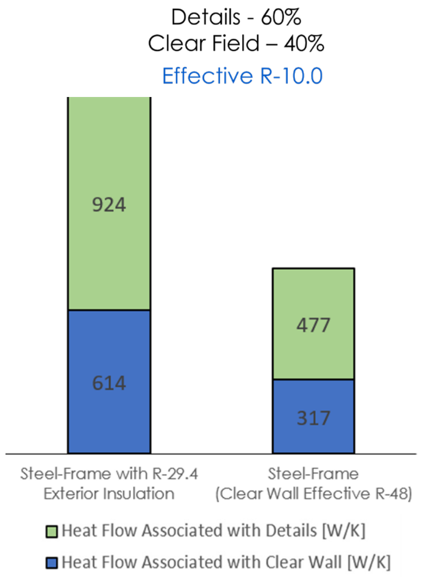




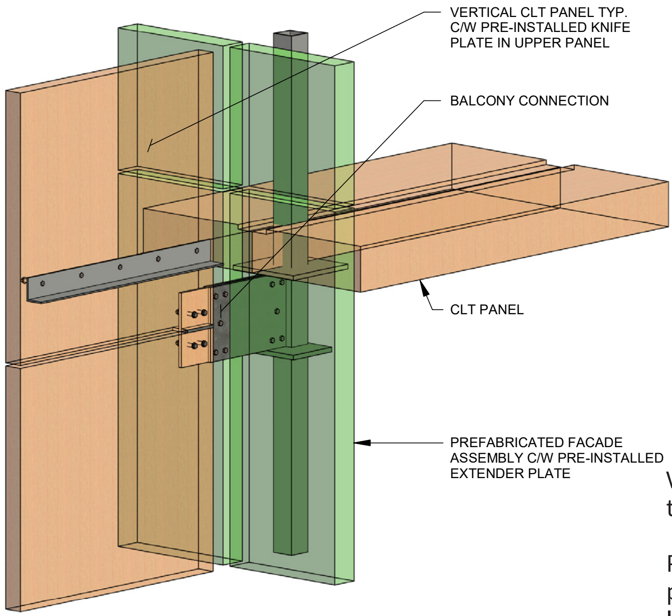


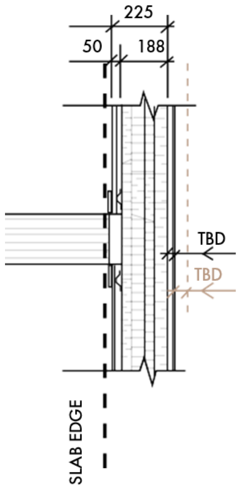
Detail	Linear Transmittance Ψ Btu/h.ft°F (W/mK)
Intermediate Floor	0.020 (0.034)
Window Interface	0.182 (0.315)
Balcony (Knife Edge)	0.444 (0.769)

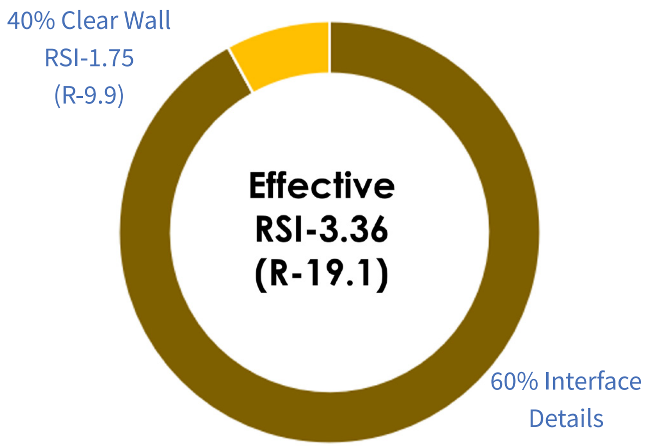
VBBL Low Carbon Energy System credit reduces the TEDI target requirement from < 30 to < 39.6 for Step Code 3	Yes - all-electric HP and VRF system
Part 2 - Where the VBBL requirements specify thermal performance with a maximum Thermal Energy Demand Intensity (TEDI) value rather than a minimum insulation value, the following formula may be used: (Required TEDI value - Proposed TEDI value) / Required TEDI value) * (Total thickness of insulation).	((39.6 – 23.4) / 39.6) * (178 mm) = 72.8mm
Part 3 - Within walls that exceed 203 mm in total thickness, exclusion may be sought for the area occupied by the rain screen elements as verified by a Building Envelope Professional, to a maximum exclusion of 152 mm. This exclusion can be combined with the exclusions in part 1 and 2 of this guide if the application meets the criteria for each exclusion. Regulations that limit building size remain in effect, except that for repairs to leaky walls, setback relaxations can be considered by the Director of Planning.	Rainscreen = 25mm Cladding = 60mm
Total VBBL FSR Exclusion allowed for the Assembly (maximum allowed 179mm)	160mm



1.47. EMTC FACADE DESIGN WITH 45% WINDOW TO WALL RATIO (WWR) IN VANCOUVER, B.C.

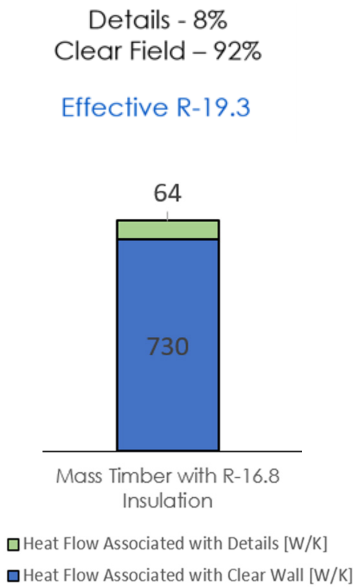






VBBL Low Carbon Energy System credit reduces the TEDI target requirement from < 30 to < 39.6 for Step Code 3	Yes - all-electric HP and VRF system
Part 2 - Where the VBBL requirements specify thermal performance with a maximum Thermal Energy Demand Intensity (TEDI) value rather than a minimum insulation value, the following formula may be used: (Required TEDI value - Proposed TEDI value) / Required TEDI value) * (Total thickness of insulation)	((39.6 – 7.9) / 39.6) * (225 mm) = 180 mm
Part 3 - Within walls that exceed 203 mm in total thickness, exclusion may be sought for the area occupied by the rain screen elements as verified by a Building Envelope Professional, to a maximum exclusion of 152 mm. This exclusion can be combined with the exclusions in part 1 and 2 of this guide if the application meets the criteria for each exclusion. Regulations that limit building size remain in effect, except that for repairs to leaky walls, setback relaxations can be considered by the Director of Planning.	Rainscreen = 25mm Cladding = 60mm
Total VBBL FSR Exclusion allowed for the Assembly (maximum allowed 179mm)	265mm

Detail	Linear Transmittance Ψ Btu/h.ft°F (W/mK)	Point Transmittance χ Btu/h°F (W/K)
Intermediate Floor	0.013 (0.023)	
Window Interface	0.008 (0.014)	
Balcony (Knife Edge)		0.514 (0.271)



1.48. BUILDING ENVELOPE PERFORMANCE – REPEATABLE EMTC STRUCTURE AND FAÇADE SYSTEM

The Step 3 and Step 4 EMTC structure and façade designs developed for the study may be considered a ‘prescription’ for future projects since they are relatively straightforward. In this regard, regulators may consider a higher performance target in the future for these designs that could further separate EMTC from conventional construction. Alternatively, current prescriptive standards in the guidelines could be relaxed to offer a ‘trade-off’ for very good envelope performance. For example, relaxing the U-values of windows or reducing the minimum heat recovery effectiveness is a good trade-off.

While designs in this report are achieving very low TEDI in some cases, ultimately EUI needs to be addressed for low operational energy (ie. “net-zero ready” or Step 5 of the BC Energy Step Code). This will only be achievable if teams are aggressively pursuing non-envelope measures in Part 3 buildings such as energy efficient household appliances and plug loads, efficient and smart lighting designs, heat pump-based corridor makeup air, domestic hot water systems, and/or drain water heat recovery systems.

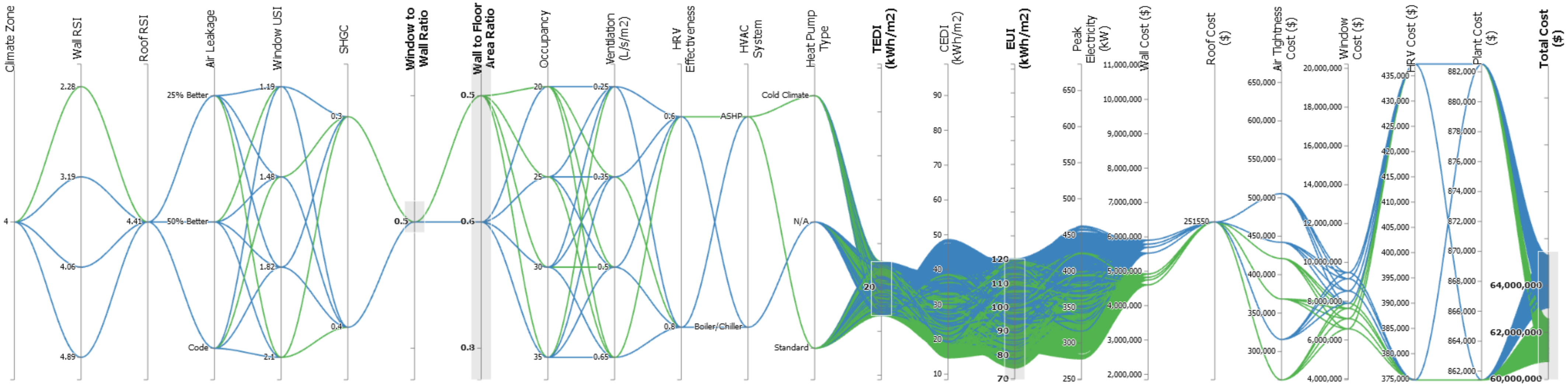


Figure 31: Demonstrating repeatable design constrained to more desirable 50% glazing area for climate zone 4 in B.C.

Policy levers or incentives addressing EUI beyond Step 4 may be the next logical consideration for residential buildings in British Columbia. This comparison develops an understanding of the affordability factor of mass-timber construction in competition with concrete for constructing an energy efficient building. The development of architectural and structural design in conjunction with façade - building envelope, energy modeling, building code, and sustainable performance has been analyzed by quantity surveyors to create benchmarking and an accurate assessment of EMTC cost and influencing factors specific to site specific development in the Interior/ North and in the Lower Mainland of British Columbia.

High Performance Building Goals:

- Minimize heat loss through the opaque envelope.
- Reduce heat loss through walls, roofs, floors.
- Improve detailing before adding insulation to assemblies.
- Minimize thermal bridging in assemblies and interface details.
- Reduce complex architectural features that contribute to thermal bridging.

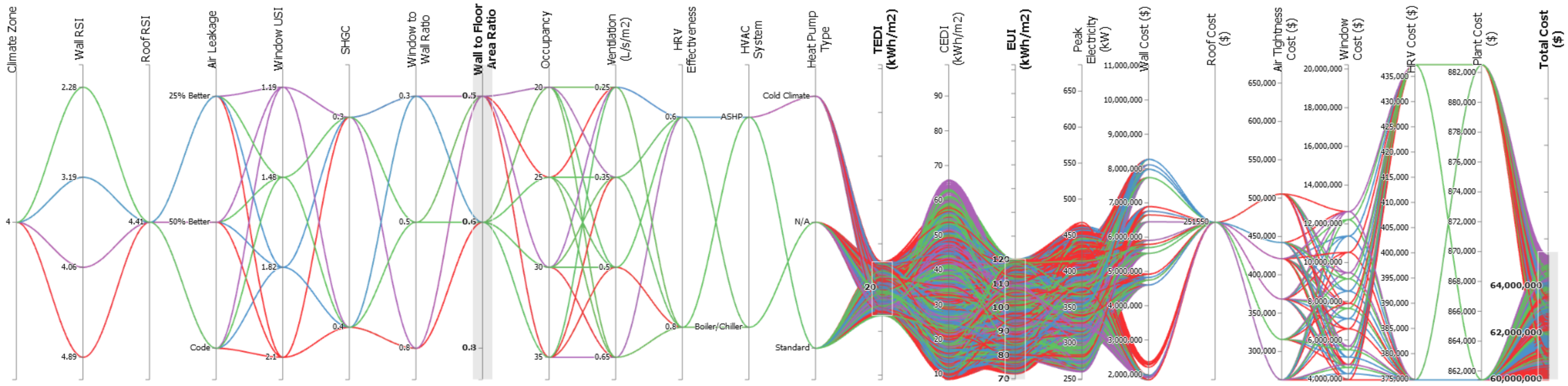


Figure 32: Demonstrating the impact of Wall to Floor Area Ratio (VFAR) for best value, low TEDI with total project cost fixed at < $65,000,000

1.49. REGIONAL ARCHETYPE COMPLIANCE – REPEATABLE EMTC STRUCTURE AND FAÇADE SYSTEM

	Vancouver				Kamloops				Coquitlam			
	Step 3		Step 4		Step 3		Step 4		Step 3		Step 4	
	EMTC	CS	EMTC	CS	EMTC	CS	EMTC	CS	EMTC	CS	EMTC	CS
Wall RSI	3.36	0.7	3.36	1.76	3.36	1.06	3.36	2.11	3.36	0.7	3.36	2.11
Roof RSI	4.41	4.41	4.41	4.41	5.46	5.46	5.46	5.46	4.41	4.41	4.41	4.41
Air Leakage	50% Imp	Code	50% Imp	Code	50% Imp	Code	50% Imp	Code	50% Imp	Code	50% Imp	Code
Window USI/SHGC	1.48/0.3	1.48/0.3	1.48/0.3	1.48/0.3	1.48/0.3	1.48/0.3	1.48/0.3	1.48/0.3	1.48/0.3	1.48/0.3	1.48/0.3	1.48/0.3
WWR	45%	45%	45%	45%	45%	45%	45%	15%	45%	45%	45%	30%
HRV	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%
DHW	Elec	Elec	Elec	Elec	Elec	Elec	Elec	Elec	Elec	Elec	Elec	Elec
TEDI	7.9	23.4	7.9	13.9	17.4	33.5	17.4	22.2	9.7	27.9	9.7	14.2
EUI	91.1	96.1	91.1	92.7	101.6	108.6	101.6	98.5	92.3	98.4	92.3	91.4
GHGI	1.0	1.0	1.0	1.0	1.1	1.2	1.1	1.1	1.0	1.1	1.0	1.0
Estimated Mass Timber Assembly Exterior Insulation Required (8.3.9)	2”		2”		2”		2”		2”		2”	
Estimated Steel Framed Assembly Exterior Insulation Required (5.1.24)		2”		7”		4”		8”		2”		8”
Estimated Annual Electricity Consumption (kWh/yr)	1,065,870	1,124,370	1,065,870	1,084,590	1,560,576	1,668,096	1,560,576	1,512,960	2,126,777	2,267,33	2,126,777	2,106,039
Effective R-Value		3.97		9.99		6.02		11.98		3.97		11.98
Clear Wall R value		9.94		24.98		15.05		26.62		9.94		26.62

The table above provides an energy performance summary of Step 3 and Step 4 designs per Region/ Typology comparing likely compliant designs outlined from the energy simulations. This table demonstrates repeatable design advantages and capability for EMTC implementation across all three regional archetypes.

When accounting for the thermal bridging losses of the steel stud framed exterior wall construction, up to 8” of exterior insulation may be required to achieve the effective R-values in the model as shown.

For comparison, all EMTC archetypes shown only require RSI-3.36 walls which are achievable with a minimum of 2” exterior mineral wool insulation.

Comparison of Regional Archetype Schedules

An effective construction schedule includes the sequence of activities, associated durations and resources needed to complete the tasks, especially when there is a high level of sequencing overlap with both structure and facade. Overall project schedule requirements (dates of completion) are typically established by the building owner and then managed by the GC/CM. Specialty subcontractors then use the master schedule to determine their schedule requirements. A project schedule is a collaborative effort between the GM/CM and specialty contractors, which reinforces the need for early procurement. Creating a comprehensive schedule and maintaining communication between all parties, then, is vital for project success.

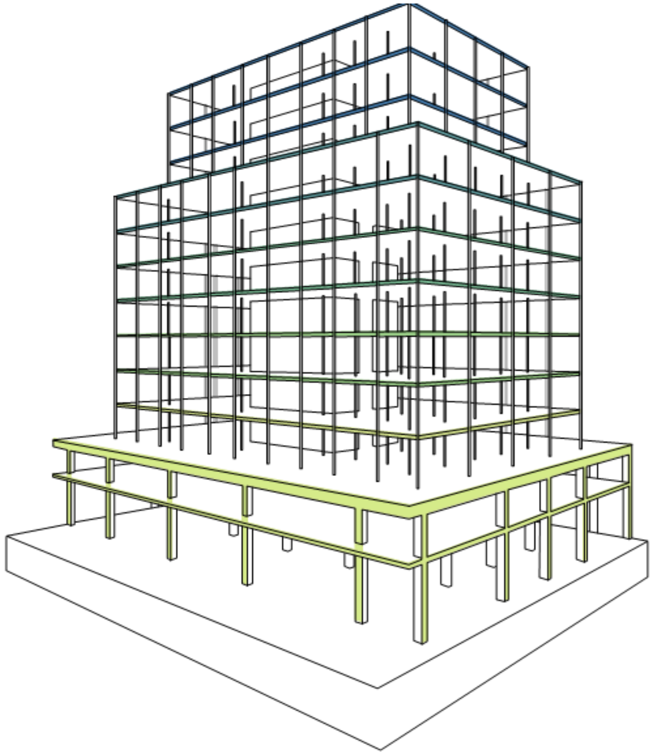
The mass timber subcontractor or self-performing GC/CM needs to identify all required activities, key milestones and constraints. They also need to communicate clearly with the owner and/or consultants to ensure alignment with other aspects of the project. Using mass timber requires extensive decision making during the preconstruction process to avoid delays on site. Shifting the preplanning, coordination and decision making to an earlier stage in the project does not necessarily increase the fees associated with design and preconstruction; rather, it shifts the timing of the fees within the overall project schedule. When properly executed, the delivery of the EMTC superstructure is accelerated and allows for compression of subsequent follow-on activities, further decreasing the critical path of the schedule. These are benefits that owners and developers can leverage to their advantage. Having a clear plan of the full project spectrum prior to complete tender of the rest of the building/ project can reduce risk of scope creep, change orders for incomplete design or coordination, escalation cost, and associated mitigation costs, whether they are derived from financing or Insurance requirements.

When preparing the schedule, it is critical to allocate adequate time for shop drawing creation, review and approvals. During the shop drawing stage, dimensional errors and constructability issues are often discovered in the digital twin through clash-detection processes with other BIM workflows, prompting additional collaboration between stakeholders. It is more cost-effective to resolve these issues before construction than to discover them in the field. The GC/CM, mass timber fabricator, mass timber installer and specialty subcontractors establish and coordinate sequencing installation of the building's structural frame and prefabricated facade. To provide an accurate and meaningful schedule, it is important to have all the necessary information and data coordinated with the digital twin model and planning. If information and data are missing, misunderstood or incomplete, the schedule and sequencing will require later revisions, which may adversely affect the mass timber installation.

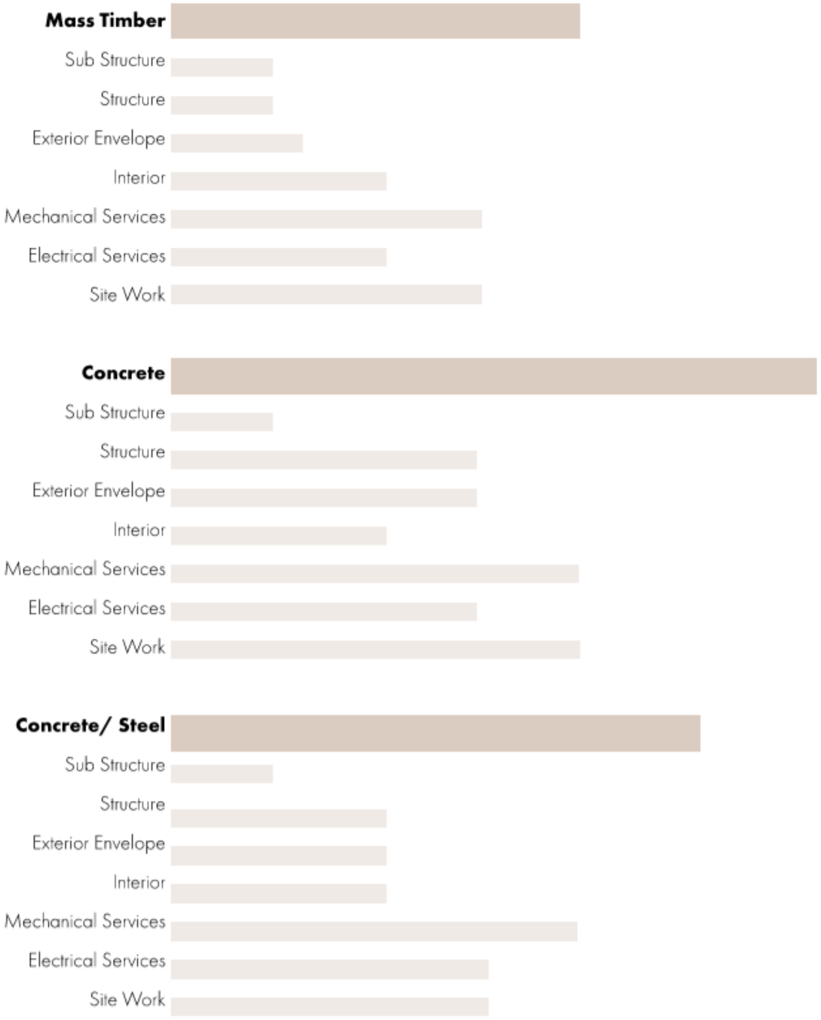
Photos of CLT Production. (Kalesnikoff)

1.50. SPEED OF EMTC OVERALL - POINT TOWER, CITY OF VANCOUVER

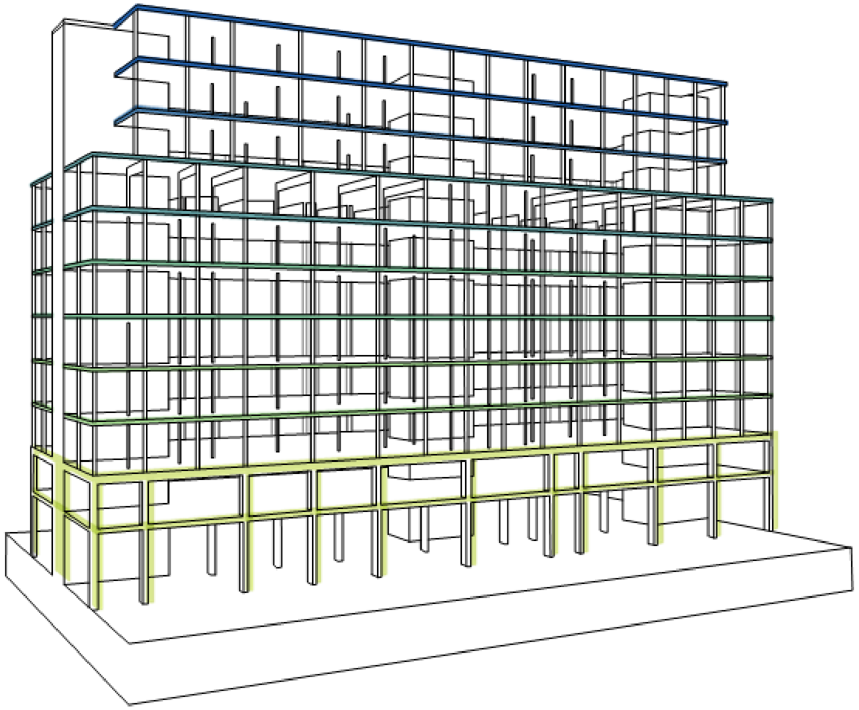
Construction sequencing planning has been studied for the three regional EMTC buildings and an average schedule breakdown by days/ weeks is provided for context.



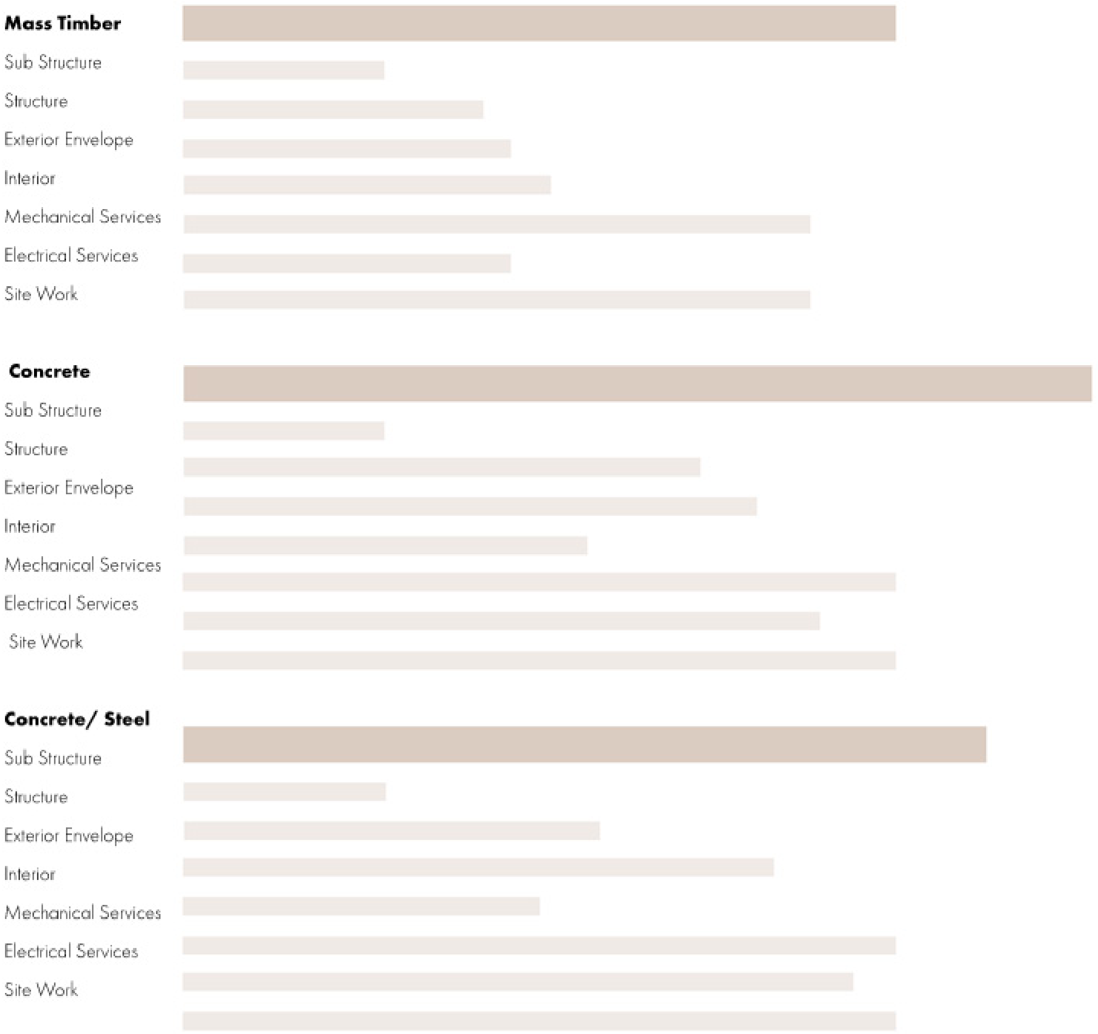
Construction Elements	**Mass Timber**	**Concrete**	**Concrete/ Steel**
- Substructure	75 days	75 days	75 days
- Structure	125 days	257 days	204 days
- Exterior Envelope	145 days	287 days	237 days
- Interior	220 days	218 days	218 days
- Mechanical Services	315 days	414 days	379 days
- Electrical Services	185 days	318 days	329 days
- Site Work	275 days	397 days	347days
Construction Schedule	**375 days**	**497 days**	**447 days**



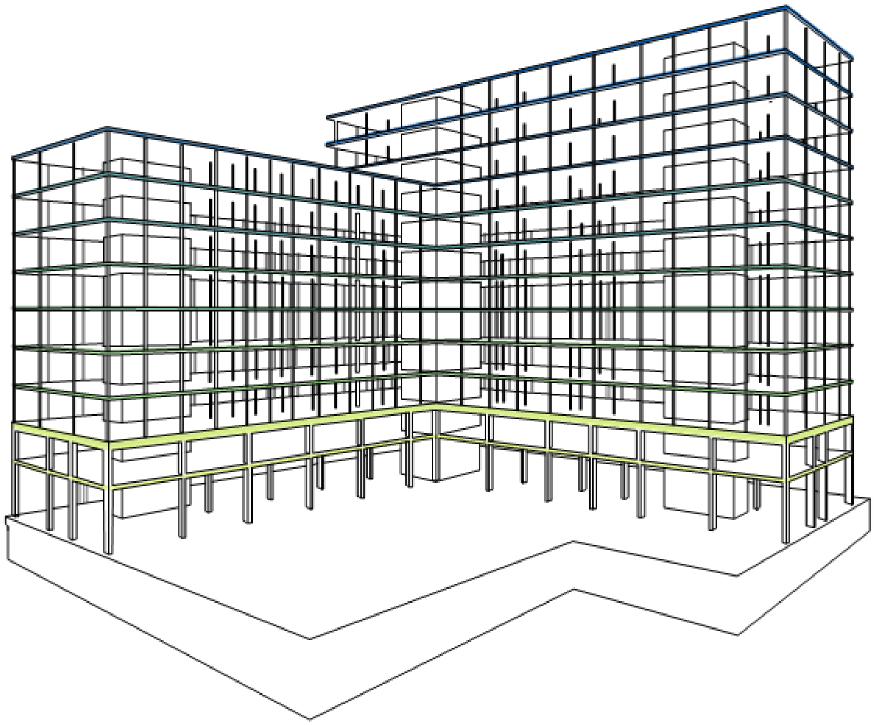
1.51. SPEED OF EMTC OVERALL - SLAB TOWER, CITY OF KAMLOOPS



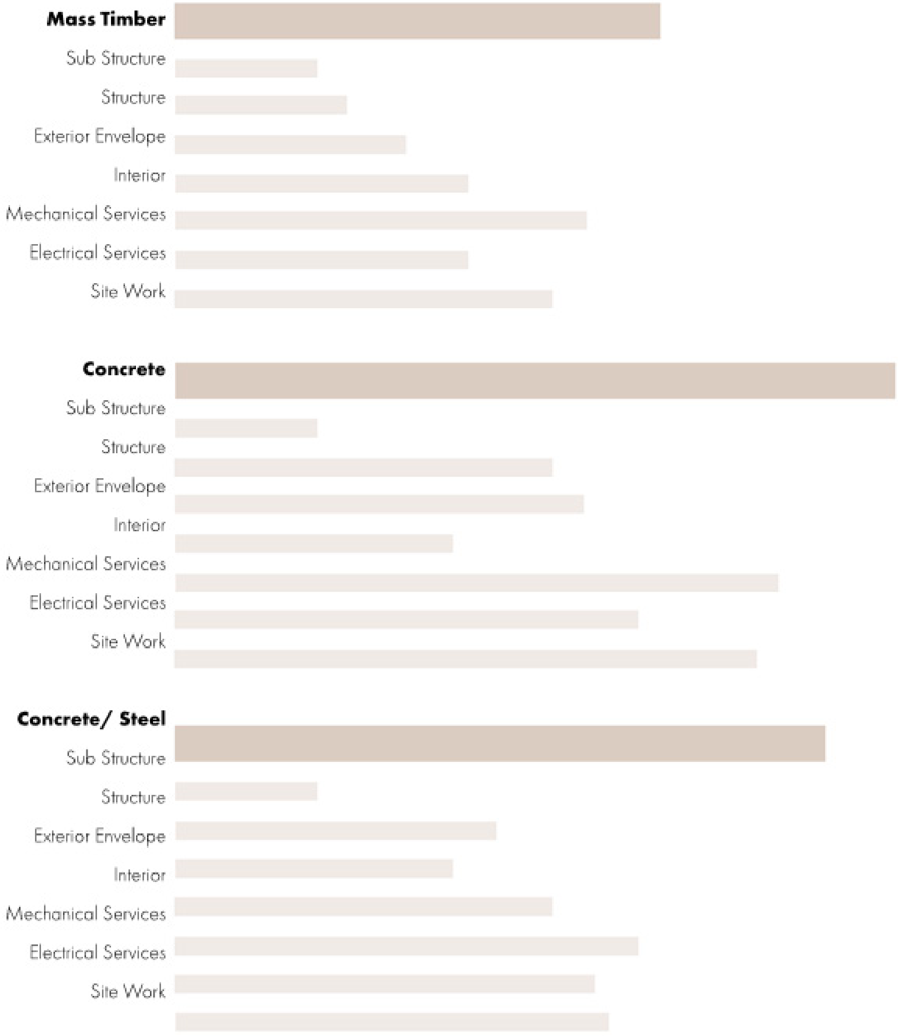
Construction Elements	Mass Timber	Concrete	Concrete/Steel
- Substructure	140 days	140 days	140 days
- Structure	175 days	328 days	275 days
- Exterior Envelope	185 days	358 days	237 days
- Interior	250 days	233 days	305 days
- Mechanical Services	380 days	505 days	470 days
- Electrical Services	205 days	395 days	395 days
- Site Work	345 days	473 days	420 days
Construction Schedule	**485 days**	**613 days**	**563 days**



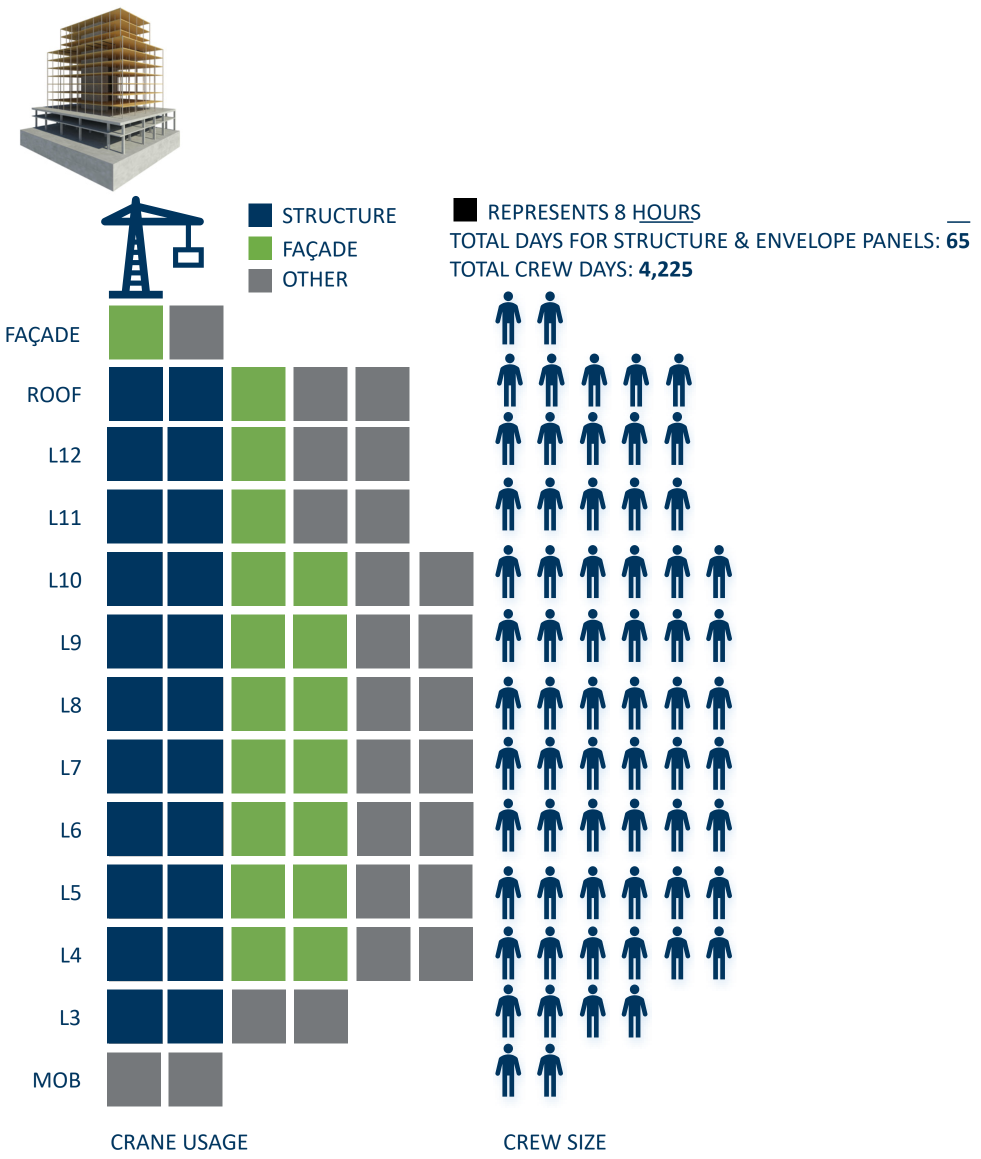
1.52. SPEED OF EMTC OVERALL – L TOWER, CITY OF COQUITLAM

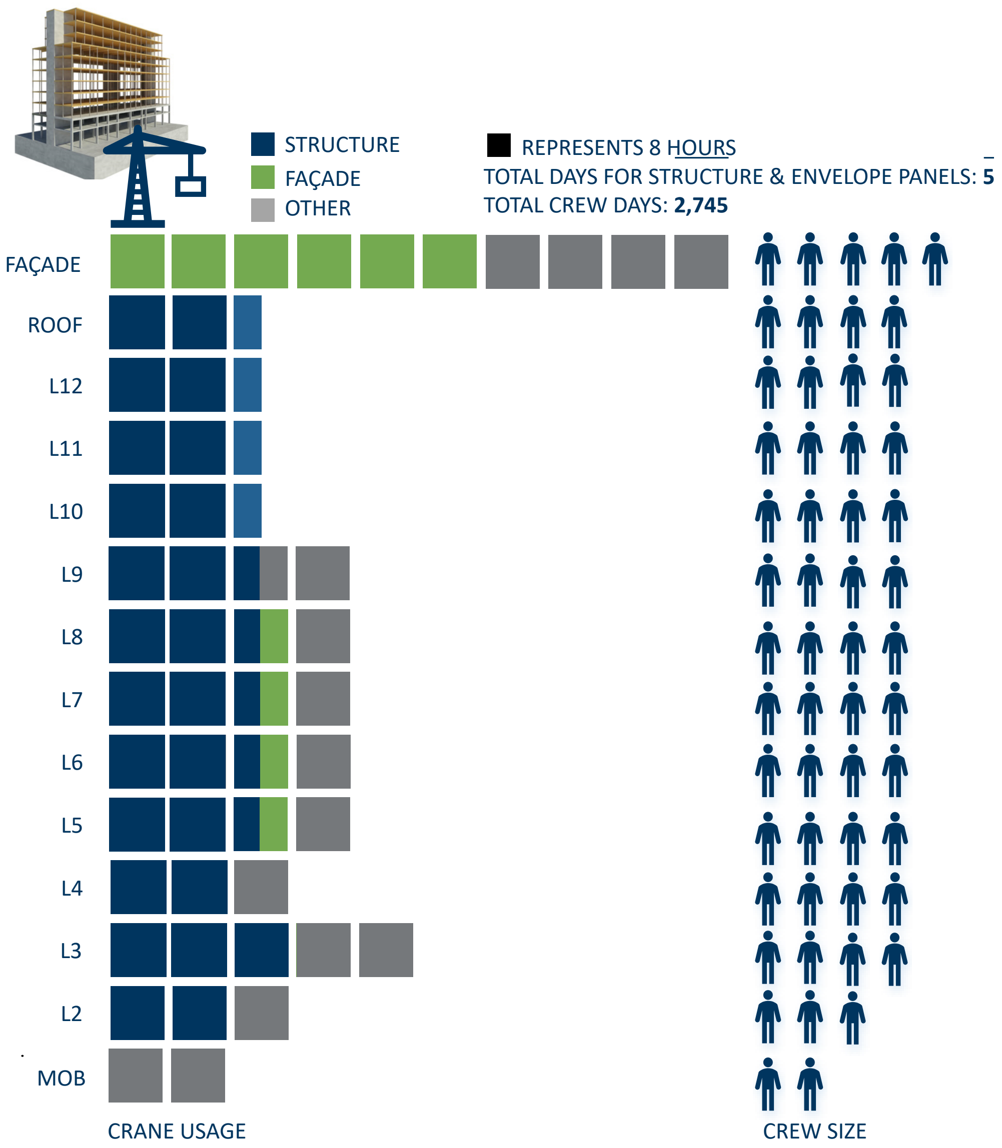


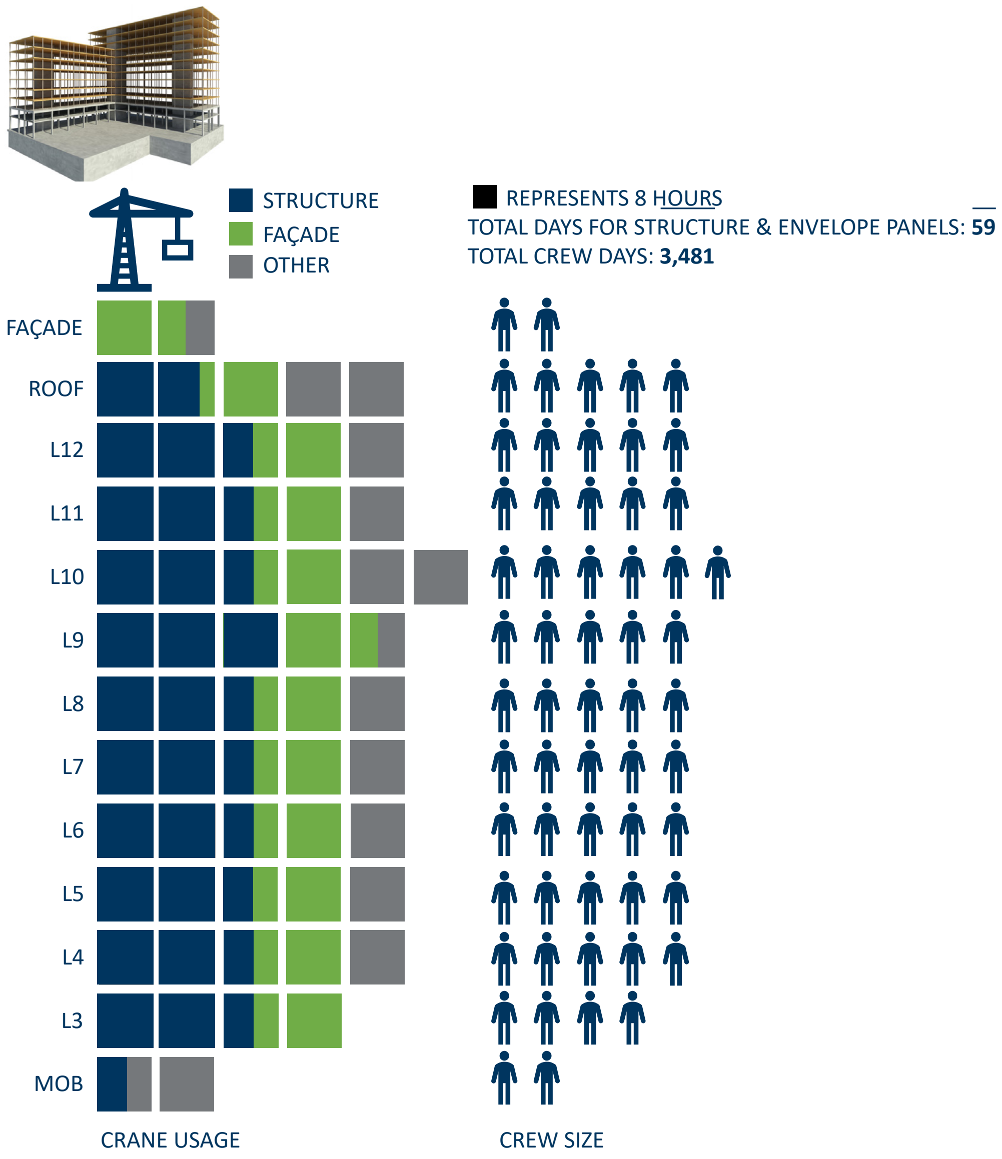
Construction Elements	**Mass Timber**	**Concrete**	**Concrete/Steel**
- Substructure	195 days	195 days	195 days
- Structure	260 days	455 days	390 days
- Exterior Envelope	275 days	485 days	425 days
- Interior	335 days	310 days	310 days
- Mechanical Services	510 days	696 days	636 days
- Electrical Services	275 days	527 days	527 days
- Site Work	510 days	660 days	600 days
Construction Schedule	**675 days**	**825 days**	**765 days**



1.53. CRANE UTILIZATION & LABOUR ACROSS EMTC INSTALL (STRUCTURAL & FACADE)

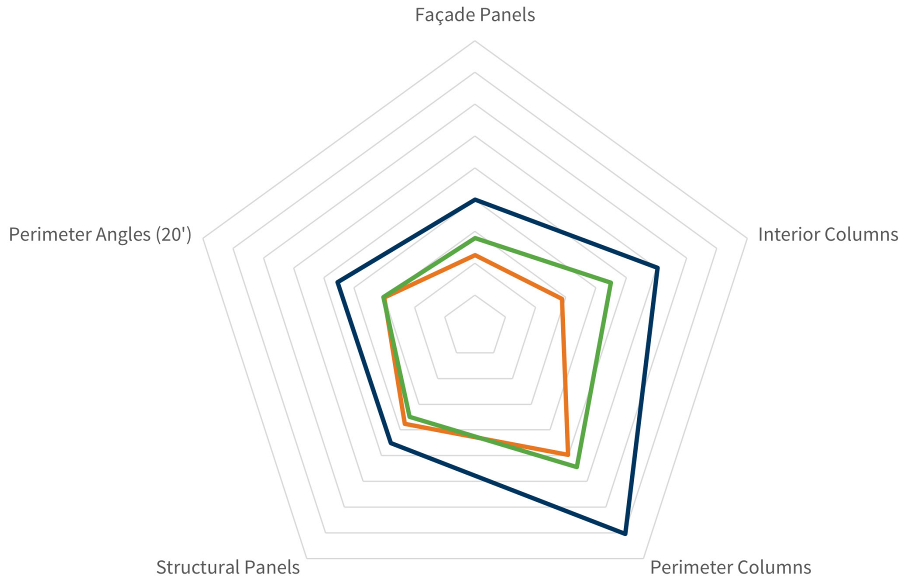


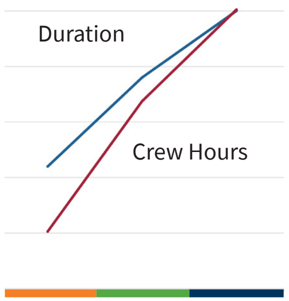




1.54. COMPONENT DENSITY & LABOUR PRODUCTIVITY

The graph and table below provide a component summary per 1,000sf of the three archetype buildings highlighting the varying levels of component efficiency relative to square footage. Construction sequencing and cost planning can utilize similar high-level approaches to the prefabricated structure and façade to measure installation rates and planned crane utilization efficiency. While total duration increases as the archetype size scales up, the productivity (crew hours per 1,000sf) increases at a greater rate based on the increased complexity of the archetype. Parametric analysis can inform costing utilizing the same component modelling required for coordination and erection of EMTC buildings.





*per 1,000sf	Vancouver	Kamloops	Coquitlam
Façade Panels	2.26	2.79	4.00
Interior Columns	2.87	4.49	6.03
Perimeter Columns	4.97	5.44	8.04
Structural Panels	3.76	3.49	4.52
Perimeter Angles (20')	3.00	3.04	4.55
Crew Hours	191	285	351

Archetype Building Cost Analysis

1.55. METHODOLOGY

A comparative analysis requires a baseline against which to compare data. To ensure a consistent baseline and to rationalize the starting point for the detailed design, the design team utilized mass timber + energy archetype costing data (recently developed by the Office of Mass Timber and BCFII) for optimized EMTC building costing estimates. A point-supported mass timber system was generated for comparison with steel and concrete buildings typologies compliant for either BC Energy Step Code level 3 or 4. The detailed designs of the EMTC and steel and concrete were based on conventional cast-in-place concrete typologies typically suitable for various development proformas and located at three unique regional sites. Therefore, the EMTC buildings created in detailed design can be studied in comparison with conventional cast-in-place concrete and a steel and concrete.

The regional sites in British Columbia (Vancouver, Coquitlam and Kamloops) provide for a broad range of design inputs and outputs, including climate data. Therefore, three unique structure typologies were studied, one structure type for each region, having a variation of mass timber, steel or concrete, for a total of nine archetype buildings in this study. Each structural typology developed is appropriate for the development location and designed to meet the minimum requirements of the B.C. Building Code or the Vancouver Building By-law in effect with regards to local bylaw and site-specific regulations. In addition, each building studied is intended to meet the requirements of the BC Energy Step Code level 3 and 4, which provides distinct design parameters.

Each of the three residential typologies have relatively equal space delineation consisting mainly of residential suites, with stair cores, elevator lobbies and corridors. The design team developed a flexible and inclusive floorplan strategy that could be utilized for all three of the building typologies and for each of the unique structural systems. A space type breakdown relative to determining the occupant density for energy modelling purposes is shown in Figure 33.

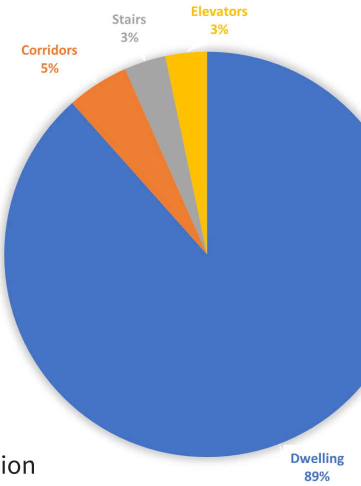


Figure 33: Building Area Allocation

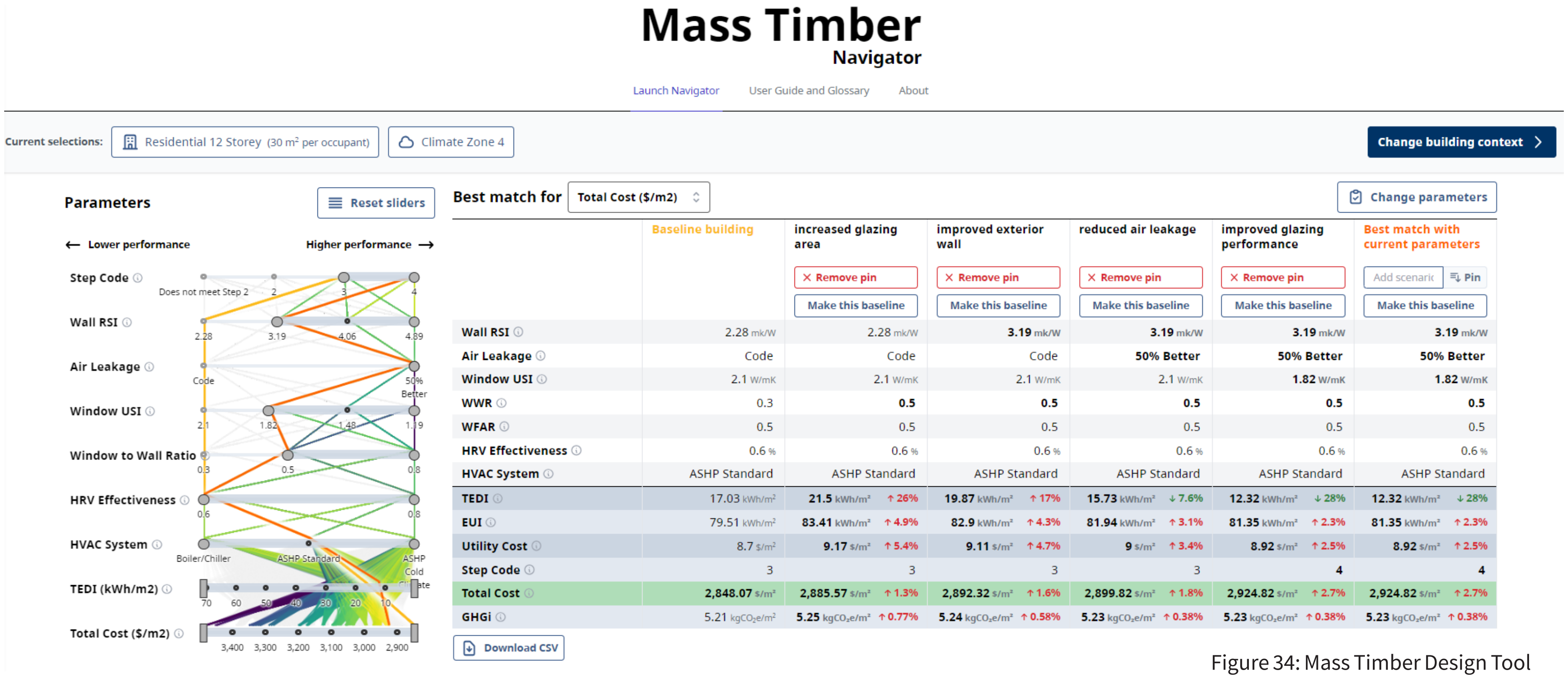
The energy analysis considered the residential building where the key performance criteria, such as building envelope characteristics, mechanical systems and efficiency, and lighting efficiency reflected typical strategies that are used in current practice. Within the singular architectural floorplan strategy, the HVAC system for all buildings studied consists of centralized HRVs providing ventilation to suites, packaged terminal heat pumps (PTHPs) serving heating and cooling loads in suites, and rooftop air handling units (with integrated electric heating coil) providing corridor pressurization. Domestic hot water tanks are modelled as electric.

To adapt the energy model geometry to apply to the three architectural massing scenarios/ locations chosen, the simulation simply adjusted the wall to floor area ratio to match what is reflected in the design drawings. From our experience on other studies and from real world projects, these assumptions are acceptable for the purposes of estimating whole building energy performance. Small articulations in the architectural expression and building orientation have very minor impacts if the overall envelope and floor area are properly accounting for conductive losses, ventilation rate, and internal gains. Likewise, occupant density (and suite ventilation rate, accordingly) is adjusted/inferred from the architectural unit counts and layouts. A detailed input table is found in Energy Performance Design Schedule.

Effective wall performance is calculated assuming thermal bridging from typical construction details for lower performing walls and introducing improvements in thermal bridging in addition to clear wall performance. Many thermal bridges may be reduced by using low-cost methods such as aligning windows with the wall insulation by using a plywood liner in the window opening or designing a building to minimize the quantity of window-to-wall transitions. High-performance wall assemblies typically require exterior insulation with thermally broken clips or clips made of less thermally conductive materials, which support exterior cladding and glazing that is aligned with the wall insulation plane. In the context of this study, thermal bridging is generally considered minimal for EMTC and substantial in concrete construction. Mass timber assemblies and transition details have relatively good thermal performance compared with steel or concrete since they primarily utilize wood, a material with a relatively mitigated thermal conductivity. Effectively, mass timber is a solution for simplifying construction and reducing materials otherwise necessary for higher conducting structures like steel and concrete.

Wall assembly cost for the building envelope is calculated based on the cost of the clear wall required to attain the effective performance after thermal bridging is accounted for. Clip performance can vary widely between manufacturers, and alternate insulation configurations can be used to obtain similar effective performance results. The building envelope construction assembly costs are subjective and are order of magnitude estimates based on generic thermally broken metal clip design with mineral wool insulation consistent with the building energy thermal bridging guide (BETBG). There are many variables and constraints on real projects that will overshadow some of the estimated cost differences between assemblies. The main point to consider is that construction costs vary quite widely in practice. This variability is part of the reason that construction projects typically have a bid process, where there can be a big difference between the highest and lowest bid. Other potential varied parameters include roof and glazing thermal performance, glazing solar heat gain coefficient (SHGC), glazing ratio, envelope airtightness, vertical envelope-to-floor-area ratio (VFAR), heat recovery efficiency, occupancy, ventilation rate, lighting savings and two central heating/cooling plant types.

1.56. EVALUATION OF EMTC BUILDING PERFORMANCE AND COST IMPACTS



	Baseline building	increased glazing area	improved exterior wall	reduced air leakage	improved glazing performance	Best match with current parameters
Wall RSI	2.28 mk/W	2.28 mk/W	**3.19** mk/W	**3.19** mk/W	**3.19** mk/W	**3.19** mk/W
Air Leakage	Code	Code	Code	**50% Better**	**50% Better**	**50% Better**
Window USI	2.1 W/mK	2.1 W/mK	2.1 W/mK	2.1 W/mK	**1.82** W/mK	**1.82** W/mK
WWR	0.3	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**
WFAR	0.5	0.5	0.5	0.5	0.5	0.5
HRV Effectiveness	0.6 %	0.6 %	0.6 %	0.6 %	0.6 %	0.6 %
HVAC System	ASHP Standard	ASHP Standard	ASHP Standard	ASHP Standard	ASHP Standard	ASHP Standard
TEDI	17.03 kWh/m^2	**21.5** kWh/m^2 ↑ 26%	**19.87** kWh/m^2 ↑ 17%	**15.73** kWh/m^2 ↓ 7.6%	**12.32** kWh/m^2 ↓ 28%	**12.32** kWh/m^2 ↓ 28%
EUI	79.51 kWh/m^2	**83.41** kWh/m^2 ↑ 4.9%	**82.9** kWh/m^2 ↑ 4.3%	**81.94** kWh/m^2 ↑ 3.1%	**81.35** kWh/m^2 ↑ 2.3%	**81.35** kWh/m^2 ↑ 2.3%
Utility Cost	8.7 $/m^2	**9.17** $/m^2 ↑ 5.4%	**9.11** $/m^2 ↑ 4.7%	**9** $/m^2 ↑ 3.4%	**8.92** $/m^2 ↑ 2.5%	**8.92** $/m^2 ↑ 2.5%
Step Code	3	3	3	3	**4**	**4**
Total Cost	**2,848.07** $/m^2	**2,885.57** $/m^2 ↑ 1.3%	**2,892.32** $/m^2 ↑ 1.6%	**2,899.82** $/m^2 ↑ 1.8%	**2,924.82** $/m^2 ↑ 2.7%	**2,924.82** $/m^2 ↑ 2.7%
GHGi	5.21 kgCO$_2$e/m^2	**5.25** kgCO$_2$e/m^2 ↑ 0.77%	**5.24** kgCO$_2$e/m^2 ↑ 0.58%	**5.23** kgCO$_2$e/m^2 ↑ 0.38%	**5.23** kgCO$_2$e/m^2 ↑ 0.38%	**5.23** kgCO$_2$e/m^2 ↑ 0.38%

Figure 34: Mass Timber Design Tool

Our intent is to evaluate variables that may impact EMTC buildings and to identify optimal conditions. The study evaluation will test fit market rental buildings using EMTC construction against conventional and concrete and steel construction.

The series of site specific and regional buildings utilize point-supported 7 ply CLT that balances the lowest possible construction costs while also maximizing the displacement of concrete/steel and reduction of construction timelines.

Estimating is the first assessment of project risk of a project and prediction of final cost. Digital twin design has an ideal process to develop design data for energy model inputs and outputs that can be factored for estimating buy-out costs much earlier and efficiently, and also re-assess thereafter.

The Mass Timber Navigator was used to provide early design EMTC building performance and costing impact studies:

https://www.masstimbernavigator.ca/tool

This online tool was developed for researchers, developers and design teams. The tool is an easy-to-use Energy + Mass Timber Parametric Costing Tool or project proforma and early design planning tool for engineered timber building projects, including the 7- to 12-storey encapsulated mass timber construction that is specific to this study. Uniquely, data derived from the 12-storey EMTC archetype occupancy developed for the tool provides both cost and energy code compliance impact scenarios for multiple baseline building comparisons. This is an evolved version of the Building Pathfinder (hyperlink to - https://www.buildingpathfinder.com/) tool that is specific for assessing the viability of mass timber projects in B.C. for climate zones 1 through 7.

The methodology for establishing construction costs in the 7 – 12 MURB rental form for EMTC involves system-based estimating and significant data development through digital twin and energy modelling scenarios in addition to the following:

- Review the project parameters, schedule, and proposed preliminary digital twin design.
- Determine the project's value for money, economy of the design, local market factors, anticipated escalation rates, supply chain issues and any other matter that may affect the cost or schedule of the project.

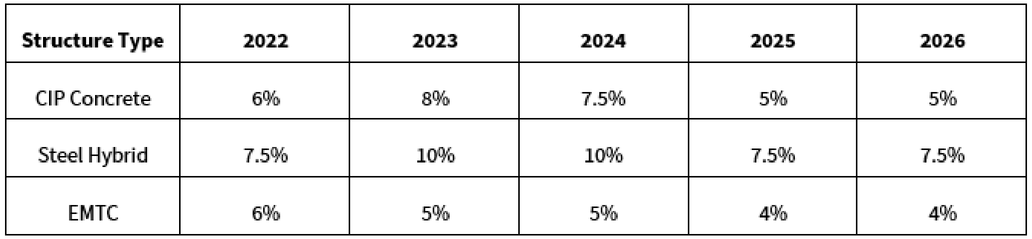
Cost estimates for the archetypes cover all aspects of the project and include construction costs, estimated site development costs, contingencies, and escalation suitable to support a risk and financial analysis:

- Plans and Specifications: We reviewed the project plans, specifications, and component and building grossing factors.
- Systems Evaluation: We assessed the cost implications of related systems such as fire sprinklers, site preparation and structure.
- Contracts: We reviewed the intent of the contract form with regards to cost and schedule implications.
- Suppliers and Subcontractors: We reviewed, in general, likely material suppliers and/or subcontractors within the regional industry area associated to key elements and considered their apparent availability and capability.
- Schedule: We reviewed the anticipated construction time schedule in relation to the project plans, specifications, and contract(s).

Risk Evaluation: We considered means and methods to eliminate, avoid, transfer, or mitigate risks:

- Market rent impacts do not affect the cost of construction, this is not relevant from a capital cost point of view. The shorter expected timeline for the prefabricated archetypes using either mass timber or steel, or any capital cost differential between the structural options, is not expected to have an impact on market rents as they are simply driven by supply and demand. Capital cost and the project delivery timeline will adjust the potential profitability of each project for any investor which, over the long run, will have an influence on the supply of rental units to the market. Overall rental market demand and supply will impact the rent more than any factor for construction.
- Supply chain issues have become problematic for a number of commodities, especially metals, given the rising cost of fossil fuels, logistics and the general supply. Locally sourced products, such as mass timber, should have a strategic advantage over the next 5 years. The mass timber industry has rapidly increased its capacity to supply an ever-growing demand for their products in Western Canada.

Given that, there is a general expectation for the following annual cost increases:



Structure Type	2022	2023	2024	2025	2026
CIP Concrete	6%	8%	7.5%	5%	5%
Steel Hybrid	7.5%	10%	10%	7.5%	7.5%
EMTC	6%	5%	5%	4%	4%

Figure 35: Five Year Forecast of Annual Cost Increases

- Cast in Place Concrete should have the best accessibility and fewest limitations within established industry conditions but that should be closely followed by EMTC given the recent industry response in addressing the demand for the mass timber. However, supply chain issues and the rising cost of fossil fuels should make Steel respectively difficult to access, expensive and limited. EMTC is still a developing construction technology that should see improvements in capital cost performance, and efficiencies as it becomes more mainstream within the construction industry.
- EMTC involves a significant amount of offsite prefabricated construction that, depending on scale and style of building, should see schedule time savings for the structure as in the following scenario:
    - Potential for time savings of 10% to 35% less than Cast-in-Place Concrete for the same project.
    - Assuming an average is 22.5%, this could add another 100-150 working days to most 7-12 storey MURB projects which is the equivalent of approximately 5-7 months.
    - Estimated General Requirements of $10,000 per month and Carrying Costs (financing, etc.) of $6,000 per month suggests that this cost could range from $86,000 to $112,000 of unnecessary costs while negating and estimated $875,000 to $1,225,000 in lost net revenue for the months of forgone rent.
    - As such, the potential financial impact of conventional construction (i.e. Cast-in-Place Concrete) over offsite prefabricated construction (i.e. EMTC) is estimated to be anywhere from $961,000 to $1,377,000 for any typical project of this scale.
    - The only Mass Timber specific factor that could truly influence the risk for rental financing would be the relative unfamiliarity any lending institution may have with building projects of this type.

1.57. ESTIMATING PROJECT CAPITAL COST AS A SYSTEM IS A FACTOR

Estimating is the first assessment of project risk and prediction of final cost. A good EMTC estimate is different than conventional construction and predicts final cost early in the project design. It provides an ideal process to estimate buy-out costs much earlier and efficiently.

The predominant noncombustible structure type across B.C. remains cast-in-place concrete. This is the most well-accepted and cost-effective approach for all high-rise building types. EMTC will have a shorter erection schedule whereas cast-in-place concrete does take longer. However, EMTC does currently experience a higher capital cost above cast-in-place concrete in the structural elements of the project budget due primarily to the comparative limitations of suppliers, installers, suitable procurement models and design professionals proficient in capitalizing on this newer building approach. This is expected to improve over time due to the benefits derived from accelerated construction schedules. When comparing the structural and architectural characteristics of the two structures we might suggest that EMTC and the concrete structure share a similar structural expression. When comparing the cost-benefits of the two types of construction there are several parallel layers to consider:

- Substructure cost of labour & materials (with a projected average cost savings of 6.54% for EMTC vs. cast-in-place concrete)
- Structure cost of labour & materials (with a projected average cost premium of 4.33% for EMTC vs. cast-in-place concrete)
- General requirements cost (with a projected average cost savings of 23.88% for EMTC vs. cast-in-place concrete)
- Time to build and the construction schedule (with a projected average time savings of 27.05% for EMTC vs. cast-in-place concrete

Alternatively, one could consider the use of steel for high-rise building types. Lightweight light-gauge steel structures (a.k.a. cold-rolled steel) are suitable for this building type because they meet seismic design requirements by using a concrete lateral resisting system. With regards to any steel structures, significant measures must be undertaken to fireproof and seismically brace the structures, in comparison with EMTC or cast-in-place concrete. This typically defeats any advantages gained in the use of light-gauge steel structures related to potential time savings.

Time savings are offset by the additional time and cost it takes to seismically brace and fireproof the structure along the additional finish work to make that structure aesthetically appealing. In addition, steel predominantly comes from either eastern Canada or the US. Therefore, steel as a primary structural system is usually cost prohibitive given the distance required for the material to travel and and or currency exchange. Currently supply volumes are usually limited and intended for specialty applications to meet a specific architectural need. All combined, we would expect any steel structure to be a cost premium over the benchmark high-rise cast-in-place concrete structure.

In summary, when comparatively considering the quality of materials we find specific advantages for EMTC. These include lighter weight structures, inherent fire resistance and enhanced qualities offered by mass timber.

However, when comparing the cost of construction we find the concrete buildings are lower compared to the EMTC buildings, while steel would be the same or higher than EMTC. When comparing the time to build, we find there is a significant time saving given the offsite of prefabricated EMTC system when compared to either cast-in-place concrete or steel. Furthermore, when comparing the operational and general maintenance costs for all three structural types, we find the common costs to be similar but with a slight potential advantage to cast-in-place concrete. The durability of a structural system is always dependant on its inherent life span and how well the building envelope has been designed to protect the structure.

EMTC Procurement is a Factor

The type of contract procurement between the general contractor/construction manager (GC/CM) and mass timber provider (fabricator, installer or combined turn key entity) will determine how the project proceeds and has a direct impact on schedule. If the project is a design-build, including design-assist contract, the mass timber production, fabrication, and installation teams are likely to be involved in the early stages of the project to minimize mass timber waste and reduce the overall schedule. A traditional "design-bid-build" linear- style contract may limit the opportunity for savings and efficiency because the contractor has a limited or nonexistent role in the design stage. The benefit of learned efficiencies and contractor experience is therefore not weighed early in the project, when it is most useful. In addition, the nature of manufacturing off-site means that the capital required to procure materials and begin production is often two to three times higher in the beginning than a typical construction project. Draw schedules for projects are comparatively more front-loaded. Moreover, it's more difficult for lenders to assess when to release new funds using a typical cost-in-place model when a building is being constructed in a factory.

Several procurement options are available to the GC/CM, each with different scope requirements and a different level of risk to the mass timber subcontractor.

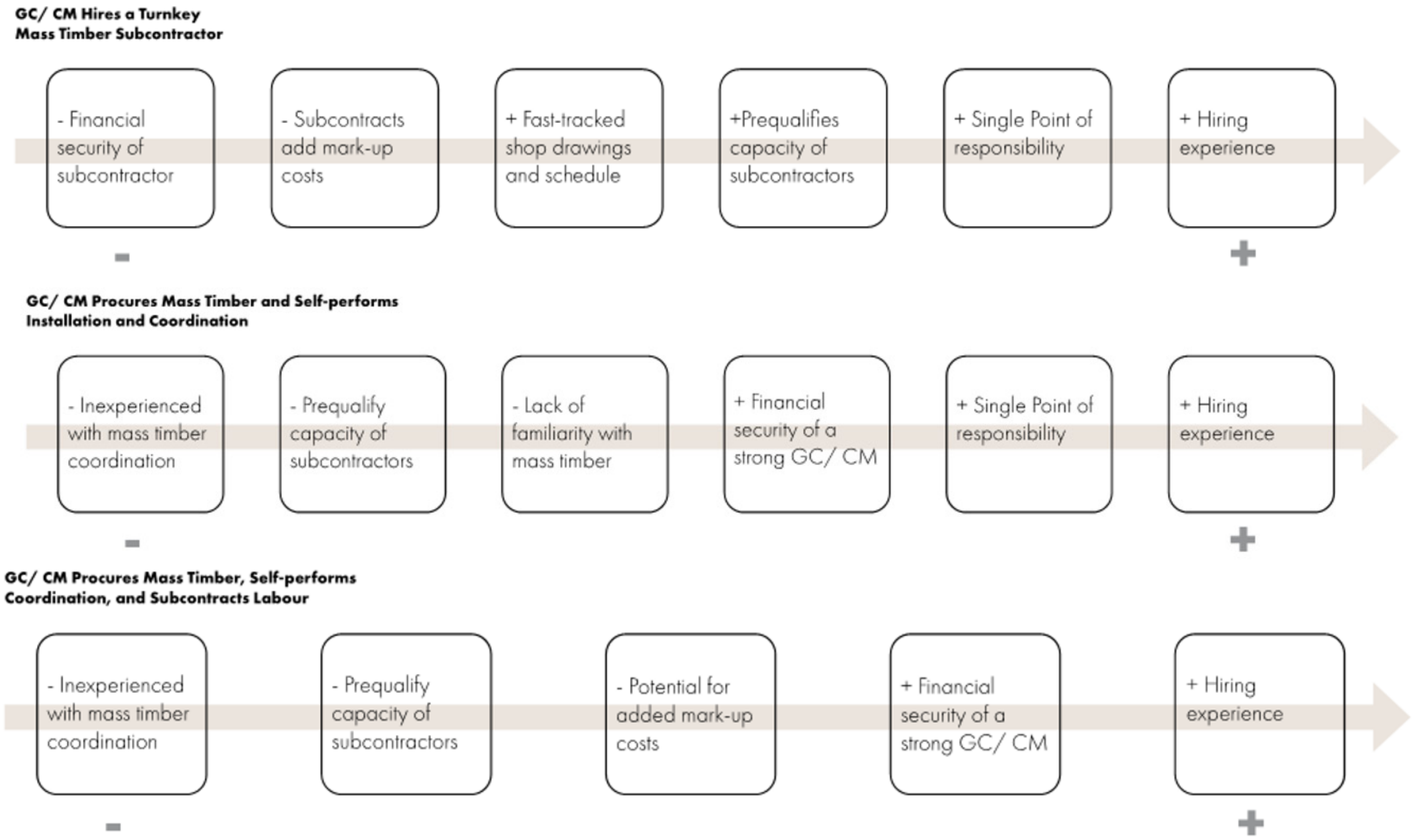


Figure 36: Contract Risk Assessment

A best practice is for the mass timber supplier(s), GC/CM and key subcontractors to engage throughout the design process and even during the conceptual phase. This ensures that constructability and prefabrication coordination are considered as part of the design process. It is more cost effective to resolve issues before construction than discover them in the field. Shifting the preplanning, coordination and decision making to an earlier stage in the project does not necessarily increase the fees associated with design and preconstruction; it just shifts the timing of the fees within the overall project schedule. Mass timber is a collaborative service and not a commodity. Leverage the precise tolerances associated with mass timber to prevent alignment and layout dimension issues in the field.

Design Assist Procurement Scenario:

- *Shop drawings started 6-8 weeks prior to Building Permit.*
  - Digital twin processes require significant coordination and communication between the GC/CM, mass timber fabricator, installer and specialty contractors. This is a critical step and must be adequately anticipated and resourced.
- *Fabrication can be started during the 10-14 weeks Building Permit phase given that the shop drawings were approved for fabrication.*
  - *Preconstruction planning required for optimized construction sequencing.*
- *Refer to detailed construction sequencing in the report. Each floor can take three days on average if using a crew of eight to erect the mass timber structure. This includes the HSS columns, CLT floors, and building envelope where applicable with the CLT floor panel perpendicular to corridor. The total design schedule can be 45-60 days.*


Photo of UBC Brock Commons during construction. (Seagate Mass Timber)

Long-term Outcomes — Inclusive and Accessible Communities, Durability, and Daylighting

When it comes to buildings, there are two types of costs: construction and operational. Over a building's lifetime, the impact and cost of maintenance, repair and operations end up outweighing the initial capital costs of construction. With this in mind, it is important to design a resilient building that is meant to last. This is done through a lifecycle costing perspective, where long term value is maximized for a resilient and high-performance building from the early design and planning stages.

A high-performance building is a building that is integrated and optimized on a lifecycle basis for all major high-performance attributes. These attributes are:

- Sustainable — environmental performance of the building
- Cost Effective — lifecycle costs
- Safe/Secure — physical protection of occupants
- Productive — occupants' well-being (air flow, lighting, tech, etc.)
- Functional — spatial performance

A systematic design approach with EMTC can achieve high-performance targets in a cost-competitive manner. It can also provide opportunities for the following community goals that are not commonly factored when buildings with limited performance capability are designed and constructed:

- Flexibility
- Long-term value
- Reduction of operation and maintenance costs
- Quality of life and improved comfort
- Family oriented community building

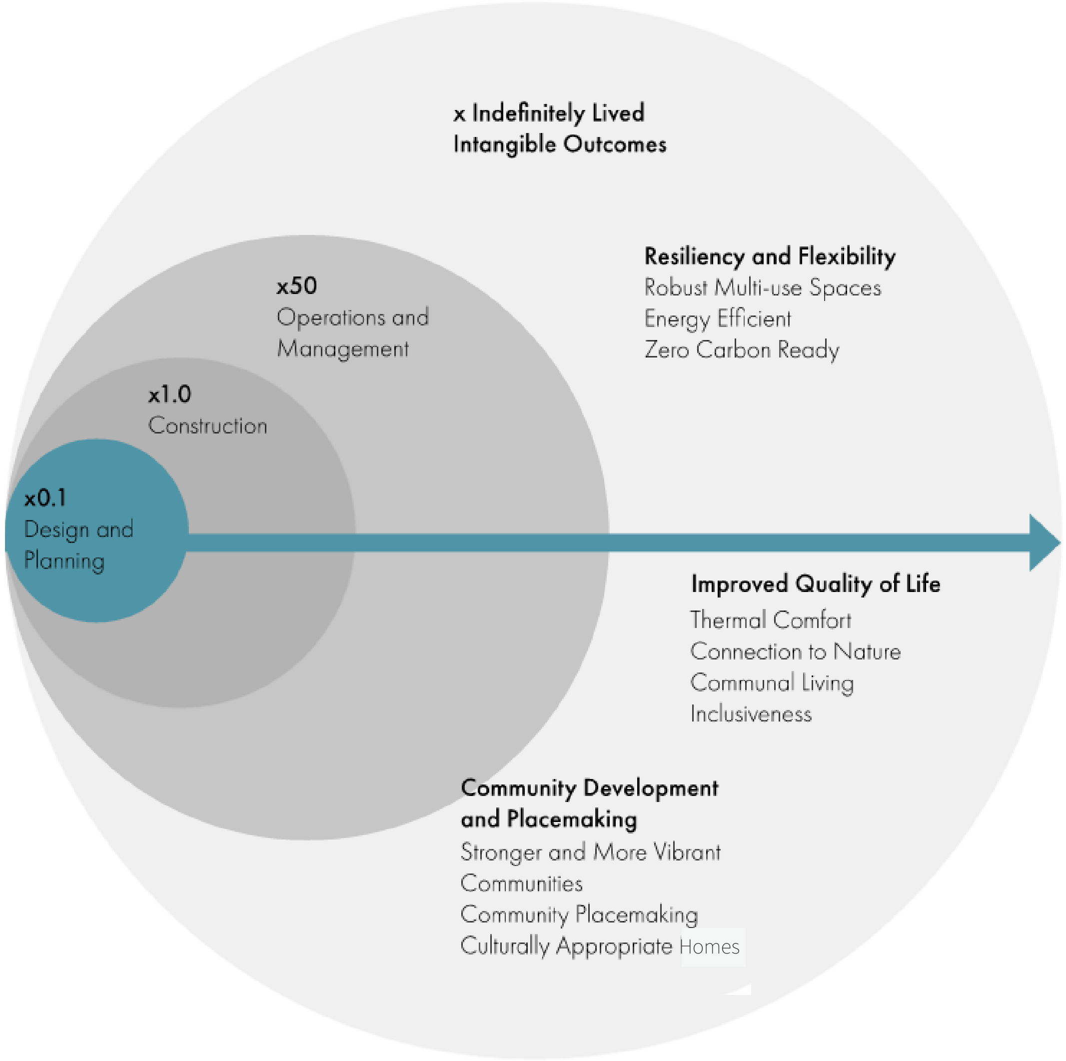


Figure 37: Potential for Community Level Impacts from High-Performance Project Design and Planning

1.58. LONG TERM DURABILITY IS A FACTOR

A primary consideration to achieve long-term durability of engineered timber structures is to provide a combination of drainage, ventilation, and breathability. It is not normally a structural issue if timber gets wet, providing water can drain away quickly and the timber is allowed to dry. Slowing down or restricting drying through the use of high resistance insulation products and/or vapour control layers on the face of the panels can slow drying to an extent that the development of fungal decay may become a risk. This is the case if engineered timber is subjected to adverse conditions during construction. However, the greatest risk of moisture related issues exists during the in-service phase due to life cycle replacement elements like windows, doors, and roofing or flooding issues from plumbing leaks or sprinklers.

The EMTC building systems studied were paired with mineral wool insulation products – these types of breathable insulation materials are typically beneficial to timber building systems. They are less likely to prevent rapid drying of the CLT panels if they are exposed to wetting, especially while in-service. The use of these types of breathable insulation products, in conjunction with good overall design detailing and a moisture management plan for the construction phase, will have a significant positive impact on the long-term durability and robustness of the mass timber structures, both gravity bearing and vertical facade.

Mass timber is still a relatively “new” construction material and there is a learning curve to overcome in understanding the strengths and weaknesses. One of the most common areas of debate with CLT is durability (and by extension, moisture). Mass timber is at risk of fungal decay if its moisture content exceeds 20% for an extended period of time. In a well-designed and detailed EMTC building, moisture content in service will be between 8% and 14% – well below the fungal decay threshold. While CLT follows the same durability principles as lightweight timber structures, its thickness and the mass of timber used present additional considerations when exposed to moisture. Timber studs, joists and rafters have a relatively large surface area to volume ratio and so typically dry rapidly when conditions allow. CLT has a much smaller surface area to volume ratio and so drying rates can be substantially slower. Careful design consideration is imperative for ensuring future durability. Key considerations included in the EMTC archetype detailed designs are as follows:

- Design of façade/ exterior wall bypasses the CLT slab edge, preventing a direct path of water ingress from the vertical plane to the horizontal plane.
- All secondary structures including balconies and prefabricated façade, windows, and doors are designed to improve the path of drainage to the exterior and limit thermal bridging while improving airtightness detailing.

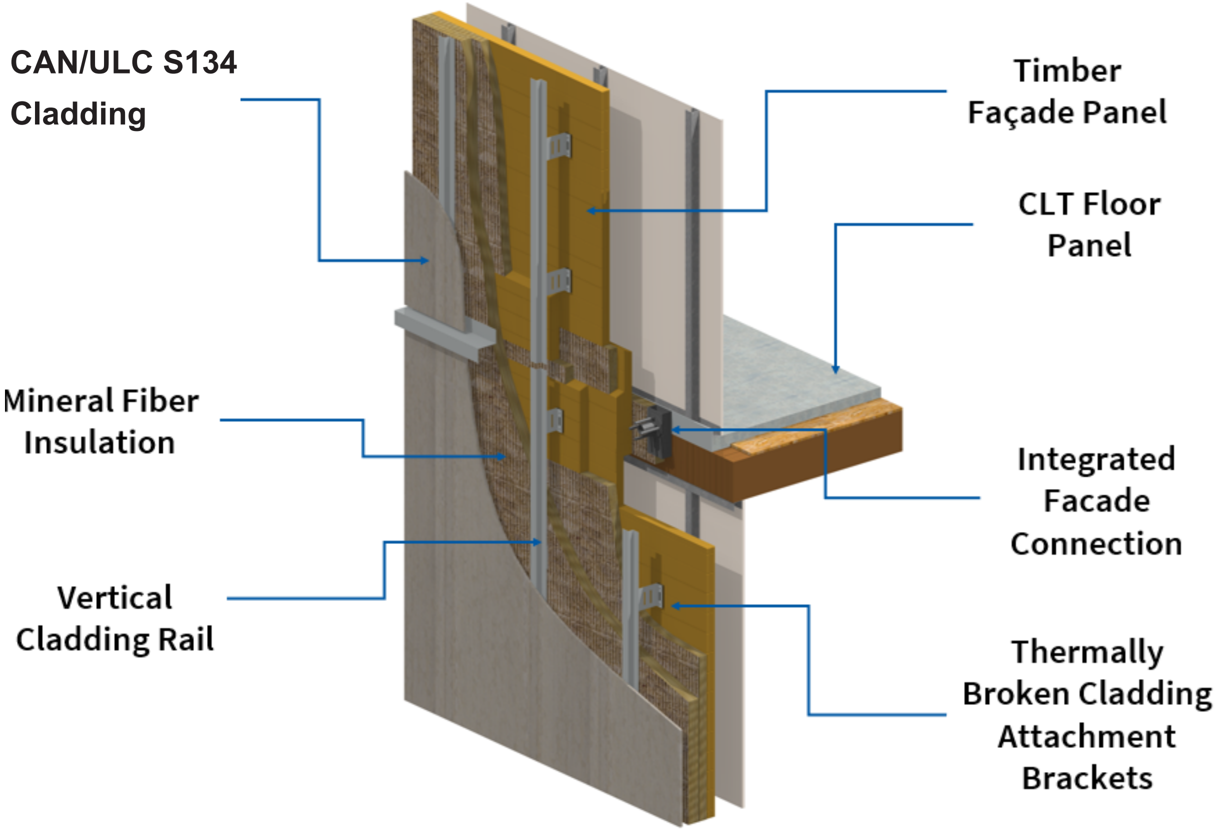


Figure 38: EMTC Facade Panel at CLT Slab Edge

1.59. HEALTH AND WELL-BEING OF EMTC BUILDINGS AND INTERIORS - DAYLIGHTING

Natural daylighting and the use of wood are significant natural elements that can simultaneously achieve four important goals: reduced embodied carbon, reduced carbon emissions, increased sustainability of a building's life cycle, and improved occupant well-being. People like the look, feel and smell of wood interiors and this could be a major marketing advantage for wood buildings and interiors compared to synthetic alternatives. However, more detailed information is needed about the specific tactile, olfactory, visual, and auditory properties of wood interiors that positively affect an occupant. These findings may eventually reinforce the more general understanding that humans thrive in natural settings including those with mass timber.

In addition, EMTC buildings can also benefit the construction workers who are involved in the full cycle of the building process because of the reduced construction time, offsite construction in climate-controlled manufacturing, reduce labour redundancy, and safer-cleaner building sites.

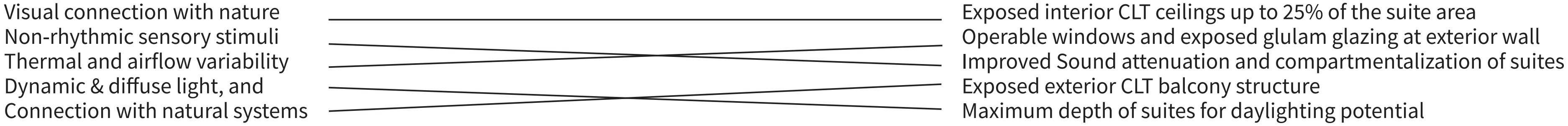
Biophilia refers to humans' innate need for a connection to nature which is an important consideration. When individuals have contact with nature, their neurological, physiological, and psychological responses result in less stress, lower blood pressure, more relaxation, positive moods, and increased concentration. Biophilic design goals were developed to incorporate natural elements into the construction and interiors of the EMTC study buildings, with daylighting as the cornerstone.

Daylight connects us to our outdoor environment, directing time through the movement of light and shadow which reveal the changing daily and seasonal cycles. In a digital age that sees more and more human activity during darkness or artificial lighting, daylight is a potential solution to our increasing alienation from the outdoors. The varied and changing material and atmospheric effects of daylight can awaken the senses and enhance our understanding the world around us.

The changing, but predictable environmental cycles of sun, wind, and weather help us to know "where we are" and "who we are." Daylight is paramount for reducing energy consumption and delivering ecological benefits that enhance comfort, health and well-being for humans when designed for appropriately.

This study embraced the distinct importance for daylighting as a design driver for a biophilic approach. It correlated site design with building for and orientation, zoning, window size, window placement, spacial organization, finishes, detailing, and envelope design for the following benefits:

Rendering of EMTC Interior



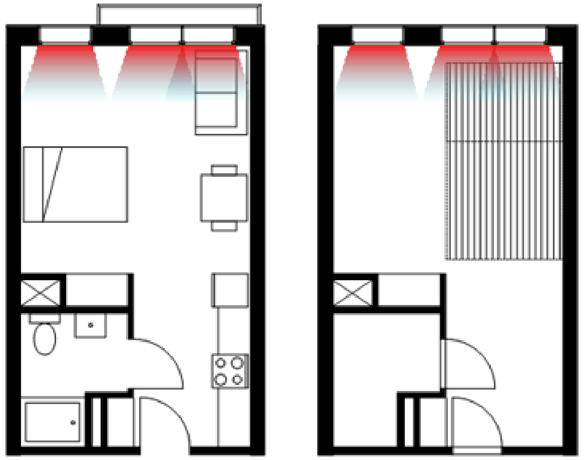
Visual connection with nature
Non-rhythmic sensory stimuli
Thermal and airflow variability
Dynamic & diffuse light, and
Connection with natural systems

Exposed interior CLT ceilings up to 25% of the suite area
Operable windows and exposed glulam glazing at exterior wall
Improved Sound attenuation and compartmentalization of suites
Exposed exterior CLT balcony structure
Maximum depth of suites for daylighting potential

1.60. INTERIOR FLOORPLAN - TYPICAL EMTC BUILDING FLOORPLAN

Window-wall ratio:

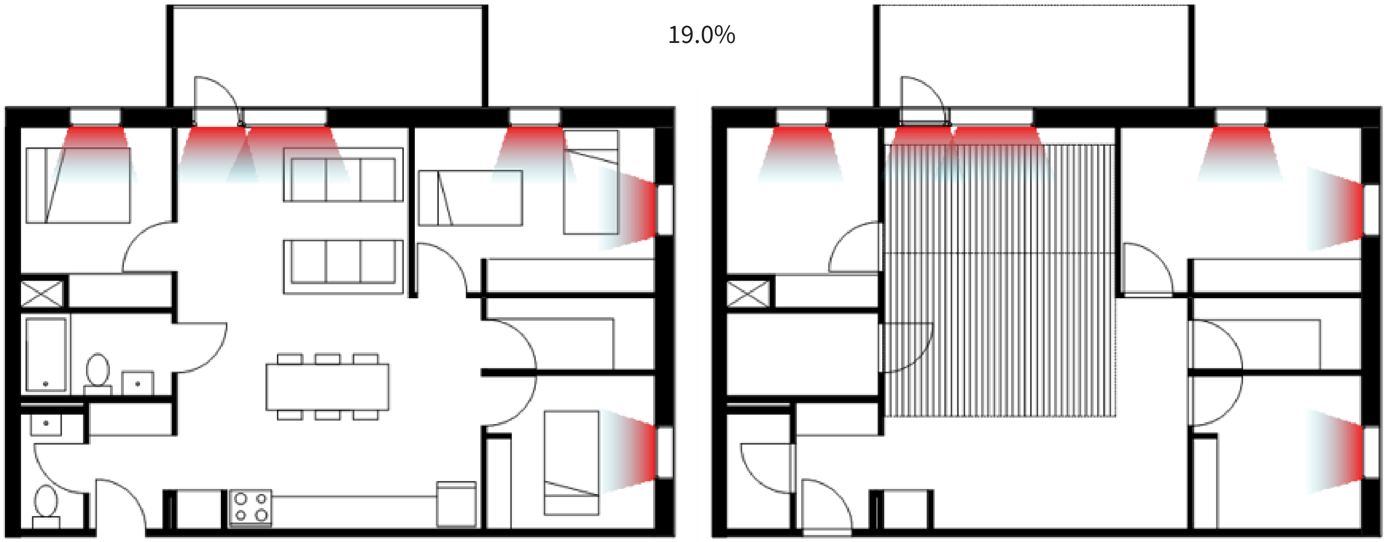
43.9%



Studio

Window-wall ratio:

19.0%



3 Bedroom

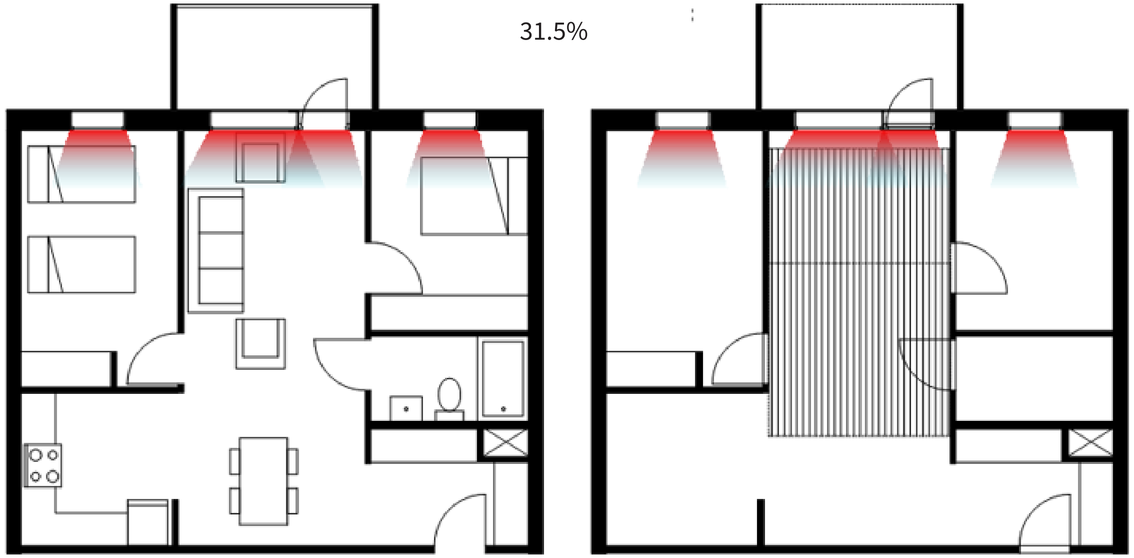
Window-wall ratio:

34.8%

1 Bedroom

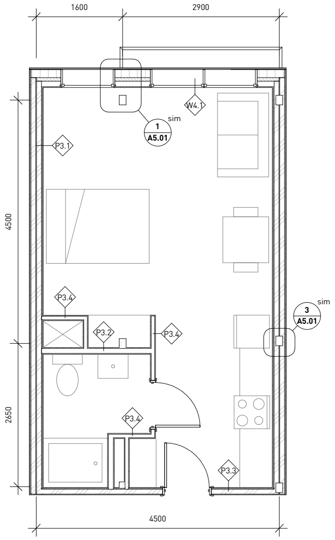
Window-wall ratio:

31.5%

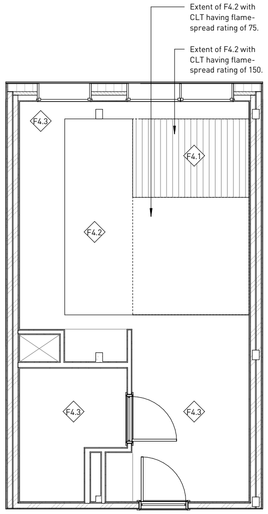


2 Bedroom

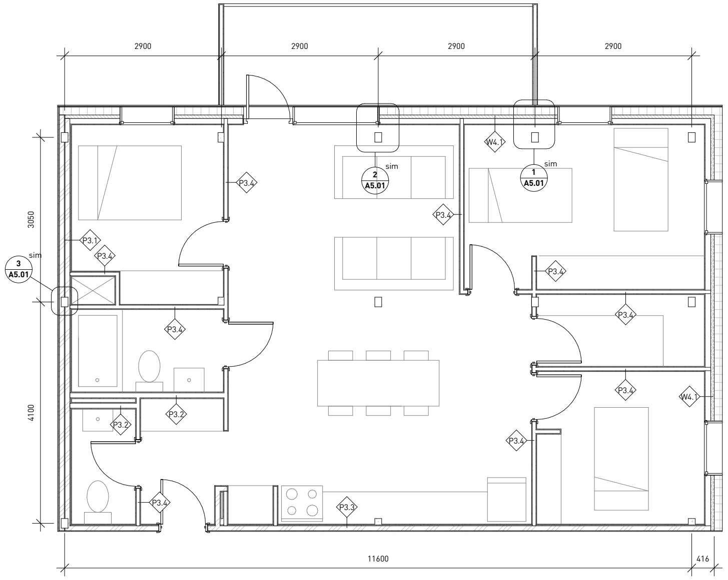
1.61. INTERIOR FLOORPLAN - TYPICAL EMTC BUILDING FLOORPLAN WITH EXPOSED CLT CEILINGS



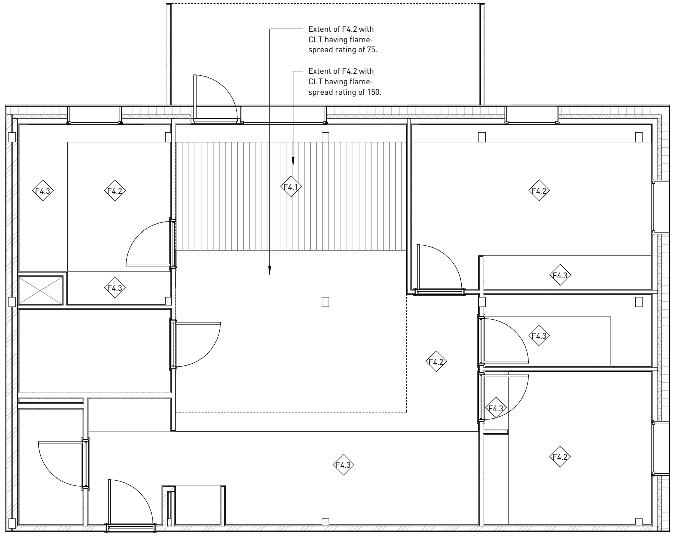
1 Enlarged plan - studio typical
1 / A1.03 1 : 50



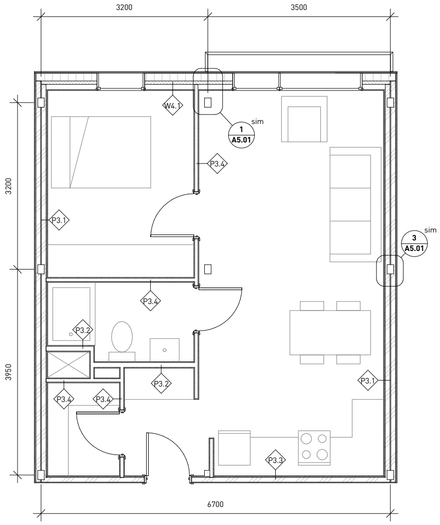
2 Enlarged RCP - studio typical
1 / A1.03 1 : 50



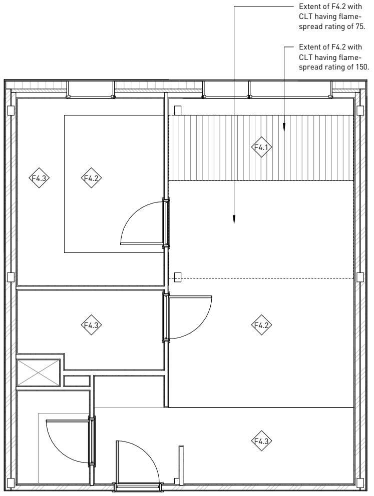
7 Enlarged plan - 3 BR typical
1 / A1.03 1 : 50



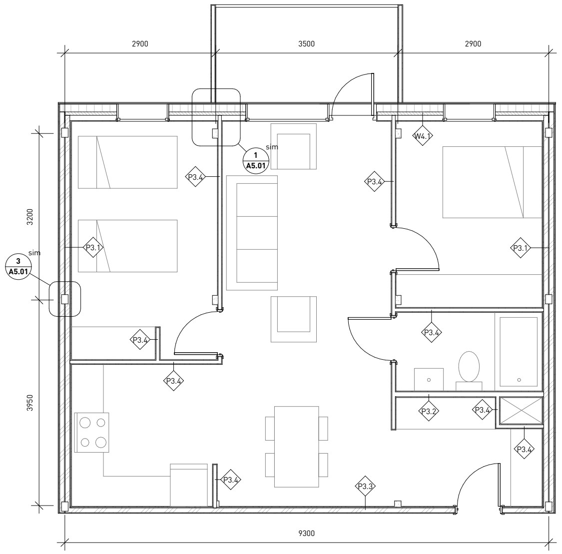
8 Enlarged RCP - 3 BR typical
1 / A1.03 1 : 50



3 Enlarged plan - 1 BR typical
1 / A1.03 1 : 50



4 Enlarged RCP - 1 BR typical
1 / A1.03 1 : 50



5 Enlarged plan - 2 BR typical
1 / A1.03 1 : 50

6 Enlarged RCP - 2 BR typical
1 / A1.03 1 : 50

1.62. EMTC BUILDINGS MEET ACCESSIBLE AND INCLUSIVE GUIDELINES

The floor plans for both EMTC and concrete buildings meet the requirements set out in the BC Housing Design Guidelines. This study also produced floorplans which can be programmed for various user groups that are inclusive of accessible and universal units on each floor plate. Each floor stacked is often done in conventional cast-in-place concrete projects. In a mixed-unit type scenario, the resulting units count for each regional building typology, as follows:

		BC HOUSING	**COV HOUSING**	**CMMC**	**VBBL**
Accessibility	Accessible Units	5% Min	5% Min	20% -or-	-
	Adaptable Units		See VBBL	100% -or-	100%
Entry Doors	Width	915 leaf min		810 Clear min	865 min
	Threshold			13 Max	13 Max
	Landing			1500x1500	
	Clearance				450 Beside latching jamb
	Vision				Glass sidelight or 2 peepholes
	Hardware				38 N max force, no twist
Interior Doors, Corridors	Corridor Width	1015-1067 (Adaptable)		920 Clear Min	900 Clear Min
	Door Width	865-915 Leaf Min (Adaptable)		810 Clear Min	800 Clear Min
	Hardware				22 N max force no twist
Bathroom	Clear areas				750x1200min in front of basin, WC bath/shower. Applies to units over 40m2 only
	3 Piece Fixtures	Studios+1Bed=Shower 2Bed+3Bed-Baths	All tub / Shower Combo		
	Bath	915x525			Provide second drain below and/or floor joist modification to allow future barrier free shower
	Shower	915x1220			
	Grab Bars			Wall Backing for future installation	Wall backing for future installation
Kitchens	Pantry		Broom Closet / Pantry		
	Recycling		Provide 4-6sf base cabinet		
	Dishwasher	Rough in at 2ft base cabinet beside sink for family projects	Provide dishwashers for family units (2-3Bed). Consider compact (21") units for studion +1 bed		
Living Room	Window/Balcony Door				Sill below 800 mm
	Ceiling Height		2430 min (2130 at bulkheads)		
Balconies	Provide Balconies		Min provision = balconies for accessible units and family (2bed+)		
Storage	Door Threshold	600x900min	Entry closet required		
	Entry Closet In Suite Storage	2.3m2 with shelving on one wall	3.7m2		

1.63. FLEXIBLE PLANNING – INCLUSIVE UNIT TYPE COUNTS OF A EMTC STUDY BUILDING

In addition, the study has provided variations in the EMTC structure to accommodate family focused two and three-bedroom units by optimizing the CLT panel layout within the disciplined structural grid. The floorplan design and structural systems can accommodate adjoining studio units which may be desirable but allows the building owner to select two-bedroom units on other floors. This provides a mixture of unit options.

Kamloops Slab Tower

	Studio	1 Bedroom	2 Bedroom	3 Bedroom	Three Parking Levels
L1 - L3	8	8	4	4	Kamloops parking bylaw for affordable downtown = 0.65 per studio + 0.8 per other unit 10% for visitors
L3- L9	28	35	21	14	
L10-L13	0	3	6	9	
Total	**36**	**46**	**31**	**27**	**120**

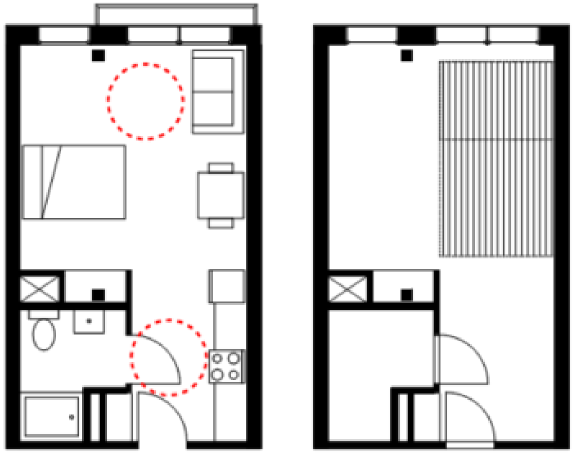
Coquitlam L Tower

	Studio	1 Bedroom	2 Bedroom	3 Bedroom	Two Parking Levels
L1 - L3	10	10	6	2	Coquitlam parking bylaw Part 7-720.1© = 0.65 spaces/ unit + 10% for visitors
L3- L9	42	42	35	28	
L10-L13		3	12	12	
Total	**52**	**55**	**53**	**42**	**172**

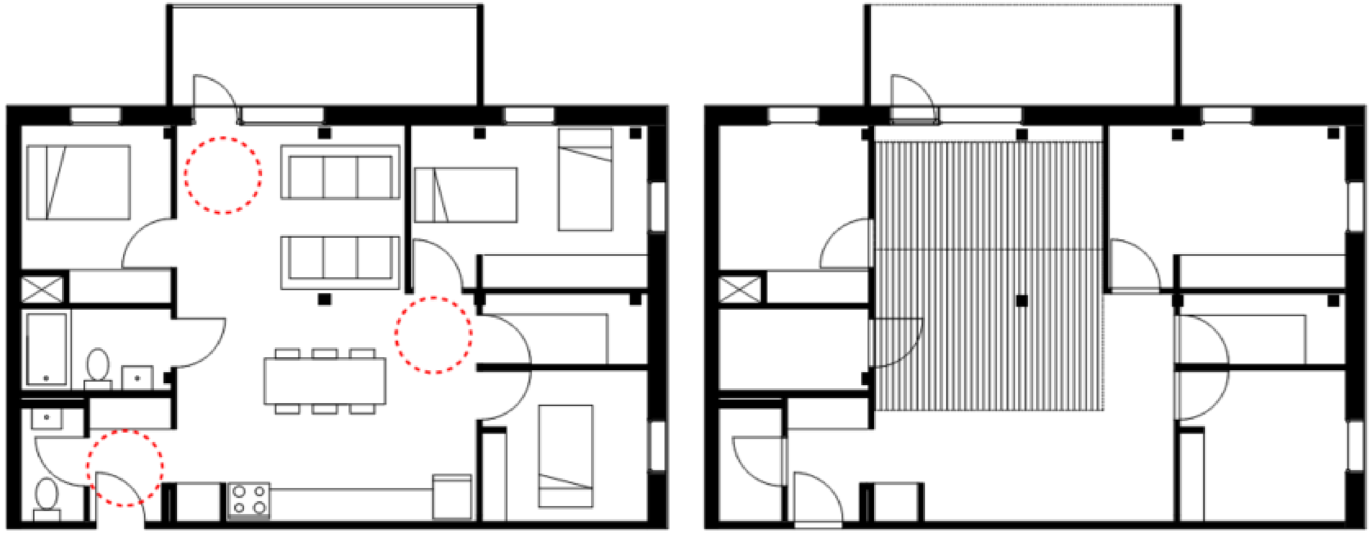
Vancouver/ Point Tower

	Studio	1 Bedroom	2 Bedroom	3 Bedroom	Two Parking Levels
L1 - L3					Vancouver parking bylaw 4.5B1 =1 space/ 125 sqm GFA
L3- L9	14	14	28	14	
L10-L13				12	
Total	**14**	**14**	**28**	**26**	**44**

1.64. INTERIOR FLOORPLAN - TYPICAL OF A EMTC STUDY BUILDING WITH ACCESSIBLE UNITS

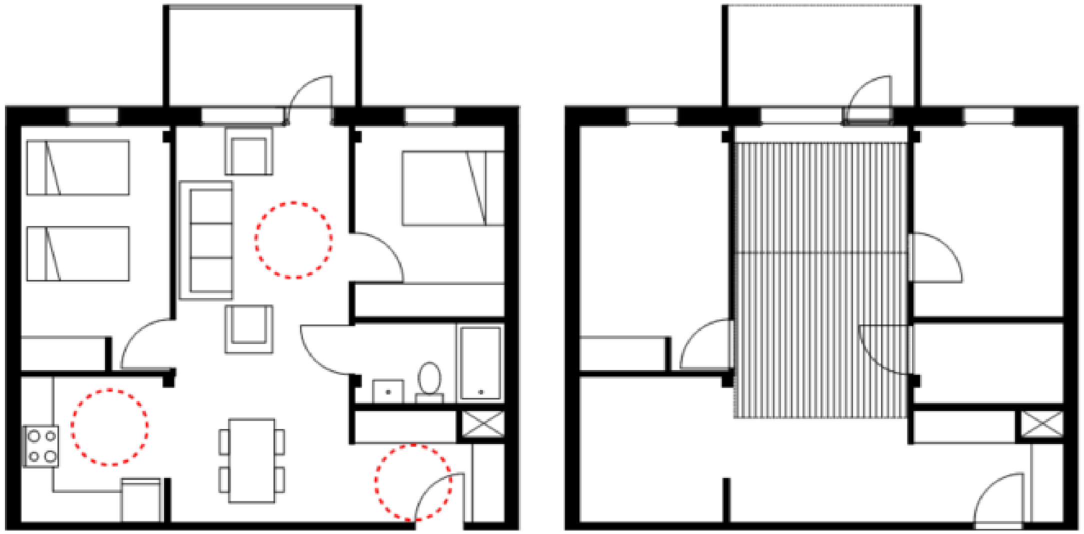


Studio



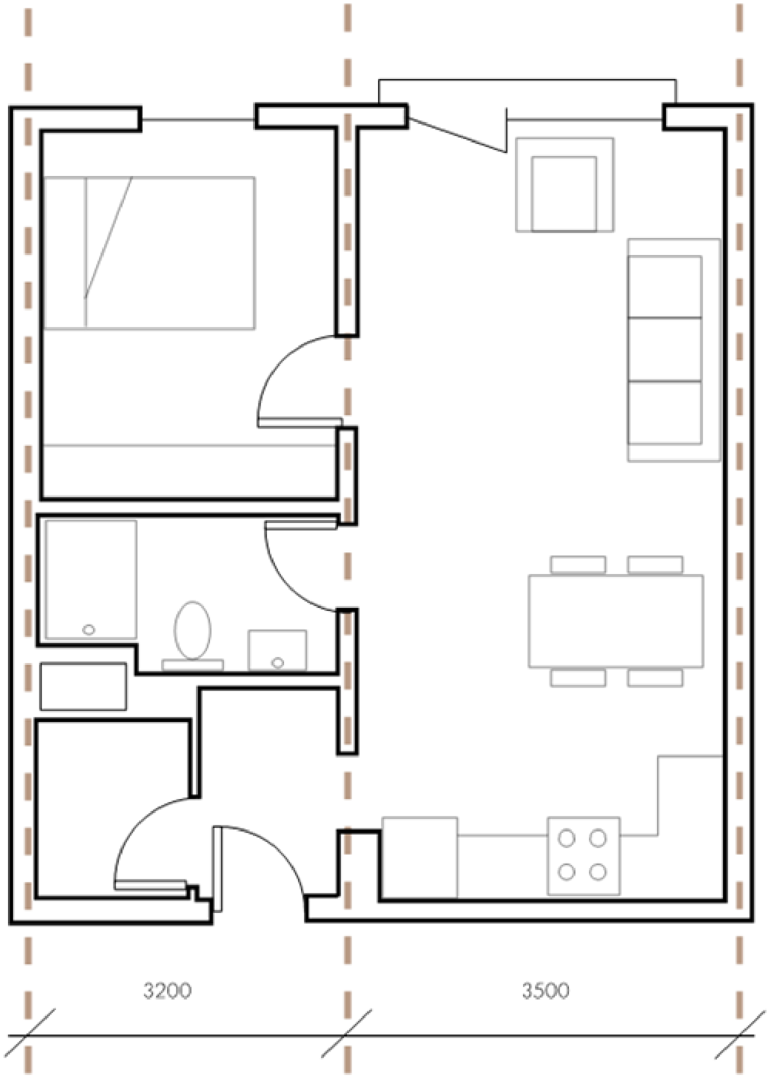
3 Bedroom

1 Bedroom



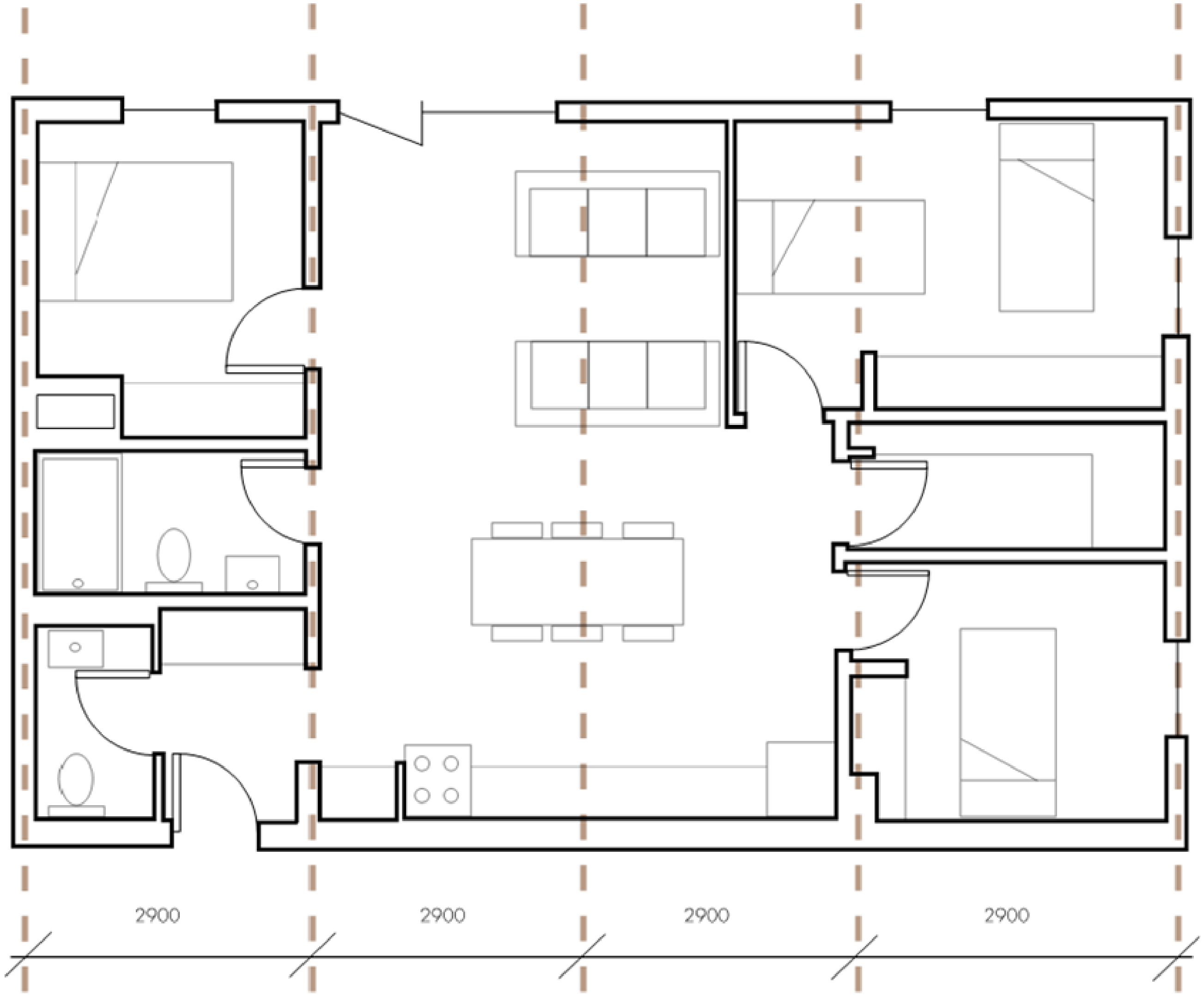
2 Bedroom

1.65. INTERIOR FLOORPLAN - TYPICAL UNIT TYPE CONFIGURATIONS OPTIMIZED WITH CLT PANEL WIDTH



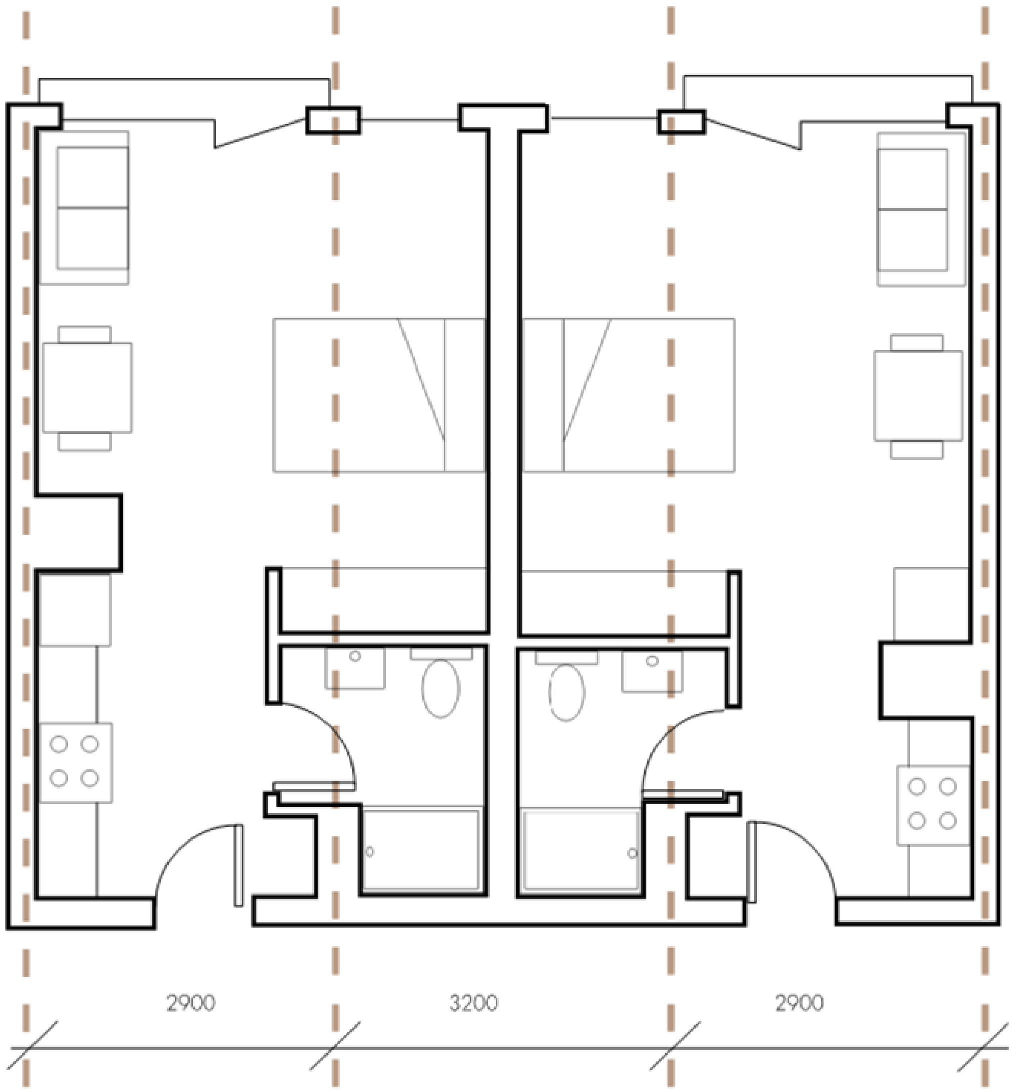
1 BEDROOM

BC HOUSING STANDARDS	4 M2
BCH + 5% FOR ADAPTABILITY	51.4M2
PROPOSED	40.4M2



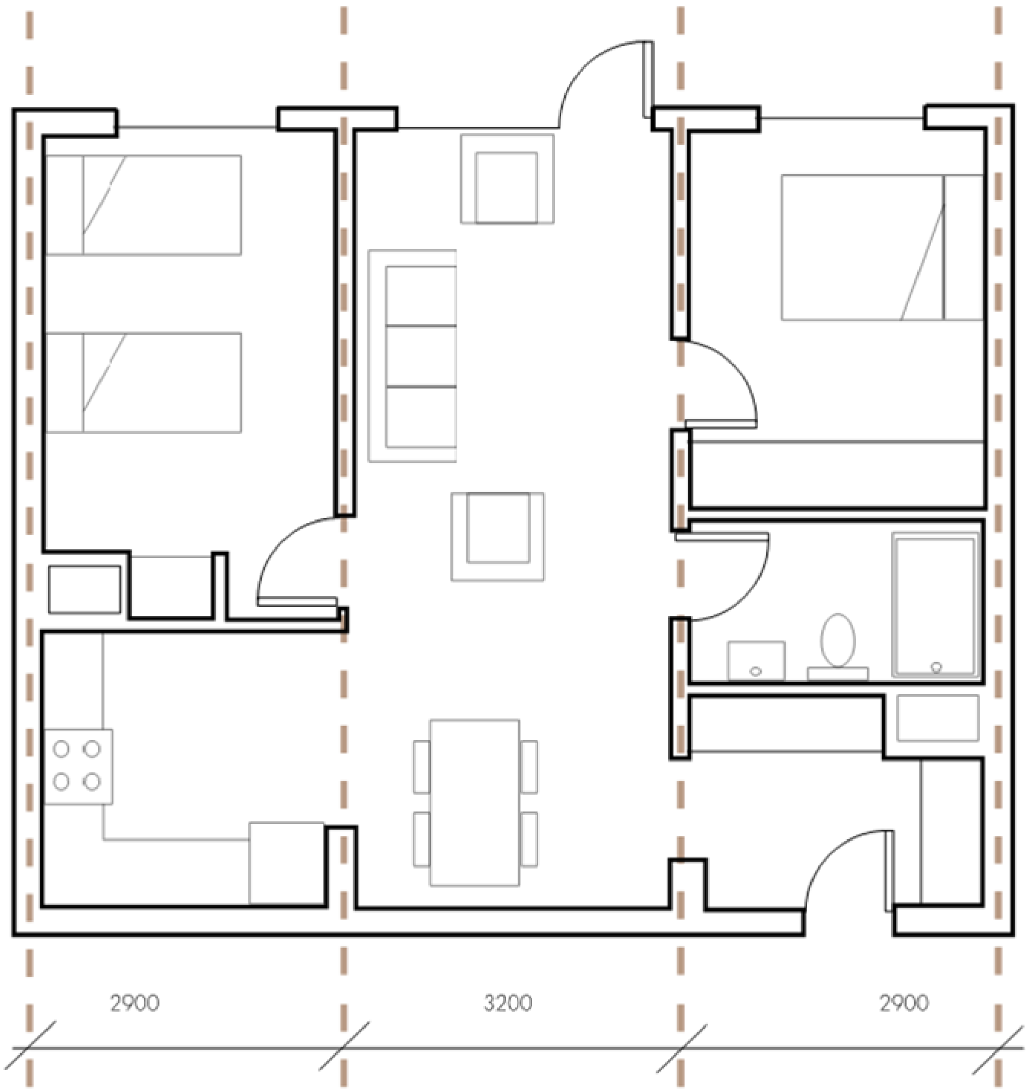
3 BEDROOM

BC HOUSING STANDARDS	86M2
BCH + 5% FOR ADAPTABILITY	90.3M2
PROPOSED	90.2M2



STUDIO

BC HOUSING STANDARDS	33 M2
BCH + 5% FOR ADAPTABILITY	34.6M2
PROPOSED	33.9M2



2 BEDROOM

BC HOUSING STANDARDS	67M2
BCH + 5% FOR ADAPTABILITY	70.3M2
PROPOSED	70.2M2

Key Building Code Analysis and Recommendations

1.66. SAFETY AND PERFORMANCE

The Building Code analysis of the archetypes and application of key fire protection and occupant safety provisions of BC Building Code 2018, BC Fire Code 2018, includes identification of differences with the Vancouver Building Bylaw 2019 and Vancouver Fire Bylaw 2019 provisions respective of the requirements for EMTC, Building Code analysis for each type of building, key provisions of construction requirements, fire separation and compartmentation, and egress/ exiting systems and fire protection systems. We have provided commentary for the feasibility of proposed prefabricated assemblies or building systems utilized by the design team and analysis of construction sequencing with respect to applicable Fire Code provisions.

Application of EMTC Provisions

The construction of encapsulated mass timber buildings using the BC Building Code or Vancouver Building Bylaw in the Province of British Columbia is currently only permitted in jurisdictions that are participating in a jurisdiction-specific regulation (JSR). Over 20 local authorities are participating in the JSR and have accepted the early adoption of EMTC provisions. This includes the City of Vancouver where the Point Tower is based, and the City of Coquitlam where the L Tower is based. The City of Kamloops, where the Slab Tower archetype is based, is currently not participating in the JSR, however province-wide application of the EMTC provisions is expected to be implemented in the next edition of BC Building Code. Other options for constructing tall EMTC buildings are via a specific site regulation (SSR) or via an alternative solution approach.

The fire safety incorporated in the EMTC study reflect current applicable code requirements. The study includes current industry best practices and insights provided from research including past project variances and evidence-based solutions. The construction of these mass timber buildings vary from current acceptable solutions that would be subject to approval processes involving fire safety experts, design professionals, and authorities having jurisdiction.

The EMTC buildings compared in the study have been designed to meet the required fire resistance ratings for the structure per the requirements for Encapsulated Mass Timber Construction (EMTC). The encapsulation in the study buildings provides enhanced fire-resistance ratings as the mass timber elements are designed to provide the requisite ratings throughout the building. The EMTC study building utilizes steel columns throughout for efficiency of reducing size/ weight where columns can be incorporated within suite separation walls. Likewise, glulam transfer beams at the setback floors, in the Point and Slab Tower cases, can be sized for either full encapsulation or exposure based on structural design and requirements of the AHJ:

- With 60 mins fire-resistance contribution from gypsum board protection - Glulam design 215x418 D.FIR 24f-E, Typical at north and south elevation floor edges at floors 10 through 12.
- With no gypsum board protection - Glulam design 315x456 D.FIR 24f-E, Typical at north and south elevation floor edges at floors 10 through 12.

The EMTC study building are comprised of a series of repetitive, compartmentalized rooms so that in the event a fire originates in one suite, it is likely the fire would be contained in the compartment in which it originated. A back-up water supply and emergency power supply are installed so the sprinkler system will function even if the building loses its standard water and electrical supply, such as in the event of an earthquake. From a seismic perspective the building exceeds code requirements. The concrete cores will provide resistance to the lateral loads while the lighter weight of the mass timber structure will result in the building experiencing lower seismic forces than a conventional equivalent all-concrete building—a key consideration in a seismic zone such as coastal British Columbia.

1.67. BUILDING AND FIRE CODE REGULATIONS

Since 1980 the Province of British Columbia (B.C.) has adopted an amended version of the National Building Code of Canada as the BC Building Code, which is a regulation made under the Building Act. Except for the City of Vancouver, the BC Building Code 2018 (BCBC) is the applicable Building Code for the design and construction of buildings throughout B.C.. Under the Vancouver Charter, the City of Vancouver adopts Vancouver Building Bylaw 2019 (VBBL) to regulate the design and construction of buildings in the City of Vancouver, except for the University of British Columbia (UBC) and the University Endowment Lands which are subject to the BCBC.

Once the construction of a new building is granted an occupancy permit the building must be maintained in conformance with the BC Fire Code 2018 (BCFC) which applies to all occupied buildings throughout B.C. and also to fire safety of buildings during construction. The City of Vancouver adopts the BC Fire Code 2018 as the Vancouver Fire Bylaw 2019 (VFBL) subject to changes noted under City of Vancouver Bylaw No. 12472.

1.68. EVOLUTION OF MASS TIMBER IN THE BC BUILDING CODE

The development of the current mass timber regulations in the BC Building Code has been documented in many guides and industry resources, and includes the following highlights of the evolution of the Building Code:

- BCBC adoption of mid-rise wood provisions for 5 and 6 storey Group C and Group D buildings
- Code Change Requests to the Canadian Commission on Building and Fire Codes to support taller wood buildings in the National Building Code
- B.C. Site Specific Regulations, including for the construction of an 18-storey residential building (Brock Commons)
- Site specific Alternative Solutions for various mass timber buildings in B.C.
- Revision to the BCBC 2018 to include encapsulated mass timber construction requirements based on the proposed changes to the 2020 NBC

Effective December 12, 2019 the BC Building Code 2018 was amended by Ministerial Order No. BA 2019 6 to include provisions to permit encapsulated mass timber construction (EMTC). It is important to note that the early adoption of EMTC provisions into the BCBC is currently presented as a jurisdictional specific regulation (JSR), meaning that municipalities have the option to opt into permitting EMTC buildings in their jurisdiction. The list of participating municipalities is in BCBC Division A Article 1.1.1.1.

1.69. FUTURE OF MASS TIMBER IN THE BC BUILDING CODE

Province wide participation for encapsulated mass timber construction is anticipated in the next edition of the BCBC. Until that time mass timber buildings are permitted under Division B in participating jurisdictions i.e. “acceptable solutions”, and by “alternative solutions” elsewhere.

It is important to note that alternative solutions are not a way to “get out” of code requirements, but are a valid compliance mechanism established in the objective based format of the codes to facilitate innovation and to provide a framework for evaluation and acceptance of designs that do not meet with the generally prescriptive requirements of Division B.

Alternative solutions can be developed for single issues or features, or for an overall building design. They have been used extensively for mass timber buildings constructed to date, both prior to and since the adoption of EMTC provisions in the BCBC. Alternative solutions to Division B provisions are required to demonstrate at least the same performance as Division B, which can include qualitative analysis, scenario analysis, fire risk assessment, calculations, computer modelling or testing. Alternative solutions can facilitate tailored solutions that consider the site-specific mitigating features and are an advantage to many projects.

Disadvantages of alternative solutions include the analysis and documentation effort that needs to be expended on each project. This is because alternative solutions are site-specific and are not automatically applicable to all buildings. Reliance on final approval from the AHJ, may only be provided late in the schedule and may not be consistently applied across jurisdictions. While there are some drawbacks to the alternative solution process, it is a useful compliance mechanism in the BCBC to address features that differ from Division B. Ideally features that are subject to regular alternative solutions will be proposed as code changes for adoption in a future edition of the Building Code.

Code change requests are under review for the next edition of the National Building Code and include proposed changes to current NBC provisions related to mass timber (see variation discussion in this report). Since British Columbia has agreed to the harmonization of construction codes across Canada, the changes adopted for the next NBC are expected to be adopted in B.C.

In the longer term, performance-based codes are expected to be developed in Canada, which will further facilitate construction with mass timber provided that acceptable performance can be demonstrated.

1.70. FIRE PROTECTION REQUIREMENTS FOR EMTC IN THE BCBC 2018

This section of the study provides a high level summary of the current regulatory requirements for mass timber in the BCBC. This will be the applicable code for new BC Housing construction with the exception of buildings in Vancouver. Differences with the VBBL are noted, however these differences are nominal and are not expected to significantly impact costs.

The BCBC was amended to include provisions for a new type of construction - encapsulated mass timber construction (EMTC) – with a corresponding maximum height of 12 storeys for Group C and D major occupancies. Previously, wood was only permitted as a construction type up to 6 storeys under “mid-rise” wood construction provisions. The basis for the increase in height to 12 storeys is captured within the code change documents, as well as numerous industry report and guides.

EMTC as a new construction type, was adopted on the basis that engineered timber elements having minimum dimensions, as part of a mass timber building, will exhibit fire performance characteristics that are different than those of lightweight and small dimension lumber in light-framing construction. The fire performance characteristics of mass timber buildings include reduced ignition propensity and reduced average rate of fuel contribution. The minimum dimensions in the Code are intended to provide a predictable charring rate and predictable fire behavior under standard fire exposure. The permission for increased height is also based on the concept of encapsulation, in which the encapsulation materials protect the engineered timber elements to delay ignition and contribution to a fire.

1.71. BCBC 2018 DIVISION B EMTC FIRE PROTECTION PROVISIONS

Most provisions specifically governing EMTC in the BCBC 2018 are located in Subsection 3.1.18. and in the relevant Subsection 3.2.2. provisions (3.2.2.48. EMTC for Group C, 12 storeys, sprinklered). These provisions are generally linked to the following objectives and functional statements:

F02, F03, F04	OS1.2, OP1.2, OP3.1

The full exercise of pairing these functional statements with their relevant objectives has not been undertaken, but are listed below to give a sense of the basis for the new EMTC provisions.

Functional Statements:

- F02 To limit the severity and effects of fire or explosions.
- F03 To retard the effects of fire on areas beyond its point of origin.
- F04 To retard failure or collapse due to the effects of fire.

Objectives:

OS1 Fire Safety

An objective of this code is to limit the probability that, as a result of the design or construction of the building, a person in or adjacent to the building will be exposed to an unacceptable risk of injury due to fire. The risks of injury due to fire addressed in this Code are those caused by –

OS1.2 – fire or explosion impacting areas beyond its point of origin

OS1.3 – collapse of physical elements due to a fire or explosion

OP1 Fire Protection of the Building

An objective of this code is to limit the probability that, as a result of its design or construction, the building will be exposed to an unacceptable risk of damage due to fire. The risks of damage due to fire addressed in this Code are those caused by –

OP1.2 – fire or explosion impacting areas beyond its point of origin

OP1.3 – collapse of physical elements due to a fire or explosion

OP3 Protection of Adjacent Buildings from Fire

An objective of this code is to limit the probability that, as a result of the design or construction of the building, adjacent buildings will be exposed to an unacceptable risk of damage due to fire. The risks of damage to adjacent buildings due to fire addressed in this Code are those caused by –

OP3.1 – fire or explosion impacting areas beyond the building of origin

The areas of performance addressed by EMTC provisions are related to fire growth, fire spread, and collapse due to fire, to limit the probability of injuries to persons or damage to buildings. The overall code change for EMTC was based on a comparison to the level of performance of a 12 storey noncombustible building. Any alternative solution or Code change related to EMTC will need to address these areas of performance.

1.72. COMPARISON OF BCBC 2018 TO 2020 NBC ENCAPSULATED MASS TIMBER PROVISIONS

The BCBC 2018 changes regulating encapsulated mass timber construction were heavily based on the draft changes proposed for the 2020 National Building Code (NBC), that were still under review at the time of this report. As such, apart from minor differences, the provisions addressing encapsulated mass timber under the BCBC 2018 are substantively the same as the requirements for encapsulated mass timber recently published in the 2020 NBC.

One obvious difference however is the location of the provisions specifically governing EMTC:

- BCBC 2018 contains Subsection 3.1.18. Encapsulated Mass Timber Construction
- 2020 NBC contains Subsection 3.1.6. Encapsulated Mass Timber Construction

1.73. MASS TIMBER IN THE INTERNATIONAL BUILDING CODE

The 2021 International Building Code (IBC) is a model code, independently developed in the United States and adopted by jurisdictions across the United States and internationally. This latest edition is the first to include provisions regulating mass timber construction.

The 2021 IBC utilizes a different system of occupancy classification to the BCBC. Occupancies are broken down as: Group A for assembly, B for business, E for educational, F for industrial, H for high-hazard, I for institutional, M for mercantile, R for residential, S for storage and U for utility and miscellaneous. And each IBC occupancy has further subcategories refining the applicability of certain Code provisions.

The IBC breaks construction into five Types, where Type I and II are noncombustible, Type III has noncombustible exterior walls and where interior building elements are of other permitted materials. Type IV construction is mass timber and has four sub-categories, A, B, C and HT. A, B and C have descending levels of protection (analogous to encapsulation) and, correspondingly declining design options from most restrictive to most permissive, and HT is traditional heavy timber construction like the BCBC with the exception that HT requires a higher fire-resistance rating of 1 hour in the IBC. Type V construction is where structural elements, exterior walls and interior walls are of any materials permitted by the IBC.

The key requirements of the BCBC and IBC as they apply to fully sprinklered residential apartment buildings greater than seven storeys, reflective of this study’s building archetypes, are presented below. This is not an exhaustive list of requirements, but rather key requirements to inform potential areas for further investigation for future BCBC and NBC code changes. Other code provisions would apply to buildings with different or multiple major occupancies. The comparison tables summarize key requirements applicable to Group C residential apartment buildings under the BCBC, relative to R-2 residential apartment buildings under the IBC.

Under the BCBC, “encapsulation rating” means the time in minutes that a material or assembly of materials will delay the ignition and combustion of encapsulated mass timber elements when it is exposed to fire under specified conditions of test and performance criteria, or as otherwise prescribed by the BCBC. Certain materials stated in the BCBC are given a certain rating, and other materials or assemblies can be assigned a rating based on testing to CAN/ULC-S146.

Under the IBC, “noncombustible protection” means time, in minutes, contributed to the fire-resistance rating by the noncombustible protection of mass timber building elements established through a comparison of assemblies tested using procedures in ASTM E119 or UL 263, where the test assemblies are identical in construction other than the noncombustible protection. The noncombustible protection time contribution is determined by subtracting the fire-resistance time of unprotected test assembly from the protected test assembly (see 2021 IBC Section 703.6), where the IBC defines “noncombustible” materials to mean materials tested in accordance with ASTM E136, or ASTM 2652 using acceptance criteria prescribed by ASTM E136 (see 2021 IBC Section 703.3).

ITEM	BCBC 2018 Encapsulated Mass Timber	2021 IBC Mass Timber Construction for R-2 Residential Occupancy		
		Type IV-A	**Type IV-B**	**Type IV-C**
Maximun Storeys	12	18	12	8
Maximum Height*	42 m (138 ft)	82 m (270 ft)	55 m (180 ft)	26 m (85 ft)
Required FRR: Loadbearing Structure Floors Roof	 2 hr 2 hr N/A	 3 hr 2 hr 1.5 hr	 2 hr 2 hr 1 hr	 2 hr 2 hr 1 hr
Mass Timber Protection	**Encapsulation**	**Noncombustible Protection**		
Determination of Rating	Test to ULC-S146 or meet deemed-to-comply options	Non Combustible protection time is based on Comparison Test to ASTM E119 or UL 263	Non Combustible protection time is based on Comparison Test to ASTM E119 or UL 263	Non Combustible protection time is based on Comparison Test to ASTM E119 or UL 263
Interior Walls and Ceilings	50 mins Some exposed areas permitted**	Non Combustible protection not less than 80 mins 120 mins for 3hr FRR loadbearing structure	Non Combustible protection 80 mins Some exposed areas permitted***	Unprotected
Upper Surface of Floor Assembly	50 min noncombustible material tested to ULC-S146 38mm Gypsum concrete or concrete or 2x12.7mm Type X Gypsum	1" (25 mm) Noncombustible material tested to ASTM E136 (or E2652 with acceptance criteria to E136)	1" (25 mm) Noncombustible material tested to ASTM E136 (or E2652 with acceptance criteria to E136)	Unprotected
Interior Surface of Mass Timber Roof Assembly	50 mins	Noncombustible protection 80 mins	Noncombustible protection 80 mins	Unprotected
Concealed Spaces	25 mins encapsulation rating, or single layer 12.7 mm Type X gypsum No protection if sprinklered and fireblocked, or if filled with mineral fibre insulation	Noncombustible protection 80 mins	Noncombustible protection 80 mins	Noncombustible protection 40 mins
Shafts	50 mins	Noncombustible construction required for the shafts	Noncombustible protection 80 mins	Noncombustible protection 40 mins

Notes:

FRR = fire resistance rating

* Mesurement of Height varies based on building type

** Some exceptions apply in Article 3.1.18.4. in the BCBC that would permit exposed mass timber surfaces: Walls - up to 35% exposed of the total wall area of perimeter of the suite; Ceilings Option 1-10% of the ceiling area exposed if beams, columns and walls are also exposed; or Ceilings Option 2-25% of the ceiling area exposed if only beams and columns are also exposed (i.e. no walls). Mass timber beams columns or arches need not be protected provided their surface area does not exceed 10% of the total wall area of perimeter of the suite or fire compartment. NOTE: Vancouver Building By-Law does not permit exposed mass timber within a residential suite.

*** Some exceptions apply in the IBC that would permit unprotected areas on the inside face of mass timber walls and columns (up to 40%) and ceilings and beams (up to 20%) or to both walls and ceilings per calculation in 602.4.2.2.3. Mass timber columns and beams that are not integral to walls or ceilings are permitted to be unprotected without restriction.

Figure 36 - Comparison of BCBC 2018 with 2021 IBC

1.74. COMPARISON OF BCBC AND IBC MASS TIMBER REQUIREMENTS

It is important to recognize that the fundamental approach taken under the IBC to address the risks posed by mass timber construction is substantively different to the approach taken under the BCBC. For this reason, several of the above provisions may appear at first to be more restrictive or permissive when examined in isolation. We must recognize that it is the interplay between the provisions when applied together, rather than in isolation, that achieves the overall desired level of life safety intended by the model Code.

However, the above comparison does help identify some key areas where there may be opportunities for Code advancement to allow for construction innovation to help increase design flexibility and reduce construction costs while maintaining a high level of protection under the BCBC.

Note that an in-depth analysis of the IBC structural and fire protection provisions for mass timber and the potential for NBC changes has been completed by GHL and Fast + Epp for Forestry Innovation Investment in June 2021 and is publicly available: 2021-06-07-Transferability-Report-GHL-7958.00-FE-GHL.pdf (bcfii.ca). The report identifies inconsequential differences for application to EMTC, and consequential differences for EMTC out of which potential changes to the NBC were identified. The overall conclusion of the Transferability Report from their Executive Summary is:

> It is the conclusion of this report that, because of the research substantiating the IBC Code changes, as well as the shared research effort between the NBCC and the IBC, the mass timber Code provisions from the IBC can generally be adopted by the NBCC with some modifications. This report recommends the existing 12 storey EMTC permitted for Groups C and D to be extended to 18 storeys and 9 storeys. In addition to Occupancy Groups C and D, Groups of reasonably similar fire risk, including A-2, B-3, E, F-2, and F-3 are also recommended based on the IBC provisions, though with shortened building heights. For simplicity, building areas are recommended to remain with the NBCC limits, noting that both the height limits and the area limits should be considered reasonable next steps in Code evolution.

Since this study is focusing on potential changes to the BCBC that could result in cost savings, specifically for residential buildings, the following key differences between IBC and BCBC provisions are identified. They are further discussed in the next section of the report.

IBC permits mass timber building heights of up to 18 storeys (Type IV-A).

Type IV-A construction permits up to 18 storeys, with the corresponding 3-hour fire resistance rating for the structural frame and primary structural elements, as well as increased duration of protection of the mass timber elements (120 minutes for 3hr FRR structural elements and 80 minutes protection rating, compared to 50 minutes encapsulation rating under BCBC, note that the protection rating and encapsulation rating are established differently and are not directly comparable). The increased height may result in cost savings relative to overall efficiency of development per square metre of land for densely populated urban sites in particular.

IBC permits mass timber buildings up to 8 storeys without protection of the mass timber (Type IV-C).

Type IV-C construction permits unencapsulated mass timber for walls, ceilings, and floors up to a maximum of 8 storeys in building height for R-2 occupancy classification. The BCBC requires the same amount of encapsulation for any mass timber building up to 12 storeys. The reduced encapsulation requirements may result in materials cost savings and in speed of construction for buildings 7-8 storeys in height.

IBC permits 1 inch of noncombustible material to protect the upper surface of a mass timber floor assembly (Type IV-A and B).

Type IV-A and B construction both require the floor assembly to have a noncombustible material, not less than 1” (25 mm) in thickness above the mass timber, where non-combustibility is determined in accordance with ASTM E136, or ASTM E2652 using acceptance criteria prescribed by ASTM E136. This is a well-established test for combustibility and a wide range of common construction materials have already been tested to this standard. This is compared to the BCBC requirement for the noncombustible material on the upper surface of the floor assembly to provide a 50 minute encapsulation rating, determined by a ULC-S146 test, or the permission to use a 38 mm thick concrete or gypsum-concrete topping.

There are several IBC mass timber provisions that are more restrictive than the BCBC when considered alone that would potentially result in additional costs if applicable under the BCBC:

- **Exterior Fire Spread:** Both the BCBC and the IBC have provisions addressing exterior protection to address external fire spread and spatial separation between buildings. However, the approach to these provisions differs between these codes. While there are differences between the requirements, the provisions under the IBC are generally more restrictive than the BCBC due to the difference in approach to exterior protection.
- **Interior Non-loadbearing Walls:** The IBC requires that interior building elements, including non-loadbearing walls and partitions be of mass timber construction or noncombustible construction. This is more restrictive than the BCBC which permits combustible elements in partitions in a building of encapsulated mass timber construction where protected (in accordance with Article 3.1.18.13).
- **Interior Encapsulation/Protection of Walls and Underside of Floors:** IBC Type IV-B (most similar to the NBC) requires that the protection contribute 80 minutes to the fire resistance rating versus the 50 minutes for an encapsulation rating required by the NBC. This means the IBC requires 2 layers of 15.9 mm Type X gypsum board to provide 80 minutes protection, versus the NBC requirement for 2 layers of 12.7 mm Type X gypsum board to provide an encapsulation rating of 50 minutes.
- **Roof Construction:** The IBC requires roof construction to provide a 1 hour fire resistance rating (Type IV-B and IV-C) or a 1.5 hour fire resistance rating (Type IV-A). This is more restrictive than the BCBC which does not mandate a minimum fire resistance rating for roof assemblies for an EMTC building, unless the roof is occupied.

The above provisions are not explored in greater detail as the purpose of this study is to identify opportunities for cost savings. The code change process will have to evaluate the evidence to support individual changes within the context of Canadian Codes and the overall approach to EMTC buildings.

1.75. PAST PROJECT VARIANCES

Past project variances to mass timber fire protection requirements of the BCBC 2018 are known from informal industry discussions, and publicly available information. When a project pursues compliance via alternative solutions, the analysis, reports and approvals are typically proprietary and owned by the professionals and project owners. A detailed search of municipal building permit documents though freedom of information requests was not part of the scope of this study.

Anecdotally, alternative solutions are regularly sought for the following features:

- Firestopping systems where the specific configuration of systems have not yet been fire tested
- Increased area of interior exposed mass timber surfaces
- Exterior wall construction that does not meet full spatial separation requirements
- Approach to fire blocking and protection of concealed spaces

Some project variances that are published are:

- Brock Commons in Vancouver, B.C. is based on the Site Specific Regulation and published project summaries:
    - 18 storey height, with 80 minutes encapsulation (3x12.7 mm Type X gypsum board) as a significant compensating measure
    - 6 storeys remaining unencapsulated during construction relying on site fire safety measures
- Terrace House in Vancouver, B.C. used exposed mass timber in the top 7 storeys of a 19 storey residential building prior to adoption of EMTC provisions
- 2150 Keith Drive in Vancouver, B.C. is a 10 storey mass timber office building with exposed CLT floor assemblies.

1.76. POTENTIAL VARIATIONS FROM CURRENT BCBC/BCFC EMTC PROVISIONS

One objective of this study is to identify possible regulatory changes that have potential for cost savings for mass timber buildings, with a focus on 7 - 12 storey residential buildings. Potential regulatory changes to fire protection related provisions have been identified through a review of available published information on constructed mass timber buildings, analysis of the International Building Code mass timber provisions (see previous section), informal consultation with designers, consultants, industry organizations, and authorities having jurisdiction, and through analysis of critical design features. These design features have the potential to demonstrate fire protection performance via alternative solution, and/or form abasis for a code change.

In some instances, the wording or intent of the BCBC or BCFC may not be clear and an interpretation on a particular Code requirement can be obtained through the BC Building Code Interpretation Committee for matters of the BCBC or the Office of the Fire Commissioner for BCFC matters. In situations where there is a dispute between a building permit applicant and a Local Building Official, they can be resolved by the decisions of the BC Building Code Appeal Board (Appeal Board decisions are binding). While these options may provide clarification on the application of the BCBC or BCFC, obtaining a decision or answer can be time consuming and may not fit with the demands or needs of a project.

The potential variations from current BCBC/BCFC EMTC provisions are discussed below, touching on:

- The current Division B provisions.
- Reasons to explore change, with a focus on potential opportunities for cost savings and/or improved performance.
- Potential basis for demonstration of performance for fire protection.
- Next steps for the feature, either as an alternative solution or as a code change.

1.77. ENCAPSULATION OF TOP SIDE OF FLOOR ASSEMBLY

A fundamental concept for mass timber in the BCBC and NBC is that the majority of mass timber is encapsulated to delay the ignition of the timber and limit its contribution to fire growth and severity. This concept is captured in Articles 3.1.18.4., 3.1.19.1 and 3.1.19.2. of Division B of the BCBC.

Encapsulation requirements include the top side of the floor assembly, which differs from typical floor assemblies that are only required to achieve a fire-resistance rating from the underside. Encapsulation materials are required to be noncombustible or limited combustible and are required to demonstrate a 50-minute encapsulation rating by a ULC-S146 test or be one of the deemed-to-comply materials that has demonstrated performance in past tests.

BCBC permits the following deemed-to-comply options for the top side of a mass timber floor assembly:

- Gypsum concrete topping – Sentence 3.1.19.2.(1)
- Concrete not less than 38 mm thick – Sentence 3.1.19.2.(1), or
- 2 layers of Type X gypsum board each not less than 12.7 mm thick – Sentence 3.1.19.2.(2)

Reasons to Explore Change

Encapsulating floors with concrete or gypsum-concrete topping requires time to cure which can result in delays to construction scheduling. Encapsulating floors with Type X gypsum is typically impractical and there are concerns with the durability of installing gypsum under finished floor assembly, and its susceptibility to impact damage.

ULC-S146 is a new test, specific to evaluating encapsulation materials for the protection of structural timber elements. Various industry stakeholders have indicated that there have been no proprietary encapsulation materials tested to ULC-S146 as of the writing of this report, aside from materials tested as part of research programs.

The IBC approach to protection of the upper surface of mass timber does not require a specific encapsulation or protection rating. Type IV-A and Type IV-B require only 1 inch of noncombustible material, and Type IV-C construction (up to 8 storeys high) does not require any specific noncombustible protection for the upper side of mass timber floor assemblies.

A change to Article 3.1.18.4. to reflect the IBC provisions, by permitting 25 mm of material tested to CAN/ULC-S114 “Standard Method of Test for Determination of Non-Combustibility in Building Materials”, would greatly expand the range of materials available for floor treatment, and would provide design flexibility and cost savings. Note that additional materials may be required to achieve acoustic performance.

Archetype Design

The archetype designs encapsulate the topside of the floor assembly with a layer of mineral wool, incorporating a proprietary acoustic material (combustible plastic domes in a grid spacing), covered by 2 layers of 12.7 mm Magnesium Oxide board). This encapsulation system has not yet been tested to ULC-S146, and it includes combustible material for acoustic performance. This system will require an approved alternative solution as part of the building permit process due to the combustible material, and demonstration of encapsulation performance on the either basis of a ULC-S146 test, or analysis under alternative solution.

The potential basis for fire protection performance of this encapsulation for the top side of a mass timber floor assembly is:

- Mineral wool has demonstrated positive performance during research using ULC-S146 fire tests.
- Cement board as a noncombustible board product has demonstrated positive performance during research ULC-S146 tests, although on its own it failed to meet the test criteria for a 50-minute duration (39 minutes achieved). A comparison of MgO and cement boards may be useful to confirm material properties related to heat transfer.
- In a limited search one manufacturer has confirmed their MgO boards meet the ASTM E136-04 “Standard Test Method for Behavior of Materials in a Vertical Tube Furnace at 750°C”. Materials passing this test are typically classified as a noncombustible material. This is a predictor that this product may satisfy the ULC-S135 test for limited combustibility.

Basis for Change and Next Steps

The encapsulation rating to protect mass timber has been a foundational concept during the development of encapsulated mass timber provisions in the NBC, supported by many fire tests and years of research. It is possible to propose compliance of floor slab top side protection via alternative solution on a project-by-project basis by demonstrating performance levels which may include analysis of related fire tests or modelling. They may also take into account other performance factors for the specific building besides the floor assembly protection.

A BCBC/NBC code change related to the protection of the top side of mass timber floor assemblies is likely to require demonstration via testing, including non-standard fire testing, to confirm that the overall objective of limiting involvement of the mass timber in a fire will still be satisfied.

1.78. EMTC EXTERIOR WALL ASSEMBLY CONSTRUCTION

BCBC Division B requires that the exterior wall assemblies for a building under Article 3.2.2.48EMTC be of encapsulated mass timber construction, or of noncombustible construction used singly or in combination. Combustible components are permitted for such an exterior wall, provided the conditions of Article 3.1.5.6. are satisfied, which requires either a ULC-S134 test, or protection of the combustible components on the exterior side by 25 mm of concrete or masonry.

Reasons to Explore Change and Archetype Design

The exterior wall assembly design and materials can have a significant impact on the thermal performance of the assembly and building. This was investigated in detail for the archetype design because of the cost implications for different wall assemblies.

The EMTC archetype exterior wall assembly is comprised of structural timber panels, with varying thickness the height of each panel. The timber thickness is 96 mm where aligned with slab edges, however the panel is reduced to 2 ply thickness of 61 mm between floor slabs, with mineral wool to “fill out” the thickness of the exterior wall. The combination of mineral wool and single layer of interior Type X gypsum is proposed as an equivalent encapsulation of the mass timber, and the timber panel less than 96 mm thick is proposed to support enhanced thermal performance relative to the full thickness of a timber panel.

Basis for Change and Possible Next Steps

The archetype exterior wall assembly will require a project-specific alternative solution for compliance with Articles 3.1.18.3. and 3.1.18.4. for the minimum thickness of mass timber, and for encapsulation using a combination of mineral wool and gypsum board. The analysis will need to demonstrate an appropriate delay to onset of charring of the timber, fire resistance characteristics, and resistance to vertical fire spread to show performance is at least as good as Division B. The overall wall assembly construction, including window framing details will need to be analyzed for behaviour during scenarios of a compartment fire, and for fire venting to the exterior out a broken window.

Reference to relevant fire tests and modelling are expected to be relied upon to demonstrate performance. This wall assembly will meet Division B with a successful ULC-S135 test, which may support future inclusion in generic wall assemblies such as those in Appendix D-6 “Fire Performance of Exterior Wall Assemblies”.

1.79. COMBUSTIBLE WINDOW FRAMES

BCBC Article 3.1.18.6. and NBC Article 3.1.6.8. establish the conditions to permit combustible window sashes and frames in EMTC construction: windows are individual units separated from each other by noncombustible or mass timber construction (meeting minimum dimensions); windows in contiguous storeys are separated by not less than 1 m of noncombustible or mass timber construction; and the aggregate area of openings in the exterior wall of a fire compartment is not more than 40% of the area of the wall face.

These conditions reflect the BCBC 2018 and 2015 NBC conditions for combustible window frames in noncombustible buildings. The 2020 NBC has a change to Sentence 3.1.5.4.(5) that imposes only one condition to use combustible window sashes and frames: “Combustible window sashes and frames are permitted in a building required to be of noncombustible construction, provided they are vertically non-contiguous between storeys.”

Reasons to Explore Change and Archetype Design

The removal in 2020 NBC of the current maximum area and separation requirements provides additional design flexibility and options for window frame materials. Additional options for window frame materials can help meet energy performance targets.

Sentence 3.1.5.4.(5) does not distinguish between all-combustible window frames and hybrid combustible window frames. Mass timber design guidelines[3] do not recommend exterior exposed wood window frames on tall wood buildings for maintenance reasons. Hybrid wood frames with wood only on the interior side can still be interpreted to be governed by Sentence 3.1.5.4.(5) since these are “in” the building, although some AHJs may accept hybrid windows.

The aluminum and wood frame windows proposed in the archetype, with glulam wood frames integrated on the interior side of the timber panels, and conventional aluminum frames for the operables. These hybrid windows are attractive for their thermal performance and aesthetics. The approach in the archetype design is that the exterior side of the window frames are noncombustible to address potential for exterior fire spread via the window frames, and to consider the interior framing as part of the permitted exposed wood surface for walls in conjunction with the permission for combustible millwork that includes interior trim.

Basis for Change and Possible Next Steps

The removal of conditions for combustible window frames in 2020 NBC Sentence 3.1.4.5.(5) in noncombustible buildings was substantially based on ULC-S134 fire testing of various combustible window frames that demonstrated limited exterior vertical fire spread and met the test criteria.

Hybrid windows could be either accepted under current EMTC provisions depending on the interpretation and judgment of the AHJ or proposed as an alternative solution supported by analysis of the exterior wall assembly and window frame details to demonstrate the same resistance to exterior fire spread and insignificant contribution to fuel load as a design with conventional noncombustible windows.

A code change to reflect 2020 NBC 3.1.5.4.(5) permission for EMTC buildings may be possible if the results of previous fire tests are referenced. An analysis of how a change to 100% wood window frames would impact the fire test results. Fire testing to ULC-S134 is also possible for either hybrid or all wood window frames; however, this additional testing may not be necessary since there is already body of completed ULC-S134 fire tests for plastic materials that generally have a higher flame spread and higher heat release than wood.

[3] Tall Wood Guide, FPI, Second Edition 2022 Section 7.6.1.4. page 35

1.80. REDUCED ENCAPSULATION DURING CONSTRUCTION (BCFC)

2018 BCFC Article 5.6.4.3. requires encapsulation of a minimum area of mass timber wall surfaces and on the underside of mass timber floor assemblies to address fire safety during construction. Not more than the four uppermost contiguous storeys are permitted to be unprotected during construction.

Reasons to Explore Change and Archetype Design

The challenges with encapsulation during construction prior to installation of the building envelope are well documented in guides and online project summaries. The installation of and sometimes re-installation of gypsum board during the construction phase has the potential to delay the construction schedule, and imposes additional costs where gypsum needs to be replaced due to water damage.

Greater exposed areas of mass timber during construction are reported to be accepted by AHJs under the alternative solution process, with compensating measures that can include strict control of combustibles on the site, fire detection, temporary sprinkler protection and site security.

The archetype designs are proposed to meet BCFC Article 5.6.4.3. as the construction schedules for the archetypes facilitate the protection of mass timber during construction with a maximum of four of the uppermost storeys unencapsulated.

Basis for Change and Possible Next Steps

A Code Change Request (CCR) has been submitted to the CCBFC to revise 2020 NFC Article 5.6.4.3. to reflect a related change to NBC 3.1.18.4. to permit 100% of the underside of each mass timber floor assembly to be exposed within a suite, supported by recent fire testing. The CCR for NFC 5.6.4.3. proposes that the underside of mass timber floor assemblies be encapsulated only outside of suites. The CCR proposes edits to NFC Sentence 5.6.4.3.(2), but keeps the fundamental approach that only the four uppermost contiguous storeys can remain unprotected.

If the CCR is accepted, and the change adopted by the BCFC, the reduced encapsulation requirements of suite ceilings is expected to realize cost savings for materials, and for improved speed of construction.

1.81. INCREASED AREA OF EXPOSED WOOD ON INTERIORS

The BCBC prescribes the maximum allowable area that mass timber can be exposed on beams, columns, walls and ceilings within suites. The BCFC has a related requirement for maximum exposed areas of mass timber walls and ceilings during construction (see previous section for BCFC discussion). Note that the VBBL does not permit exposed wood at the underside of mass timber floor assemblies.

The IBC Type IV-B construction has similar permitted areas for unprotected wood as the BCBC; however, Type IV-C construction permits 100% unencapsulated mass timber up to a maximum of 8 storeys in building height.

Reasons to Explore Change and Archetype Design

Additional areas for exposed wood, in particular on ceilings, does yield material savings both in the finished building and during construction. The labour saved for installation of encapsulation materials is one of the intended offsets for the increase in size of mass timber elements sized for fire resistance rating without any encapsulation (which would be required for any design that includes exposed surfaces of mass timber). If the underside encapsulation of floor assemblies is eliminated, this may increase the amount of materials needed for the upper side of floor assemblies in order to meet acoustic requirements. The archetype designs consider two options, one that is fully encapsulated, and one that meets the current exposed area limitations of the BCBC.

Basis for Change and Possible Next Steps

If the proposed code change for increased exposed area of wood is accepted, and the change adopted by the BCFC, the reduced encapsulation requirements on suite ceilings is expected to realize cost savings for materials, and for improved speed of construction. Prior to adoption in the Codes, increased areas for exposed wood can be proposed under alternative solution, which is currently required in Vancouver to meet the VBBL.

1.82. INCREASED MAXIMUM HEIGHT FROM 42 M TO 50 M

The BCBC 2018 limits an EMTC building to 42 metres in height between the floor of the first storey and the uppermost floor level. This means that the average storey height is 3.8 m for a 12 storey building. A change has been proposed to the 2020 NBC, accepted for the 2025 NBC, to modify the maximum height to 50 metres which would result in an average storey height of 4.6 metres.

Reasons to Explore Change and Archetype Design

Anecdotally EMTC buildings are being constructed with average storey heights greater than 3.8 metres in order to accommodate the depth of mass timber. This is in conjunction with encapsulation and acoustic requirements, and also to achieve design objectives with higher ceiling heights. The 2021 IBC Type IV-B permits a height of 55 m for a mass timber building with similar fire protection requirements (see earlier section, measured from grade to average roof height).

Basis for Change and Possible Next Steps

The technical basis for the current height limit is reported to be an extrapolation of storey heights for conventional construction and is intended to limit the addition of many mezzanines that could increase building height, but retain the maximum storey height. The technical basis for the increased height to 50 m as an alternative solution in the near term, is expected to include an overall assessment of fire safety. It will include an impact on fire department operations in a taller building, as well as documentation of the practicality of the proposed storey and overall heights.

1.83. INCREASED HEIGHT TO 18 STOREYS

The BCBC 2018 limits EMTC buildings to 12 storeys. The most prominent early EMTC building in B.C., Brock Commons, is 18 storeys, and has corresponding fire protection measures that are more restrictive than those for 12 storey buildings under the BCBC 2018.

Type IV-A construction permits up to 18 storeys; however, there are additional requirements for such buildings, including: an increased duration of protection of the mass timber elements (80 minutes protection rating compared to 50 minutes encapsulation rating under BCBC), increased fire resistance rating for the primary structural frame and bearing walls (3 hours), noncombustible construction for exit enclosures and elevator hoist ways, redundant water supplies for fire pumps, etc.

Reasons to Explore Change

While the cost per floor level for these additional features may increase relative to a building constructed to current BCBC provisions, the flexibility this provides may result in an overall decrease in development costs by facilitating more units per building. This can lead to a greater density of units per site by reducing the number of buildings that need to be constructed to service the same number of people.

Basis for Change and Possible Next Steps

One challenge of adopting the IBC fire resistance ratings of 3 hours is that it could tie encapsulation level and fire-resistance ratings to building height without a fully evidence-based reason. This rating may need to be revisited for buildings greater than 18 storeys in height. These may need to be pursued using alternative solutions or future code changes. Further research and testing, as well as built experience will inform the path forward for heights greater than 18 storeys.

The IBC approach and conditions for EMTC buildings between 13 – 18 storeys forms a basis for alternative solutions in the absence of code provisions permitting greater than 12 storeys.

1.84. FIRE RESISTANCE RATING OF 1.5 HOURS FOR FLOORS AND LOAD BEARING STRUCTURE

The BCBC 2018 requires a 2 hour fire resistance rating for floor assemblies and loadbearing structures for an EMTC building. A reduction to a 1.5 hour fire resistance rating was identified in the RFP as a potential variation from the BCBC. It is not known if any EMTC buildings between 7 to 12 storeys have been constructed with less than 2 hour fire resistance ratings for floor assemblies and loadbearing structure.

Reasons to Explore Change

The BCBC requires 1 hour fire-resistance ratings for floors and loadbearing structure for residential buildings up to 6 storeys. There is a step change to require 2 hour fire-resistance ratings at 7 storeys and higher, whether EMTC or noncombustible construction. However, the increased time for evacuation and for firefighting in a taller building, risks of injuries and damage to buildings does not double between 6 and 7 storeys, but rather increases incrementally.

Basis for Change and Possible Next Steps

The 6 storey height is significant since it is generally the height that fire department apparatus can reach for exterior rescue and attack for firefighting. Residential buildings often are classified high buildings when they are over 6 storeys. This depends on the storey heights and the location of grade.

Nonetheless, the reduction in fire-resistance rating from 2 hours to 1.5 hours for building heights in the 7 to 8 storey range could be explored as a cost-savings measure. An alternative solution would be necessary to demonstrate the adequacy of a 1.5 hour fire resistance rating, which is expected to require significant effort to run fire modelling for a specific building design.

It is noted that not all authorities having jurisdiction in B.C. have adopted the EMTC provisions. A reduction of fire-resistance rating to less than 2 hours could be an uphill battle for acceptance since EMTC in the BCBC is still relatively new. Even if a 1.5 hour fire-resistance rating could be demonstrated through fire modelling and testing to be sufficient, the 2 hour fire-resistance rating may be requested to provide an additional factor of safety. The creation and implementation of performance based codes in B.C. may change this approach; however, for the time, the 2 hour fire-resistance rating established for building heights over 6 storeys is to be expected by authorities.

1.85. PERFORMANCE BASED DESIGN

Energy models have been developed for the three regional buildings to inform expectations for energy performance relative to NECB 2015 and metrics outlined in the B.C. Energy Step Code. The building energy analysis in this report utilizes EnergyPlus 9.4. The impact of a variety of parameters including envelope performance, HVAC system performance, building window-to-wall ratio, lighting and internal load savings are assessed.

For each typology and climate zone considered, energy results and financial impacts are outlined for:

- Step 3 and 4 (or equivalent) compliant designs
- The lowest energy/GHG solution, which would allow for a net zero design with the smallest on-site energy generation capacity
- The lowest energy cost solution

1.86. MARKET BASED ENERGY PERFORMANCE METRICS

Energy Savings over NECB

This metric looks at the relative energy savings of a particular design over an NECB reference building. Since the NECB Reference Building fuel sources vary depending on the design, it was deemed more appropriate to use a fixed fuel source for this metric, based on the most common heating systems used in B.C..

GHG Savings Over NECB

This metric looks at the relative operational GHG savings of a particular design over a gas based NECB reference building (i.e. an NECB Reference Building that uses a natural gas boiler plant to supply hydronic terminal space heating systems). Similar to the Energy Savings over NECB metric, since the NECB Reference Building fuel sources vary depending on the design, it was deemed more appropriate to use a fixed fuel source for this metric based on the most common heating systems used in B.C. This metric is similar to the Energy Savings over NECB metric, but the focus is on operational GHG emissions rather than energy savings.

Energy Cost Savings Over NECB

This metric looks at the relative energy (utility) cost savings of a particular design over a gas based NECB reference building (i.e. an NECB Reference Building that uses a natural gas boiler plant to supply hydronic terminal space heating systems). Likewise, since the NECB Reference Building fuel sources vary depending on the design, it was deemed more appropriate to use a fixed fuel source for this metric based on the most common heating systems used in B.C. This metric is similar to the Energy Savings over NECB or GHG Savings over NECB metrics, but the focus is on utility cost savings that highlights economic impacts of designing beyond minimum code. Energy costs are also presented as a floor area-normalized metric, known as Energy Cost Intensity ($/m2), to facilitate easier comparison of costs across building archetypes.

Energy Use Intensity (EUI)

This metric looks at the absolute energy use of the building divided over the building floor area and is typically varied depending on building type and climate.

GHG Emissions Intensity (GHGI)

This metric is similar to EUI, but instead of focusing on absolute energy use, it focuses on absolute operational GHG savings, with the intent of maximizing GHG reductions by prioritizing savings for high GHG fuels.

Thermal Energy Demand Intensity (TEDI)

This metric represents the amount of heating a building needs to offset building envelope losses and temper ventilation air, prior to any mechanical interventions (with the exception of ventilation heat recovery equipment). The intent of this metric is to maximize passive or near passive systems before looking at heating delivery methods and technology. This metric has been made popular by Passive House, an international high-performance building standard, which promotes highly insulated buildings with exceptional ventilation heat recovery and otherwise simple mechanical systems. More recently, ventilation heat recovery has become a popular design element is critical to achieve higher steps of the B.C. Energy Step Code.

Utility Cost

This is the total annualized cost of energy utilities (gas and/or electricity), a metric more commonly used by building owners and managers.

1.87. ENERGY PERFORMANCE DESIGN SCHEDULE

CHARACTERISTIC	MURB ARCHETYPE
Weather	Vancouver CWEC and Kamloops CWEC (2016)
Software	EnergyPlus v9.4
Climate zone	4 and 5
Building area	14,005 m^2 Conditioned / 3,300 m^2 Parking
Operating hours	NECB Schedule G occupancy, lighting, and plug loads. Parking lighting always on.
Occupancy	Options: 20 to 35m^2 / person in dwellings
Plug and process loads	5W/m^2 Dwellings 3kW elevator load (dwellings equipment schedule) 7kW general exhaust fans, 2h/day 10.5kW parking exhaust fans, 4h/day
Outdoor air	In-suite HRV options 0.21 to 0.65$L/s/m^2$ total suite area Corridor make-up air 0.0837$L/s/m^2$ total above grade floor area Ventilation effectiveness 1 for DOAS system
Infiltration	Options: 0.1 to 0.2 $L/s/m^2$ exterior wall area
Wall R-Value	Options: Mass timber RSI 2.37 to 5.3m^2k/W Concrete RSI 0.70 to 2.1m^2k/W
Roof R-Value	RSI 4.41 to 6.17m^2k/W
Window U-Value	Options: USI - 1.19 to 2.4
Window SHGH	Options: 0.3 to 0.4
Window Area %	Options: 15% to 45%
Lighting	5W/m^2 Dwellings 5W/m^2 Corridor 1.5W/m^2 Parking
HVAC systems	Suites: Multi split heat pumps and fan coils for heating and cooling Corridor: Makeup Air Unit (MAU) with electric heating coil (no cooling)
Heat recovery	Options: 60% to 80% effectivness electric prehead to -5%
Fans	HEC's and MAU: 1W/cfm Fan Coils: 0.3W/cfm
DHW	Electric DHW tanks calculation based on 500w/person dwellings
GHG emission factors	3.0 kgCo2e/GJ electricity

1.88. INITIAL ARCHETYPE 7-12-STOREY RESIDENTIAL BUILDING CONCEPT DEVELOPMENT

For preliminary costing exercises, it is recommended that conventional pad and strip foundations founded on glacial till be carried out. Underground parking levels will be comprised of typical concrete construction. In general, the design strategy is to carry the column grid from the tower down through the parking levels, transitioning to concrete columns at L1, and avoiding a costly transfer slab. The initial assumptions are that underground parking and levels below grade are a 125mm thick slab on grade, typical internal columns of 300x600 in the parking areas, typical concrete columns of 400x400 under the tower, 250mm thick perimeter concrete walls, and 400mm thick concrete walls at the cores. For the parking slabs, a slab band approach or two-way concrete flat plate could be utilized. Based on our experience and the current high cost of formwork, a two-way concrete flat plate is recommended. For required parking levels, a 300mm thick slab is recommended.

Multiple mass timber and mass timber hybrid gravity systems are being reviewed for applicability and alignment with the project goals. These include but are not limited to: a glulam post and beam frame with CLT decking, CLT floors paired with CLT bearing walls, castellated steel beams on steel columns with CLT decking, flush steel “delta” beams on steel columns with CLT decking, and lastly, point supported CLT on steel columns.

The point supported CLT gravity system was chosen as the initial base case building footprint, building on the known success of the TallWood House at Brock Commons. Point supported CLT is a two-way spanning system, where the panel is loaded in punching shear. There is little guidance from Canadian building codes on how to design the system, so contemporary research is used to predict internal forces and material strengths of the system. Simplified equations from Marcel Muster’s 2020 thesis are used to assess the shear and moment capacity of the material strength of the system.

Deflections in the system are approximated using a girder-girder analogy, where the deflection of a beam and column strip are used to assess the net deflection of the system. The long-term deflection of the system considered in this analysis is the limit proposed in CSA. O86.14, where the dead load deflection is doubled. Point-supported CLT - flat plate slab structure without dropped beams:

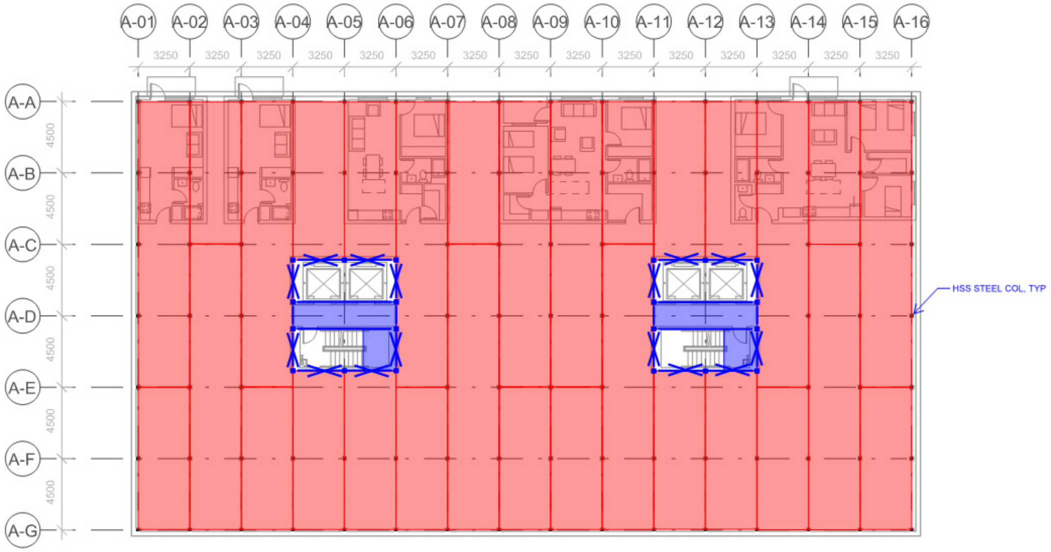
- Simplistic service distribution
- Basic drywalling and steel stud back framing of partitions at ceilings
- Thin floor structures with less pieces to install - increases structure erection speed
- Reduced floor to floor heights - reductions in building envelope materials and cost

There are three key aspects of the point supported CLT gravity system design that are being investigated:

- The first key aspect to evaluate is glulam columns or steel columns. Potentially, steel columns can drastically simplify the connections at the panel nodes, lighten the columns for easy manual placement on site, and reduces their overall area which in turn can make the party walls thinner – allowing for larger suites and better suite-to-suite acoustic performance. However, glulam columns sized for exposure can be un-encapsulated within the suites allowing for flexibility of floorplan layouts and contributing to biophilia and a reduced-embodied carbon footprint.

- The second key aspect is the pairing of the point supported CLT gravity system with a hybrid of steel framed stairs and jump formed concrete elevator cores to better align with crane and install worker efficiencies during the mass timber erection. Steel stairs would be utilized with the intent that these go up in tandem with the frame and act as construction access stairs.

The third key aspect is an optimized structural grid size and panel layout. These bay sizes are chosen to utilize up to a maximum width of CLT panels that can be manufactured, which is 3.5m. This grid works with typical residential layouts while also limiting span sizes to address typical mass timber framing limitations more effectively, allowing the fully encapsulated point supported CLT option to potentially use a 5 ply panel. The figure below shows the initial test-fit of an optimized structural grid with varying floorplans. Wider CLT panels are available in the B.C. market which means larger and varied grids can be utilized. Considering this industry development, grids using CLT panels up to 3500mm (11'6") wide are being explored. For the initial base case grid, a panel width of 3200mm (11'0) wide was selected and in the other direction, a 4570mm (15'0") spacing, corresponding to the maximum length that a 175mm 5 ply CLT panel can span and ideal panel lengths (multiples of 30' for press bed efficiency).



Initial Test-Fit of an Optimized Structural Grid with Varying Floorplans

With an optimized structural grid developed, floorplan test-fits were undertaken through drawing iterations to locate party walls that could be aligned at panel seams and establish a panel break and an acoustic isolation pad under the plywood spline as frequently as possible. This detail will drastically increase the acoustic performance between units. The figure 39 shows the results of floorplan alignment to the structural grid and three potential variations discovered that align with the proposed outline specifications and BC Housing Design Guidelines and Construction Standards.

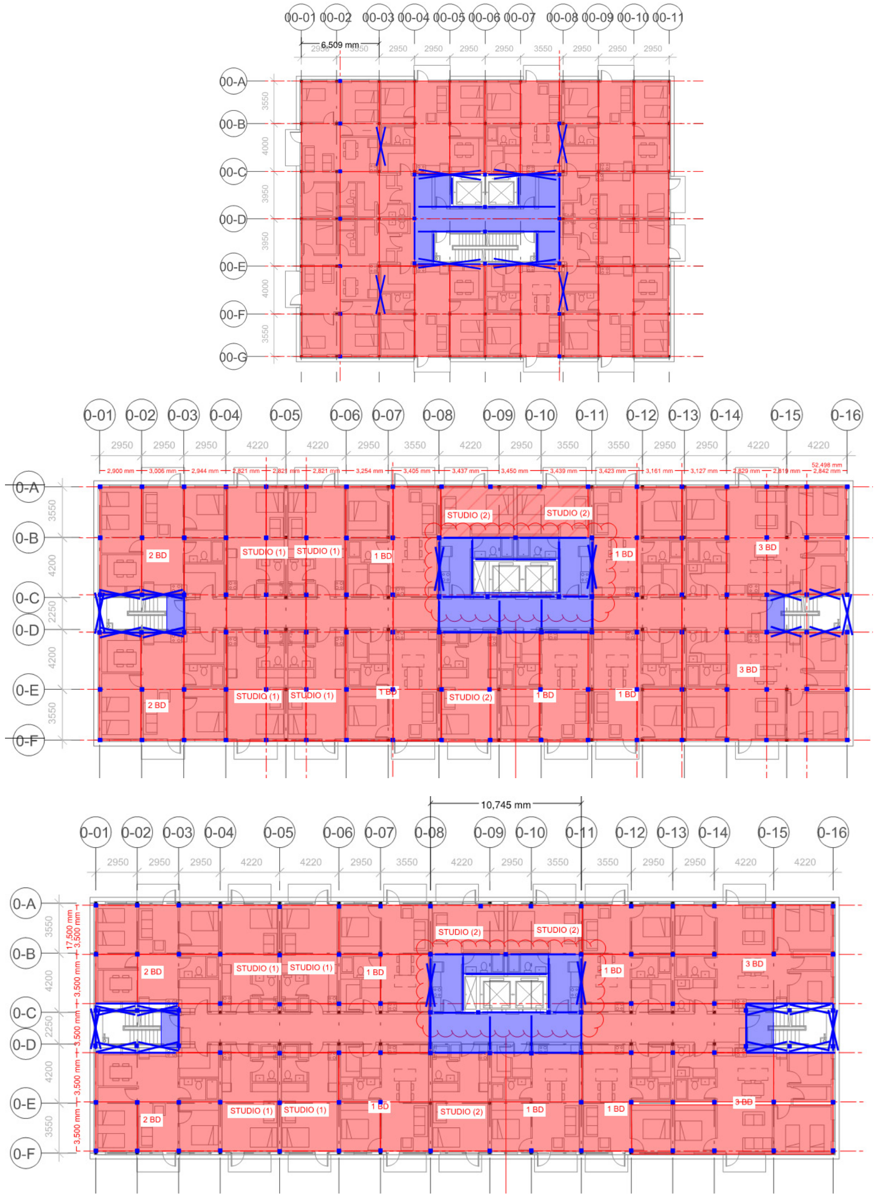


Figure 39 - Three Optimized EMTC Grids

1.89. MULTI-UNIT 7-12-STOREY RESIDENTIAL BUILDING REGIONAL EVALUATION

The design team selected three regional variations of building massing that were intended to suit typical area site plans and market comparison typologies in Vancouver, Coquitlam, and Kamloops. Vancouver holds an abundance of concrete “Point Towers “, which are the predominant market typology. The initial analysis shows a distinct difference in the orientation of building cores for either concrete or timber superstructure types. This suggests that the EMTC buildings will have a unique footprint in comparison to more conventional concrete buildings. The following concept floorplan grids (Figures 39, 40, 41) are intended to encompass the following study aspects along with more detailed design in their specific location:

- Livable space outcomes and FSR efficiencies.
- Supply chain considerations.
- Local product availability and limitations.
- Indicate site-specific considerations including those related to municipality.
- Other noteworthy factors that will inform cost differences.

1.90. 7-12-STOREY MULTI-UNIT RESIDENTIAL BUILDING CONSTRUCTABILITY

A prefabricated structural kit should be able to be erected quickly and easily. As noted in the previous sections, lighter steel columns could allow for manual installation after bundles are landed on the active deck, although associated encapsulation is necessary and would slow progress at later stages of construction. The quicker install of steel columns could free up the crane for perimeter envelope installation and keep the overall erection time down.

There are predominately two main options to explore when it comes to the erection of a structure. The first option is to install the steel and concrete cores in full, to the roof, before the hybrid gravity system is erected around it. This may be advantageous as the ironworker and mass timber erection crews can be separated. It may also be advantageous depending on if the procurement lead time of the timber and steel components are significantly different. The second option would be to install the core in multiple level lifts and then chased by the hybrid gravity system. This would also allow for division of crews and is perhaps more schedule aggressive than the first option. There are certainly nuances to this discussion when mobile cranes, unions, bonding, etc. are considered. All structural steel connections will be designed to be field bolted rather than field welded, eliminating any hot work on site and mitigating the risk of a construction fire.

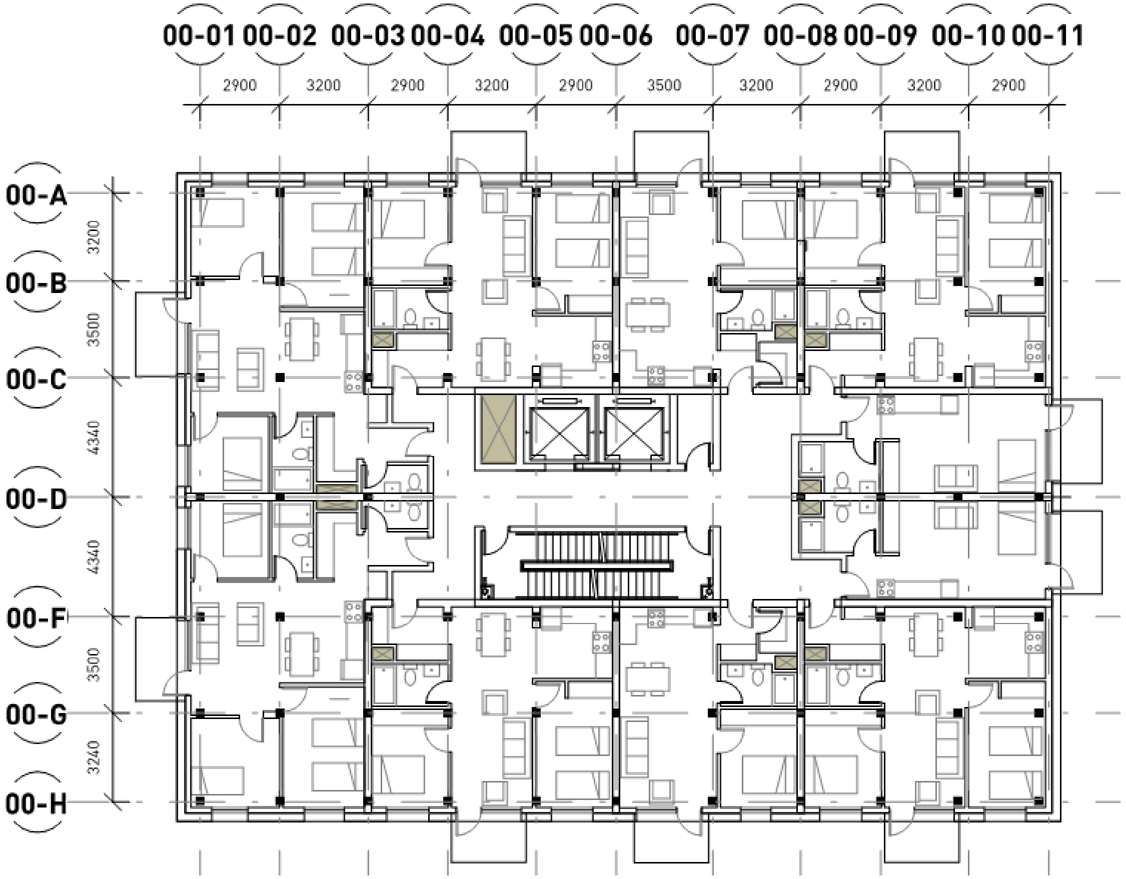


Figure 40: Point Tower – City of Vancouver EMTC Building

Figure 41: Slab Tower – City of Kamloops EMTC Building

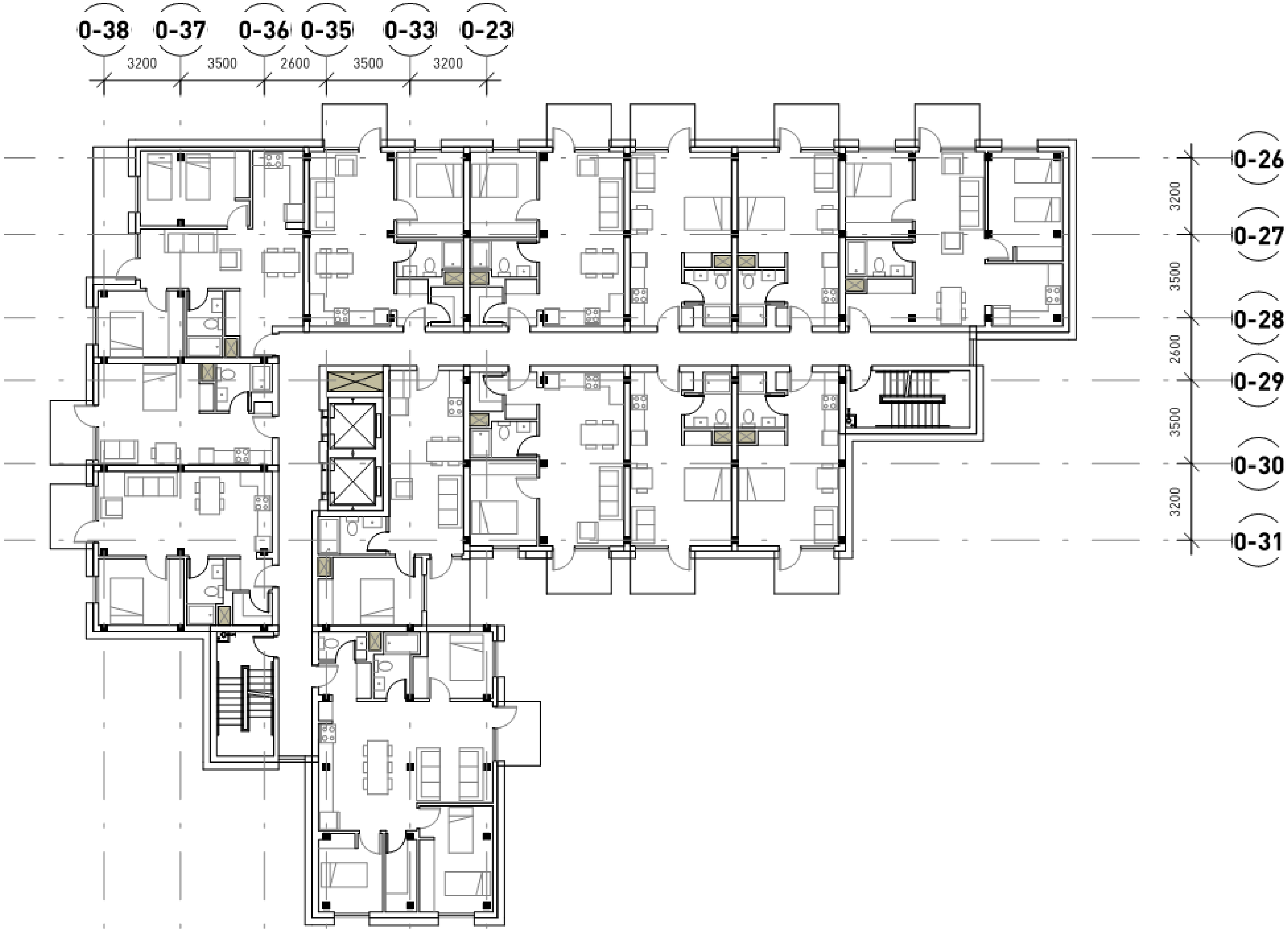
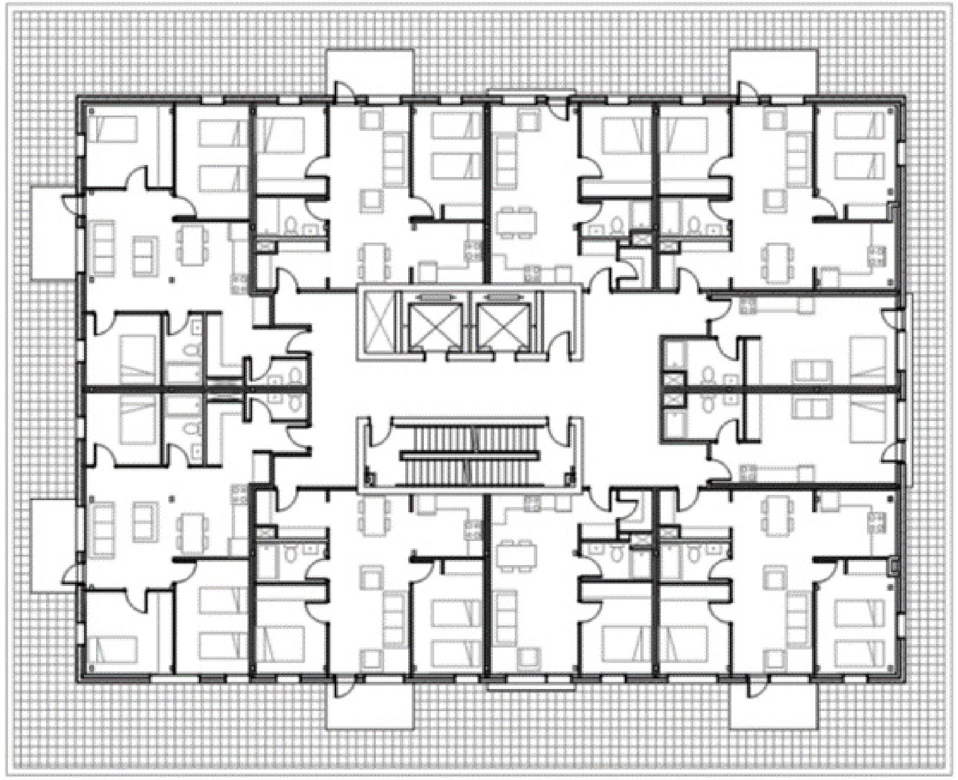


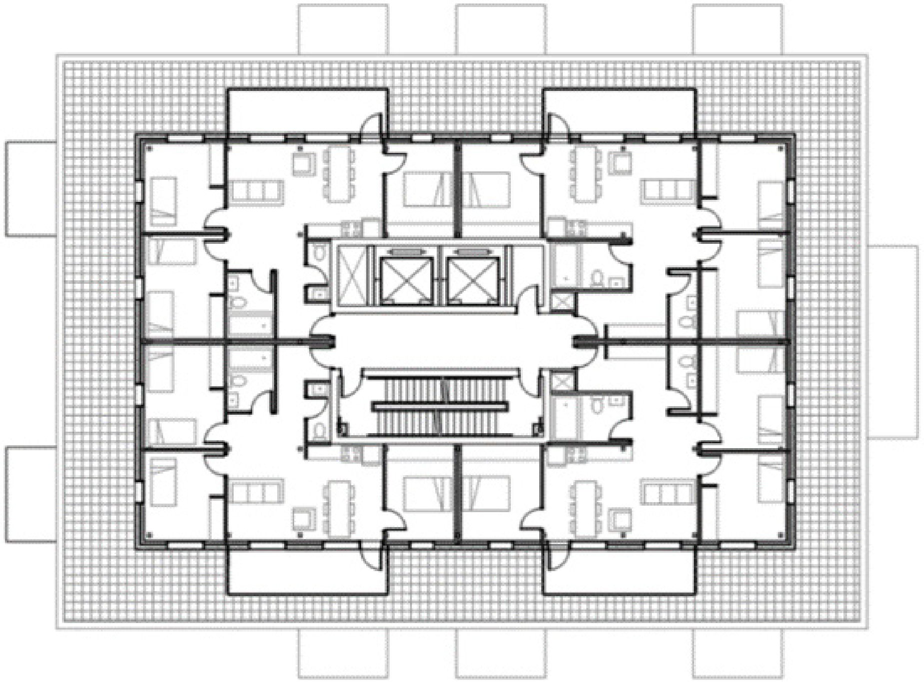
Figure 42:“L” Shaped Slab Tower – City of Coquitlam EMTC Building

Archetype Buildings - Detailed Design

1.91. POINT TOWER - REFERENCE FLOORS 3 - 9

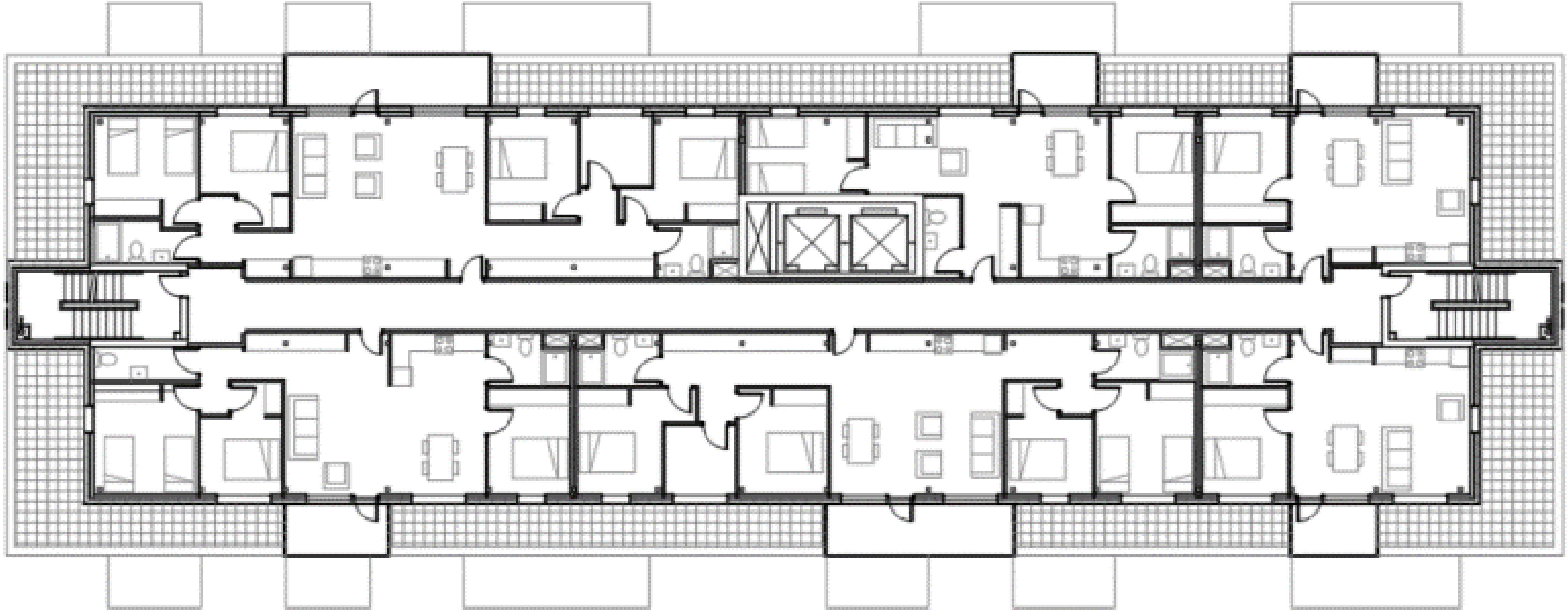


1.92. POINT TOWER - REFERENCE FLOORS 10 -12



1.93. SLAB TOWER - REFERENCE FLOORS 2 - 9

1.94. SLAB TOWER - REFERENCE FLOORS 10 -12



1.95. L TOWER - REFERENCE FLOORS 2 - 9

1.96 L TOWER - REFERENCE FLOORS 10 -12

Resources

Resources consulted at the time of preparation of this guide, and further information on mass timber and encapsulated mass timber are presented below:

- "Encapsulated Mass Timber Construction: Guidelines for Encapsulation Details and Techniques", by Morrison Hershfield Limited and FPInnovations
  (Encapsulated mass timber construction: Guidelines for encapsulation details and techniques | Research Library | FPInnovations)
- "Technical Guide for the Design and Construction of Tall Wood Buildings in Canada: 2022 – Second Edition" by FPInnovations
  (Technical Guide for the Design and Construction of Tall Wood Buildings in Canada - FPInnovations)
- "Encapsulated Mass Timber Construction up to 12 Storeys," by Architectural Institute of British Columbia and Engineers and Geoscientists British Columbia
  (Joint Professional Practice Guidelines: Encapsulated Mass Timber Construction Up to 12 Storeys Now Available (aibc.ca))
- "Tall Wood Building Demonstration Initiative 2021" by Natural Resources Canada, Canadian Forest Service, and Green Construction through Wood (GCWood) Program
  (Tall Wood Building Demonstration Initiative | Canadian Forest Service Publications | Natural Resources Canada (nrcan.gc.ca))
- "The State of Mass Timber in Canada 2021", by Natural Resources Canada, Canadian Forest Service, and Green Construction through Wood (GCWood) Program
  (The State of Mass Timber in Canada 2021 | Canadian Forest Service Publications | Natural Resources Canada (nrcan.gc.ca)

An extensive library is available on mass timber as a construction material and on encapsulation techniques for use by designers, contractors, and owners. The providers of this information intend to facilitate the use of mass timber in construction projects and aim for consideration of wood as a sustainable construction material early in the design process. There are many websites, brochures, design guides, and other resources that document the benefits of wood and assist designers in applying the building codes for wood and encapsulated mass timber construction. Some examples include:

- Wood WORKS! at wood-works.ca
  (Wood-Works – Program of the Canadian Wood Council)
- Canadian Wood Council at cwc.ca
  (Home - The Canadian Wood Council - CWC)
- Canadian Wood Council Technical Publications at cwc.ca
  (Technical Publications (Free) Archives - The Canadian Wood Council - CWC)
- American Wood Council at awc.org
  (American Wood Council (awc.org))
- FPInnovations at fpinnovations.ca/publications
  (Publications - FPInnovations)
- Natural Resources Canada at nrcan.gc.ca
  (Forest products and applications (nrcan.gc.ca)

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