Making Mass Timber Work for High-Rise Residential in BC

The Developers' Guide to Cost, Schedule & Code Implications

bty AXIOM BUILDERS wsp ZGF

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14-Storey Tower Designed/Constructed by ZGF Architects/Axiom Builders

1.0 executive summary

"What will it cost to build my high-rise project with mass timber?"

Mass timber continues to be a hot topic of discussion within the development industry in British Columbia. The International Building Code now allows for mass timber to be used for buildings up to 18 storeys. The change allows developers to consider it for residential multi-family projects and prompts one big question: "What will it cost to build my high-rise project with mass timber in our market?"

The team that developed this report represents an independent team of architects, structural engineers, quantity surveyors, and a general contractor. Consultants from fire, building code, and acoustic industries also provided expertise to the study. In late Fall 2020, we formed an industry group in Vancouver to answer this question with an exclusive focus on the local market. We identified a need for a significant shift in the local industry's building philosophy when using mass timber as a structural material.

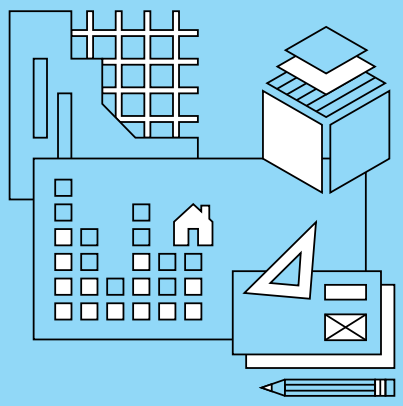
Our goal was to assess the viability of mass timber for this product type in British Columbia by comparing the cost, construction methods, and schedules of a typical concrete high-rise in Vancouver to those for the same building using mass timber as the principal structural material. To undertake the study, the group created virtual models of the base building and conceptual models for side-by-side detailed comparisons.

While gaining in popularity, building a high-rise with engineered mass timber remains an unconventional method in British Columbia. To support the industry, we wanted to fill in gaps in data to better understand and help solve the challenges of working with new materials and techniques needed for mass timber construction at scale.

This study presents what we learned about cost, schedule, and code implications as well as methodology efficiencies. It must be noted that the study took place over a period in Q2 and Q3 of 2021 when lumber and steel prices – two of the principal materials – experienced high volatility in supply and record increases in price.

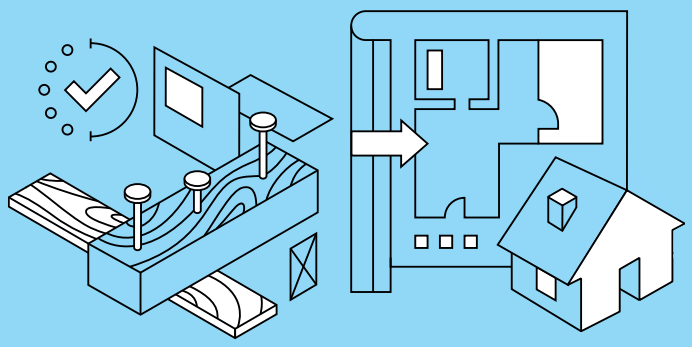
Since every building project and market is unique, the report makes no claims concerning specific cost or time frame. Rather, it identifies what to consider in creating a reliable framework for optimizing costs and schedules while meeting code requirements when building residential high-rise mass timber buildings.

1.1 Highlights of Our Conclusions and Recommendations



1. Design for either timber or concrete, not both

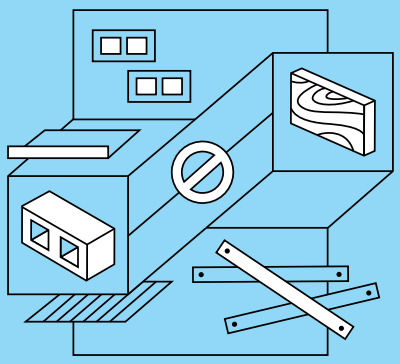
Combining prefabricated structural materials with built-in-place methods for the building structure and envelope produces only a marginal net increase in any potential efficiencies. An over-arching construction philosophy must be chosen early on and remain consistent through the design of all aspects of the building – architecture, structure and systems.



2. Design for Manufacturing and Assembly (DfMA), not construction

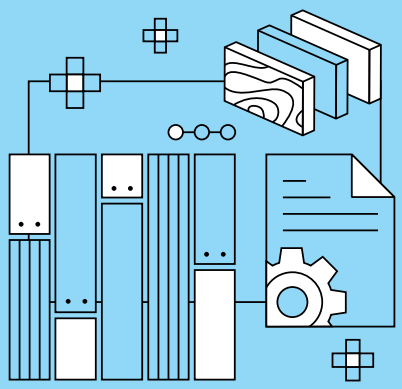
Optimized design for mass timber, increased off-site fabrication, appropriate code changes, and expansion of prefabrication trades and suppliers will accelerate development of mass timber's cost-competitiveness in the BC market.

We see prefabrication as key to the future of mass timber high-rise buildings at scale.



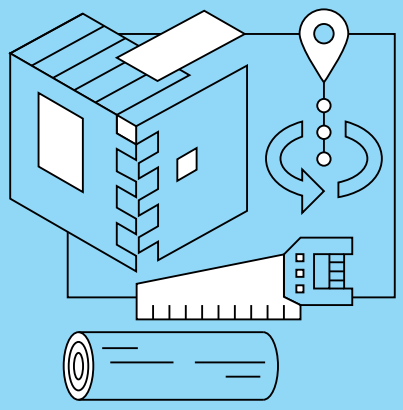
3. Stay with the method you choose

A design developed to maximize the benefits of reinforced concrete (RC) buildings does not translate to mass timber (MT) for cost competitiveness and adaptable unit design. Switching from RC to MT (or vice versa) at any stage past early conceptual building design and massing is inefficient – and not recommended.



4. Adapt codes to support mass timber and off-site fabrication

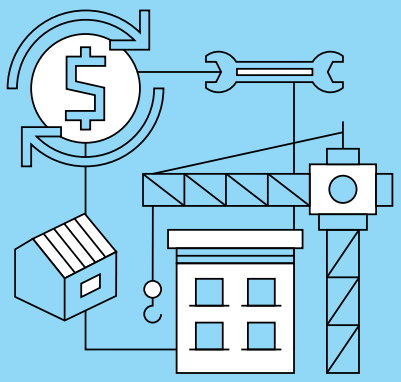
Current codes need to adapt to mass timber and off-site fabrication methods. Further testing of materials and assemblies need to be completed to allow codes to adapt to mass timber and steel hybrid buildings.



5. Integrate, prefabricate and coordinate to accelerate schedule

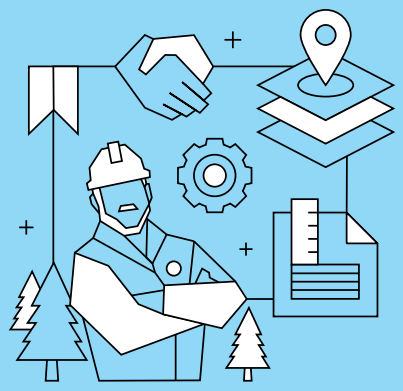
Designing structure and envelope systems to maximize off-site prefabrication of all aspects of timber hybrid buildings, including the lateral system, will lead to faster on-site assembly, higher quality control and fewer trades involved. Any prefabricated design for structure and envelope systems requires significant coordination and procurement in pre-construction.

For high-rise mass timber to work sustainably at scale, our local industry needs a shift in philosophy from "On-site Building" to "On-site Assembling"



6. Schedule savings remain theoretical

Anticipated holistic schedule savings attributed to high-rise mass timber buildings have yet to be thoroughly proven in the field.



7. The industry's building philosophy must shift

The industry needs to shift its philosophy from "on-site building" to "on-site assembling" to be sustainable as prefabricated mass timber construction gains market share. This shift puts more emphasis on skilled designers and less emphasis on skilled labour.

A design developed to maximize the benefits of reinforced concrete (RC) buildings does not translate to mass timber (MT) for cost competitiveness.

introduction 2.0

2.1 Why This Study?

Repeated requests for accurate data on cost, schedule and constructability of mass timber residential buildings revealed a substantial information gap in the industry in British Columbia.

This dearth of data in the face of persistent local market interest led to our respective firms partnering to investigate this in detail, and we set out to answer the questions the market was asking:

- **What are the cost considerations for mass timber?**
- **How does a mass timber schedule compare to that of reinforced concrete?**
- **Can mass timber high-rise residential be delivered at scale in the BC market?**

Recognizing that every construction project is unique, we make no claim that our findings will apply in every instance. We believe that the value of the study lies in educating developers, builders and owners in British Columbia on relative cost, schedule, and code compliance, among other issues and implications, when considering the construction of a 12-to-18-storey mass timber project.

We chose a residential tower because the combination of strong local market interest and a gap in data for the type and height presented an opportunity to investigate whether there is a business in building high-rise mass timber residential at scale.

Our aim is to narrow the data gap and add to the knowledge base for making sound development decisions for this building type.

Many topics and discussions throughout the study refer to comparisons amongst the above grade structures.

2.2 Project Evolution at a Glance

Our study has been a journey of discovery.

The base building model is a Cast-in-Place (CIP) reinforced concrete building in British Columbia's Lower Mainland. The base building, completed in Summer 2020, we refer to as Version 1 (V1). Our initial approach was to develop a hybrid model with mass timber floors and CIP core, which we called Version 2 (V2). Our exploration led us to Version 3 (V3), the Prefabricated Hybrid Concept.

The hybrid V2 model explored the use of concrete cores constructed in two methods. The first method conducted was level by level, following the timber floor installation. The second was slip-formed to roof level before commencing the floors. Through detailed schedule analysis, one of our first discoveries was that the level-by-level V2 model would result in a severe loss of productivity by the trades, which would significantly extend the schedule and increase the cost. The slip formed option showed no net schedule gains to the complete project.

Following extensive consultation with trades and suppliers from the structural steel industry, we envisioned a Prefabricated Hybrid Concept (V3). This option takes greater advantage of prefabrication to capture the reputed schedule benefits attributed to mass timber. We call the prefabricated concept an optimized "kit of parts" building that could be assembled much faster when compared to either a reinforced concrete building, or hybrid building with concrete cores.

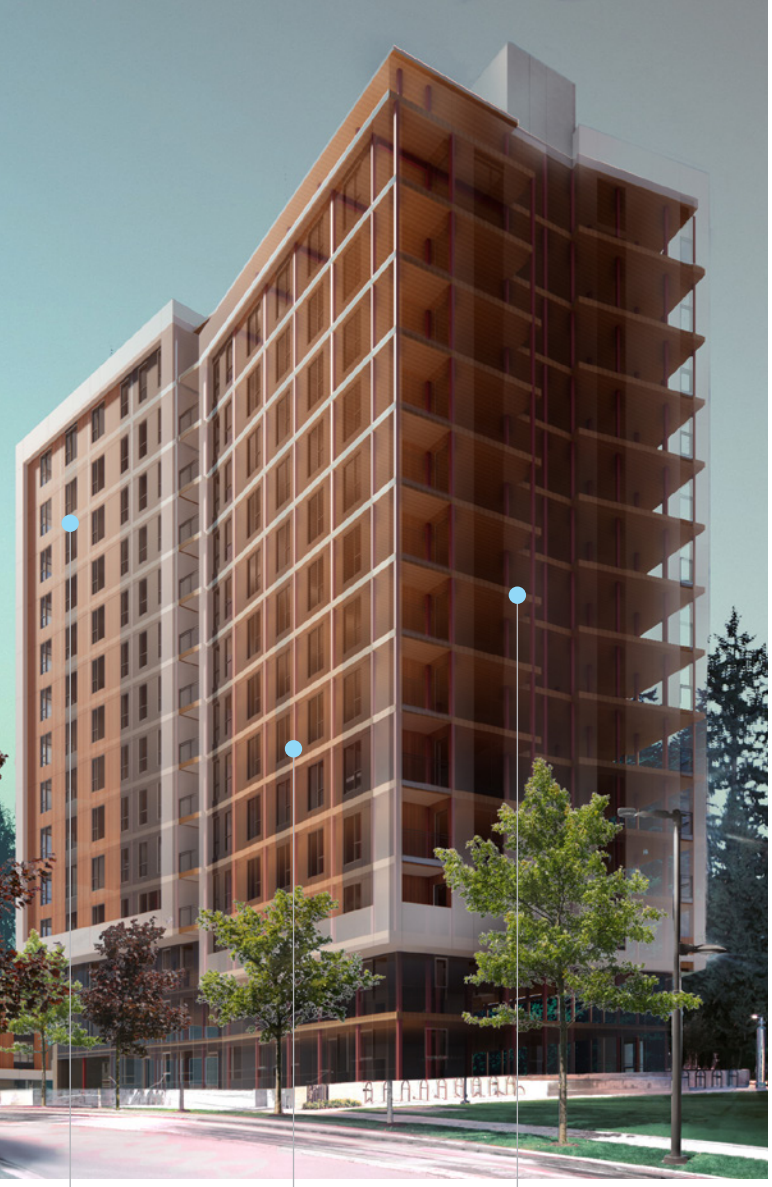
For the V3 "kit of parts" option, we initially explored a heavy structural steel core, but this orientation proved to carry a significant cost premium based on the steel tonnage alone. To drive the cost efficiency, we developed a steel braced frame on the facade, and simplified the internal structure.

Collaboration is key

Our journey has shown that effective collaboration among design, consulting, construction and fabrication teams from the start will be key to the "kit of parts" approach. Enhanced pre-planning and coordination will be especially critical earlier in the design process.

V1 Base Building CIP

Cast-in-place, reinforced concrete with two cores originally built to BC Building Code 2012 (Part 3 – Tower) and completed in 2020. Updated V1 designed to BC Building Code 2018 (Part 3 - Tower).



V2 Hybrid–Mass Timber & CIP Core

Concrete cores for lateral system, mass timber Cross Laminated Timber (CLT) floors, cantilevered decks, steel columns. and built-in-place envelope and cladding.

V3 Prefabricated Hybrid Concept

Prefabricated elements include lateral steel brace frame system, CLT floors, steel columns, bolt-on steel balconies, and modules for the envelope and cladding.

2.3 Model Attributes

Attributes	V1 - Reinforced Concrete	V2 - Hybrid Mass Timber with Concrete Cores	V3 - Prefabricated Hybrid Mass Timber Concept with Steel Frame
Floor Plate Structure	Reinforced Concrete	2-way 5-ply CLT	2-way 7-ply CLT
Core Structure	Reinforced Concrete	Reinforced Concrete	Steel HSS Posts
Vertical Structure	Reinforced Concrete	Steel HSS	a) Steel HSS Posts for point loads b) Prefabricated structure steel external braced frames for lateral loading
Above Grade Transfer(s)	Reinforced Concrete	Structural Steel	None - building loads continuous to Podium transfer slab
Envelope	Built-in-place, building fully scaffolded.	Built-in-place, building fully scaffolded.	Prefabricated
Tower Cranes Required	1	1	2
Balconies	Cantilevered Reinforced Concrete	Cantilevered 5-ply CLT	Prefabricated Steel/Aluminum Cassettes bolted on and cable supported.
Structure Encapsulation	Partly encapsulated w/ GWB. Concrete ceilings in dining/ living areas are painted/ sprayed. Other suite areas are dropped.	Fully encapsulated w/ GWB. Acoustic treatments applied to floor assembly.	30% Exposed within Suites (Isolated to LR, acoustic treatment to floor assembly).
Building Height	137'-8"	143'-0" (add 5'-0") Added height required to switch from 8" concrete slab to 5-ply floor assembly; keeps same clear height in each suite.	143'-0" (add 5'-0") Added height required to switch from 8" concrete slab to 7-ply floor assembly; keeps same clear height in each suite).

3.0 key findings

Cost Premium

V2 (Hybrid Mass Timber and CIP Core) has a 12% cost premium compared to V1 (Base Building). The structural costs were the major cost variance as expected.

V3 (Prefabricated Hybrid Concept) had a 20-25% cost premium over V1 (Base Building). In this case it was a combination of the structural costs and the prefabricated envelope.

Code Issues

- V3 (Prefabricated Hybrid Concept) would need several upgrades to achieve BC Energy Code Step 3 performance ranges.
- The required 2-hour Fire Resistance Rating for the floor assembly can be achieved by encapsulating mass timber, or by adding additional plies of CLT to the buildup. *(See page 35 for further details)*
- Projects proposing to exceed the current BC code limit of 12 storeys for encapsulated mass timber would need to pursue an alternative solution.

Schedule*

13 week schedule gain for V3 (Prefabricated Hybrid Concept) over V1 (Base Building)

12 week gain over V2 (Hybrid Mass Timber and CIP Core)

V1 Base Building CIP:	**68 weeks**
V2 Hybrid Mass Timber & CIP Core:	**67 weeks**
V3 Prefabricated Hybrid Concept:	**55 weeks**

**Schedule Disclaimer: schedule was based on the above grade building only; no schedule considerations included for the below grade parking structure.*

3.1 Model Trade-Offs

The choice to build with mass timber entails trade-offs beyond cost and schedule. The trade-offs occur in a wide range of aspects, from the degree of architectural flexibility, trades required and building heights to above grade transfers, envelopes and decks, and structure encapsulation. The matrix provides an overview of trade-offs to expect from the different model scenarios.

Items	V1 - Reinforced Concrete	V2 - Hybrid Mass Timber with Concrete Cores	V3 - Prefabricated Hybrid Mass Timber Concept with Steel Frame
Architecture	Highly flexible; industry standard for high-rise design/construction.	Limited flexibility; can reproduce model. Code challenge and height above 24m with exposed CLT.	Limited flexibility in design features; limited suppliers in BC. Panels can follow 1 floor behind structure, solves code issue.
Trades Required to Produce Structure	Concrete Forming/Placing, Reinforcing Steel, Plumbing, Electrical, HVAC (x5).	Concrete Forming/Placing, Reinforcing Steel, Plumbing, Electrical, Structural Steel, Mass Timber installer (x5).	Structural Steel Trade handles Mass Timber as well.
Trades Required to Produce Envelope	Scaffolding, Steel Stud/Drywall/Insulation, Windows, Waterproofing, Cladding (x4).	Scaffolding, Steel Stud/Drywall/Insulation, Windows, Waterproofing, Cladding (x4).	Windows, Wall Panels; potential for Structural Steel Trade to install wall panels (x1).
Above Grade Transfer(s)	Concrete - Allows double height expansive lobbies & amenity spaces, step-backs/soffits allow for sense of arrival.	Structural Steel - Allows double height expansive lobbies & amenity spaces, step-backs/soffits allow for sense of arrival.	Less flexible braced frames cannot step, resulting in more linear vertical envelope.
Elevator	Install starts at Structural Completion.	Install starts at Structural Completion.	Install starts after elevator shaft framing infill and fire ratings are complete.
Envelope & Balconies	Highly flexible, many options for designers and trades.	Flexible in design. Must consider & monitor protecting CLTs in construction as well as lifetime performance. Potential for exposed CLT soffits.	Least flexible in design & local suppliers; features limited to panel capability. Added structural steel needed for pre-fabricated deck cable tie-backs.
Structure Encapsulation	Not required. Exposed concrete within suites not considered a feature in multi-family.	5-ply CLT - fire code requires all timber be encapsulated with GWB.	Use of 7-ply opens up opportunity to expose Mass Timber ceilings. Need to consider acoustic build-up on floors: materials, schedule/ sequencing, thus adding cost.
Building Height	Falls within zoning height requirements.	Would exceed max building height of 141' by 8".	Would exceed max building height of 141' by 8".
Cost	Least Expensive	Premium	Significant Premium
Schedule	Longest	Nominal Reduction	Significant Reduction

3.2 Major Cost Implications

- In direct capital cost comparison, 12-to-18-storey concrete construction has the advantage over mass timber in the BC market.
- V2 (Hybrid Mass Timber and CIP Core) had a 12% cost premium compared to V1 (Base Building).
- It is estimated that half this premium is attributed to conversion of concrete design to timber and could be mitigated through early adoption of timber in the design process.
- V3 (Prefabricated Hybrid Concept) had a 20-25% cost premium over V1 (Base Building). We believe that prefabricated construction will change how buildings are constructed. In time, this cost premium – a combination of structural and envelop costs – will fall considerably.
- Using prefabricated steel cores to accommodate lateral loads instead of concrete requires oversized cores that significantly increase cost, and multiple custom connections that lengthen schedule.

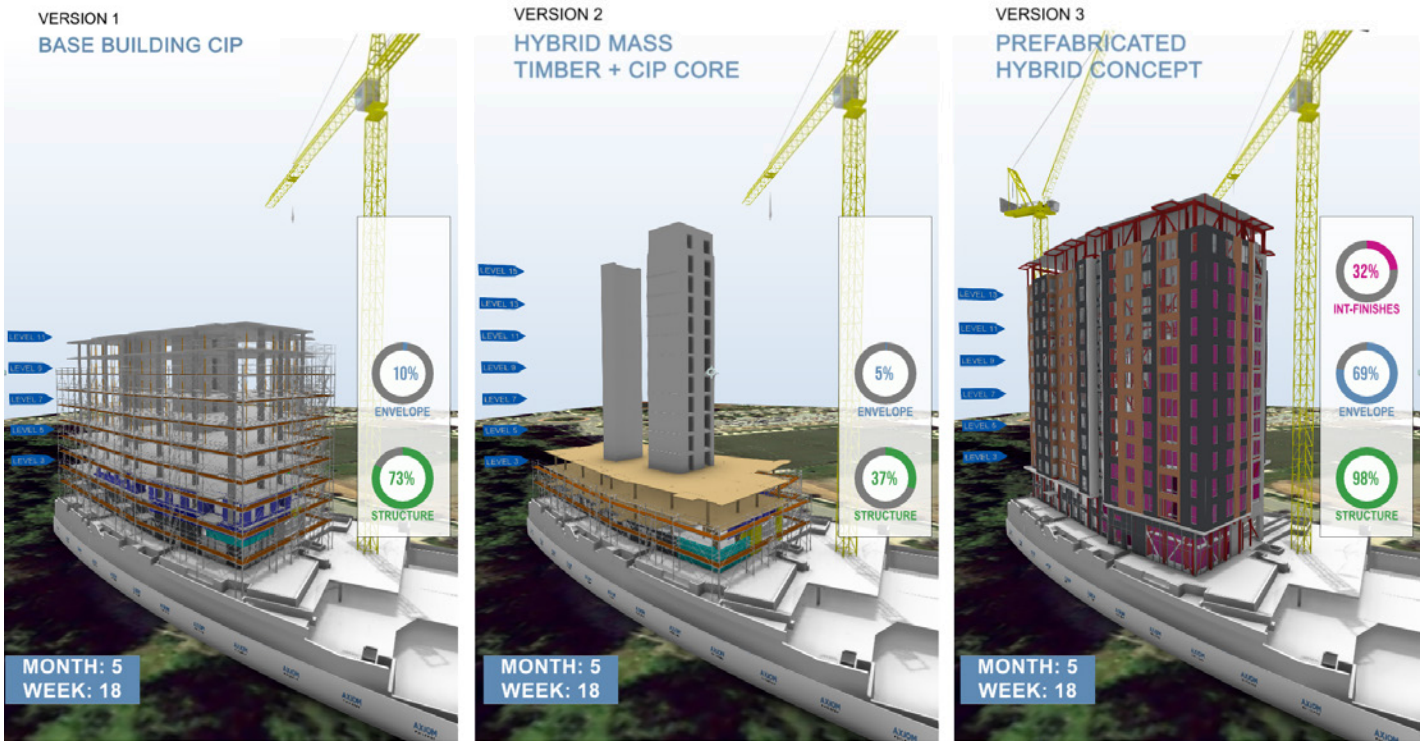
We believe the future of mass timber will be part of a complete prefabrication concept. We see cost premiums decreasing and schedule gains increasing with expanding industry maturity in prefabrication.

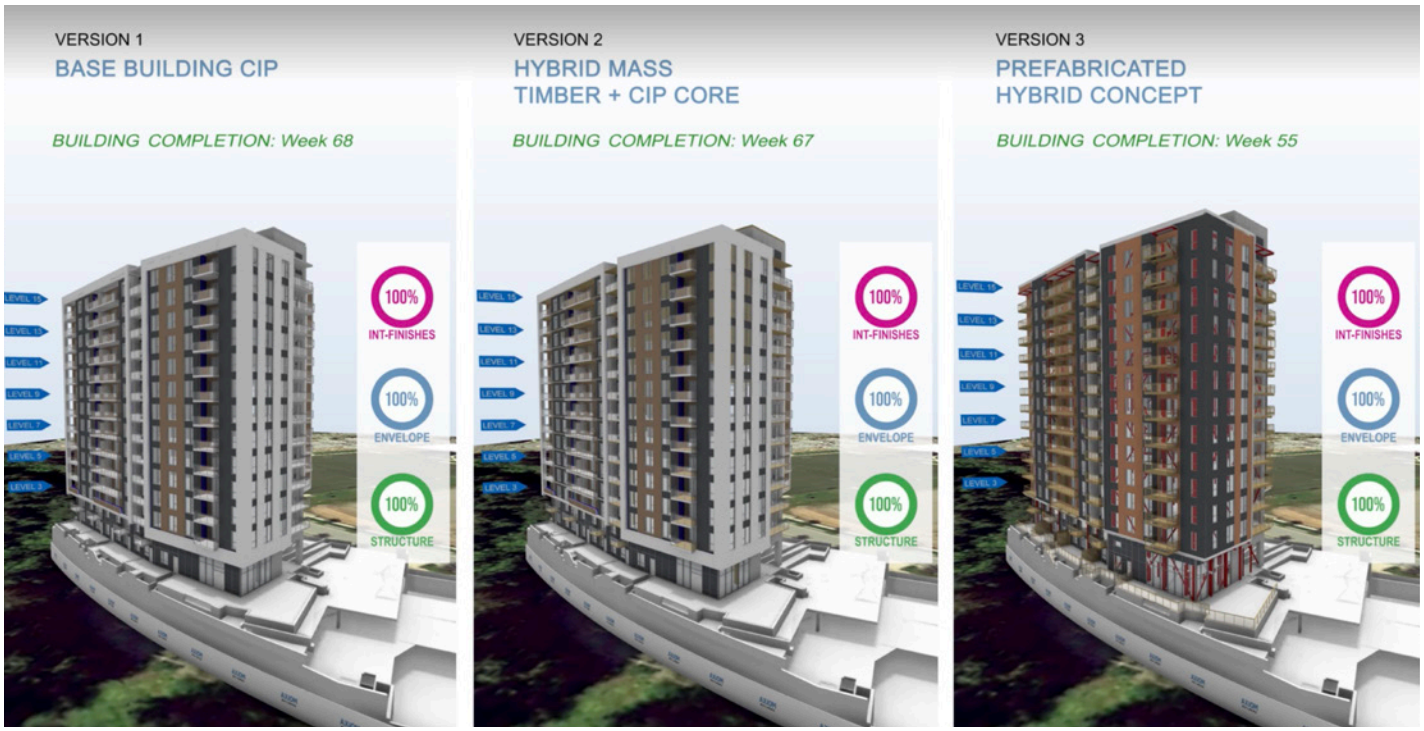
3.3 Major Schedule Implications

- Using concrete core design does not support potential schedule savings from mass timber CLT floor plates.
- Using a concrete formwork structural cycle for mass timber lowers productivity and therefore cost competitiveness. The cycle – completing vertical and horizontal elements in sequence level by level – causes excessive downtime between built-in-place trades (formwork and reinforcing steel) and pre-fab trades (CLT floorplates and structural steel), decreasing productivity while increasing cost and risk to schedule.
- The use of steel braced frames can resolve the schedule challenges posed by concrete cores.
- To accommodate perimeter steel braced frames, the unit plans would need to be designed to accommodate the diagonal members.
- Construction scheduling and sequencing must consider the building code's fire protection requirements to encapsulate every 4th level of mass timber structure as construction progresses.

3.4 Major Code Implications

- Current BC building codes limit the height of encapsulated mass timber construction to not more than 42 m from the first storey floor to the uppermost floor level. Buildings exceeding these height limits need an alternative solution. A project seeking additional building height should engage an experienced code consultant at the outset. Projects exceeding the 12-storey limit would need to negotiate exposure limits of mass timber elements.
- For projects meeting the building height limitations, current BC building codes impose prescriptive percentage-based limitations (detailed in section 3.1.18 of the BCBC) on the amount of exposed mass timber within each fire compartment or suite.
- The relatively lower density of CLT panels requires that there be additional acoustic measures incorporated into the mass timber floor assemblies to meet the required STC ratings.
- Current seismic code increase structural requirements to existing building by roughly 25%.





Watch 4D Construction Simulation comparing V1 (Base Building CIP), V2 (Hybrid Mass Timber CIP core), and V3 (Prefabricated Hybrid Concept).

Pause the video at the 1:45 mark to see the relative completion rates for Structure, Envelope and Interior Finishes with timelines for building completion for each version.

key recommendations

4.0

Optimize design to maximize benefits of using mass timber and prefabrication methods. This does not necessarily have to mean box-like, rectangular building forms.

1

Adopt modern methods of construction and DfMA (Design for Manufacture and Assembly) holistically to amplify the inherent properties of prefabricated timber – and accelerate innovation in the design of an efficient and prefabricated lateral system.

2

Focus on developing mass timber steel hybrid buildings. A steel lateral system maximizes potential for significant schedule savings. Such hybrids lend themselves to the methods and skills of the steel fabrication and erection industry. These include 3D drafting and estimating, certified installers and welders, prefabrication shops, shop-to-site logistics, proficiency in meeting tolerances (mass timber can meet or exceed steel tolerances), access to specialty product manufacturers, availability of industry engineers and a strong track record of innovation.

3

Prefabricate the lateral systems so that they are modular like the gravity system of columns, connectors and CLT panels. Consider prefabricated exterior envelope systems and balconies for optimal construction efficiencies, and prefabricated bathroom and kitchen elements. This level of prefabrication will help enable mass timber/steel hybrids to become part of the residential mix.

4

[3] *UK Construction Industry Council. (2013). Offsite Housing Review. Available online: cic.org.uk/download. php?f=offsite-housing-review-feb-2013-for-web.pdf (Retrieved April 21, 2021).p27*

Space and unit planning in a prefabricated mass timber building should be more “structure forward” than in a comparatively flexible concrete building. Address the floor plate concept early and more systematically to avoid inefficient constraints on the building footprint and materials.

5

Adopt extensive offsite prefabircation throughout the project for its broader benefits: faster construction times, better quality products and finish, and less waste. Other benefits include less noise, dust and site disruption, improved health and safety, workforce upskilling, predictable product performance, and lower product operational costs.

6

Evolve local codes to accept building materials and processes that maximize mass timber and prefabrication benefits for the design and construction of buildings exceeding 12 storeys. Focus on 12-to-18-storey segment.

7

Upskill the local mass timber construction market on prefabrication methods to deliver schedule advantages.

8

Educate insurers about mass timber building performance and create a new classification for buildings utilizing mass timber.

9

Develop a comprehensive moisture management plan early in project planning. Mass timber buildings in coastal areas of the BC market should ideally be built in the drier months, May through September.

10

detailed cost comparison

5.0

We developed cost comparisons for each of the three models.

The figures for V1 show the Base Building's original construction costs in Q3 2021 dollars. We applied escalation to bring the pricing to Q3 2021 dollars and changed some baseline costs to account for current code requirements.

For V2 figures, Axiom and BTY independently priced the design for the proposed scheme. V1 cost data was used for finishes, mechanical and electrical systems, and site work since design for these components remained unchanged from V1. We focused on the substructure, structure, envelope and general conditions. Upon completion of the independent pricing, BTY and Axiom compared estimates and identified the variances to agree on a realistic estimate for V2 compared to V1.

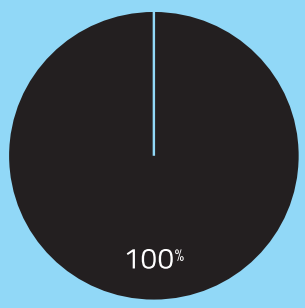
V3 was also priced to better understand where we see the industry with regard to componentized construction. Pricing information was limited due to the lack of supply and choice for prefabricated systems that our team proposed. Therefore, the V3 model is not shown in the table below but we have provided an opinion on the cost premium for that scheme in today's market.

5.1 Cost Summary Base Building CIP vs. Hybrid-Mass Timber + CIP Core

Table 1	Cost Summary V1	V2
Architectural	41%	38%
Structural	21%	27%
Mechanical	15%	14%
Electrical	7%	6%
Site Work	3%	3%
GR & Fee	13%	12%
Total	**100%**	**100%**
		↓↓
Premium for Hybrid- Mass Timber +CIP Core		**12%**
Substructure	6%	5%
Structure	15%	22%
Exterior Enclosure	16%	16%
Partitions & Doors	10%	8%
Finishes	6%	6%
Fittings & Equipment	9%	8%
Mechanical	15%	14%
Electrical	7%	6%
Site Work	3%	3%
GR & Fees	13%	12%
Total	**100%**	**100%**

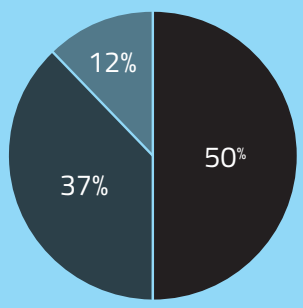
5.2 Structural Cost Ratio by Material

Construction Costs



Base Building CIP

Concrete

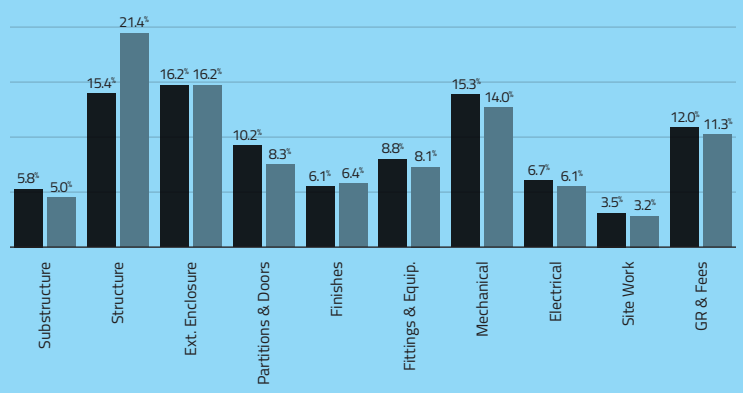


Hybrid-Mass Timber + CIP Core

Concrete · Mass Timber · Structural Steel

55% - 65%
cost increase for above grade structure

V1 vs V2 Cost Comparison



5.3 Key Metrics

- Major fluctuations in material prices and labour costs in 2021 added challenges to forecasting construction costs.
- V2 (Mass Timber CIP Hybrid) had a 12% cost premium compared to V1 (Base Building). The group found inefficiencies that arose from converting an inherently concrete design to a timber design were estimated to account for roughly half of the cost premium of V2 over V1.
- Structural costs were the major cost variance between V2 and V1, as expected.
- There was a 55% to 65% cost premium in the above grade structure from V1 to V2, much higher than expected. The primary drivers are the HSS columns and connections required for this particular scheme.
- Had the team been designing V2 as a mass timber hybrid project from the start, the structure would have been designed to better align with the properties of mass timber elements. The study reveals the need for careful consideration and early adoption to avoid cost premiums.
- V3 had a 20-25% cost premium over V1 due to structure and envelope. While this is significant, we believe that advancement in off-site construction and prefabrication will change how buildings are constructed. In time, as the industry matures, this cost premium will fall considerably.

5.4 Key Considerations

- Carefully consider the delivery model when choosing a mass timber hybrid structure.
- Employ relevant industry expertise early in the design process; it is critical to limiting risk and enabling project success.
- Cost unpredictability of primary materials in superstructure in V2 (Mass Timber Hybrid) is a significant risk for developers. In 2021, lumber pricing for superstructure in our market was highly volatile due to the Covid-19 pandemic, a spike in the U.S. housing market, forest fires, shipping tariffs and import costs.
- Timing of construction is fundamental to success in mass timber construction in the Lower Mainland. Seasonal changes have huge impacts on water management and the associated costs.
- Time related cost savings have yet to be recognized in mass timber high-rise construction. While many anticipate faster construction when comparing pre-construction schedule models, this has not been proven on any of the projects we visited and reviewed.

detailed schedule comparison

6.0

Schedule & Commitment Considerations For V1, V2 & V3 in Lower Mainland and British Columbia

PRE-CONSTRUCTION

Schedule Attributes	V1 - Reinforced Concrete	V2 - Hybrid Mass Timber with Concrete Cores	V3 - Prefabricated Hybrid Concept (Mass Timber with Steel Frame)
Municipal Process for Permit Application	Most Experienced	Little Experience	Least Experienced
Contractor Input Prior To DP Application	Recommended for Value Engineering Only	Strongly recommended	Strongly recommended
Commitment to Prime Contractor Prior to DP	None	Contract strongly recommended	Contract strongly recommended
Commitment to Supply Chain & Sub-Trades Prior to DP	None	Contracts strongly recommended for Mass Timber & Structural Steel Connection Scopes.	Contracts strongly recommended for Mass Timber & Structural Steel Connection Scopes. Recommended for Envelope, Cladding & Pre-fab Deck Scopes.
Material Procurement Prior to Construction Start	None	Required for Mass Timber and Structural Steel Connections.	Required for Mass Timber, Structural Steel Connections, Structural & Structural Steel Lateral System. Recommended for Envelope, Cladding & Pre-Fab Decks.

Schedule & Commitment Considerations For V1, V2 & V3 in Lower Mainland and British Columbia

CONSTRUCTION

Schedule Attributes	V1 - Reinforced Concrete	V2 - Hybrid Mass Timber with Concrete Cores	V3 - Prefabricated Hybrid Concept (Mass Timber with Steel Frame)
Seasonal Considerations Relative to Construction	None, other than typical measures taken for similar projects in the lower mainland.	Parkade and Core Completion Required in the Spring / Early Summer for Mass Timber Start.	Parkade Completion Spring / Early Summer for Mass Timber Start.
Winter Considerations Relative to Construction	None, other than typical measures taken for similar projects in the lower mainland.	Rain Water Management strategies include: Temp Vertical Envelope Enclosures, Horizontal Scaffolding Enclosures over Exposed Mass Timber, Drainage, Measures to mitigate Damage to Drywall and Finishes such as Factory-installed top coat and edge sealer, Factory-installed self adhered membrane over all areas or just at panel splines and core interfaces (RWL can be installed as the structure is erected and help drain the decks).	Rain Water Management strategies include: Temp Vertical Envelope Enclosures, Horizontal Scaffolding Enclosures over Exposed Mass Timber, Drainage, Measures to mitigate Damage to Drywall and Finishes such as Factory-installed top coat and edge sealer, Factory-installed self adhered membrane over all areas or just at panel splines and core interfaces (RWL can be installed as the structure is erected and help drain the decks).
Structure & Envelope Cycle Considerations	One Typical Structural Level every 6 Days. Envelope 7-8 Floors Below Level of Live Structure. Note: Elevator Rails can potentially start prior to Superstructure Completion.	One Level of Core Structures (2 each) every 5 days. Mass Timber structure starts post completion of Cores. One Typical Level of Mass Timber every 5 days. Built in Place Envelope Follows as close as possible behind live Mass Timber level. Note: 1) Code allows no more than 4 levels between live Mass Timber install and Envelope install 2) Elevator Rails can potentially start prior to structure completion.	One Typical Structural Level every 7 days (includes 2 day overlap between Structural Steel Frames and Mass Timber Floor Plates) Pre-fab Envelope panel install follows as close as possible behind Mass Timber install. Pre-fab Deck install starts when (crane time frees up) Mass Timber is complete. Note: 1) Code allows no more than 4 levels between live Mass Timber install and Envelope install. 2) Elevators cannot start until Shafts are completed, enclosed and fire-rated.
Superstructure (Excluding Parkade) to Building Completion	68 Weeks	67 Weeks	55 Weeks

our approach 7.0

7.1 What We Studied

We compared the cost of building a 14-storey residential tower using mass timber to that of an existing, equivalent 14-storey residential concrete tower in Vancouver, BC.

We chose an existing building for two reasons. First, it is already proven to meet market requirements. Second, it provided a complete design and actual costs that could be used as a base case comparable.

The initial concept was that the product and outcome of the alternative must be of similar value to what the base building offers in terms of area, flow, layout, finish, glazing, and balconies, etc., to ensure a like-for-like comparison. Moreover, this is not a typical building; it is rectangular with two lateral systems. This would make our findings applicable beyond standard design for square, single lateral system buildings.

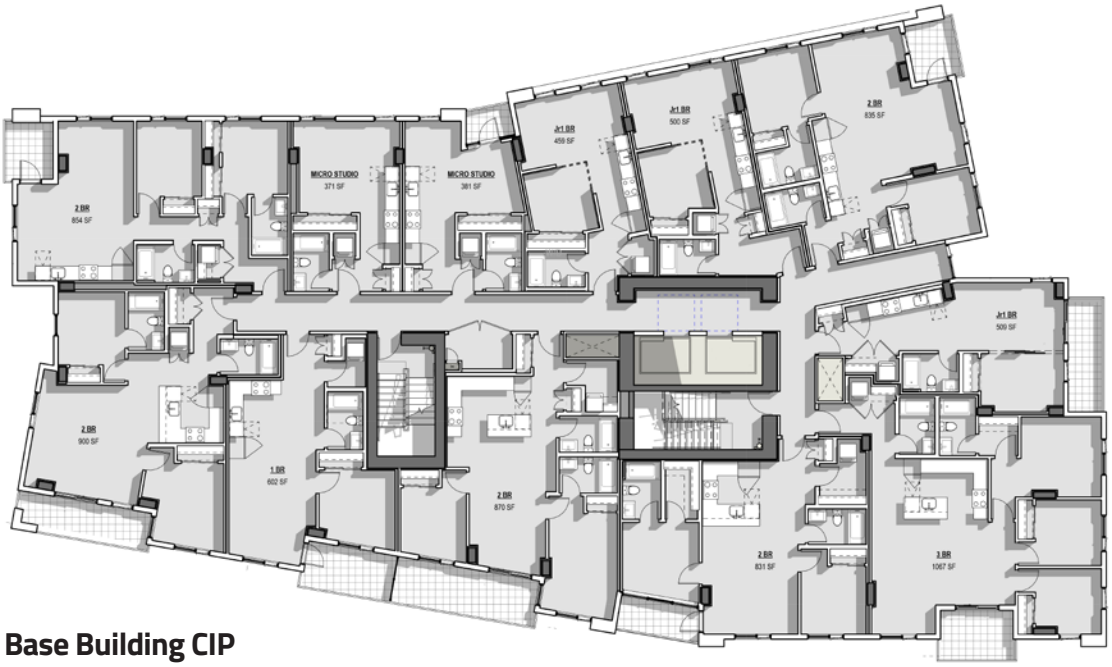
Had we designed a unique building, specifically with timber in mind, it would have been more efficient, but would have made the task of comparison more subjective.

7.2 Our Guiding Principles

- The value can change as a consequence of the material chosen, e.g. concrete, steel or timber.
- Design should, however, be developed so that the type of material is not unfairly compromised; that is, do not make timber do a job that concrete is made to do.
- Had we decided to design with a mass timber system in mind from the start, we ask what we could have done differently.

Space and unit planning in a prefabricated mass timber building should be more "structure forward" than in a comparatively flexible concrete building.

Clarity early in the design process with respect to structural grid spacing is key. Certain CLT manufacturers produce specific panel widths which ultimately impact the grid spacing and unit planning throughout the building. Rigour around unit planning and the stacking of unit types through the height of the building are important strategies for success.



V1 Base Building CIP

V2 Hybrid Mass Timber & CIP Core

7.3 Mass Timber Hybrid Solutions

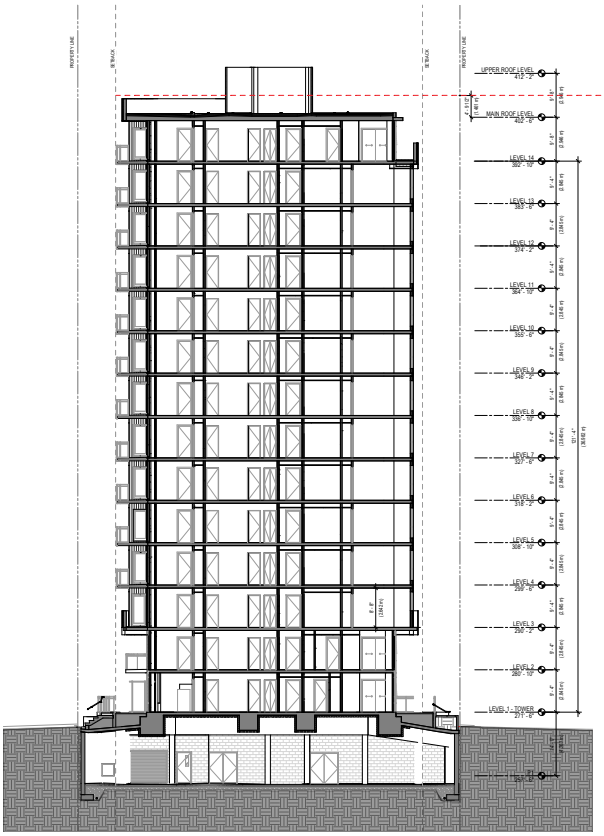
7.3.1 Assumptions

- The building height did increase by approximately 5’-0” to keep the same clear heights in each unit and to accommodate the increase in the floor slab assembly.
- Steel stud infill between steel post structure, with services running in partition and demising walls as in a typical concrete or steel building. Coring through CLT floors on site should be avoided. It should be done in the factory with proper design coordination.
- Price volatility in each of the lateral systems structural materials; pricing based on then current market values (July-August 2021).
- Single crane locations are the same for V1 Base Building and V2 Mass Timber & CIP Core Hybrid. Prefabricated Concept Model V3 uses two cranes.
- Current seismic code increases structural requirements (core, shear walls, footings) to existing building by roughly 25% overall to bring to current code standards for Base Building.
- Exterior envelope systems are equivalent in both the Base Building design and the modeled Hybrid Mass Timber V2 building to keep the look and feel of both buildings similar, i.e., steel stud exterior walls paired with segments of window wall and curtain wall.
- Equal heating system for both V1 and V2 models: hydronic baseboard heat with Heat Recovery Ventilators (HRV).

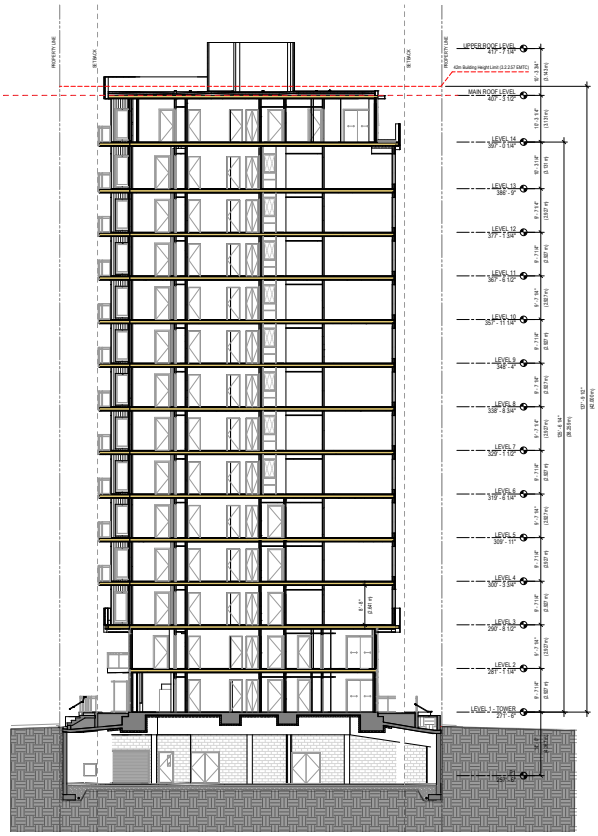
Increased building heights keep consistent clear heights in each suite

We kept the clear height in each of the units the same across each version and adjusted the floor-to-floor heights to account for the additional 4” in floor assembly thickness between the mass timber and concrete assemblies.

This adjustment grew the overall building height of V2/V3 by approximately 5’-0” highlighting an inequity between floor to ceiling heights in concrete compared to mass timber construction.



BASE BUILDING: SECTION



HYBRID V2/V3: SECTION

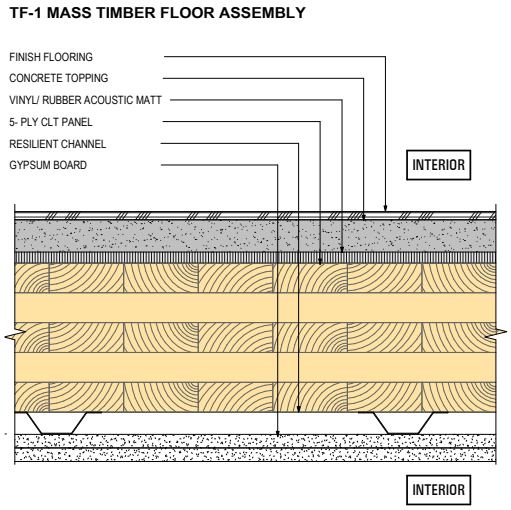
7.3.2 Structure

what we chose and why

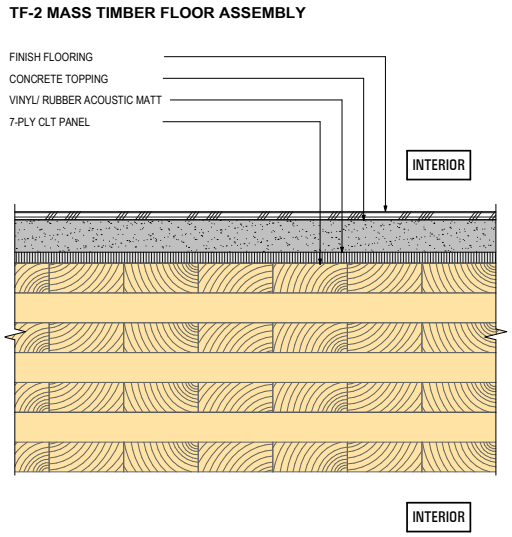
An exclusively mass timber building, while possible, would be unrealistic given the price of mass timber. Our goal of developing a financially feasible and market competitive timber building meant that a hybrid approach would be necessary and preferable. It would allow for a significant timber volume while leveraging the optimal performance characteristics of other building materials, specifically steel.

As the largest volume of timber is the floor structure, this became our primary focus. We chose Cross Laminated Timber (CLT) for the floor plates as it is the most widely available and easily accessible in the local market, the best understood by the industry, and has the best supply chain support. We chose to add a topping *(see Assemblies on page 35 for details on acoustics and finishes)*. The lack of a structural requirement for the topping to act compositely allowed for acoustic separation above the timber floor.

5-ply CLT



7-ply CLT

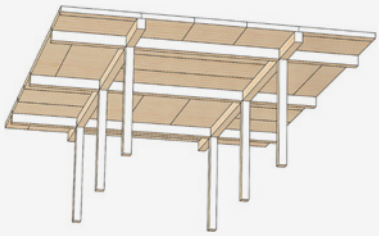


7.3.2.1 Primary Frame

Floors

We reviewed several structural framing options for a typical floor (See Assemblies):

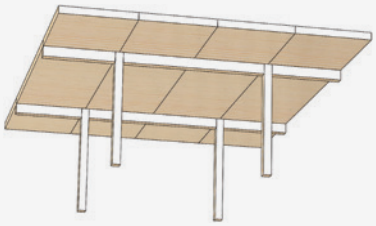
1.



Thinnest floor laid on to two-way beam system; purlins on to primaries.

While efficient in terms of overall timber fiber, we rejected it due to build complexity, impact on overall building height (and additional envelope) and increased complexity on running mechanical and electrical services.

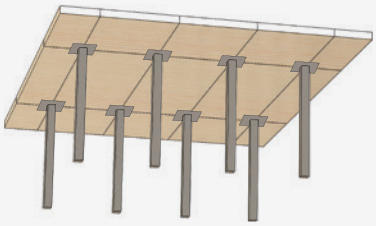
2.



One-way CLT on to beams located within/above demising walls.

This approach was reasonably efficient in terms of fiber, and structurally simple and robust, even though it would slightly increase the complexity for routing mechanical and electrical services.

3.



Point supported CLT panels on to columns strategically located in walls between and within units.

This was also reasonably efficient, and the flat plate system was favourable for systems reticulation. The flat underside provided a like-for-like comparison to the reinforced concrete base building.

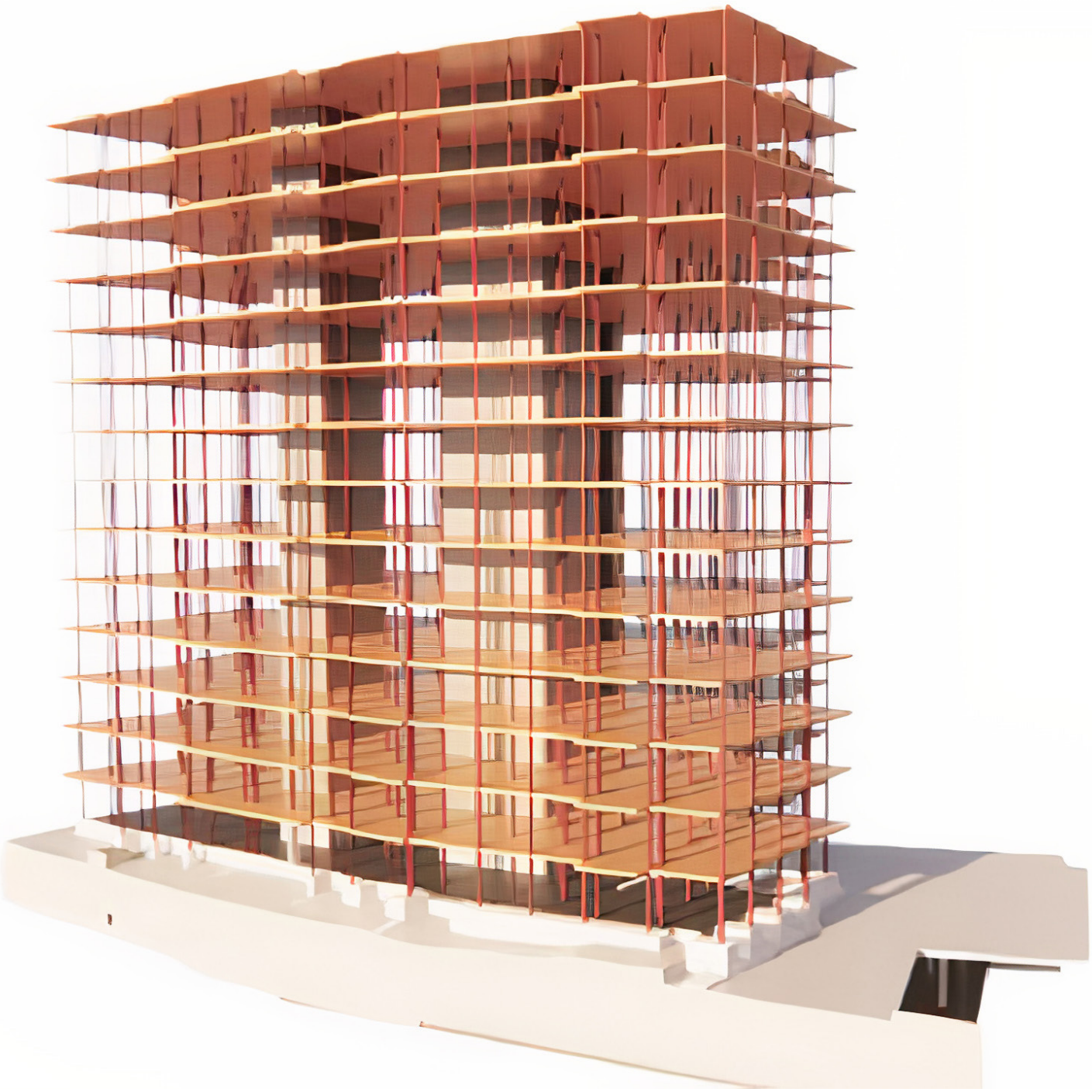
We selected a point supported solution since this would permit the free distribution of M&E services on the soffit of each floor. The CLT thickness for a point supported and for beam supported were both 5 ply.

Image credit: J. David Bowick
canadianarchitect.com/mass-timber-primer

Columns

We chose steel – rather than timber – posts for columns to minimize size and improve fit within demising walls.

This prevents encroachment that would have occurred due to the size of the much larger timber columns. In some designs the unit layout might accommodate this encroachment, but with the irregular nature of this floorplate it would become problematic. There may be concerns about risk to the structure from a flooded floor – and potential rotting – of a timber column. Since there are multiple ways to address and resolve this risk, it should not be cause for avoiding the use of timber columns.



Lateral System

The base building has two cores of reinforced, cast-in-place (CIP) concrete. We took a two-pronged approach to the timber options.

1.

The first was to replicate the lateral system of two concrete cores, reduced for the lower seismic mass of a timber building. We considered both a sequentially poured core, floor by floor, and a slip formed core with the timber floors to follow, as was done in the base building, and a commonly cited case, Brock Commons. While both work from a technical and structural perspective, the schedule posed a challenge.

- The issue with the sequentially constructed core is that after each lift, the concrete team would have to leave the site while the floor plate and columns were installed. While this option would be relatively rapid because the installed items are prefabricated, it would cause significant disruption to work flow for concrete and associated trades.
- The issue with slip forming the cores, in the context of the full schedule, does not provide a net favourable result based on the established time, duration to execute, and availability of local expertise.

2.

The second approach was a pre-fabricated lateral system that would integrate well with mass timber construction, which works best with a Design for Manufacture and Assembly (DfMA) approach: fabricate offsite and assemble "a kit of parts" on-site.

We determined that at 12 to 18-storeys, getting timber shear walls to fight the lateral forces involved is an inefficient use of (costly) timber fiber. In a like-for-like swap, we developed a steel core concept that considered:

- Braced frames
- Eccentrically braced frames to facilitate doorway access through the frame
- Moment frames where required by the layout and corridors
- Prefabricated proprietary steel core wall systems

In every case, the building's geometry, and the relative inefficiency of trying to make steel behave like concrete, resulted in substantially higher cost than the concrete alternative. We explored placing a structural steel lateral system on the existing cores, but the cost premium proved prohibitive. Notwithstanding the unfavourable schedule and workflow implications, the mass timber hybrid solution proceeded with a concrete core.

3.

The recommended cost and time efficient solution.

The path forward we recommend is to develop a (steel) lateral system placed on the perimeter of the structure, either as a full or partial exo-skeleton. This approach provides an efficient – and cost-effective – lateral system while also supporting the significant schedule benefits that can be realized from a Design for Manufacture and Assembly philosophy that maximizes offsite fabrication, which, in turn, minimizes time on-site.

Mass Timber Floors

We considered two options for CLT floor structures:

Option 1

1-way spanning 5 ply CLT supported on beams, which allows for larger CLT panels that would reduce crane time, but increase cost from adding beams that would interfere with mechanical, sprinkler, HVAC and electrical service distribution on the underside of suite and common corridor ceilings. Introducing beams requires additional floor-to-floor height to maintain required clear heights in suites and corridors, and adds significantly to the complexity of coordination.

Option 2

2-Way spanning 5 ply CLT point supported on columns with steel connections, which requires a tighter structural grid with columns spaced between 3m and 3.5m. This approach is akin to a concrete slab as there are no drop beams to contend with, simplifying mechanical electrical distribution/routing.

7.3.2.2 CLT and Exterior Exposure

Exposing CLT structure to the exterior is generally not recommended. A timber structure can be serviceable and safe from decomposition for decades or more if kept dry.

When cantilevered mass timber is used as a projected balcony – even when waterproofed with modern materials and methods – there remain many potential avenues for moisture penetration. Even minimal moisture penetration without adequate ventilation for drying can result in decay and compromise mass timber's structural integrity. In a concrete building moisture penetration would not have the same drastic structural effects.

Exposed mass timber elements are to be designed for the life of the building. Regular maintenance and possible removal and replacement of the elements need to be considered during the design phase.

important considerations

8.0

8.1 Insurance

In our market the insurance industry needs to be further educated about mass timber buildings. Currently, mass timber has been classified with traditional stick frame construction. Underwriters are very limited, so a large enough group is required to insure the course of construction for larger scale mass timber buildings will be difficult. The biggest challenge is moisture, not fire. A comprehensive moisture management plan needs to be in place for any mass timber building.

8.2 Energy Efficiency

The base building design achieved an energy modeled performance with a TEUI of 117 kWh/m2-yr and TEDI of 42.3 kWh/m2-yr. These building performance metrics are in line with the BC Energy Step Code Step 2 performance targets with a TEUI of 130 kWh/m2-yr and TEDI of 45 kWh/m2-yr.

The Hybrid Mass Timber V2 design achieves equivalent building performance metrics as the Base Building design, with the envelope and building systems remaining the same.

The Hybrid Mass Timber V2 design would need several upgrades to achieve the BC Energy Step Code Step 3 performance targets with a TEUI of 120 kWh/m^2-yr and TEDI of 30 kWh/m^2-yr. They include:

- Additional exterior insulation for both vertical and horizontal building envelope assemblies
- High Efficiency HRVs
- High performance triple glazed windows
- Thermally broken balconies

8.2.1 FFR & Fire Safety Considerations

Fire safety was an implicit aspect of every design consideration, helping to push the boundaries of what is possible. The efforts of the fire protection engineer were instrumental to ensure code compliance for both V2 and V3 structures.

Designing and constructing a mass timber building must address multiple fire safety considerations, including:

- Encapsulation during construction. Not more than four levels can be exposed, which imposes significant additional construction costs. At a minimum developing an alternative method of protection would likely also warrant additional field reviews.
- Authorities Having Jurisdiction (AHJ) require a special report on construction fires, which is not required for a concrete project.
- Combustible Building Fire Exposure Analysis is required in Vancouver for any combustible building over four storeys.
- Alternate solution for combustible building over 12 storeys (42m), assuming no exposed timber:
    - Additional fire safety systems forming part of this alternative solution might include on site water supply, additional pump(s), additional flow switches and valves.
- Alternative solution for exposed mass timber (if feasible).
- Enhanced field review services related to fireblocking, firestopping, and fire separations.

The required 2HR Fire Resistance Rating for the floor assembly in a project of this nature can be achieved a few different ways:

1. By fully encapsulating the CLT with 3 layers of 5/8" GWB.
2. By partially encapsulating with 2 layers of 1/2" GWB which provides 60 min of the resistance rating with the remainder provided via a char allowance to the CLT panel of 55mm.
3. in instances where exposure is desired, by adding additional plies of CLT to the buildup (7+) so that the char depth is increased further to achieve the required rating time, before the layers needed for structure start to be compromised.

The V2 design uses a 5 ply encapsulated floor assembly to achieve the required FRR. This option is likely the easiest to get AHJ approval for a timber building over 12 storeys.

The V3 design uses a 7 ply floor assembly in certain areas to achieve the required FRR. In this application, parts of the timber panel are exposed within suites. Since a percentage of these panels are expressed, they require an elevated (visually graded) finish and thus are more expensive – so extra wood volume, and premium graded wood need to be factored where exposed mass timber is desired for aesthetic reasons.

8.2.2 Acoustic Considerations

The relatively lower density of CLT panels compared to concrete requires that there be additional acoustic measures incorporated into the mass timber floor assemblies to meet the required STC ratings set out in the building code. These measures can include:

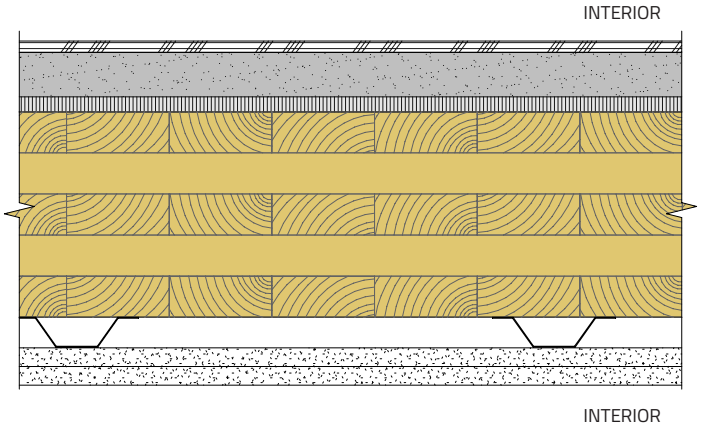
- Adding a concrete topping to provide additional mass.
- Adding decoupling interlays such as an acoustic mat interlayer.
- Adding sound isolation devices such as resilient channel.

Another key acoustic consideration on mass timber projects is the control of sound transmission through secondary or flanking paths. The latest Code iteration seeks to significantly limit the flanking sound paths. This relies heavily on discontinuous structures at the junctions with adjoining constructions, making it impractical to not have a discontinuous floor topping between horizontal dwelling unit separations.

Consequently, our recommendation is to stop the topping at the vertical separations as this provides the most consistent, repeatable and complete resistance to sound transmission per the design intent of the Code. Where, for non-acoustic reasons, the topping is continuous then the treatments to the adjoining construction and floor finishes would need to be commensurate and include a high degree of acoustic detailing to accord with the Code.

After considering multiple assemblies structured around both dry-pack systems as well as wet systems (concrete toppings), we arrived at consensus on the following assemblies for the simplicity they offered during the construction process:

Draft Floor Assemblies for Hybrid – Mass Timber + CIP Core [V2]



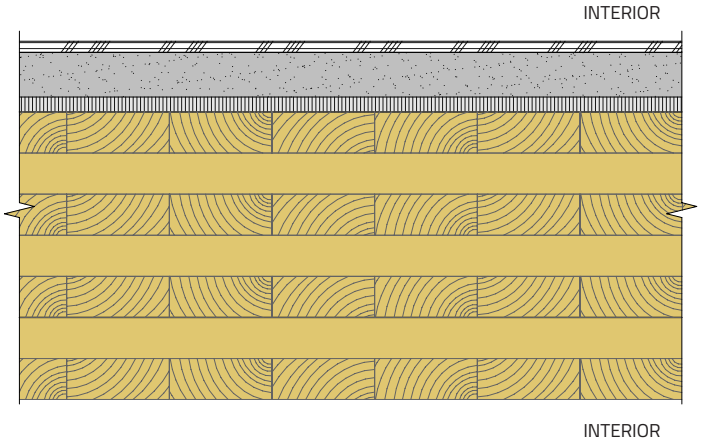
5-ply Assembly (STC Rating 55)

- 9mm finished flooring
- 38mm concrete topping
- 12.7mm acoustic mat inter-layer
- 175mm 5 Ply CLT
- 25mm Hat track
- 2 Layers 15.8mm Type X Gypsum wall board

(Suspended GWB Ceiling where required)

The overall floor assembly thickness at each typical level has increased by approximately 101.6mm (4”) over the typical 8” concrete slab in the base building. To keep the same clear height throughout the suites and corridors, the building height would need to increase by approximately 1.2m (5’-0”).

Draft Assemblies for Prefabricated Hybrid Concept [V3]



7-ply Assembly (STC Rating 55)

- 9mm finished flooring
- 38mm concrete topping
- 12.7mm acoustic mat inter-layer
- 245mm 7 Ply CLT

Where CLT is not exposed add

- 25mm Hat track
- 2 Layers 15.8mm Type X Gypsum wall board

(Suspended GWB Ceiling where required)

The overall floor assembly thickness at each typical level has increased by approximately 101.6mm (4”) over the typical 8” concrete slab in the base building. To keep the same clear height throughout the suites and corridors, the building height would need to increase by approximately 1.2m (5’-0”).

Note: *the base concrete building with 203mm (8”) typical concrete floor slabs achieved an STC floor rating of 58.*

Our evaluation of the implications of exposing CLT ceilings found that:

- An alternative solution would need to be negotiated with the AHJ to establish exposure limits where buildings exceed 42m in height. An alternative solution is required for any building exceeding 42m or 12 storeys. For many authorities, exceeding 12 storeys or significant exposed timber is a non-starter. Other authorities are open to alternative solutions. An alternative solution would also be required for any occupancies other than a primarily Group C (residential) or Group D (office) building.
- The BC Code allows small portions of exposed timber, which is typically uneconomic as the entire structural member needs to be 7 ply CLT. While an alternative solution may enable additional exposed timber, the costs and acoustic challenges would be significant.
- The CLT panel thickness would need to be increased from 175mm 5 Ply to 245mm 7 ply in order to provide sufficient char depth to achieve the required fire resistance rating where the panels would be exposed for aesthetic reasons.
- The additional CLT plies increase the floor assembly depth and necessitates additional building height.

8.2.3 Seismic Considerations

All designs were completed to the BC Building Code current at the time of the study.

In the case of the existing base building, the design was updated to accommodate the increased seismic loads of the current code compared to the original design.

8.2.4 Water Management/Protection

Given British Columbia's coastal climate, building a high-rise mass timber building in our region requires a comprehensive water management plan.

Ideally, the concrete parkade would be completed in the spring and summer to enable the superstructure to be completed through the drier summer months into September. There are many strategies to consider for a moisture management program. The plan could include temporary vertical envelope enclosures, horizontal scaffolding enclosures over exposed mass timber, drainage, and measures to mitigate damage to drywall and finishes. The CLT panels can have factory-installed top coat or edge sealer, or factory-installed self-adhered membrane over all areas, or just at panel splines and core interfaces. Temporary rain water leader installation during structure erection is a key element in a comprehensive moisture management plan.

industry team 9.0

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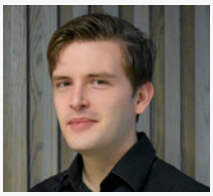

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AXIOM BUILDERS

wsp

ZGF