

July 10, 2014

Canadian Wood Council

Etienne Lalonde,
Vice President
Market Development & Wood Works! National Director
99 Bank Street, Suite 400
Ottawa, Ontario K1P 6B9
Canada

Dear Etienne

BENCHMARKING MASS TIMBER, STRUCTURAL STEEL and REINFORCED CONCRETE BUILDING SOLUTIONS, FINAL REPORT

EXECUTIVE SUMMARY

The Mountain Equipment Coop (MEC) project located in Vancouver, BC is a 123,460 ft² (GFA) hybrid mass timber - steel office building approved for construction through the 'Alternative Solution' provision allowed within the Canadian Building Code. The projects 'as built' design and costs were used as a basis for the benchmarking cost comparison.

The MEC project team including, Fast&Epp, Proscenium Architect, LMDG Code Consultants, Ventana Construction Corporation and Seagate Consulting Ltd, initially evaluated the building design and cost parameters then re-worked a number of project variables to create four similar hypothetical buildings.

The four hypothetical buildings and building systems considered were:

- A mass timber system - incorporating glulam post and beam structural elements, nail laminated lumber panels using commodity dimensional lumber sheeted with plywood and steel buckling-restrained braces (BRB's) for shafts and cores.
- A structural steel frame system - incorporating open web steel joists (OWSJ) supporting metal with concrete topping and steel buckling restrained braces (BRB's) for shafts and cores.
- A structural steel system - incorporating precast concrete hollow core panels and buckling restrained braces (BRB's) for shafts and cores.
- A reinforced concrete system – incorporating a two way flat plate and concrete shear walls.

The new designs and specifications created by the project team were further reviewed from a secondary impact and related cost perspective and each hypothetical building was then estimated and compared at a Class 'C' construction cost level and then the four options were compared. The estimated costs for the four hypothetical buildings were based on 'Spring 2014' Vancouver construction costs from qualified Ventana Construction suppliers and trades and internal Ventana stats and figures. The estimated construction costs for the four buildings are:

- Hypothetical mass timber structure - \$276.16 per square ft
- Hypothetical steel structure using OWSJ - \$277.69 per square ft
- Hypothetical steel structure using hollow core planks - \$280.68 per square ft; and
- Hypothetical reinforced concrete structure - \$273.41 per square ft

The benchmarking cost comparison and related design analysis of the four hypothetical buildings suggests that the design, specification and construction of large 4 storey commercial offices buildings utilizing mass timber products and hybrid structural steel details are viable and cost competitive when building design and specification, material selection and construction methodology is coordinated and site conditions are favourable.

It's estimated that approximately 15 equivalent foot board measure (15fbm/sqft) of glulam, lumber and plywood per gross square foot of construction is incorporated within the hypothetical wood building.

Not included in the cost provided are required allowances for weather protection during construction.

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1 INTRODUCTION

Recently, several new mass timber and hybrid wood building systems have been used to construct tall buildings in Europe. However, glulam post and beam frames with nail laminated mass timber floors represent a promising practical and cost effective option for mid and tall wood construction. The system is easy to design, fabricate and construct. It uses standard and commodity wood products that are readily available across North America from many supply sources. This structural system is currently being used successfully at the new 123,460 ft² (GFA) 4 storey Mountain Equipment Coop (MEC) building located in Vancouver BC.

Creatively developed as an 'alternative solution' the Hypothetical Wood Building System could be effectively applied to taller than 4 storey commercial or residential buildings as well.

This building technology is not new; it's been used in the past. The Steamer's Pub building, a retrofitted 9 storey wood structure in Vancouver's Gastown area was built 100 years ago with similar mass timber technology. The difference today with the MEC project is that the design and construction team has brought together advanced CAD design and engineering solutions with better performing and predictable mass timber/commodity elements (glulam and plywood) and compatible complementary products (adhesives and connectors).

The scope of work for Part 1 covered the schematic design of two hypothetical 4 storey commercial structural steel building, a hypothetical reinforced concrete building and a hypothetical wood building, similar to the MEC building. The evaluation includes a listing of secondary components and their impacts on schedule and cost for the buildings considered. The study was carried out to a schematic design level to allow for a 'Class C' construction cost estimate of the four systems by Ventana Construction Company and Seagate Consultants Ltd, the MEC general contractor and structural sub-contractor respectively.

Special attention was given to the cost of secondary impacts to various elements of the building that will occur by changing the structural framing systems.

This report includes the cost comparison and secondary impact analysis of the building systems described above.

2 PROJECT TEAM

All project members were part of the design and construction of the Mountain Equipment Coop (MEC) building.

Fast + Epp, Structural Engineering, Project Lead

Paul Fast
P.Eng., Struct. Eng., FStructE, P.E.,
BK Berlin, LEED® AP, Principal

Tanya Lüthi
M.Sc.Eng., P.E.

Bernhard Gafner
P.Eng, MStructE, CEng, Dipl. Ing. FH/STV

201 - 1672 West 1st Avenue,
Vancouver, BC V6J 1G1
604 731 7412
www.fastepp.com

Fast &Epp provided project management and structural engineering expertise for the study.

Proscenium Architecture + Interiors Inc., Architect

Hugh Cochlin
Architect AIBC, AAA, MRAIC, LEED®AP,
Principal

Greg Piccini
Architect AIBC

1 west 7th Ave.,
Vancouver, BC V5Y 1L4
604 879 0118
www.proscenium.ca

Proscenium provided architectural expertise for the study.

LMDG, Building Codes & Fire Science

Geoff Triggs
AScT, Eng.L.

David Steer
M.Eng., P.Eng. C

4th Floor, 780 Beatty Street,
Vancouver, BC V6B 2M1
604 682 7146
www.lmdg.com

LMDG provided building code and fire science expertise for the study.

Ventana Construction Company, General Contractor

Maurice Creagh
Operations Manager

Bryan Jones
Senior Estimator

3875 Henning Dr.
Burnaby, BC V5C 6N5
604 291 9000

www.ventanaconstruction.com

Ventana Construction provided cost information and construction expertise from a general contractor's perspective for the study.

Seagate Consulting Ltd, Timber Contractor

Ralph Austin
Owner

64 - 20449 66 Ave,
Langley, BC V2Y 3C1
604 240 1119

www.seagatestructures.ca

Seagate Consulting provided cost information and construction expertise from a timber installer's perspective for the study.

3 METHODOLOGY

3.1 PHASE 1, STRUCTURAL DESIGN OF HYPOTHETICAL STRUCTURE:

The base assumptions were:

- 4 storey commercial building.
- Located at 1077 Great Northern Way, Vancouver BC.
- On grade with a basement mechanical space, no underground parking.
- Hypothetical buildings to be similar fit within the footprint of the 'as built' MEC headquarter.

Fast + Epp provided hypothetical designs for:

- A mass timber building.
- A structural steel building.
- An alternate floor system for the steel option consisting of precast hollow core concrete planks - discussed in a letter supplementary to the drawing.
- A reinforced concrete building structure.

The building options were carried out to a schematic design level. LMDG provided a letter summarizing the code and fire requirements for the two hypothetical buildings in addition to the related code aspects of the 'as built' MEC building. Proscenium provided schematic designs for the envelope assembly.

3.2 PHASE 2, IDENTIFICATION OF SECONDARY IMPACTS:

Secondary impacts are defined as cost items significantly impacted if the main structural system is changed. These secondary components or assemblies are important to be identified in order to achieve a comprehensive understanding of the actual cost of the structural systems under consideration. The team defined several items prior to the costing and others were identified during the costing in phase 3.

3.3 PHASE 3, COST ESTIMATE OF HYPOTHETICAL STRUCTURES

Ventana used the schematic design drawings and supplementary information from phases 1 and 2 and carried out a class C cost estimate.

A class C cost estimate is defined¹ as a schematic design development estimate, where the program is set; the consultants have provided plans, elevations, sections, and an approximate palette of materials, as well as a concept design to allow form and spaces, and the design is generally completed up to 33%. From the documentation and information provided, possible quantities of all major elements are assessed, measured and priced. The estimate is a determination of the fair market value for the construction of the project, not a prediction of the low bid.

3.4 PHASE 4, COMPARISON, SUMMARY REPORT AND PRESENTATION

In this summary report, the cost information of the hypothetical buildings are compared and presented.

¹ Guide to Cost Predictability in Construction. Prepared by the Joint Federal Government / Industry Cost Predictability Taskforce. November 2012

4 HYPOTHETICAL BUILDINGS

4.1 ASSUMPTIONS

4.1.1 Architectural Concept

The major occupancy of the building will be office with meeting rooms, loading bay, product testing rooms, and service rooms considered as subsidiary occupancies. Furthermore, additional subsidiary amenity facilities will be provided including a roof garden, climbing wall and large multi-purpose room on the ground floor. The building has one basement level and four floor levels above; the main roof is approximately 19 meters above grade. The buildable area is 123,460ft².

The proposed building is comprised of two intersecting masses. The larger primary mass and principal building façade is aligned with Great Northern Way (GNW). The secondary mass is aligned to optimise solar orientation and is at approximately forty degrees to the primary mass. The building is located to the south of the site, proximal to GNW, moving it away from the SkyTrain tracks to the north. Parking and loading are located to the north of the site, where they are screened from GNW by the building.

The alignment of the principal façade reinforces the street edge and with a proposed 11.0 -metre set back from GNW (formerly 10.0 metres at Rezoning) provides a separation from the street and sufficient space for the 9.0 metre wide statutory right-of-way for the development of the Central Valley Greenway, which is to be integrated with the landscaped buffer including three inboard of the boulevard. The principal entry and associated plaza is oriented towards Glen Drive. The secondary façade facing Glen Drive is set back 13.0 metres at the Principal Entrance to provide extensive opportunities for hard and soft landscaping, expression of the storm water management system ('Infiltration Area'), and a pronounced sense of arrival. The GNW and Glen Drive edges of the site are entirely landscaped, enhancing the public realm and pedestrian street character.

The building form is driven by the desire to provide effective natural lighting to the majority of work spaces. Light penetration has a rough ratio of 1:2; with one being the window height and two being the resulting horizontal distance light will penetrate. This ratio informs the floor width and floor-to-floor height and results in relatively narrow floor plates (20m) and relatively high floor-to-floor heights (4.9m typ.) The floor plate width is also informed by internal programming requirements.

Programmatically, the form supports the desire for interconnected spaces and naturally links individuals and workgroups within the building. The intersection of the two stacks is anchored by a feature stair and climbing wall that rises through the building. The interior space is organized with enclosed private work areas confined to a centre spine with the intersection reinforced by clustering amenity areas. Open work areas are located along the building perimeter where access to natural light and views are maximized.

For the purpose of this study, the team with input from the CWC decided to keep the same architecture (building layout) for all hypothetical building designs. The structural framing will have to fit within the given building volume while respecting the functional program as much as possible.

The same approach is used for the stairs, mechanical shafts, pop up roof structures and miscellaneous framing. Further, the use of a raised floor assembly as per the 'As Built' is considered for all hypothetical buildings.

4.1.2 Building Code

The fire-resistance rating requirements of the hypothetical concrete and steel structures are the same, based on the applicable construction article of the Vancouver Building By-Law 2007. All code references provided are with respect to the VBBL 2007, unless otherwise noted.

Applicable building code part:	Part 3, Article 3.2.2.52.
Building height:	4 storeys
Sprinkler required:	Yes
Major Occupancy:	Group D (Offices)
Construction type:	Non-combustible (concrete or steel)
Interconnected Floor Space	Applicable
Requirements:	

See appendix C for the details.

4.1.3 Mechanical / Electrical

The solar optimisation, high-performance envelope, and natural lighting significantly reduce the mechanical loads.

The fresh air delivery system is structured around three vertical stacks handling fresh air, exhaust, and internal distribution. The stacks are designed to move high volumes of air at low pressure and velocity; wind effects at the roof level have been taken into account, further reducing energy required to operate the system. Displacement ventilation will provide fresh air by means of floor plenums throughout the occupied areas. Local ventilation controls will be provided along with operable windows. Fresh air will pass through a high-efficiency heat recovery ventilator.

Heating and cooling will be provided by a ground source heat pump system optimized with thermal reservoirs for balancing loads by time of day and building exposure. Incoming fresh air will be tempered as required with space heating and cooling provided through hydronic ceiling mounted radiant panels.

The objective for energy performance is a 70% improvement over the MNECB with a target total energy intensity of 100 kWh/m²/annum.

For the purpose of this study, the mechanical and electrical systems are considered the same for the four hypothetical buildings.

While considering envelope option #2, a change in mechanical requirements can be anticipated due to the decreased performance of the envelope. The impact of this change to the cost of the mechanical / electrical system goes beyond the scope of this study and is not considered.

Due to the similar concept of having an exposed structure, the same lighting strategy and systems is used in all hypothetical buildings.

4.1.4 Acoustics

For the purpose of this study, the same acoustic strategy and systems are used in all hypothetical buildings.

4.2 HYPOTHETICAL WOOD BUILDING

4.2.1 Structural Framing

The building contains a mix of structural materials, with concrete foundations, wood superstructure for gravity loads, and steel superstructure for lateral loads and cantilevers.

The building foundation is a 600mm-thick reinforced concrete raft slab one level below grade. Concrete walls and columns support a suspended reinforced concrete flat plate at the main floor, forming the basement of the building.

The superstructure consists primarily of a glulam post and beam structure with 6.1-meter spans in both directions. The floor structure consists of nail-laminated timber (NLT) floor panels sheeted with plywood. NLT panels were fabricated from solid dimensional lumber pieces placed on edge and nailed together, 38x184 (2x8) at the typical floors and 38x235 (2x10) at the green roof. The glulam columns, beams, and NLT soffits are exposed to view.

Figure 1: Schematic Framing Section shows a schematic floor section:

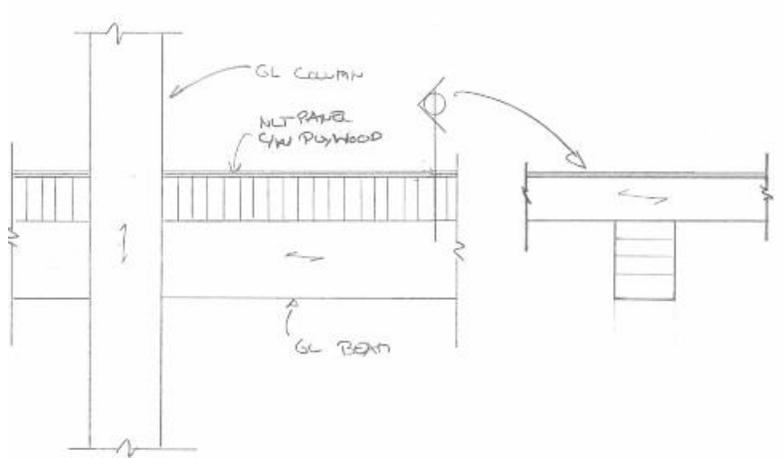


Figure 1: Schematic Framing Section

The seismic force resisting system (SFRS) consists of buckling-restrained braces (BRBs) within steel frames. These frames are mainly concentrated around the mechanical towers and stair cores, providing flexibility for the planning of interior spaces. The braced frames are tied to the lateral diaphragms using long steel plates that are fastened to the wood floor assemblies with threaded screws and welded to the steel frame columns.

4.2.2 Envelope

The building envelope is constructed of Structural Insulated Panels (SIP) with additional wood framing and mineral wool insulation in order to achieve an average R-value of 50. The exterior cladding is a combination of prefinished metal cladding, cementitious composite panels, and engineered cedar panels supported by a rain-screen system. On the upper floors the windows are highly efficient, triple glazed fibreglass windows, while the ground floor glazing is a thermally-broken, triple-glazed curtain wall. This represents a high performance assembly.

Figures below show the typical assembly:

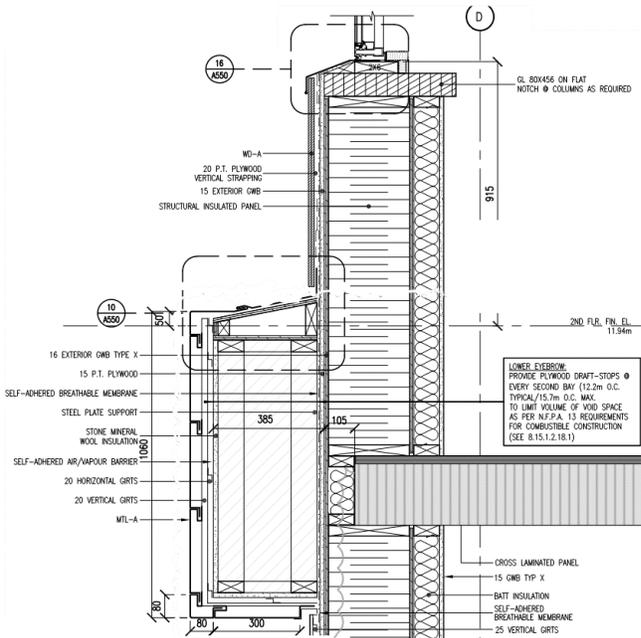


Figure 2: SIP Panel Envelope

There are two roofing systems on the building. The upper roof, which is not accessible by the public, is a highly reflective Thermoplastic PolyOlefin (TPO) roofing system on an average of R-70 insulation. The lower roofs are occupied and include a green roof system and paving stones on a modified bituminous membrane.

4.2.3 Building Code

This paragraph represents a summary from the Building Code Concepts Report by LMDG for the Hypothetical Wood Building, listing items relevant to this study only.

Overview

The Project will be 4 storeys in building height with 1 below-grade level, and will be fully interconnected. All reference numbers indicated in this report refer to Division B of the City of Vancouver Building By-law 2007 (VBBL), unless otherwise indicated.

Applicable Building Code:	Part: 3
Building Height:	4 storeys
Sprinkler required:	Yes
Major Occupancy:	Group D (Offices)
Construction Type:	Heavy Timber and Non-combustible
Interconnected Floor Space	Applicable
Requirements:	

Construction Type and Fire Rating of Structural Assemblies

The construction/structural fire protection and major occupancy requirements are summarized below:

- floor assemblies, including occupied roof decks required to be constructed as fire separations having a 1-hour fire-resistance rating (FRR),²
- heavy timber and noncombustible construction permitted,
- load-bearing walls and columns are required to have the same fire-resistance rating as the supported assembly, and
- fire-resistance rating is not required for unoccupied roof assemblies.

Interconnected Floor Space

The above-grade levels of the project, except for the multi-purpose room and photo lab area, will be interconnected via an open stair and a floor opening. The interconnected floor space requirements for this Project will include the following:

- the building will be constructed of heavy timber. The use of NLT wood panel floor assemblies will be demonstrated to be equivalent to or better than heavy timber construction having a minimum 1-hour fire-resistance rating, on an alternative solution basis.
- the building will have a sprinkler system throughout

Alternative Solution for NLT Floor

The construction requirements and interconnected floor space requirements for the project permits the building to be constructed with heavy timber. The Nail Laminated Timber (NLT) panels are considered heavy timber construction. A char rate analysis based on exposure to fire for 1-hour demonstrates the remaining thickness of load-carrying wood will support the loading conditions required under fire conditions. The top surface of the NLT panel are layered with a plywood diaphragm covered with a concrete topping or other noncombustible finish to provide noncombustible surfaces within the plenum space (raised floor).The provision of the noncombustible finish is required to create a noncombustible concealed space but has the added benefit of reducing heat transfer through the assembly, and therefore is an additional feature contributing to the overall fire resistance of the floor assembly.

² It is proposed to address the construction of the floor assemblies using Nail Laminated Timber (NLT) on alternative solution basis.

4.3 HYPOTHETICAL STEEL BUILDINGS

4.3.1 Structural Framing

The foundation consists of a raft slab, supporting a suspended two way concrete flat plate, forming the basement of the building (similar to the hypothetical wood building) The superstructure consist of a steel post and beam structure with composite steel deck on Open Web Steel Joists (OWSJ).

The Seismic Force Resisting System (SFRS) is provided by Buckling Restrained Braces (BRB). This represents the same SFRS used in the hypothetical wood building. See appendix A for structural drawings showing the structural steel framing.

Figure 3 shows a schematic floor section:

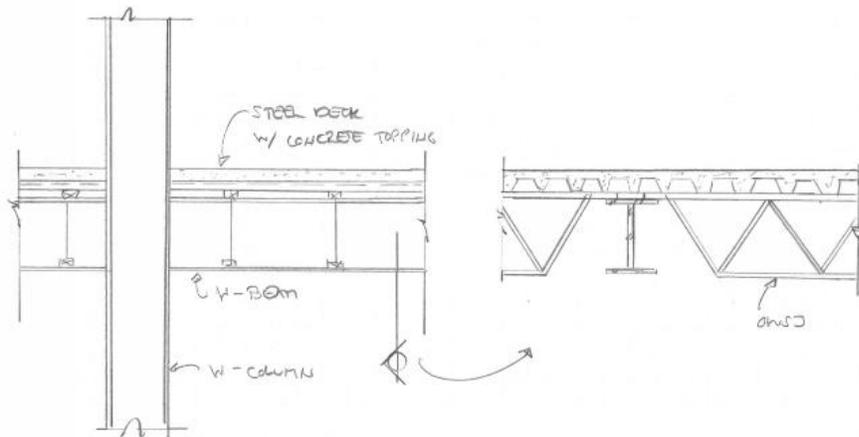


Figure 3: Schematic Framing Section

4.3.2 Envelope

For the purpose of the study, two envelope options are considered.

1. Steel Stud framing matching the thermal performance of the SIP panels as per above.
2. Steel Stud framing representing an industry standard in today's market place.

Envelope option 1 consists of 2 – 152mm steel stud walls with mineral wool insulation. The inner wall is bearing on the floor framing while the outer wall is continuous, thus minimizing the thermal heat loss. The required structural supports are located within the inner wall and connected to the edge of the deck framing.

Envelope option 2 consists of 1 – 152mm steel stud walls with mineral wool insulation, running past the edge of the steel deck, thus minimizing the thermal heat loss. The required structural supports are located within that wall and connected to the edge of the deck framing.

Figures below show the two assemblies:

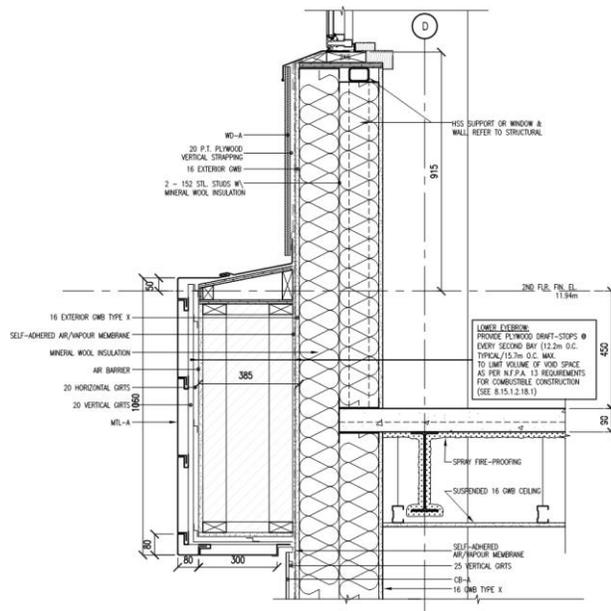


Figure 4: Envelope Option #1

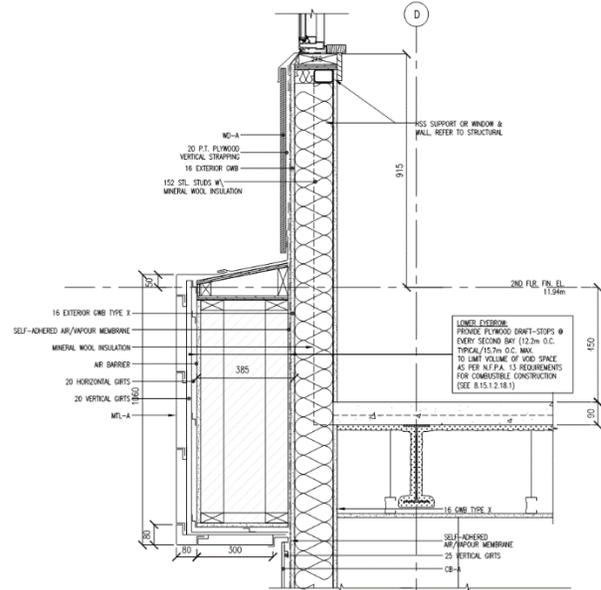


Figure 5: Envelope Option #2

The envelope requires different architectural & structural details for each building systems as well as for each option. See appendix A.

There are two roofing systems on the building. The upper roof, which is not accessible by the public, is a highly reflective TPO roofing system on an average of R-70 insulation. The lower roofs are occupied and include a green roof system and paving stones on a modified bituminous membrane.

4.3.3 Ceilings

A dropped ceiling is considered over the entire area to hide the spray-applied fireproofing.

4.3.4 Fire Rating

Method used to achieve floor assemblies with a 1-hour fire-resistance rating:

- Proprietary spray-applied fireproofing to structural steel floor assembly members (e.g., a commonly used steel floor assembly would consist of open-web steel joists with spray-applied fireproofing supporting metal decking with concrete topping).

Method used to achieve load bearing steel columns with a 1-hour fire-resistance rating:

- Proprietary spray-applied fireproofing or intumescent coating to steel columns applied in accordance with listings³.

In addition, the building is required to have a sprinkler system throughout.

³listed with ULC, cUL, Warnock-Hersey or other approved testing agency

4.3.5 Alternate Framing Option

In order to achieve a steel structure with a panelized floor system similar to the hypothetical wood building, an alternate steel framing option is considered.

This option would consist of the same foundation / basement concept as the hypothetical steel structure. The superstructure consist of a steel post and beam structure with 200mm precast hollow core panels with 75mm CIP topping. The stair, penthouse roof and other miscellaneous framing stays the same as per the first hypothetical steel structure.

Figure 6 shows a schematic floor section:

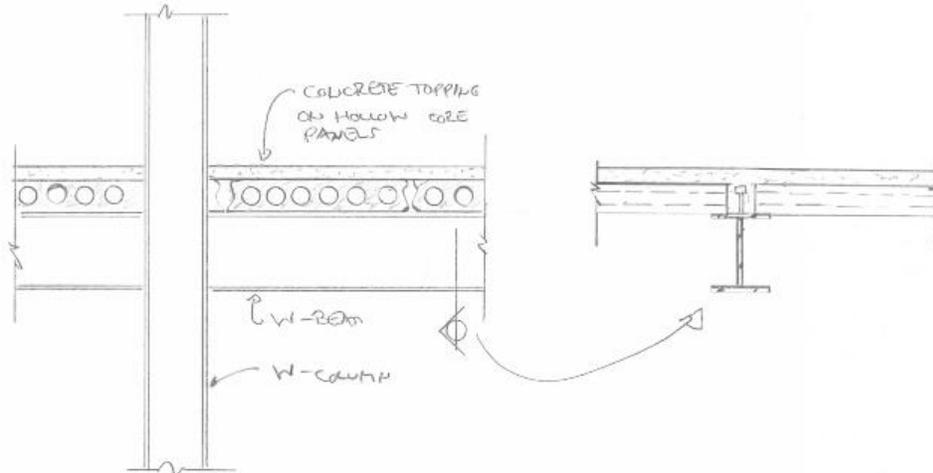


Figure 6: Schematic Framing Section

Regarding the SFRS, the capacity of the Buckling Restrained Braces (BRB) would have to increase by 50% and the steel columns around the braced frames would have to increase by one column size while keeping the same weight.

The fire rating for the floor panels is achieved with the inherent fire resistance of concrete. The panel joints are considered to be caulked and dropped ceilings are not required.

See appendix A for details.

4.4 HYPOTHETICAL REINFORCED CONCRETE BUILDING

4.4.1 Structural Framing

The foundation consists of a reinforced concrete raft slab, supporting 5 storeys of suspended two way concrete flat plates, supported by concrete columns and strategically placed concrete beams.

Figure 7 shows a schematic floor section:

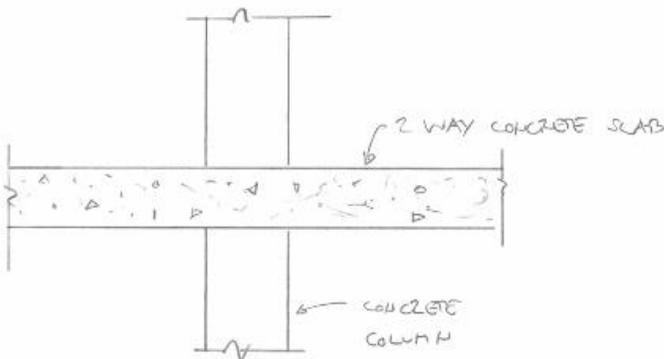


Figure 7: Schematic Framing Section

The Seismic Force Resisting System (SFRS) is provided by concrete shear walls. See appendix B for structural drawings showing the structural concrete framing.

4.4.2 Envelope

For the purpose of the study, two envelope options are considered.

1. Steel Stud framing matching the thermal performance of the SIP panels as per above.
2. Steel Stud framing representing an industry standard in today's market place.

Envelope option 1 consists of 2 – 152mm steel stud walls with mineral wool insulation. The inner wall is bearing on the concrete slab while the outer wall is continuous, thus minimizing the thermal heat loss. The required structural supports are located in the inner wall and connected to the concrete slab.

Envelope option 2 consists of 1 – 152mm steel stud walls with mineral wool insulation, running past the edge of the concrete slab, thus minimizing the thermal heat loss. The required structural supports are located within that wall and connected to the concrete slab edge.

Figures below show the two assemblies:

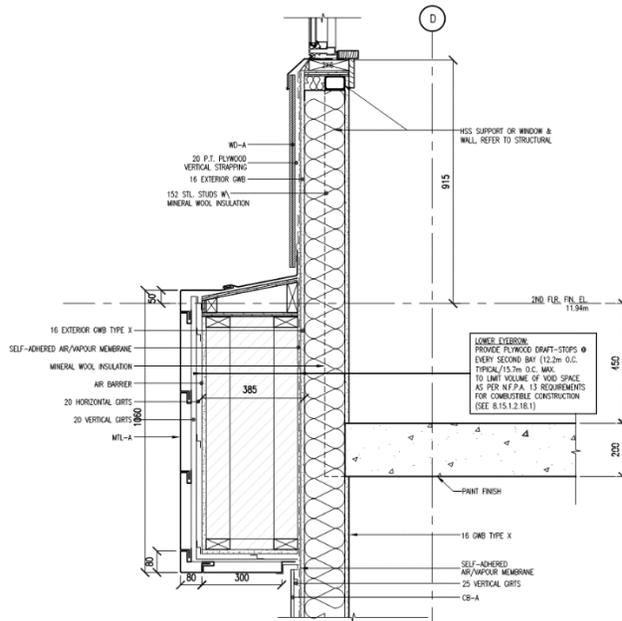


Figure 8: Envelope Option #1

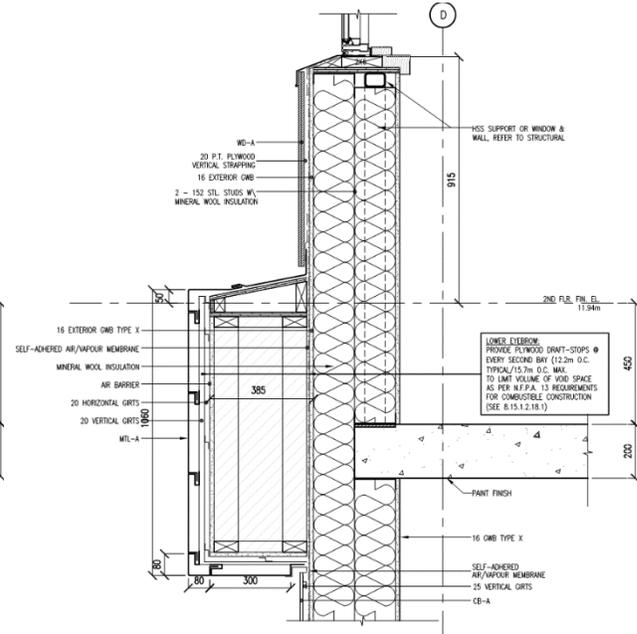


Figure 9: Envelope Option #2

See appendix B for architectural details.

There are two roofing systems on the building. The upper roof, which is not accessible by the public, is a highly reflective TPO roofing system on an average of R-70 insulation. The lower roofs are occupied and include a green roof system and paving stones on a modified bituminous membrane.

4.4.3 Ceilings

No dropped ceiling is considered, the concrete will be painted.

4.4.4 Fire Rating

Due to the inherent fire resistance of the reinforced concrete framing, no special considerations are required. The building is required to have a sprinkler system due to the interconnected spaces.

5 COST COMPARISON

5.1 ASSUMPTIONS

The cost for the hypothetical buildings is based on the Vancouver market condition at the time of the study. The cost for the hypothetical buildings was assembled through trade input as well as through in-house values from Ventana Construction Company. The cost provided by Ventana includes all items of work required to obtain a total building cost, meaning these buildings can be built - today – in Vancouver for that cost.

These items of work were summarized under the following categories:

- Foundation
- Superstructure
- Envelope
- M&E
- Interiors & Finishes
- Landscaping
- Soft Cost
- Rest

See Appendix C for a list of all items of work. The cost charts provided include envelope option #1.

5.2 COST OVERVIEW

5.2.1 Building Comparison

The total cost of the buildings is shown in Figure 10:



Figure 10: Cost Overview

Table 1: Building Cost Comparison

Building	Total Cost	\$ / ft ²	%
Hypothetical Wood Building	\$ 34,094,300	\$276	+ 1.0%
Hypothetical Steel Building w/ OWSJ	\$ 34,283,800	\$277	+ 1.5%
Hypothetical Steel Building w/ Hollow Core Panels	\$ 34,653,000	\$280	+ 2.5%
Hypothetical Concrete Building	\$ 33,755,500	\$273	-

In general, the total costs for the four hypothetical buildings are comparable. The total building cost is the highest for the hypothetical steel building using hollow core panels and the lowest for the hypothetical concrete building. The difference between the two is 2.5% only. The hypothetical steel building using OWSJ and the hypothetical wood building have a marginally higher cost than the hypothetical reinforced concrete building.

5.2.2 Hypothetical Wood Building

The cost summary of Hypothetical Wood Building is shown in Table 2:

Table 2: Cost Category Hypothetical Wood Building

Cost Category	Cost ⁴	%
Foundation	\$2,962,656	9%
Superstructure ⁵	\$5,474,570	16%
Envelope	\$5,756,617	17%
M&E	\$9,836,890	29%
Interiors & Finishes	\$4,762,607	14%
Landscaping	\$1,412,930	4%
Soft Cost	\$2,528,941	7%
Rest	\$1,359,064	4%
Total	\$34,094,274	100%

Figure 11 shows relative cost distribution for the given cost categories:

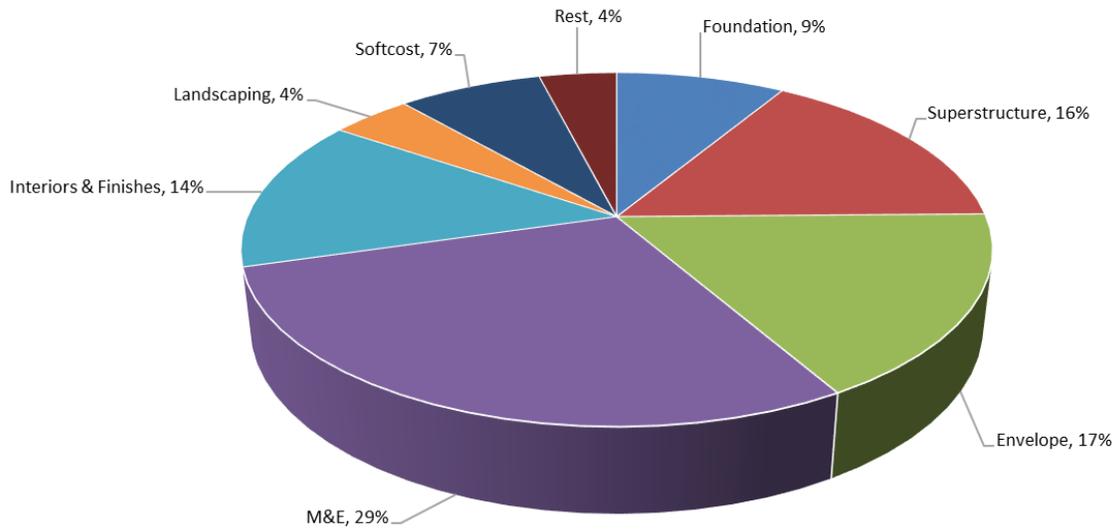


Figure 11: Cost Distribution Hypothetical Wood Building

⁴ Rounded Values

⁵ This cost for the hypothetical wood superstructure represents not only the mass timber scope, but also the Masonry, Structural Steel and other Structural Framing required.

5.2.3 Hypothetical Steel Building with Open Web Steel Joists

The cost summary of the Structural Steel Framing with Open Web Steel Joists is shown in Table 3.

Table 3: Cost Category Hypothetical Structural Steel Building with Open Web Steel Joists

Cost Category	Cost ⁶	%
Foundation	\$3,161,118	9%
Superstructure	\$4,311,565	13%
Envelope	\$5,756,617	17%
M&E	\$9,926,890	29%
Interiors & Finishes	\$5,685,457	17%
Landscaping	\$1,412,930	4%
Soft Cost	\$2,670,841	8%
Rest	\$1,359,064	4%
Total	\$34,284,482	100%

Figure 12 shows the relative cost distribution for the given cost categories:

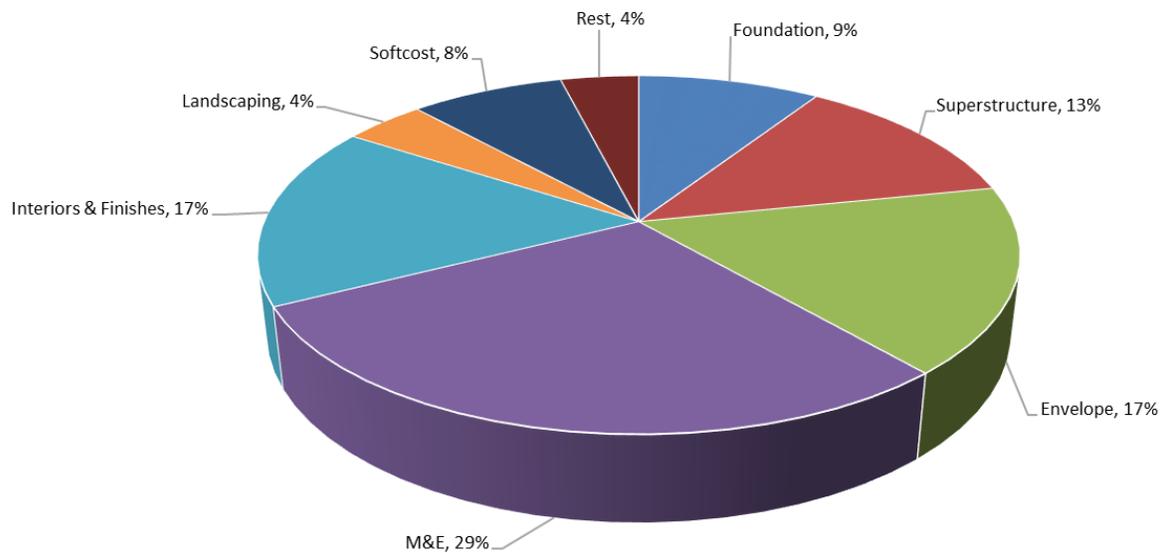


Figure 12: Cost Distribution Hypothetical Structural Steel Building with Open Web Steel Joists

⁶ Rounded Values

5.2.4 Hypothetical Steel Building with Hollow Core Panels

The cost summary of the Hypothetical Structural Steel Building with Hollow Core Panels is shown in Table 4.

Table 4: Cost Category Hypothetical Structural Steel Building with Hollow Core Panels

Cost Category	Cost ⁷	%
Foundation	\$3,161,118	9%
Superstructure	\$5,230,195	15%
Envelope	\$5,756,617	17%
M&E	\$9,926,890	29%
Interiors & Finishes	\$5,161,457	15%
Landscaping	\$1,412,930	4%
Soft Cost	\$2,645,041	8%
Rest	\$1,359,064	4%
Total	\$34,653,312	100%

Figure 13 shows the relative cost distribution for the given cost categories:

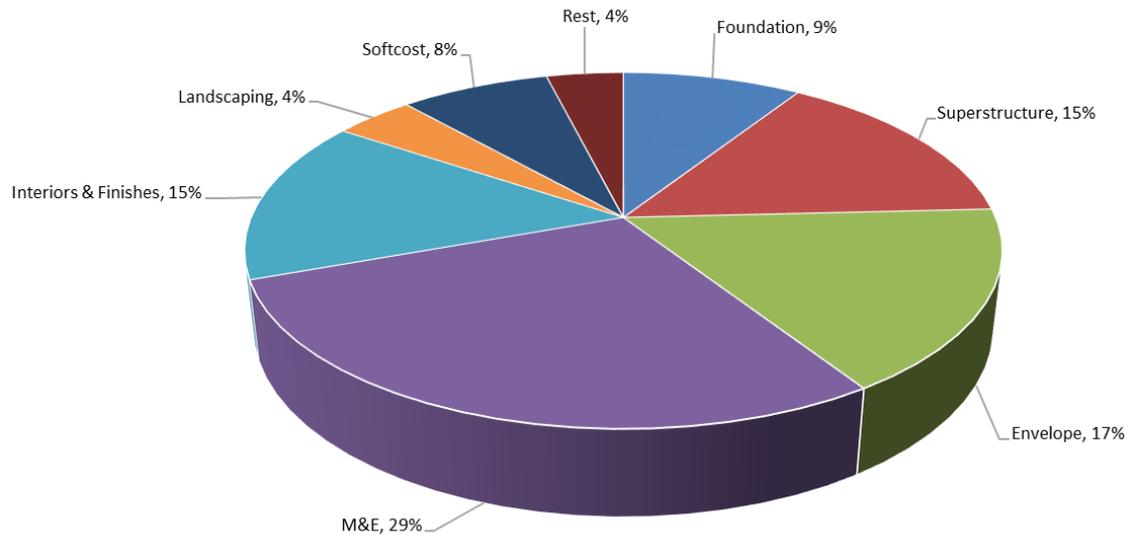


Figure 13: Cost Distribution Hypothetical Structural Steel Building with Hollow Core Panels

⁷ Rounded Values

5.2.5 Hypothetical Reinforced Concrete Building

The cost summary of the Reinforced Concrete Framing is shown in Table 5:

Table 5: Cost Category Hypothetical Reinforced Concrete Building

Cost Category	Cost ⁸	%
Foundation	\$3,404,654	10%
Superstructure	\$4,189,351	12%
Envelope	\$5,756,617	17%
M&E	\$9,926,890	29%
Interiors & Finishes	\$5,087,607	15%
Landscaping	\$1,412,930	4%
Soft Cost	\$2,619,241	8%
Rest	\$1,359,064	4%
Total	\$33,756,352	100%

Figure 14 shows the relative cost distribution for the given cost categories:

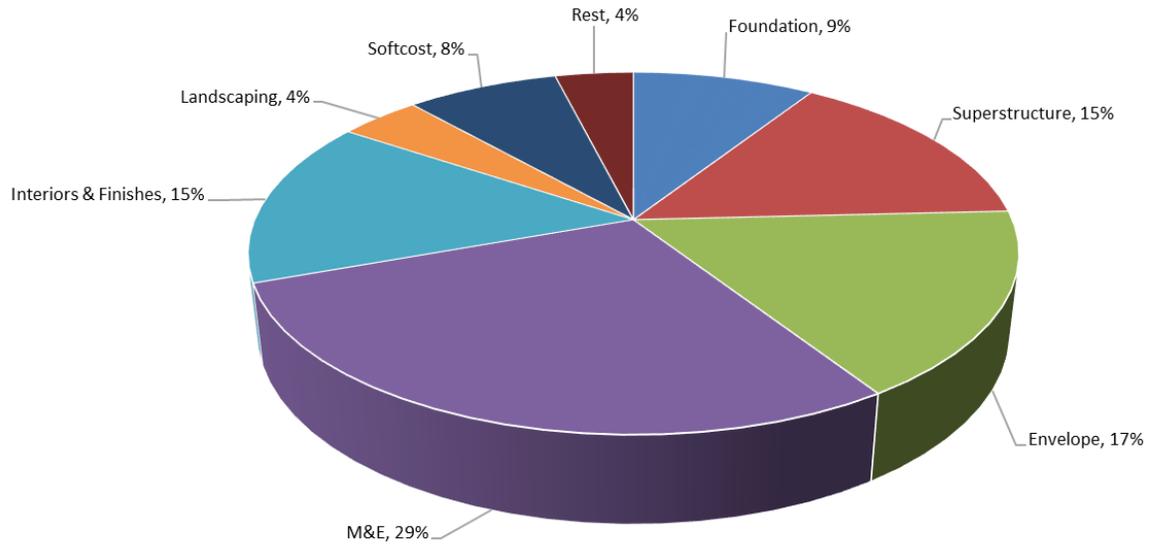


Figure 14: Cost Distribution Hypothetical Reinforced Concrete Building

⁸ Rounded Values

5.3 COST CATEGORIES

5.3.1 General

The cost categories shown are as identified under 5.1. If a category shows different costs for the different buildings considered, either primary and/or secondary impacts are the reason. Primary impacts are defined by the change in cost of structure itself, depending on which structural system is considered. Secondary impacts are defined as cost items (other than the structure itself) significantly impacted if the main structural system is changed. These are discussed in 5.4.

5.3.2 Cost of Foundation

Items of work included in the foundation cost are bulk & detailed excavation and all related concrete work.

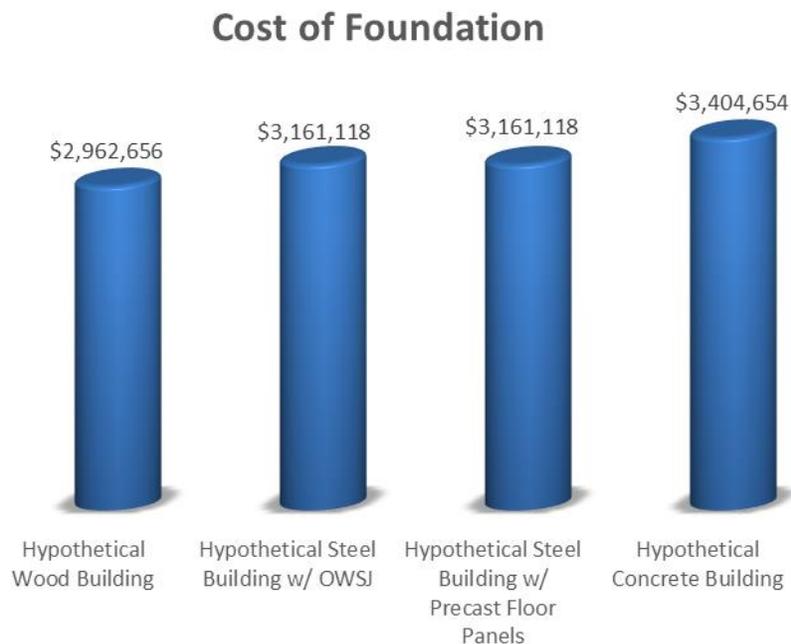


Figure 15: Cost of Foundation

The cost for the foundations is the highest for the reinforced concrete options. It is shown, that the cost of foundation increases with the increased weight of the structural framing. This is especially true with the given poor soils conditions. On another site with better soils, it can be anticipated that the difference would only be marginal.

In this category, no secondary impacts were identified.

5.3.3 Cost of Superstructure

Items of work included in the cost of superstructure are all structural items required, such as mass timber framing, structural steel, concrete including formwork and reinforcing, masonry as well as speed of construction.



Figure 16: Cost of Superstructure

The cost for the superstructure is the highest for the hypothetical wood building. The reinforced concrete option is the least expensive with the structural steel framing using open web steel joist (OWSJ) only marginally more expensive. The structural steel framing using hollow core panels is approximately 21% more expensive than the option using OWSJ, but 5% less expensive than the hypothetical wood building. The difference between the lowest and highest cost is 23%.

In this category, the schedule/speed of construction was identified as a secondary impact. See 5.4 for details.

5.3.4 Cost of Envelope

Items of work included in the cost of envelope are all items required, such as roofing, wall framing, glazing, water proofing etc.

The cost for the envelope of \$5,739,225 is the same amount for all four buildings considered. The costing shows, that the SIP system used is cost neutral compared to a steel stud assembly of equal thermal performance (option #1). If an industry standard system is used (option #2), cost savings of \$80,000 could be achieved. This is for the framing of the envelope only and does not include anticipated higher cost for the mechanical systems associated with the lower thermal performance of option #2.

In this category, no secondary impacts were identified.

5.3.5 Cost of Mechanical & Electrical

All items of work related to mechanical and electrical are included in this cost, including sprinklers. The total cost for mechanical and electrical is typically \$9,926,890. Cost savings of \$90,000 for the hypothetical wood building could be achieved due to easier installation of hangers (simple screws vs concrete anchors), drilling (wood drilling vs concrete coring) and scheduling advantages such as not requiring the mechanical or electrical trade to be on site during the installation of the structure (placing pipes & conduits in the concrete slab etc.).

5.3.6 Cost of Interiors & Finishes

Items of work included in the cost of interiors and finishes are millwork and finish carpentry, doors and hardware, drywall ceilings, painting, floors including access floor, interior windows and shades and spray fireproofing. For the comparison, it was assumed that the detailing of interior finishes has to match the quality and performance of the exposed wood elements.



Figure 17: Cost of Interiors and Finishes

The cost for the interiors and finishes is the highest for the structural steel framing using OWSJ. The Hypothetical Wood Building is the least expensive. The reinforced concrete option and the steel building using precast floor panels are in between and almost equal in cost.

In this category, the requirement for ceilings / drywall and fire proofing were identified as a secondary impact. See 5.4 for details.

5.3.7 Cost of Landscaping

All items of work related to landscaping are included in this cost.

The cost for landscaping of \$1,412,930 is the same amount for all four buildings considered.

In this category, no secondary impacts were identified.

5.3.8 Soft Cost

Items of work included in the soft cost are fees, general conditions, project management and insurance (Course of Construction and wrap up).



Figure 18: Soft Cost

The soft cost is the highest for the hypothetical steel building with OWSJ, with the other steel option and the reinforced concrete building close behind it. The hypothetical wood building is the least expensive.

In this category, the fees, project management (speed of construction) and cost of insurance were identified as a secondary impact. See 5.4 for details.

5.3.9 Rest

All items of work not covered in the cost categories above, such as site security, demolition, site services, elevators etc. are included in this cost.

This cost amounts to \$ \$1,359,064 and is the same amount for all four buildings considered.

In this category, no secondary impacts were identified.

5.4 SECONDARY IMPACTS

5.4.1 Speed of Construction

It is assumed that the builder will erect the mass timber structure in three vertical stages, meaning the floor plate would be divided into three approximately equal areas. The focus would be on completing the vertical structure to the roof in the first phase before moving on to the ground level of phase two. Based on that, the estimated construction times for the hypothetical buildings are:

Hypothetical Wood Building:	4.5 Months
Hypothetical Steel Building w/ OWSJ:	7 ¼ Months
Hypothetical Steel Building w/ Hollow Core	6 ¾ Months
Reinforced Concrete Structure	6 ¼ Months

The time frames given above are the times required onsite to erect the various structures, not just the actual time to erect the specific structural element.

Hypothetical Wood Building

As the mass timber structure is made up of pre-fabricated members and floor panels, it will result in a short installation time. A well-coordinated set of shop drawings is the key to achieve that level of performance.

Hypothetical Steel Building w/ OWSJ:

As the steel structure is made up of pre-fabricated members, it would take approximately the same time as the mass timber structure to physically erect on site. However, the additional time required to pour the concrete toppings to all the floors needs to be added. Additional time will be required to fireproof the underside of all of the steel structure and to clean up after the fireproof installation. In addition, additional time is required to add a ceiling finish and the associated work to accommodate that ceiling.

Hypothetical Steel Building w/ Hollow Core

This type of structure would add a small amount of time to the steel structure w/ OWSJ system because of the accommodation of an additional trade to install the hollow core flooring system, which will slow down the steel erection as the steel sub-trade would be unable to install all his steel all the way up to the roof. The steel sub-trade has to install one floor level then wait for the hollow core installation on that floor level before he can move up to the next floor level. However, in this scenario there is no need to fireproof the underside of the floor structure or add a drywall ceiling, which will save time in the overall construction schedule.

Reinforced Concrete Structure

The reinforced concrete structure would take longer than the hypothetical wood building because the concrete sub-contract would require additional time to site build his first set of forms for the first third of the floor plate. The extra time required to build the forms plus the extra time required to set the forms, place reinforcing steel and place electrical conduits on each level as you move the building would increase the time to complete this structural phase of work by approximately one and a quarter months compared to the Hypothetical Wood Building.

The figure below shows the estimated additional cost related for the elongated construction time for each building system considered. The values represent the cost occurring for a general contractor to operate the construction site.

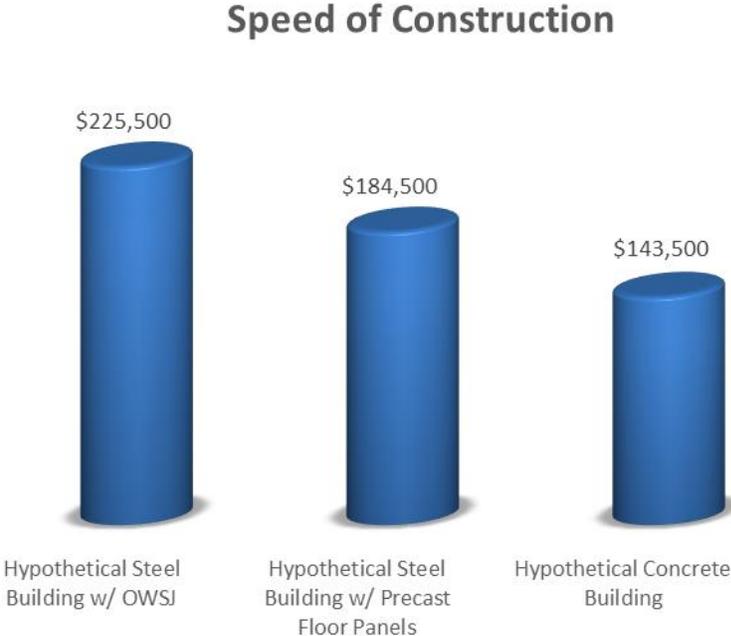


Figure 19: Speed of Construction

The estimated cost as shown above do not reflect other cost factors such as an earlier hand over to owner or the impact on capital cost.

5.4.2 Ceilings & Drywall

The different structural systems require different treatments regarding the finishes.

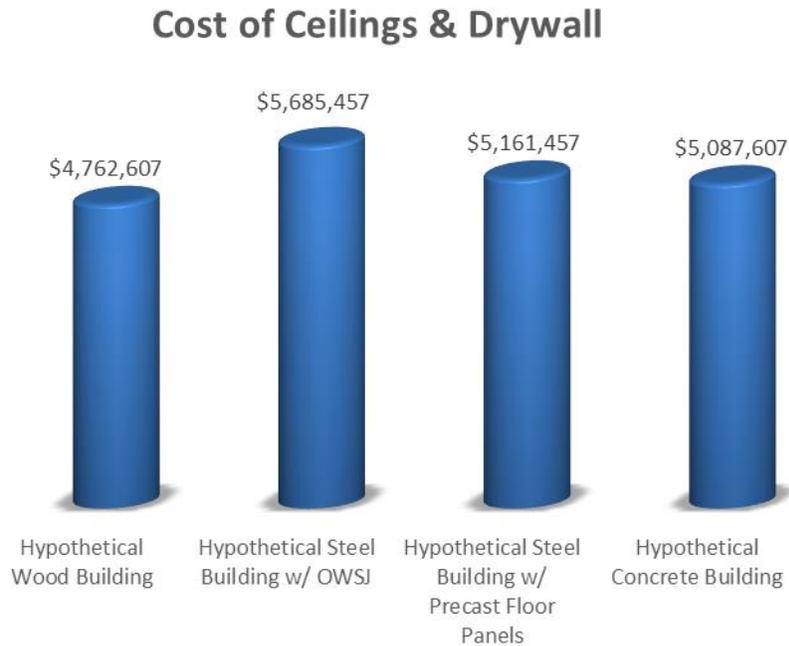


Figure 20: Cost of Ceilings & Drywall

The hypothetical structural steel option using open web steel joists (OWSJ) is the most expensive. The hypothetical wood building is the least expensive. The reinforced concrete option and the steel framing using hollow core panels are in between.

The steel option using OWSJ requires a dropped ceiling throughout to conceal the spray applied fire proofing. Further, the columns in both steel options as well as the concrete option are assumed to require cladding.

5.4.3 Fire Protection

Spray-Applied Fireproofing

Both structural steel options require spray fireproofing to achieve the required fire rating. The figure below shows the cost of fireproofing for these two options.



Figure 21: Cost of Spray Fireproofing

The difference in cost for these two options lays in the requirement for spray fireproof the floor framing using open web steel joist, which can be omitted at the option using hollow core panels. Due to the inherent fire resistance of concrete, the hollow core panels require fire rated caulking at the joints only.

That additional cost of \$236,000 and \$56,000 respectively does not occur at the hypothetical wood and concrete structures. See also 5.4.1, Speed of Construction for the impact on schedule related to the fireproofing of the structure.

Sprinkler

All buildings are required to have a sprinkler system since the building incorporates an interconnected floor space. The only difference in sprinkler cost between the hypothetical buildings would come from sub-trades being more familiar with one building systems over another. For the purpose of the study, the same cost was assumed for all hypothetical buildings.

If there was no interconnected floor space in the building and the building does not fall under the City of Vancouver Building By-Law (i.e. the building is located outside of the City of Vancouver), the steel and concrete (non-combustible) buildings could be permitted without a sprinkler system, provided the roof assemblies are required to have a 1-hour fire-resistance rating. This would represent a cost advantage over the hypothetical wood building for the non-combustible structures. Note, the cost saving in eliminating the sprinkler system is estimated to be in the order of \$290,000 for the given building layout outside of the City of Vancouver.

5.4.4 Insurance

In the current market place, the cost for course of construction (COC) and wrap up insurance is significantly higher for wood structures than for steel and reinforced concrete structures. The cost for insurance for a wood structure could be significantly higher than the cost of an equivalent steel or reinforced concrete structure. It is believed, that through negotiations and over time with a greater number of wood buildings constructed and performing well that the cost premium could be reduced. This additional cost needs to be accounted for on a project by project basis. Unfortunately there is no separation between traditional stick frame and heavy timber made, even though it is proven that heavy timber structures have a different behaviour under fire than stick frame. For the purpose of this analysis, insurance premiums have been kept the same for each hypothetical building.

5.5 DETAILED BREAKDOWN MASS TIMBER USED IN HYPOTHETICAL WOOD BUILDING

The cost summary of the detailed breakdown for the mass timber solution is shown in Table 6. This cost represents the mass timber scope only and does not include the foundations, masonry, structural steel, concrete toppings etc. The cost includes both material and labour.

Table 6: Cost Breakdown Mass Timber used in Hypothetical Wood Building

Cost Category	Cost ⁹	%
Columns	\$430,000	11%
Beams	\$630,000	16%
Floor Panels	\$1,176,000	31%
Floor Sheathing	\$200,200	5%
Wall Framing	\$192,000	5%
Misc Framing	\$407,000	11%
Miscellaneous	\$506,000	13%
Indirect Cost	\$290,218	8%
Total	\$3,831,418	100%

The total area considered is 123,460ft², which results in 31\$/ft² for the mass timber structure only. Figure 22 represents a relative cost distribution for the hypothetical wood building - wood superstructure only.

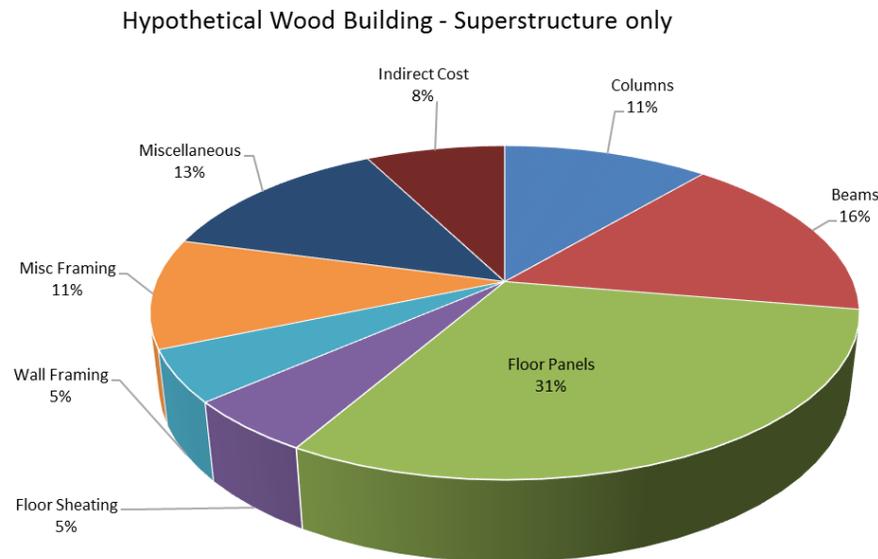


Figure 22: Hypothetical Wood Structure

Miscellaneous items include transportation, cranes, sundries, hoarding and clean up. The cost for the main structural members (columns, beams, floor & wall panels) makes up 63% of the total mass timber cost. The cost for material is approximately 68% of the total cost, where 24% go towards labour. 8% are indirect cost such as supervision, project management and worker benefits.

⁹ Rounded Values

The cost of a substantial weather protection strategy is not included in the cost provided. Further work from all different parties involved in the construction process is required in order to try and minimize this expense. Weather protection becomes increasingly important as timber buildings get taller and larger. It is estimated that the cost for tenting of the entire structure would be in the order of 10% of the cost of superstructure. A well planned strategy for weather protection can significantly reduce the related expenses and further enhance the speed and quality of construction – especially if the structural framing is left exposed in order to save cost on finishes.

It's estimated that approximately 1,881,000 fbm (equivalent of lumber, glulam and plywood) would be used to construct the hypothetical wood building. This equates to about 15 fbm per square foot GFA.

See Appendix D2 - Hypothetical Wood Building Cost Details.

6 HYPOTHETICAL WOOD BUILDING - ADDITIONAL CONSIDERATIONS

6.1 ALTERNATE FRAMING OPTIONS

6.1.1 Mass Timber

The hypothetical design was based Nail Laminated Timber (NLT) Panels. A possible alternative would be the use of Cross Laminated Timber (CLT). Typical panels would be seven-ply (239mm thick); nine-ply panels (309mm thick) were required at the green roof. In this design, the panels would also serve as the diaphragm for lateral loads, without an additional plywood layer, but more robust and costly than typical splices. It is expected, that the supply cost for the NLT floor would be less than the CLT option, but the CLT system is faster to install and could further reduce installation time and all cost associated with it.

The hypothetical design did not rely on CLT shear walls, as shear walls in general would not provide the required flexibility for the mechanical systems and required mechanical shafts employed in the design. If CLT walls would have been used, approximately 10 bays at 6.1 meters in each direction would have been required. The panel thickness would need to be seven-ply (239mm thick) at the base. The upper two floors could be five-ply (169mm thick) panels. No costing data is provided in this report for the above noted details.

6.1.2 Concrete

The use of cast in place (CIP) concrete shear walls was discussed in the hypothetical concrete structure. The use of precast (PC) concrete shear walls in combination with mass timber floors would be another option. The benefit of this option is in the reduced construction time required to install the walls compared to the CIP shear wall option. The walls themselves would have the same layout as in the hypothetical CIP structure. This option does however not provide the same ductility as the buckling-restrained braces (BRBs). Both of these systems are prefabricated and require approximately the same lead time. No costing data is provided in this report for the above noted details.

6.2 IMPORTANT LESSONS LEARNED

Based on the experience of the project team, the following items were identified as important lessons learned from this study:

1. Ideally the contractor and suppliers/installers are involved in the early stages of the design.
2. Weather protection strategy options during construction should be part of the design discussions. Large, flat areas have proven to be challenging regarding rain water management during construction. A weather protection strategy during construction is paramount.
3. Prefabrication is important to maintain an accelerated schedule. Coordination between consultants during the design is important to allow for a smooth prefabrication process. Site-built framing can considerably slow down the installation process.
4. The appropriate choice of the (mass) timber systems used should not only be driven by cost of the material itself. Supplier capacity, logistics, prefabrication, installation time, connection strategies, construction tolerances trade skill and system familiarity and acceptable / available industry standards should be factored in as well.
5. Pre-finishing of the wood products may not be the best suited as it is difficult for areas requiring touch ups to match the appearance of the original finish.
6. Ideally, the scaffolding rises at the same time as the timber structure to provide easy access for the building installation team.

These lessons learned provide valuable insight and will allow project teams to address them in future building projects with similar type of construction, further reducing the cost of such structures.

7 CONCLUSION

This study, Benchmarking Mass Timber, Structural Steel and Reinforced Concrete Building Solutions, concludes the first part of a suggested three part study.

The study showed the cost competitiveness of mass timber building systems compared to reinforced concrete and structural steel options under current Vancouver market conditions. The study showed that the total cost for all buildings systems considered is within 2.5%.

For the hypothetical wood building, the cost of foundation is the lowest and the cost of superstructure is the highest. -15% and +30% respectively compared to the hypothetical concrete option. Secondary impacts help to offset that additional net cost for mass timber building solutions.

In general, these secondary impacts favour the use of mass timber and help to offset the additional net cost for mass timber building solutions. By understanding the relation between a structural framing system and these secondary impacts, building designers can make an informed decision when considering the overall budget of a given project.

Weather protection can be a significant part of the cost of a mass timber build structure and it becomes increasingly important as timber buildings get taller and larger. A well planned strategy for weather protection can significantly reduce the related expenses and further enhance the speed and quality of construction – especially if the structural framing is left exposed in order to save cost on finishes (i.e. exposed structural surfaces)

Cost competitiveness of mass timber building systems can be further increased with early input from general contractors / construction managers, suppliers, timber installers and other sub-trades. That approach will achieve a material and system compatible design that fully respects the manufacturing, assembly, logistics and installation sequencing, therefore further reducing the total cost. This is in general true for any material, but it's amplified when using prefabricated elements which are typically found in mass timber systems.

It is understood, that the greatest cost efficiency can be achieved by using repetitive and simple construction systems and details. It is also understood that buildings with a strong architectural expression will in most cases create unique situations within the building structure. It is up to the designers involved, to find effective and efficient solutions by using repetitive and simple construction systems and details as much as possible.

8 NEXT STEPS & RECOMMENDATIONS

The study showed the cost competitiveness of a multi storey mass timber building systems. These building systems still have potential to be further refined and made more efficient from a design, supply, construction and most importantly, a cost perspective. This includes different procurement processes and the increased use of advanced design, engineering and construction solutions commonly summarized under Building Information Modeling (BIM).

Further, the study team is of the opinion that taller and larger building structures can safely be built using mass timber systems similar to the one used in the Hypothetical Wood Building. Further work regarding architectural and structural detailing, building code compliance, constructability and supply chain logistics is required to deliver such projects in a cost efficient way and with excellence.

The study team recommends that further analysis of mass timber buildings is carried out. One focus could be the framing itself. Comparing the different mass timber framing options will identify the most cost competitive system. Recommendations on how to best implement that specific framing system could then be developed to further help architects, engineers and builders.

The larger the buildings, the more important secondary impacts may become. Further work to better understand those impacts is required. One area of interest is the dependency on the size of project and if they are of the same magnitude for industrial and residential buildings. It is also recommended, to provide design aids that help designers to better understand those items and their impacts in order to make an informed decision when choosing building components used to construct a building.

The study team would be delighted to continue working with Canadian Wood Council and to provide specific proposals for the opportunities and recommendations identified in this report.

Kindest regards,

Fast + Epp

A handwritten signature in black ink, appearing to read 'B. Gafner', written in a cursive style.

Bernhard Gafner
P.Eng., MStructE, C.Eng., Dipl.Ing.FH/STV (Switzerland)