World Conference on Timber Engineering Oslo 2023

Case Study in the Next Generation of Point-Supported CLT Structures

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ABSTRACT: The new Tall Timber Student Housing tower in Burnaby, British Columbia at the British Columbia Institute of Technology (BCIT) represents a shift forward in tall, hybrid, encapsulated mass timber construction (EMTC). The tower comprises of flat, two-way spanning cross-laminated timber (CLT) floor plates, point-supported on hollow structural steel columns. The structure is encapsulated per the 2018 British Columbia Building Code and uses the latest advances in engineered wood products, prefabrication, and encapsulation strategies for fire resistance. The following case study provides an overview for the next generation of point-supported CLT structures, as encapsulated tall timber buildings, highlighting design challenges and their solutions.

KEYWORDS: Tall Wood Buildings, Mass Timber Encapsulation, Mass Timber, CLT, Point-supported CLT

1 INTRODUCTION

Until recently, timber construction was restricted in height due to limitations in stability and in fire resistance. However, recent advancements in engineered wood products, prefabrication, construction approaches, and codified encapsulation have led to a shift in these restrictions. These advancements include lessons learned in mitigating wood moisture during construction and shipping, and the prevalence of larger high-frequency presses that allow fabrication of wide-format cross laminated timber (CLT) panels beyond the traditional 3.0-metre (10'-0") width. As a result, delivery of mass timber projects has significantly improved. Better understanding of fire resistance in mass timber with use of encapsulation measures, alongside demonstration in precedent projects, has catalysed the use of mass timber in increasingly taller, EMTC-compliant hybrid buildings.

The TallWood House at the University of British Columbia in Vancouver, BC set the precedent for tall timber buildings. With 17 mass timber levels over 1 level of concrete podium above grade, TallWood House achieved a cost competitive alternative to the common concrete student residential tower. The mass timber superstructure comprised of two-way spanning CLT panels supported by glulam timber (GLT) columns; a point-supported CLT system. This flat slab system uses no beams, allowing for unobstructed service distribution. Thus, the need for significant penetrations through supporting structure is minimized, and allows for more compact floor-to-floor heights without sacrificing head room.

Early coordination and construction modelling allowed for an accelerated construction timeline, with the construction of the building completed 2 months ahead of schedule. This success demonstrated what is achievable in tall mass timber structures and that point-supported CLT is cost competitive system for tall-rise, multi-unit residential construction. Stemming from this success, the British Columbia Institute of Technology (BCIT) undertook the development of the Tall Timber Student Housing (BCIT Tall Timber Tower) as the latest tall-timber project incorporating a point-supported CLT floor structure. This project takes advantage of the latest advancements in product fabrication, as well as the new Encapsulated Mass Timber Construction (EMTC) [1] provisions in the National Building Code of Canada (NBCC 2020) [2], which provides a code compliant approach to tall timber using provisions for encapsulated mass timber. Using lessons learned from TallWood House, the BCIT Tall Timber Tower utilizes a wide format panel on hollow structural steel (HSS) columns that aim to further accelerate structural and construction schedule efficiencies. The following case study highlights the Tower's unique design challenges and the proposed solutions implemented to resolve those challenges that aim to make it the next generation in tall, hybrid, ETMC-compliant point-supported CLT structures.

2 CODES AND STANDARDS

BCIT Tall Timber is located in the province of British Columbia in Canada and is governed by the 2018 British Columbia Building Code (BCBC) [3], which was updated in 2019 to include the provisions for EMTC from the 2020 NBCC [2] for tall-rise timber buildings up to 12 storeys.

2.1 Code Compliance and Fire Design

BCBC 2018 Division B [3] classifies encapsulated mass timber construction up to 12 storeys. The Architectural Institute of British Columbia (AIBC) and the Engineers and Geoscientists of British Columbia (EGBC) jointly published the Joint Professional Practice Guidelines for EMTC [1], which include guidelines to the 2019 revisions to the BCBC requirements for minimum member sizes,

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https://doi.org/10.52202/069179-0550

fire rating requirements (FRR), and minimum thickness and extent of gypsum encapsulation of the wood. Under the 2018 BCBC Division B, EMTC is required to be at least partially encapsulated to ensure fire safety, with the structural system designed to achieve a 2-hour fire resistance rating through any combination of encapsulation and/or char. A typical encapsulated floor assembly that meets this fire resistance rating includes a build up of 38mm (1½") thick concrete topping over a mass timber floor panel and 2 layers of 12.7mm thick Type X gypsum board at the underside, which achieves a maximum 50-minute encapsulation rating; or 60 minutes, if the gypsum layers are directly applied to the CLT per a prescribed spacing according to CSA O86-19 [4]. See Figure 1 below. The remaining 60 or 70 minutes required to achieve a 2-hour fire resistance rating must be achieved through char on the underside of the CLT panel. The concrete topping provides the full 2-hour fire resistance rating at the top side of the floor assembly, as well as providing separation between floors.

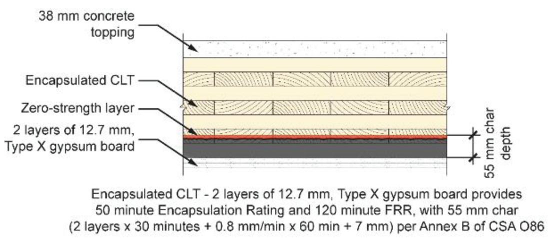

Figure 1: *Encapsulation of CLT from the Joint Professional Practice Guidelines published by AIBC and EGBC [1].*

The HSS columns must also be fire rated or encapsulated, and must meet a mass (M) to perimeter (D) ratio of 75 in conjunction with minimum 31.8mm of Type X gypsum board in order to provide a 2-hour fire resistance rating per Appendix D of the 2018 BCBC Division B. The minimum M/D ratios can control the design of the HSS column, where axial loads may be low.

2.2 Material Standards and Timber Design

The material standards for wood construction in Canada (CSA O86-19) [4] provides prescriptive approaches for the design of timber elements for typical gravity conditions, and for both exposed and encapsulated conditions in fire. Within the CSA wood material standard, guidance is provided on the bending capacity, stiffness, and fire design of CLT panels.

Unlike a post-and-beam system where panels are line-supported, a main consideration for point-supported system design is rolling shear at the column supports, similar to punching shear in a concrete flat slab system. Rolling shear in wood is defined when timber grains "roll over" each other under shear stresses perpendicular to grain. Rolling shear strength is much lower than longitudinal shear strength in timber. Testing shows that panel configuration and confinement at the supports result in added restraint against rolling shear, and thus, effectively increases the assumed rolling shear strength. However, low rolling shear strength values often result in rolling shear being a controlling factor. The punching shear resistance and reinforcing is not addressed in Canadian standards, and thus, research completed in Europe and Canada is used as a baseline for the punching shear evaluation [6,7], similar to the design of TallWood House [5]. Further desktop studies and physical testing [6,7] has also helped to justify values and methods that go beyond the codified CLT design approaches.

To design for resistance against rolling shear, strategies similar to those used for punching shear design in a concrete flat slab are available. This includes using larger supports at column locations to increase shear area, or using inclined fully-threaded screws to reinforce the CLT locally, similar to stud rails in a concrete slab. In general, however, reinforcing is avoided.

3 CASE STUDY OVERVIEW

BCIT Tall Timber Tower is a 22,800 m^2 12-storey building with 11 stories of encapsulated point-supported CLT floors over 1 level of concrete podium above grade and one level of basement below ground. The Tower will house 464 studio units in the upper stories; offices, student lounges, and storage will be contained within the ground and below-grade basement levels. Levels L2 through L6 contains single studio units with a common amenity room at the northwest corner and communal kitchens for residents. Above, at Levels L7 through L12, the same single studio units and common amenity rooms occur as they do in the floors below, but the communal kitchen areas are replaced with accessible studio apartments. See Figure 2 below for a typical architectural layout at the BCIT Tall Timber Tower.

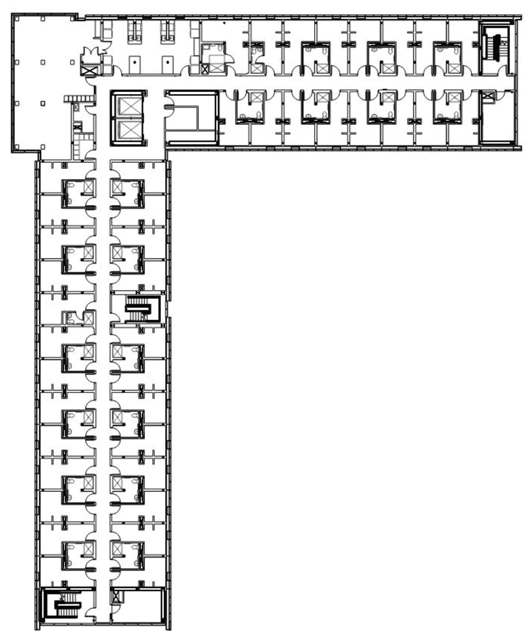

Figure 2: *Architectural Plan for BCIT Tall Timber Student Housing, Courtesy: Perkins&Will*

https://doi.org/10.52202/069179-0550

Given the consistent architectural layout at each floor, the CLT panel sizes are consistent throughout the majority of the typical floor plate. 3.5-metre (11'-6") wide CLT floor panels are supported by HSS columns at the edges and spaced at 4.5 metres across the building width along the length of the panel. The CLT panels are designed for two-way bending with consideration for punching shear, and are designed to develop a 2-hour fire resistance through 1 hour of effective encapsulation and 1-hour char in the panel. The use of steel columns simplifies the column-to-column connection, in comparison to the GLT column-to-column connection used at TallWood House, which minimizes fabrication time and adds speed to steel erection. The smaller HSS sections also allows for columns to occur within suite-to-suite party 152mm (6") deep steel stud walls that align with column grid spacing. This results in the use a of a standard party wall assembly. The lateral resisting system at the BCIT Tall Timber Tower consists of moderately ductile, concentrically braced frames above level L2 and concrete shear walls below level L2 down to the foundation. The braced frames are situated at the egress cores: at the northeast and southwest "bookends", the central elevator and service room core, and the central stair core. Like the typical HSS columns, braced frame columns are encapsulated within the walls, and anchor down into the concrete shear walls that support them with anchor bars continuing down to foundations from level L2. See Figure 3 below for a 3D rendering of the structural framing for the building.

4 KEY DETAILS

The design at BCIT Tall Timber Tower takes advantage of opportunities in wood technology, updated provisions in the building code for encapsulation, and lessons learnt from TallWood House, representing the next generation in point-supported CLT. It optimizes efficient panel design and utilizes added benefits in use of a hybrid design by way of the HSS columns and steel braced frame lateral resisting system. The success of these improvements to TallWood House further underline mass timber's viability in cost and constructability against the more conventional concrete tower residential construction.

4.1 CLT Layup

CLT panels for BCIT Tall Timber Tower consist of 5 total layers of machine stress-rated (MSR) and visually graded lumber interlaced to provide adequate bending resistance and stiffness in two directions. To reduce the number of columns and maximize the CLT span in the strong axis, MSR grade lumber is specified for the primary (outer) layers for increased bending resistance and stiffness. Weak axis bending is significant for point supported CLT, and due to the large panel width, a minimum of No.1/No. 2 visually graded lumber is required in the weak direction. Figure 4 below summarizes the layers used. At the time of design, most North American CLT manufacturers only

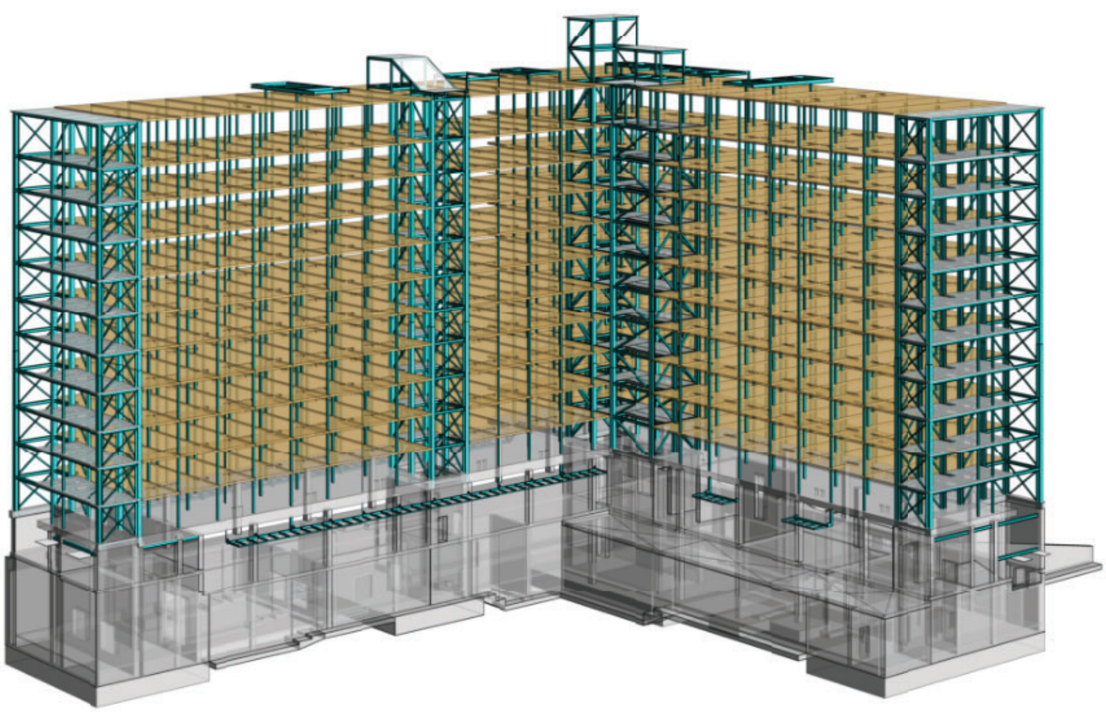

Figure 3: *A 3D rendering of the structural elements for BCIT Tall Timber Student Housing*

provided No.3 laminations in the weak axis, and therefore a custom CLT panel was required.

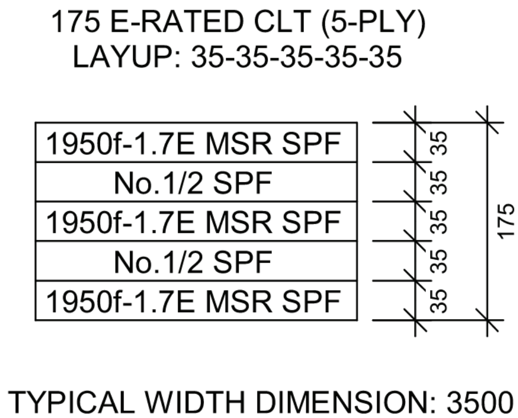

Figure 4: *CLT Panel Layup, BCIT Tall Timber Student Housing*

4.2 CLT Floor Panel Layout

As mentioned previously, the architectural layout lends to an efficient CLT panel layout. Each studio bedroom unit is sized to a maximum 3.5-metre width (see Figure 2), which aligns with the maximum width available for a CLT panel currently available in North America. The depth of the building, governed by the depth of two studio units plus the corridor width, is also sized to be within a maximum CLT panel length. This setup, in which the architectural layout aligns with maximum CLT panel dimensions, means that panel supports can align within suite-to-suite party walls. The CLT panel design is designed to maximize the spacing of HSS supports, in order to further minimize the number of column lines across the building depth. This leads to minimization on overall steel material. The shared washrooms and service risers were located to avoid spatial conflict with columns and reduce openings near column supports. See Figure 5 for the CLT floor panel layout.

More importantly, the architectural layout allows one CLT panel length to be the width of the building, which leads to efficiencies in panel press fabrication and installation. The construction schedule currently shows that each floor level will be erected in one week. At 22,800 m^2, the BCIT Tall Timber Tower is 2x the building area as Tall Wood House, which also erected 1 floor per week during construction. Therefore, BCIT Tall Timber Tower will aim to accelerate construction by a factor of 2 in comparison to that of TallWood House.

Shipping is a primary challenge of utilizing a wide format CLT panel at a maximum length of 12.8 metres. The traditional 2.3- and 3.0-metre wide CLT panel dimensions allow for panels to be shipped within a sea container from Europe or trucked in from outside of the province. Therefore, without a local plant with wide-format press capabilities, the viability of a wide format is limiting. However, the opening of a new CLT plant in the Kootenay Region, an area just east of Metro Vancouver where BCIT Tall Timber Tower is located, made the wide-format CLT panel dimensions viable from a procurement and cost perspective. While this has limited the number of manufacturers that could competitively tender the project, the key stakeholders, specifically BCIT, were willing to take advantage of the benefits of the wide format panels for the project.

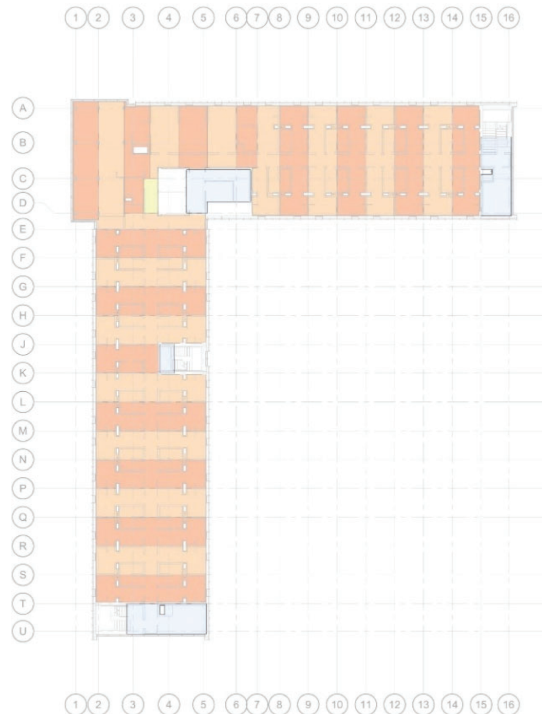

Figure 5: *CLT Panel Layout, BCIT Tall Timber Student Housing*

4.3 HSS Column Supports

HSS columns are sized as 127mm x 127mm square typically, with larger rectangular sizes, as required by increased axial forces at the lower stories. The size limitation is aimed so that the columns can occur within a standard 152mm deep steel stud party wall between units. Columns are then kept to within walls only, at least for the typical residential layouts, and allows for a higher net-to-gross floor space ratio, which is key to maximizing occupiable space, a benefit particularly for developers.

Column lines are then fully encapsulated within the fire-rated demising walls,. and take advantage of the encapsulation already required by BCBC 2018. Added Type X gypsum layers are included to provide the steel column its required fire resistance rating.

Steel columns require a mass to perimeter dimension (M/D) ratio, as required by BCBC 2018 [3], to meet EMTC and fire resistance ratings. Sizing of the HSS column thicknesses, specifically at the smaller plan dimension sizes that were targeted so that the columns can fit within demising walls, is therefore governed by this M/D ratio at the upper stories that contain lower axial

 https://doi.org/10.52202/069179-0550

loads. This leads to oversized column weights where not required by structural loading.

To balance this, further analysis and specification of the encapsulation strategy, as shown in Figure 6, were included as part of an alternative solution proposed by GHL Consultants. Within an encapsulated wall, the HSS column perimeter, D, can be considered to only be the sum of column dimensions parallel to the wall length, as long as additional layers of Type X gypsum board are applied to the perpendicular dimensions. This refinement results in a higher M/D ratios for columns, well above the code requirements, which then allows for reduction in column weights, M, where axial loads are low, or at the upper stories.

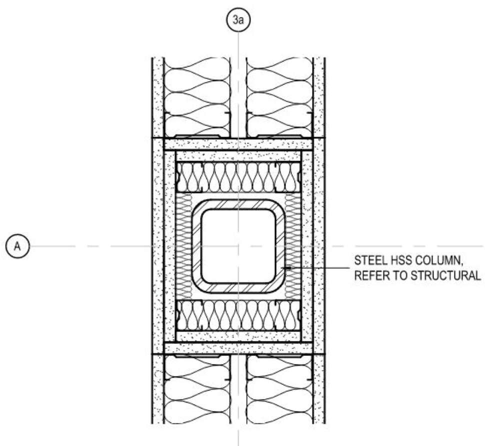

Figure 6: *In-wall Encapsulation of the Steel HSS Columns at BCIT Tall Timber Student Housing, Courtesy: Perkins&Will*

For HSS columns encapsulated outside of walls all four sides of the column are considered for the variable D. These columns are a small percentage of the overall number of columns across the building. Therefore, the cost increase for added weight in these columns is not as significant as the added weight for all of the columns to meet fire resistance requirements.

The lower weight not only reduces material, but also reduces weight and lifting effort required to erect the columns on site. Installation of the glued-laminated columns at TallWood House was celebrated for being so light-weight that 4 installers could lift each column without use of a crane. In the aim to achieve a similar ease of construction, BCIT Tall Timber Tower also anticipates a similar strategy for the column installation by maintaining lighter column weights wherever possible.

4.4 Column-to-Column Connection

The column-to-panel connection comprises of a flat bearing plate that supports the CLT floor and receives the column for the floor above, using a telescopic detail to position and lock in the column above. The 25mm-thick bearing plate is sized to provide vertical stiffness to the connection, as well as sufficient bearing capacity for the CLT panel (See Figure 7). The connection detail accommodates a direct transfer of axial forces between columns and eliminates perpendicular-to-grain bearing issues that might otherwise limit the CLT panel capacity. Shrinkage is a common issue in wood and mass timber buildings, specifically in wood bearing wall and post-and-beam configurations, but this detail also limits the effect of shrinkage and eliminates cumulative shrinkage over the height of the building. Likewise, by using steel column everywhere, including the lateral resisting system, any axial shortening that might be expected in wood columns due to axial load and shrinkage, as well as any differential deformation, is avoided. If wood and steel columns are desired to be used in conjunction on any given floor, shrinkage and any differential deformation is an important consideration.

The detail provides simplicity in design and construction. Once the supporting HSS columns are erected, the CLT panels can be directly dropped in place. Vertical bolts dapped into four corners of the bearing plate are used to position the CLT panel during install with oversized holes through the CLT to allow for tolerance. Then, the HSS column above is lowered into place and bolted to the telescope, and rods through the CLT are then fastened to the CLT with a top plate at the column, providing a nominal panel-to-panel connection. Installation of this detail in the field is simple and provides accuracy, and thus accelerates construction schedule.

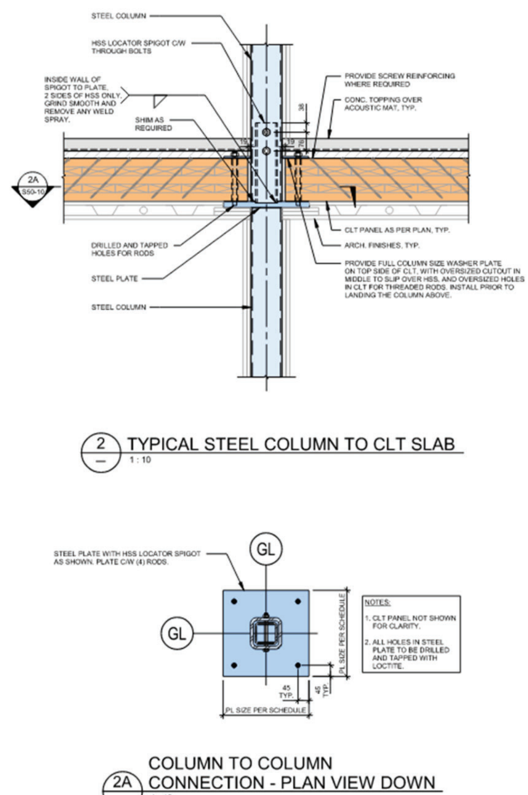

Figure 7: *Structural Column-to-Column Detail for Point-Supported CLT at BCIT Tall Timber Student Housing*

4.5 EMTC Compliant

The CLT floor assembly comprises of a 50mm concrete topping over an acoustic mat, the 175mm thick 5-ply CLT panel, and two layers of 16mm thick Type X gypsum board. The two layers of gypsum are directly attached to the underside of the CLT panel, using provisions listed in CSA 086-19 Annex B [4]. According to the BCBC 2018 Division B [3] provisions and the EMTC Guidelines [1], this assembly is code compliant.

Figure 8 illustrates the gypsum layers where they intersect at the HSS columns and the bearing plate. Careful consideration was given to encapsulation of the steel bearing plate at the HSS columns. Where dapping the bearing plate into the underside of the CLT panels would have eased installation of the encapsulating layers, this would have added considerable time and effort in the shop. Each panel, after pressing, would have been required to be flipped and run through the computer-numerical control (CNC) machine to router the recess for the plate. Additionally, a reduction in CLT panel thickness at the column locations, where shear is highest, would have resulted in added shear reinforcing near the corridors. It was determined that this effort impact plus the addition of screw reinforcing outweighed the install effort of the gypsum layers, and therefore, the following detail was maintained as a result.

Within the single bedroom and studio suites, however, this detail changes slightly to allow for a 25mm deep hat track. This was done to allow for small electrical and communications conduit in a minimal dropped ceiling over the bedroom areas. Despite this slight change, the two layers of 16mm Type X gypsum are still present and are ultimately attached to the CLT, as per CSA O86-19 Annex B. Therefore, the system is still considered to be fully encapsulated under the BCBC 2018 Division B provisions.

Along with the HSS encapsulation strategy as discussed in the previous section, floor assemblies are EMTC compliant

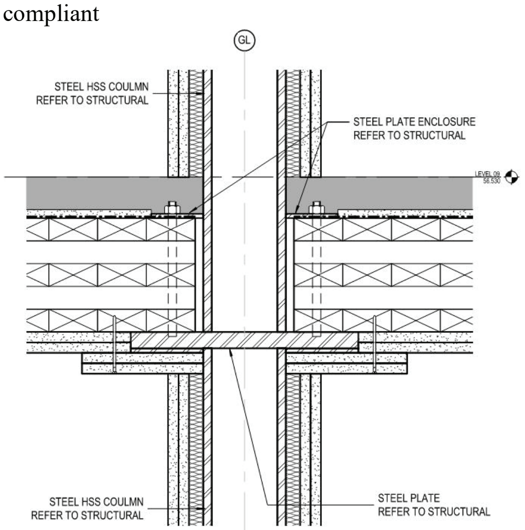

Figure 8: *A Typical CLT floor assembly with encapsulation, Courtesy: Perkins&Will*

4.6 Steel Lateral Resisting System

A moderately ductile, steel concentrically braced frame lateral resisting system is utilized at BCIT Tall Timber Tower, see Figure 9. The steel braced frames occur from the L2 concrete podium slab to the roof level. The is laid out to provide lateral resisting redundancy in both orthogonal directions, while seamlessly integrating the lateral resisting system within cores required for egress.

By placing the braces at the cores, location and frequency of the braced frames limit the mass timber diaphragm span lengths, and therefore diaphragm shear demands. Most importantly, taking advantage of the cores also results in cores that are self-stabilizing during construction, similar to a concrete tower. This significantly reduces the need for temporary bracing of the braced frames during construction.

A steel braced frame lateral resisting system was promoted due to its benefits in construction schedule over a concrete lateral resisting core that extends completely to the roof level. The steel frame is proposed to be completely erected from top of concrete podium at level L2 to the roof before the installation of any CLT floors. The self-stabilizing cores further bolster this strategy. Additionally, up to six levels of the steel frame are proposed to be prefabricated and lifted as one piece, which further limits crane picks and time on site. As a result, this strategy avoids trade overlap and crane sharing, and accelerates construction efficiency.

The concrete shear walls align with the steel braced frames to transfer loads down to foundations below L2. Additional walls added at L1 and at B1 ensure significant added stiffness below the steel braced frame system. The concrete podium lateral resisting shear walls are designed to the capacity of the steel braced frames above. The additional concrete walls further ensure added stiffness below L2 to allow for a two-stage lateral analysis of the structure. Due to the added stiffness of the concrete shear walls in comparison to the steel braced frames above, a two-stage analysis was considered for overall design of the lateral resisting system.

The transition between a concrete shear wall system and a steel braced frame system comes with complications. Balancing a base plate with anchor bolt design that can provide sufficient uplift capacity while still maintaining a reasonable concrete core wall thickness, not greater than 600mm, was a challenge. Another challenge was finding a braced frame layout configuration that allowed for necessary access to the stair and elevator cores. However, the lighter weight of the steel braced frame structure, as well as its capabilities for prefabrication over a concrete jump-forming system to accelerate the construction schedule, far outweigh the benefits of maintaining a consistent concrete core shear wall system from foundation level to roof level.

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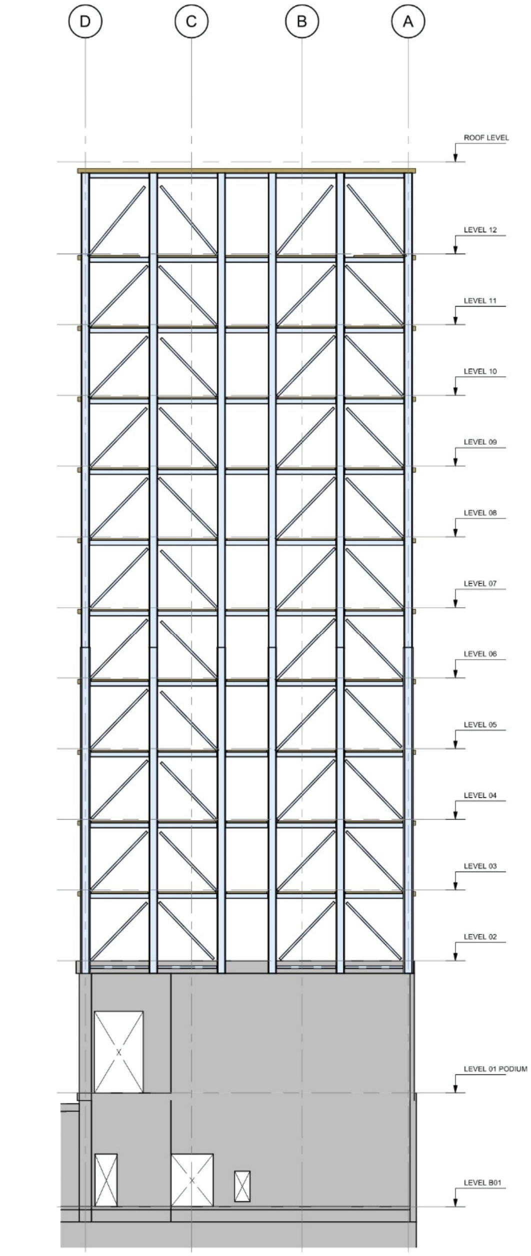

Figure 9: *Steel concentrically braced frames over concrete shear walls, BCIT Tall Timber Student Housing*

5 CONCLUSIONS

The use of point-supported CLT offers benefits to construction, architecture, and building services. The latest point-supported CLT projects, such as the BCIT Tall Timber Tower, showcase updated advances in wood products. The introduction of new mass timber suppliers in BC has resulted in cost and procurement viability for wider panels to allow column grid spacing that aligns with architectural layout. Recent research and lessons learned has further developed the point-supported design approach, pushing for use of wider panel sizes and longer spans that maximize panel layout efficiency and construction. Industry acceptance of encapsulation assemblies to resist fire have also progressed, now codified into both Canadian national and provincial building code provisions. Codification particularly has minimized the need for a peer review, as was done with Tallwood, smoothing the path to acceptance of the project overall, and has allowed for partial encapsulation to reduce the number of Type X gypsum layers to achieve sufficient encapsulation resistance.

The design of the BCIT Tall Timber Tower takes full advantage of the technological advancements in wood and fire design. In particular, mass timber panel and steel braced frame prefabrication is utilized in such a way to minimize construction time. While this might increase costs upfront, by requiring pre-planning and more work in the shop for prefabrication, the benefits outweigh the cost in quality control within a more protected environment, and lower construction tolerances in the field, and thus less construction waste. As was observed at TallWood, this upfront cost for prefabrication and the early coordination that it requires, pays dividends in construction.

More importantly, BCIT Tall Timber and the details at which it employs, underline that encapsulated mass timber construction up to 12 storeys is not only achievable, but a true cost competitor to a more typical concrete tower construction. It should also be noted that by going to mass timber construction, it does not mean that the whole system must be purely comprised of mass timber. BCIT Tall Timber capitalizes on a hybrid structure to maximize the timber product that is most effective by volume and weight; in this case, the CLT floor panels. By using details that are intentional to the EMTC provisions, while employing mass timber to its maximum benefit, BCIT Tall Timber Tower is the next generation of tall, hybrid, CLT point-supported structures.

ACKNOWLEDGEMENT

The Authors would like to thank British Columbia Institute of Technology, whose campus at the City of Burnaby will be home to the Tall Timber Student Housing Tower; to Perkins&Will, the Architect of Record; and to GHL Consultants, the building code consultants and fire design engineers for the project.

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