CASE STUDY: AN 18-STOREY TALL MASS TIMBER HYBRID STUDENT RESIDENCE AT THE UNIVERSITY OF BRITISH COLUMBIA

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Figure 1: *Brock Commons at the University of British Columbia – the world's tallest wood building. Courtesy of Seagate Structures.*

1 INTRODUCTION

Brock Commons is an 18-storey mass timber hybrid student residence currently under construction at the University of British Columbia in Vancouver, Canada. When completed in the summer of 2017, it will be the tallest mass timber hybrid building in the world, reaching 53m (Fig. 1). Fast + Epp structural engineers have been working in conjunction with Acton Ostry Architects and Hermann Kaufmann Architekten. The total project cost inclusive of fees, permits etc. is $51.5M.

Brock Commons is comprised of 17 storeys of five-ply cross laminated timber (CLT) floor panels and glue laminated columns, a concrete transfer slab at level two and a steel framed roof. The CLT panels are point supported on glulam columns at a 2.85m X 4.0m grid. Beams were eliminated from the design by utilizing CLT's two-way spanning capabilities and two full-height concrete cores provide lateral stability. Building renderings can be seen in Fig. 2.

2 PROJECT BACKGROUND

The University of British Columbia (UBC) is committed to a sustainable campus that acts as a "Living Laboratory" where innovation is encouraged, not only in academia, but also in building and infrastructure. In recent years, UBC has experienced an increasing demand for student housing. Pairing these two motivators with the opportunity for external funding related to mass timber research, the project was

Figure 2: *Brock Commons Renderings. Courtesy of Acton Ostry Architects and the University of British Columbia.*

born.

Key goals were to create a safe, functional, sustainable and cost effective residence for UBC students. Moreover, it was crucial to deliver a mass timber building with a construction cost that would align with the unit cost of a comparable traditional concrete tower in Vancouver, to demonstrate the viability of wood as practical material for tall building applications.

To facilitate this effort, an integrated design team was assembled by UBC Properties Trust. A construction manager was appointed and the timber installer and concrete trades joined the team in a design-assist role, providing real-time feedback on the evolving structural design and offering valuable constructability advice.

With an aggressive budget and timeline in mind, construction commenced in November 2015, just 11 months after the design team was assembled.

3 STRUCTURAL CONCEPT

The design intent was to keep the structure simple and sensible: develop a prefabricated “kit-of-parts” that could be quickly and easily installed with minimal labour on site. Materials were used where they made the most sense, rather than maintaining a strict wood-only approach.

CLT is quite often used as a one-way decking system, ignoring the two-way spanning capability afforded by its cross laminations. By utilizing CLT to span in both directions, the design team was able to eliminate beams and significantly reduce the overall structural depth. This created a clean, flat, point-supported surface which allowed for unobstructed service distribution, as is commonly found in flat-plate concrete construction. Further, by adjusting the column grid and architectural program to suit the maximum available panel size, the team was able to both minimize the overall number of panels (and therefore the number of crane picks), maximize structural efficiency and reduce waste.

The primary lateral support for earthquake and wind loading is provided by two concrete cores. Although timber-based lateral force-resisting systems such as CLT walls/cores, timber braced frames, or post-tensioned/self-centering systems were feasible design options for this project, the testing, time and costs required to obtain regulatory approvals would have negatively impacted the client’s budget and desired completion date (Fig. 3).

4 DESIGN CHALLENGES

Like any project with this level of innovation, there were several key design challenges that needed to be worked through:

4.1 Codes and Standards

The current British Columbia Building Code (BCBC 2012) limits the height of wood buildings to six storeys. As such, a special approvals process was required for this project. The design was based on a Site Specific Regulation (SSR), administered by the Building Safety

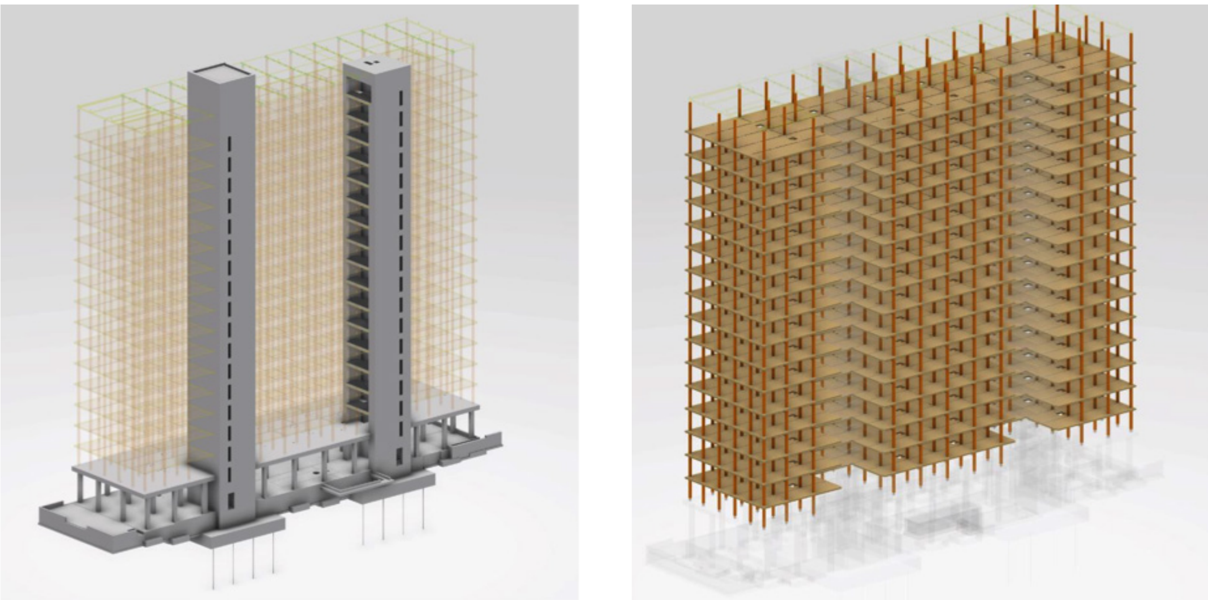

Figure 3: *Concrete cores and timber elements. Courtesy of CadMakers.*

and Standards Branch of the BC Provincial Government and was solely applicable to this project and site.

One specific requirement of the SSR was that the building be designed according to the not-yet-adopted 2015 National Building Code of Canada (NBCC) rather than the prevailing BCBC 2012. The main impact of this requirement was an increase in the applicable seismic acceleration values, approximately 50% higher than those associated with the current code.

Due to the novelty of the structural concept, two independent structural peer reviews were also completed. The first independent review was timber focused and was completed by Merz Kley Partner ZT GmbH in Dornbirn, Austria. The second was carried out by Vancouver-based Read Jones Christoffersen Consulting Engineers.

4.2 Prefabrication

Prefabrication is an essential consideration when designing large scale wood structures. Well-planned erection and shop drawings were key to ensuring smooth production and installation of the timber elements for Brock Commons, to ensure fewer errors on site, less remedial work and a shorter overall construction schedule. All CLT and glulam elements were CNC machined with quality control protocols to better ensure seamless erection of the timber superstructure.

To achieve a high level of prefabrication for all design disciplines, CadMakers (a third-party consultant) modelled the building and helped coordinate design documents prior to and during construction. Their 3D model, created with CATIA software, included fully-detailed structural elements and connections, as well as mechanical/electrical systems and architectural fit-outs. The model allowed all CLT penetrations for mechanical and electrical sleeves to be fully coordinated during the design process and to be converted into the fabrication files (CAD/CAM) needed for CNC machining.

With this level of prefabrication, thorough quality control measures were critical as there was much more up-front information and documentation required than that of a typical project.

4.3 Point-supported CLT

In addition to stiffness and bending requirements, rolling shear stresses at the supports are typically a controlling factor in two-way, point-supported CLT floor plates. A rolling shear failure is one in which the fibers "roll over" each other due to shear forces perpendicular to grain.

After designing the custom layup to suit the rolling shear and flexural demands, the design team completed 18 full-scale load tests on panels from three prospective CLT suppliers at FPInnovations laboratory in Vancouver to validate the analysis. The testing apparatus and typical failure modes can be seen in Fig. 4. Based on this testing, rolling shear capacities were found to be higher than published.

4.4 Column Shortening and Shrinkage

In tall wood buildings, axial column shortening needs

Figure 4: *Point Supported CLT Panel Testing Apparatus and Failure.*

to be considered during design. When properly accounted for, the shortening should not negatively affect the construction, use or long-term performance of the building.

Several factors affect glulam column shortening:

- Dead load elastic axial shortening (Δ = PL/AE)
- Live load elastic axial shortening (Δ = PL/AE)
- Shrinkage parallel to grain
- Joint settlement
- Column length tolerances
- Wood creep

The main concerns surrounding these shortening effects are the impact of the deformations on the vertical mechanical services, as well as the differential movement between the wood superstructure and the stiff concrete cores.

The effects of these factors culminate at the roof level, where all columns below contribute to the shortening. To mitigate these effects, a series of 1.6mm-thick steel shim plates were added at the column-to-column connections on three strategic levels.

A detailed design of the connection can be seen in Fig. 5: hollow structural section (HSS) spigots with base plates slide into one another to provide steel-to-steel bearing. At the strategic levels, the shim plates were installed at the steel-to-steel bearing interface.

4.5 Concept Mock-up

To validate the constructability of the proposed design, the construction team constructed a full-scale mock-up of a portion of the building, 8m x 12m in plan and two storeys tall, shown in Fig. 6. The mock-up

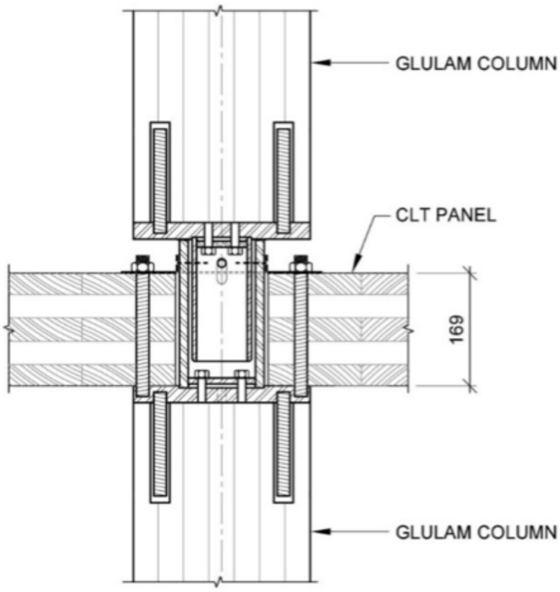

Figure 5: *Column connection.*

included several connection types to help determine and optimize the details used in the final design. In addition, the mock-up was used for the development and evaluation of various building envelope systems considered for the project.

To facilitate the use of one crane and provide sufficient time for manufacturing and shipping of the heavy timber elements, the construction team erected all 18 storeys of the concrete cores before the wood arrived on site.

5 TIMBER AND ENVELOPE INSTALLATION

5.1 Construction Tolerances and Sequencing

The timber and envelope installation sequence was completed in four phases. The first involved erecting all columns on one level, diagonally bracing them and using horizontal spreader bars at the column caps to

Figure 6: *Proof of concept mock-up.*

set the grid. The columns were installed by hand from bundles on the active deck, freeing up the crane for envelope panel installation. The second phase was installation of the CLT panels, stitching adjacent panels as the active deck moved away from the cores. The third phase was the installation of the steel drag plates at the concrete cores and perimeter angles to support the curtain wall system. The fourth was the installation of the envelope elements on the floor below the active deck. Erection of the timber and envelope panels was completed in just nine weeks, with the four-step installation sequence repeating itself (Fig. 7+8).

5.2 Weather Protection Services

Considerable effort was made to complete the concrete work to level 18 during the winter and spring months, in order to facilitate a summer installation window for the timber and envelope elements. The timber arrived on site in early June 2016, which is typically a dry summer month in Vancouver. However, there was a significant amount of rainfall in June, impacting the installations of the first six levels. A weather protection strategy was put in place by the construction manager and changed throughout the construction process as the team learned what worked and what didn't.

The first strategy was to bring up the timber elements with speed, in tandem with the envelope panels. This worked well to protect against the driving rain. The second strategy provided a temporary coating on the exposed face of the CLT panels to repel moisture when it rained. In general, the sealer itself performed well and stopped moisture from penetrating the timber directly through the surface. However, as the CLT panels are not edge glued, the lamination lines often opened up as the material shrank, ultimately providing a pathway for the water to the panel edges. This resulted in water leaking through the floors at the spline locations. The third strategy was the installation of peel-and-stick tape over all machined mechanical penetrations and along the splines to stop water from penetrating to the floor below. However, this was not an effective strategy – the lamination lines opened up and drove water to the splines, under the tape, and to the floors below. In the end, the concrete topping that trailed the active deck by four levels was taped at its crack lines and proved to be a formidable barrier for the rain water. Lastly, a sink-style drain was created with plywood at each of the ten 800mm x 800mm mechanical shafts per floor. Again, this was found to not be an effective strategy because the drains could not attract water with any significance since the structure was installed level with no slope to the mechanical shafts.

Temporary cover solutions were considered for the project but were found to be too costly and restrictive for the erection sequencing.

6 MONITORING

In an effort to better understand the future behaviour of this building, the structure was fitted with accelerometers, moisture meters, and vertical shortening string pots. Research teams at UBC and SMT Research Ltd undertook this work.

The accelerometers will allow research teams to

Figure 7: *Crews installed columns by hand. Courtesy of Seagate Structures.*

Figure 8: *Prefabricated façade installation. Courtesy of Seagate Structures.*

determine in-situ damping values from ambient vibration testing (wind). These values will help to determine a baseline damping ratio for future hybrid buildings of this type, specifically useful for dynamic wind acceleration calculations.

Additionally, sensors were placed on the concrete cores to record the building's angle of inclination during a seismic event. The data collected from the accelerometers and inclination gauges will help to verify the building's performance in a significant seismic event.

String pots will measure the floor-to-floor axial column shortening at strategic levels and provide more insight into axial column shortening in highly-loaded glulam columns.

Lastly, moisture meters (Fig. 9) and data loggers were installed in the CLT panels, collecting data from the manufacturing plant to the final installed condition. The meters will continue to measure moisture content throughout the service life of the building. In a few years' time, this will provide an effective moisture content timeline from fabrication to moisture equilibrium.

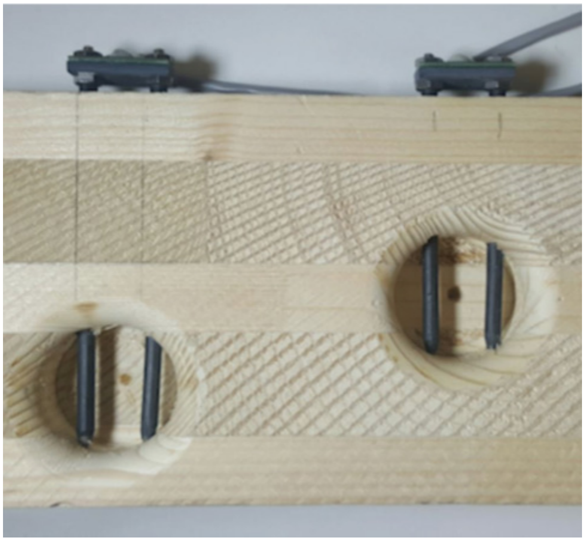

Figure 9: *Moisture Meter Probes.*

7 CONCLUSION

A mass timber building of this scale carries a unique set of engineering and management challenges, many of which can be mitigated through the use of innovative design strategies and strong quality control protocols. To date, the project has proven cost-competitive with concrete towers in the local marketplace, largely achieved by an integrated design team, real-time input from trades and structural discipline. This large scale prefabricated project is a testament to fresh thinking and holistic design (Fig. 10+11).

8 AUTHORS

Paul Fast, P.Eng., Struct.Eng., P.E., FIStructE, LEED AP is Partner at Fast + Epp, actively contributing more than 30 years of design insight and innovative structural concepts to the Brock Commons project as Principal-in-Charge.

Robert Jackson, EIT, is a project engineer at Fast + Epp and has been heavily involved in the design and construction of UBC Brock Commons.

Figure 10: *Aerial view of Brock Commons. Courtesy of Naturally Wood.*

Figure 11: *Interior view of Brock Commons. Courtesy of Seagate Structures.*