An overview of the construction of a tall wood building: Brock Commons Tallwood House

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Abstract

Brock Commons Tallwood House is an 18-storey student residence with a hybrid mass-timber structure recently completed at the University of British Columbia (UBC) in Vancouver, Canada. Currently the tallest contemporary wood building in the world, Brock Commons showcases innovations in the application of mass-timber products and in design and construction practices, while providing a unique learning experience for academic researchers and the predominantly local design and construction firms. The project team used an integrated design process, enhanced by the use of virtual design and construction (VDC) modelling. Extensive construction planning and sequencing, highly-controlled prefabrication of the building structure and envelope, and detailed coordination of on-site erection and installation activities all contributed to a successful project.

The Urban Innovation Research group within UBC's Sustainability Initiative (USI) develops and manages interdisciplinary research and educational programmes, using UBC's campus as a living lab for learning opportunities to advance sustainable practices and policies. USI Urban Innovation Research has been leading a multi-year project, working with researchers in the departments of Forestry and Civil Engineering, to study the design, construction and performance of Brock Commons and compile the lessons learned for future projects.

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Completed building, Brock Commons Tallwood House. Photo courtesy of Acton Ostry. Photographer: Michael Elkan

Introduction

The University of British Columbia (UBC), one of Canada's premier universities, is a community of academic, residential, commercial, and agricultural functions and facilities, in Vancouver, British Columbia. The university has a strong commitment to sustainability and the integration of research, teaching, and operations in capital projects. Over the last 20 years, UBC has gained significant experience working with mass-timber and engineered wood products and developed a large portfolio of innovative wood buildings on campus. In May 2017, the university completed the latest addition to this portfolio and its first tall wood residential building – the 53 m high, 18-storey Brock Commons Tallwood House.

Brock Commons was the tallest contemporary wood building in the world at the time of its construction. It is part of a student residential complex, with 404 beds in studios and four-bed units, plus amenities for the campus community on the ground level. The structure is a mass-timber hybrid. The foundation, ground floor, second floor slab and stair/elevator cores are concrete, while the superstructure is composed of prefabricated cross-laminated timber (CLT) panel floor assemblies supported on glue-laminated timber (GLT), and parallel strand lumber (PSL) columns with steel connections. The building envelope is comprised of prefabricated steel-stud frame panels with a wood-fibre laminate cladding, and a traditional styrene-butadiene-styrene (SBS) roof assembly on metal decking (Naturally Wood, 2016).[1]

The mass-timber products were fabricated and erected by local British Columbian companies – Structurlam Products LP and Seagate Structures. The CLT panels are composed of five layers of dimensional spruce-pine-fir (SPF) lumber, arranged perpendicular to each other and bonded by a structural glue. The GLT and PSL columns are composed of Douglas-fir, solid-sawn lumber and strands respectively, glued together under heat and pressure. The wood products are harvested from regional forests, which are certified as sustainably managed through either the Canadian Standards Association or Sustainable Forests Initiative programmes.

From UBC's perspective there are clear benefits to using mass-timber. It is a locally resourced and fabricated material that is both renewable and sequesters carbon – from the carbon dioxide absorbed during the tree's life. The regularity of the prefabricated mass-timber structure is a good fit with the repetitive layout of a residential building and the fast erection time helped address a growing demand for student housing on campus. The project was able to be developed under the provincial building code by developing a site-specific regulation, the UBC Tall Wood Building Regulation, through a stringent code approval process that uses peer review and expert review panels to ensure that the design performs as well or better than a comparable building with a non-combustible structure.[2]

Brock Commons Tallwood House is one of the demonstration projects supported by the 2013 Natural Resources Canada and Canada Wood Council competition, the Tall Wood Building Demonstration Initiative, which was aimed at advancing the design and production of wood products in Canada and demonstrating that wood is a viable structural option for mid-rise and high-rise buildings. Forestry is a significant industry in Canada and there is a recognised opportunity to advance the manufacturing and building industries in enhancing the value of this natural resource through the design, fabrication and application of engineered wood products like CLT, GLT and PSL. Projects under the Demonstration Initiative were selected through a competitive process and were awarded third party funding to help offset the higher design and construction costs incurred as early adopters of a new structural typology.

While UBC had considered utilising a mass-timber structure in a few other high-rise building projects on campus, the Demonstration Initiative provided the impetus to move forward from concept to design. Brock Commons Tallwood House was selected as the appropriate project due to the timing and to the simple nature of the programme as a residential building. From experience with previous mass-timber projects, UBC recognised that the requirements of certain academic uses, such as laboratories, were not a good fit with wood structures because of issues such as the equipment vibrations transfer and risk of water damage. As a multi-unit residential building, Brock Commons had less stringent requirements in these areas, as well as a regular and a repetitive floor plan that worked with the spanning and spacing constraints of a mass-timber structural system. The overall design approach to the project was to keep it as simple as possible to allow the team to focus on the design and construction requirements of the mass-timber structure.

Brock Commons Tallwood House has the following dimensions:

Height: 53 m (18 storeys)

Site area: 2,315 m²

Gross area: 15,120 m²

Footprint: 15 x 56 m, totalling 840 m²

Typical floor-to-floor height: 5 m on the ground floor, 2.81 m on the upper floors

29 CLT panels per floor: 169 mm thick, 285 mm wide and of varying lengths (600, 800, 1000 and 1200 mm)

78 columns per floor: GLT except for 18 PSL columns on Floors 2–5; cross-section of 265 x 265 mm on Floors 2–9 and 265 x 215 mm on Floors 10–18

Brock Commons Tallwood House is operated by the university's Department of Student Housing and Hospitality Services, while the Department of Infrastructure Development oversees design and construction. UBC

[1] Naturally:wood. 2016. Brock Commons Tallwood House: Design and Preconstruction Overview. Retrieved from www.naturallywood.com/resources/brock-commons-design-preconstruction-overview

[2] Naturally:wood. 2016. Brock Commons Tallwood House: Code Compliance. Retrieved from www.naturallywood.com/resources/brock-commons-code-compliance.

Brock Commons under construction – the project showcases innovations in mass-timber products and design and construction practices. Photo courtesy of naturally:wood

utilises a construction management project delivery method, in which the project manager, UBC Properties Trust, directly supervises the design, construction and commissioning processes on behalf of the university. Leaders within these departments, as well as the office of the Vice-President of Research, recognised tall wood as a logical next step in the evolution of mass-timber at UBC and championed the project throughout its development.

To address the unique and innovative nature of the project, Properties Trust selected firms that were locally based, and large enough to have relevant experience but small enough to have their senior personnel involved on a day-to-day basis. The structural engineer was Fast & Epp, the architect of record was Acton Ostry Architects, with Hermann Kaufmann ZT GmbH (a European firm with expertise in mass-timber) serving in advisory capacity, and the construction manager was Urban One Builders. In addition to the design consultants, key construction team members were involved in the design and pre-construction phase, including the construction manager, the mass-timber fabricator, the timber erector, and the concrete forming and placement contractor. Their input regarding the feasibility, constructability and cost of design decisions was crucial in facilitating and accelerating the construction phase.

The virtual design and construction (VDC) modellers, CadMakers Inc, played a critical role in the success of the project.[3] The modellers collected information from the consultants, construction manager and key trades in order to develop a comprehensive and highly-detailed 3D virtual model of the building. The VDC model was not part of the legal contract documents, but served as a key communication and planning tool among the project team. During design and pre-construction, the VDC model was used to assess the constructability and cost of different options, to identify conflicts, and to develop shop drawings for the proof-of-concept and lab mock-ups.

During construction, the VDC model was used in the prefabrication of mass-timber elements and to coordinate the mechanical, electrical and plumbing systems to ensure all the system pathways and structural penetrations were designed prior to fabrication and on-site construction.[4] The modellers also worked with the

[3] Naturally:wood. 2017. Brock Commons Tallwood House: Design Modelling. Retrieved from www.naturallywood.com/resources/brock-commons-design-modelling.

[4] Naturally:wood. 2017. Brock Commons Tallwood House: Construction Modelling. Retrieved from www.naturallywood.com/resources/brock-commons-construction-modelling.

construction manager and trades to create animated sequences of the installation and assembly of all the components of the project. This significantly reduced the number of design changes during construction because the building was essentially constructed in virtual form before it was constructed in reality, making it possible to identify and address areas of potential conflict or improvements well ahead of time.

Construction process overview

The schedule for the Brock Commons Tallwood House project was very aggressive (Figure 1). Design and approvals took eight months, and construction (starting in November of 2015 through to completion in May 2017) took 18 months. On-site construction was broadly divided into three phases – concrete, mass-timber structure and building envelope, and interiors and building systems. Students moved into the building in August for the start of the 2017 academic year.

As part of the pre-construction phase, a full-scale mock-up of a section of the building was built to test and validate a variety of the design solutions, to determine constructability and appropriate sequencing, and to inform the manufacturing and installation schedules and trade coordination. The mock-up experience was a unique opportunity for the project team to identify challenges and improvement opportunities in advance of the actual construction.

The concrete foundation, ground floor and second floor slab, and the two freestanding concrete cores were completed in seven months. Concrete work was scheduled during the winter months and was completed entirely before the rest of the building. This allowed for the mass-timber structure work to take place during the drier spring and summer seasons. It also simplified the scheduling and use of the project's single crane and minimised congestion of crews and materials on the narrow site. Although the elevator cores were in place, there was no construction elevator. Instead, the crane was used to bring materials to the upper floors of the building by way of a cantilevered loading platform which was moved between floors, as needed.

While completion of the concrete work was underway, the mass-timber structural components and the envelope panels were prefabricated concurrently by separate manufacturers over a three month period. The owner and the project team wanted to use prefabrication as much as possible due to its numerous advantages, such as increased accuracy and productivity in a controlled factory environment, reduced on-site construction time, and fast enclosure of the mass-timber structure.

Erection of the mass-timber CLT panels and GLT/PSL columns and installation of the building envelope panels were executed in a highly-coordinated process, which took about three months. This was two months faster than planned – the original schedule did not take into account the increase in speed that occurred as the trades became familiar with the processes and techniques.

The average speed of the mass-timber erection and envelope installation was two floors per week by an average crew of nine workers. This included the erection of the columns and CLT panels, installation of the envelope panels, pouring of a concrete topping, and encapsulation of the wood components with a single layer of gypsum board. One envelope panel on each floor remained uninstalled until near the end of construction, to provide an easy entry point for the delivery of interior materials and components via the loading platform.

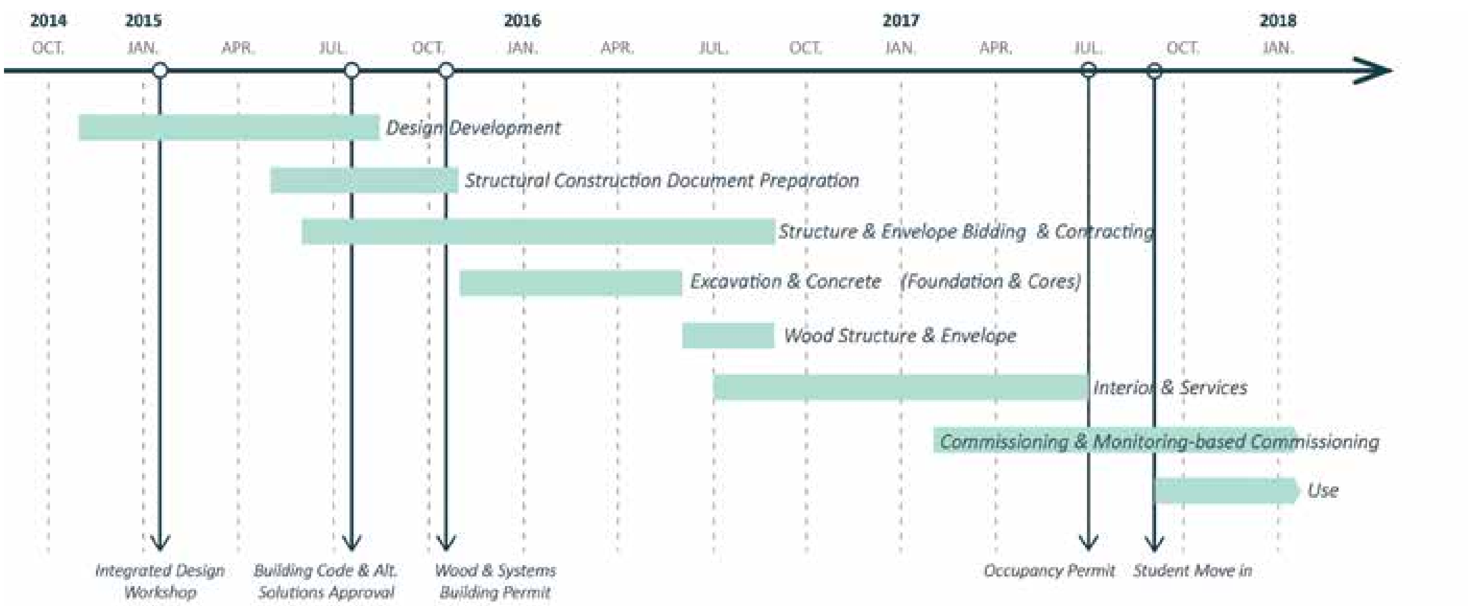

Figure 1: The use of prefabricated mass-timber elements for the superstructure facilitated on-site construction and helped the project meet its aggressive schedule

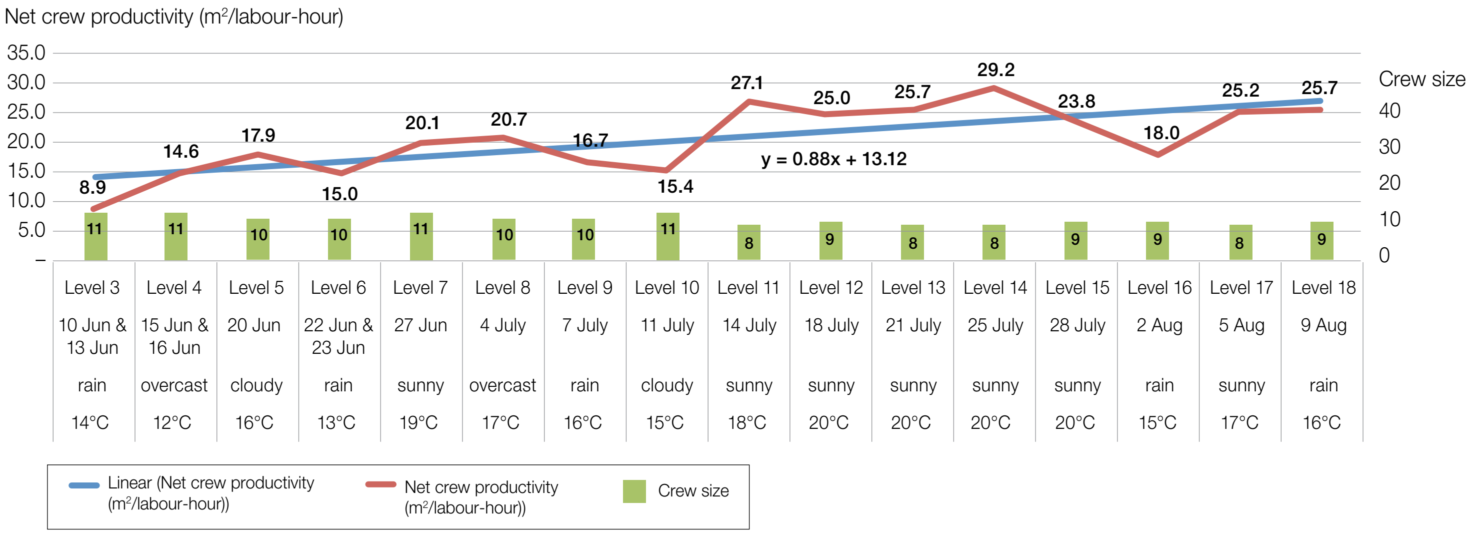

Figure 2: Net crew productivity is the ratio of total area of CLT panels in each floor (722 m²) to net crew time. Net crew time is the product of the crew size and the duration of a crane cycle (hook time) to install CLT panels

Construction productivity analysis (Kasbar, 2017) showed the net crew productivity related to the CLT panels increased from 8.9 m² per labour hour at Floor 3 to 29.2 m² per labour hour at Floor 14. A similar trend in productivity occurred for the envelope panels, which increased from 6.84 m² per labour hour at Floor 3 to 15.59 m² per labour hour at Floor 15. Although factors such as weather, wind speed and changes in the crew members created variations in this metric, the consistent increase in the net crew productivity indicated a learning curve effect, which often happens with the adoption of new building systems and technologies.

Because of Brock Commons' repetitive design and construction, the metrics in Figure 2 are accurate tools for measuring variations in construction productivity.

Work on the interiors, finishes and building systems took about 10 months, at an average of about 65 working days (13 weeks) per floor, with crews working concurrently on multiple floors. The interiors and mechanical, electrical and plumbing (MEP) systems were typical of high-rise residential construction in Canada. Adaptations for a mass-timber structure included consolidation of ducts and piping to minimise penetrations through the CLT floors, use of expansion joints, flex ducts and suspended storm stacks to accommodate differential structural movement, and installation of floor drains in all the bathrooms to minimise the risk of damage from water accumulation.

A detailed bill of materials was created from the VDC model that included the exact dimensions and sizes for all building components. This allowed for a significant portion of the mechanical and electrical systems work to be completed off-site, including the pre-assembly of equipment, cutting of ducts and pipes, and most of the welding, thus reducing timelines and congestion on the site. For example, the mechanical room, which would typically take three to four months of on-site work, was assembled in less than one month.

The use of CLT panels for the stair and elevator cores was considered for the project, but concrete helped streamline the structural design (in particular the lateral resistance) and reduce costs, as well as simplify the already complicated permitting and approval process. Photo courtesy of naturally:wood

Concrete foundation and structure

The building foundation, the ground floor, the second floor slab and the stair/elevator cores are reinforced cast-in-place concrete. The second floor slab acts as a transfer slab, which transfers the gravity load from the upper-level mass-timber structure to the lower-level concrete structure. The cores and foundation also provide the building with the necessary rigidity to resist wind and seismic lateral forces.

A special crane-lifted formwork system was used to pour the concrete for the cores, which included interior and exterior steel and wood forms and a safety platform for the workers. The formwork enabled tighter control of the lateral tolerances of the freestanding cores for more accurate alignment with the mass-timber structure. The exact locations of mechanical and electrical penetrations in the concrete slab and cores were specified with the VDC model, to ensure they matched the penetrations through the CLT panels and did not clash with reinforcement or connections.

Mass-timber structure

The primary structure of Brock Commons Tallwood House is composed of CLT floor panels, and GLT and PSL columns with embedded steel connections. The mass-timber is encapsulated by a concrete topping on the floor and three to four layers of Type X gypsum board on the columns and ceilings, as a fire protection measure per code requirements.

The mass-timber elements were modelled in the VDC model and exported as geometric STP files containing all the base geometry and dimensions. The mass-timber fabricator imported the STP file into its own software and made adjustments to account for manufacturing requirements, such as saw thickness and drill bit diameters, to create the fabrication model. All the mass-timber components were cut with CNC machines, including the penetration cut-outs in the CLT panels and the connection holes in both ends of the columns. The steel connections were fabricated separately and installed on the columns by the mass-timber fabricator as part of the prefabrication process to ensure the ±2 mm fitted column length (floor-to-floor) tolerance was met.

The installation sequences of the mass-timber components, which included truck-loading and just-in-time site-delivery schedules, were developed with input from all the relevant trades. The trucks were loaded with components in the reverse order of actual installation, which arrived at the construction site at planned intervals on the day of installation, and components were unloaded directly into position in the building.

Lifting hardware for the CLT panels was custom engineered by the timber erector, based on the use of four lifting points to safely and easily balance the mass of each panel during installation. The panels were lifted at an angle so that one end could be lowered into place before the other, then positioned and aligned with the help of a laser pointer and bolted into place on the columns below. When the floor's 29 panels were in place, plywood splines were nailed and screwed between the panels to connect them all into a single diaphragm. Finally, steel drag straps were screwed to the panels and bolted to the cores at each floor to transfer the lateral loads of the CLT floor diaphragm to the concrete cores.

For each floor, 10 bundles of columns were craned up, two bundles at a time, and then individually placed at their prescribed locations. A special rig was developed by the mass-timber erector to safely lift the perimeter columns with the crane, while inside columns were manually lifted. To secure each column, the steel tube connection of the top column was fitted inside the bottom column connection and fixed with a steel pin. Temporary diagonal supports and braces were placed to keep the columns from tilting and rotating before the upper floor of CLT panels was installed.

The mass-timber elements were completely sealed and encapsulated as water and fire protection measures. Water sealant was applied to the CLT panels at the factory and then again on-site after the splines were installed. The floor panels were covered with a concrete topping, at a lag time of no more than five floors below the leading level of mass-timber. The concrete topping was designed primarily for acoustic purposes, but was also used as a water- and fire-management measure. The underside of the CLT panels and the columns were enclosed with one layer of gypsum board lagging no


The prefabricated enveloped panel was a new product specifically designed for Brock Commons by Centura Building Systems. Photo courtesy of Acton Ostry. Photographer: Michael Elkan

more than six floors below the leading level of mass-timber. Two or three additional layers of gypsum board were added later during the interior work.

The project team incorporated multiple quality control and quality assurance measures while installing the mass-timber. A unique identifier was assigned to each mass-timber component for tracking through design, fabrication and installation on-site, and laser measurements were used to verify the accuracy of tolerances and heights. Additionally, a worker was tasked with logging column compressions by shooting the benchmark elevation of a representative sample of 19 columns on every floor after the installation of the next level of CLT panels. The results were used to determine whether shimming was required to level the columns or to reach the required height for the next floor.

Building envelope

While the ground floor of Brock Commons is enclosed in a conventional glazed curtain wall system, the building envelope panels for the upper floors are comprised of steel-stud frames with punched windows, a rain-screen system and wood-fibre laminate cladding. A new envelope panel product was developed specifically for this project based on aesthetic, structural connection and performance requirements.

The development of the prefabricated envelope panels included comprehensive lab tests with the enveloped consultant, RDH Building Science, to ensure structural performance (wind and design loads), thermal cycling, thermal performance, condensation and air and watertightness. Each floor has a total of 22 envelope panels, standardised in 14 different designs based on dimensions and window placement, and partially prefabricated. The factory assembled components were the steel stud frame, a layer of fibreglass mat gypsum sheathing, a layer of semi-rigid stone-wool weather and thermal insulation, the exterior wood-fibre laminate panels and the window assemblies. The interior batt insulation, vapour barrier and final drywall layer were added on-site as part of the interior work.

On the construction site, the envelope panels were lifted with an I-beam spreader bar directly from the truck into position on the building. Each panel was hung from a steel L-angle mounted at the perimeter of each floor and fitted into the header connection of the panel below it. The L angles, which also provide additional stiffness for the CLT floors, were used so that the envelope panels would be in-plane with the building's face even if the CLT panel edges were slightly out of alignment. Detailed flashings and seals were used to ensure minimal-to-no leakages at the panel connections, and caulking was applied on the interior side to reduce failure due to weathering.

The roof structure of Brock Commons is composed of a traditional built-up roofing assembly, steel decking, and steel beams supported by GLT columns. Combining a traditional roofing system with the prefabricated superstructure and envelope required the roof to be constructed to a much tighter tolerance rate (±3 mm) than the industry norm, to ensure the connections and interfaces between systems and materials were secure.

Risk management and safety measures

Rigorous risk management and life safety measures were implemented throughout the construction of Brock Commons. Comprehensive and integrated fire and water management plans were in effect for the site, with a focus on the mass-timber, and a safety officer was an active presence in all construction planning.

The primary strategy was to enclose each floor of the building with the envelope no more than three floors behind the erection of the mass-timber structure, to limit exposure of the mass-timber structure. Before the envelope was in place, a re-usable guardrail system and fall protection secured the trades on the open floors. Additional protection measures included encapsulation of the mass-timber, sprinkler standpipes in concrete cores, no welding or hot work after the mass-timber was installed, enforcement of a high level of site cleanliness and minimal material storage to reduce flammable debris, fire prevention and response training, and limited and secure access to the site.

Many of the challenges associated with working on a small and narrow site were addressed through detailed sequence planning aimed at limiting the number of trades and the amount of materials at any given time. The use of prefabrication transferred a large portion of the construction processes to controlled factory environments so critical tasks could be completed in the shop rather than exposed at heights on the construction site. This also limited the impacts of any work stoppages and delays caused by wind and weather (e.g. the shutting down of crane operations), as well as construction-related noise and disturbance to the campus.

Design and construction costs

The total project costs for Brock Commons Tallwood House were $51.5 million in Canadian dollars. The design cost was $3.8 million and the construction cost was about $40.5 million ($248.90 per gross square foot). The cost of the structural elements, which include concrete, mass-timber and steel connections, form about 20% of the total construction costs. The next largest contributors are the building envelope, mechanical and electrical systems, and finishes. These systems, which are largely independent of the structure, together account for close to 50% of the total construction costs.

As an early adopter of an innovative structural system, the Brock Commons project had additional design and construction activities and requirements that would not be part of a conventional building project and carried additional costs. The construction manager estimated that the construction cost premium for innovation was about $2.7 million in an analysis comparing Brock Commons to a theoretical, equivalent high-rise with a conventional concrete structure. The difference was due to a multitude of variables, not attributable to a single design decision or building feature, and the total structural costs of mass-timber and concrete were actually similar.

The Tall Wood Building Demonstration Initiative provided about $4.5 million in financial support for Brock Commons to help defray this cost of innovation. Approximately $3 million was used to offset the construction costs. The other $1.5 million was used to offset incremental design costs, such as extra fees for specialised consultants, the site-specific regulatory approval process, and lab tests and mock-ups.

The project team expects that project costs will drop for future projects, as the industry becomes more familiar with tall wood buildings and new design and construction solutions are developed. For example, to expedite the building permit process a very conservative approach was taken to fire protection for Brock Commons. However, recent lab tests have shown that the mass-timber would still maintain a high level of fire resistance with two layers of gypsum board instead of the three to four layers used. Reducing one to two layers of mass-timber encapsulation could potentially reduce up to one-third of the total innovation construction cost premium.

Summary of lessons learned

Extensive and integrative planning and communication translated to direct benefits in the field.

- The use of comprehensive VDC visualisation helped identify constructability issues and cost implications, which in turn reduced the number of changes and surprises during the construction phase.
- Continuous and consistent communication amongst the project team, including the site manager, trades, VDC modellers and site safety officer, ensured the construction plan was realistic, efficient and safe.

As an early adopter of novel construction solutions, the project team took extra steps to ensure the successful implementation of innovative solutions while delivering a project on schedule and on budget.

- The project team tested and validated alternative designs and construction methods through iterative design and pre-construction processes, including the integrative design workshops, virtual modelling, and laboratory and mock-up tests, in order to optimise the actual construction process.
- Although the trades experienced a learning curve while adjusting to the aggressive schedule, the necessary high level of coordination and the need to learn new techniques, they achieved the expected assembly tolerances and overall outperformed the schedule, completing the mass-timber erection two months ahead of schedule.
- The integrative design and construction strategy encouraged the entire project team – design consultants, construction manager and trades – to take ownership of and actively contribute to the success of this innovative project.

One major advantage of using mass-timber is the prefabrication opportunity it provides. Prefabrication increased the construction accuracy and productivity, reduced on-site construction time and waste, and allowed for concurrent off-site work to occur under controlled conditions.

- The VDC model was used to develop a full design of the MEP systems, which determined the exact locations for shafts and penetrations to be cut into the CLT panels during prefabrication. It also enabled the accurate off-site cutting of ducts, pipes and other systems, and partial off-site assembly of the mechanical room.
- Prefabrication of the envelope panels allowed for fast enclosure of the mass-timber components by significantly reducing the number of fastening steps required on-site.

The successful employment of innovative solutions in this project opened up a set of opportunities to be explored in future projects and through academic research.

- Further prefabrication opportunities exist in building typologies with repetitive layouts, including framing for demising walls, bathroom units, electrical cabinets, roof systems and core walls.
- More advanced technologies could be used for water and fire management in order to reduce the required on-site work and keep up with the fast pace of mass-timber erection.
- The stringent dimensional quality control that was applied to the mass-timber elements proved to be somewhat excessive and costly. For future tall wood buildings, quality control measurements and levels of auditing of the mass-timber components should be re-evaluated and linked to acceptable industry norms and standards, but without compromising on safety or performance.

Reference

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