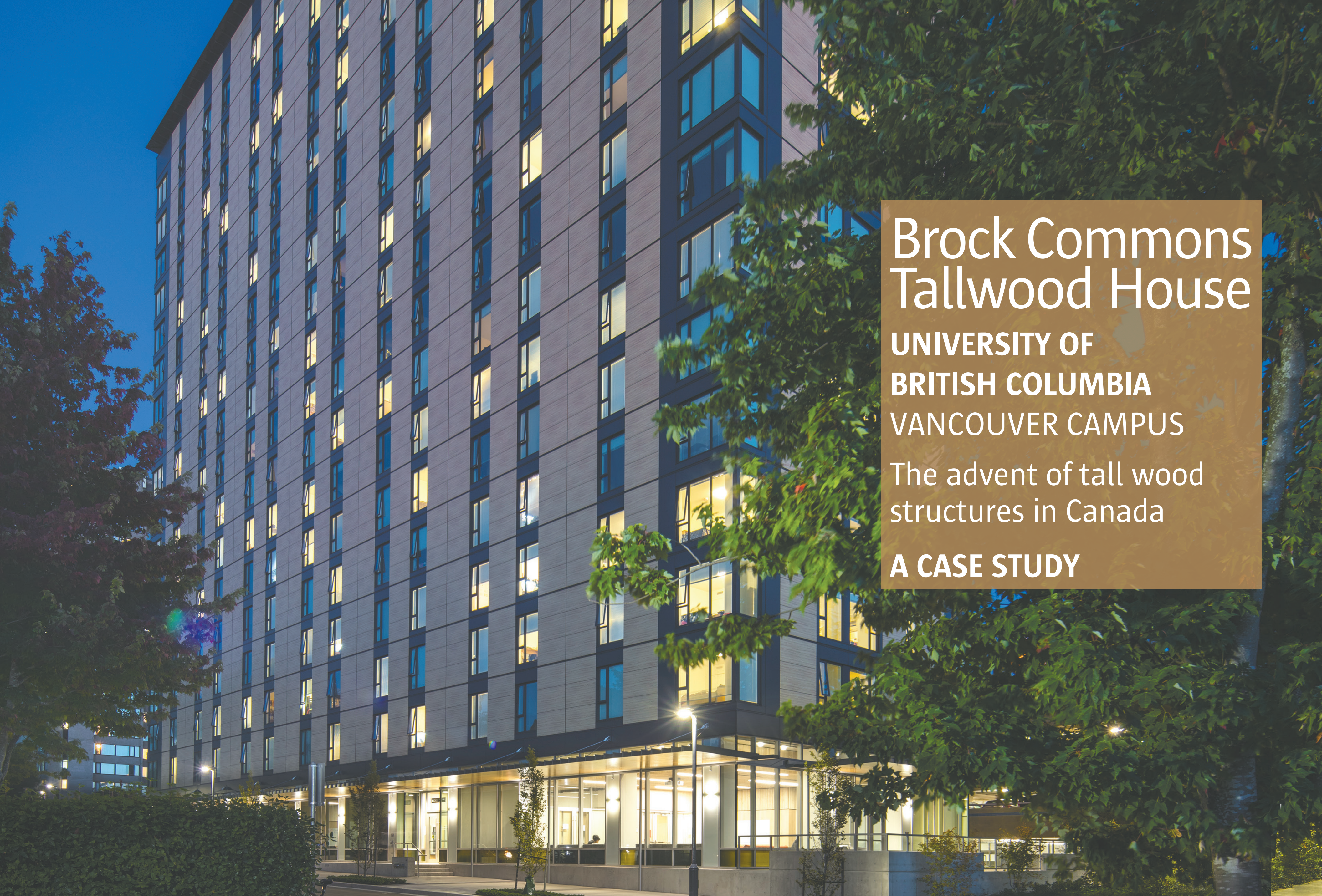

Brock Commons Tallwood House

UNIVERSITY OF BRITISH COLUMBIA

VANCOUVER CAMPUS

The advent of tall wood structures in Canada

A CASE STUDY

woodWORKS! Program of the Canadian Wood Council

Canadian Wood Council
Conseil canadien du bois

© Photo: Stéphane Groleau, courtesy of Cecobois

Origine – Quebec City, Canada

While BC has taken a leadership role in Canada for taller wood buildings with the construction of Brock Commons Tallwood House and the Wood Innovation and Design Centre in Prince George, other jurisdictions in Canada are close behind. The 13-storey Origine condo building in the Pointe-aux-Lièvres eco-neighbourhood in Quebec City has recently been completed, making it the tallest wood building in eastern Canada and the tallest wood-construction condo tower in North America. This tall solid timber structure, built on a concrete podium, is 134 feet in height. It is distinguished by the fact that its structure consists entirely of solid wood, as are the staircase and elevator shafts as well as the cross and exterior walls. The building's structural system features a combination of CLT panels and glulam beams and columns.

The opportunity for new, larger and taller wood buildings is now being recognized as a viable option in Canada by the design and building community, and made possible by the evolution of wood products and building systems. The Canadian Wood *WORKS!* program is pleased to provide resources such as this case study to support and help advance this exciting revolution in design and building.

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Cover photo: Michael Elkan Photography. Courtesy: naturallywood.com

This case study is based on information collected by the Canadian Wood Council (CWC) and its representatives and represents our interpretation about the facts and information gathered about the Brock Commons Tallwood House project. The CWC wishes to acknowledge and thank Natural Resources Canada for funding and support of this case study, as well as the Brock Commons project team members for sharing their expertise, experience and technical resources.


Credit: Urban One Builders. Photographer: Lara Schecter

Introduction

A stunning coastal forest in Vancouver, BC is the gateway to the University of British Columbia (UBC) which has provided inspiration for the institution's long-standing relationship with wood. The result is an enviable inventory of wood buildings interspersed throughout the campus which showcases ground-breaking technologies and sustainable design.

UBC's commitment to promoting locally sourced, environmentally responsible, leading-edge engineered wood products and building technologies has culminated in the most recent addition to the UBC Vancouver Campus: the Brock Commons Tallwood House. The newest of the UBC's student residence buildings, Brock Commons Tallwood House currently stands as the tallest contemporary hybrid mass timber building in the world.

Over the years, with an ever-increasing demand for student housing, UBC developed a preferred typology for its student residences, creating mixed-use residential hubs to enhance campus life. For this latest project, the University was determined to demonstrate the applicability of an advanced systems solution to BC's development and construction industries while advancing its reputation as a hub of sustainable and innovative design.

Wood use from the 18th to the early 20th centuries frequently included seven-storey wood buildings; taller wood structures such as church towers and pagodas were built worldwide earlier still. Today, pushing the envelope of wood use comes with challenges. Authorities having jurisdiction and oversight of the approval process for a new generation of tall wood building designs require comprehensive scientific data to evaluate their safety since there are no prescriptive provisions in the Canadian building codes to permit them. Until such a time as building codes establish provisions for tall wood buildings, performance aspects of their design must be proven on a design-by-design basis.

Natural Resources Canada (NRCan), in recognition of the technical challenges inherent in the design and construction of modern tall wood structures, has provided targeted funding to support demonstration projects that use innovative engineered wood products and construction systems.

Credit: Acton Ostry Architects & University of British Columbia. Photographer: Michael Elkan

Brock Commons Tallwood House

In 2013, NRCan announced financial support to encourage the regulatory and commercial acceptance of tall wood building construction in Canada: The Tall Wood Building Demonstration Initiative (TWBDI). The TWBDI and the recently issued NRCan 2017 Green Construction through Wood (GCWood) Tall Wood Program Expression of Interest will help Canadian developers, building officials and industry stakeholders resolve some of the critical design and construction issues that come with tall wood structures.

Following the submission and due diligence evaluation exercise, the Brock Commons student residence project was selected as one of two projects to receive federal funding through the TWBDI. These funds were indispensable in bridging the innovation funding gap in the preliminary design, approval and construction phase of the project. The resulting technical knowledge will benefit future teams designing and building mass timber structures and will support the adoption and advancement of tall wood buildings in Canada.

The building

The 54-metre-tall UBC Brock Commons student residence houses 404 students in studio and four-bed units. The building is a mixed-use residential complex (residential occupancy, Group C, with subsidiary assembly spaces, Group A-2).

Student housing is located on levels 2 through 18 of the building, with two quad units per floor on levels 2 through 17, one located at either end of the building and 16 studio suites. Level 18 is laid out with one quad unit, 16 studios and a student lounge. Each quad unit contains a common space, a kitchen, two bathrooms and four separate bedrooms. The studio units each contain a pass-through kitchen, a bathroom and a bedroom.

There are public amenity spaces, assembly and study rooms on the ground floor, along with building service spaces for mechanical, electrical, waste and recycling services; a student study-social lounge is located at the 18th floor, where 10 – 265 mm by 215 mm glulam columns are left exposed for demonstration and educational purposes.

The student residence is the world's first mass timber, structural steel and reinforced concrete hybrid building to reach 18 storeys. The building is supported on a foundation comprising of reinforced concrete footings, below grade shear walls and columns and a raft slab. Reinforced concrete columns support the second level transfer slab and the two 18-storey reinforced concrete shafts provide structure for building stairs, elevators and services.

Sixteen levels of super-structure above the second level reinforced concrete transfer slab are comprised of cross-laminated timber (CLT) floor panel assemblies that are supported on glued-laminated timber (GLT) or parallel strand lumber (PSL) columns, using steel connections – no beams are required with the two-way spanning capabilities of the CLT floor panels. Glulam columns on level 18 support a structural steel roof assembly.

The structural steel roof assembly is supported partially on both the 18th floor glulam columns and the reinforced concrete core.

The transfer slab allows the ground-floor structural grid that accommodates large assembly spaces to be independent of the wood structural grid on the upper storeys.

The two full-height concrete cores assist in providing lateral stability for the building, in conjunction with the diaphragm action of the CLT floor slabs.

The building envelope is comprised of a curtain wall at level 1 and a prefabricated steel-stud framed laminated panel window wall system on levels 2 through 18.

The roof is a steel beam structure supported on GLT columns and the core, topped by steel decking and a conventional styrene-butadiene-styrene (SBS) built-up roof assembly. The building is crowned with a metal cornice.

A canopy constructed with CLT panels covers the walkways on the north and west side of the building. The underside of the CLT canopy panel is exposed.

Credit: Acton Ostry Architects & University of British Columbia. Photographer: Michael Elkan

Student Lounge – Level 18

Credit: naturallywood.com. Photographer: KK Law

Under construction – Late June 2016

Bioenergy Research and Demonstration Facility

Demonstration Projects

The TWBDI builds on the success of another NRCan program: The Large-Scale Wood Demonstration Initiative (2009-2011). This initiative supported the construction of several mass timber projects across Canada including two state-of-the-art mass timber buildings at the UBC Vancouver Campus: the Bioenergy Research and Demonstration Facility that is the first large-scale wood project to be built with cross-laminated timber (CLT) in North America; and the 5-storey Earth Sciences Building that is a showcase for the use of hybrid wood-concrete composite panels, cross-laminated timber (CLT), glued-laminated timber (GLT) and a variety of novel connections. In addition, the Earth Sciences Building's atrium features a 5-storey cantilevered free-floating glulam composite staircase.

The Right Approach

The University of British Columbia deploys UBC Properties Trust (UBC PT), an internal property development – project management organization, to assist campus infrastructure and organization groups with key or specific campus projects. *UBC PT's mission is to assist UBC, through optimization of land assets, to achieve the academic and community goals of UBC's Place and Promise mandate.*

After initial UBC Board of Governors – Board 1 approval was received for the design development of the Brock Commons project, UBC PT issued an Expression of Interest (EOI) for Architectural Services. Once the architect for the project was selected, UBC PT made the decision to assemble an experienced multi-disciplined project team up front, including not only the architects and engineers, but construction managers and key sub-trades as well. In light of the technical and cost risks associated with constructing an 18-storey hybrid mass timber structure for the first time, they reasoned that it only made sense to include both design and construction expertise at the table from the outset.

As their previous experience with mass timber projects at UBC had demonstrated, UBC organizations were familiar with the fundamental risk presented by moisture ingress into such a structure during construction: too much moisture could delay enclosure, thus impacting both schedule and budget, not to downplay the potential for future mould and rot problems. They therefore knew that it would be beneficial to assemble and enclose the structure during the dry summer months. This provided an approximately 16-week window to assemble the mass timber super-structure.

Developing a design that could be constructed in a 16-week timeframe required the detailed input of both builder and fabricator, whose collaboration could provide precise feedback on the schedule (and cost) implications of different structural system and building envelope options. The architects, along with the engineers and a tall wood advisor from Austria, were selected to inform the design team; each time a new team member was designated, the collective experience around the table helped to identify subsequent qualified team members.

Once the design professionals, fabricators, erection and construction management teams were involved, everyone rallied around common goals: simplicity and efficiency of design, constructability, target budget and schedule. UBC staff knowledge of efficient and durable operation requirements was also considered during the design process. The coordinated and cooperative approach afforded by this expanded design team provided real-time feedback on the evolving structural design, thus allowing for more accurate scheduling projections and resulting in valuable constructability advice. All team members felt this approach was very rewarding and efficient.

Added to the mix was the use of 3D modelling during the design phase. 3D modelling resulted in fully detailed structural elements and connections, mechanical and electrical systems, and architectural fit-outs; all integrated during the design process. When it came time for production, information from the 3D modelling was converted to fabrication files for CNC machining. This, in combination with the precision of prefabricated wood elements, led to extremely tight tolerances, especially when compared with concrete construction; the potential for misalignments on site were reduced dramatically.

The multi-disciplinary approach up front made it possible for the design team to hone in on a simple, cost-effective structural design that could be assembled within the tight schedule restrictions. When all was said and done, the efficiencies and details identified by the expanded design and construction team led to a nine and a half week construction time for the mass timber super-structure, shaving 40 per cent off of an already tight schedule. The practical benefits of this shorter-than-predicted construction time: cost-effectiveness, improved site safety and less neighbourhood disruption.

None of the above would have mattered, however, had code compliance not been addressed during the design phase. The British Columbia Building Code (BCBC), modelled on the National Building Code of Canada (NBCC), limits wood construction for sprinklered residential buildings to six storeys, with a maximum building area of 1,200 m^2.

UBC brought in an expert fire protection engineer, with experience in combustible construction, fire science and the requirements of the BCBC, to work closely with the project team from the outset. The consultant ensured that fire safety was an implicit aspect of every design consideration, helping to push the boundaries of what *was* to what *could* and *would be*. The efforts of the fire protection engineer were instrumental in securing code compliance for the Brock Commons tall hybrid mass timber structure.

Credit: Photography West

Earth Sciences Building

Total Project Budget and Construction Costs

September 2015 – The total Brock Commons project budget approved by the UBC Board of Governors was $51.5 million. The sum included design and associated incremental innovation costs, project management, permitting and approvals, infrastructure, landscaping, contingencies, furniture, IT, construction financing and taxes.

February 2017 – The Brock Commons Tallwood House Student Residence – The hybrid wood structure is being completed with very little use of contingency. The project is expected to be ready for occupancy in June 2017, ahead of the original August 2017 completion target – a report forwarded to the UBC Board of Governors on the recommendation of Santa J. Ono, President and Vice-Chancellor, UBC.

January 2018 – Total construction costs for the 162,700 gross square feet (gsf) Brock Commons hybrid project was approximately $40.5 million or $248.90 per gross square foot. The cost of the structural elements, which includes reinforced concrete, mass timber and metal connectors and accessories was about 20 per cent of the total construction cost – Brock Common Tallwood House Project, Construction Managers, Urban One Builders.

Design Philosophy

"Our philosophy and approach for the project proposal was to use materials the way they wanted to be used, which is how we arrived at the hybrid system of mass timber with concrete cores. Our manifesto for the team would be: KEEP IT SIMPLE!"

Russell Acton
Lead Architect
Acton Ostry Architects

Carbon Overview:
Brock Commons Tallwood House

Wood is a sustainable and versatile building material that stores, rather than emits, carbon dioxide. The building is designed to meet Leadership in Energy and Environmental Design (LEED) Gold certification, a rating system that promotes environmental responsibility for building designers, builders, owners and operators.

Estimated environmental impact of wood use

Volume of wood products used: **2,233 cubic meters of CLT and glulam**

Carbon stored in the wood: **1,753 metric tons of CO_2**

Avoided greenhouse gas emissions: **679 metric tons of CO_2**

Total potential carbon benefit: **2,432 metric tons of CO_2**

The above GHG emissions are equivalent to:

511 cars* off the road for a year

Energy to operate a home for **222** years

Estimated by the Wood Carbon Calculator for Buildings, based on research by Sathre, R. and J. O'Connor, 2010, A Synthesis of Research on Wood Products and Greenhouse Gas Impacts, FPInnovations (this relates to carbon stored and avoided GHG).

CO_2 in this case study refers to CO_2 equivalent

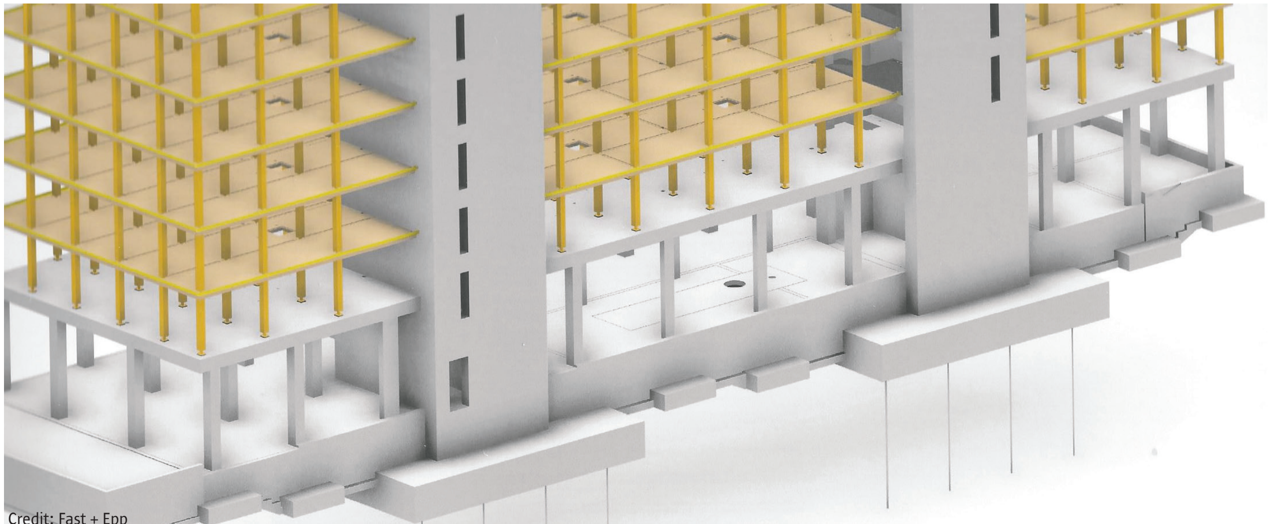
**Cars are defined as 2-axle 4-tire vehicles, including cars, vans and pick-up trucks*

The Design Process

The design development process began in earnest in January 2015 and was completed in October 2015. UBC PT and Acton Ostry Architects Inc. approached the design from a collaborative integrated design standpoint. UBC PT clearly stipulated in the Expression of Interest issued for design services that using known design solutions would be preferred and minimize the need for testing of assemblies. With an effective use of trades expertise, in combination with a strategic use of prefabricated elements and carefully controlled risk, they felt they would arrive at the realization of a successful tall wood project – and they were right.

A three-day integrated design workshop held in January 2015 significantly advanced the design process. Its key focus was to facilitate a determination of the structural approach in terms of costs, constructability and impacts on the building's engineering systems.

The design workshop was attended by the core project team members, including the architect; structural, mechanical and electrical engineers; the fire protection engineer; the virtual modeller; and the key design advisors and assistants, including the construction manager. In addition, some design-assist from trades and contractors provided real-time feedback on the evolving structural design and informed the team on constructability, trade safety, cost estimates and scheduling projections. An experienced tall wood architectural firm from Austria also advised the group.



Credit: Fast + Epp

Project rendering – Foundation, cores and super-structure

During the workshop, the project schedule was reviewed, targeting a summer construction schedule for the mass-timber elements. The objectives of keeping it simple and economical were presented to the team; preliminary planning studies were presented and scrutinized, and the consulting tall wood advisors shared important historical information from lessons learned in Europe with respect to prefabrication, constructability and the speed of erection for mass timber structures.

The engineers presented 64 potential structural approaches and eight schematic options, which were evaluated with an eye to cost factors per material type, labour requirements for fabrication and installation, single span vs. multi-span orientations, and the integration of services. Once consultations were concluded, the preferred option was for the use of GLT and PSL columns, and a longitudinal two-way CLT flat-plate system, which eliminated the need for beams in the mass timber super-structure.

The design team proposed an 18-level tower to meet the acceptable maximum building height on the UBC Vancouver campus, which is 53 metres high, but allows for minor variance to address practical design and site issues. The number of storeys, total available square footage and building program also matched what was possible with a reinforced concrete building.

Three potential prefabricated building enclosure systems were also evaluated during the workshop. Precedent buildings were visited on campus, as were other student residences, including Ponderosa Commons, for which UBC's Student Housing and Hospitality Services had already developed a preferred suite layout and overall building design.

Work progressed and by the end of January 2015, the design was finalized. The innovative hybrid building would be 18 storeys and 54 metres tall: the foundation, ground floor, second-floor slab, and two stair/elevator cores constructed in cast-in-place concrete; a super-structure composed of prefabricated cross-laminated timber (CLT) panel floor assemblies supported on parallel strand lumber (PSL) and glued-laminated timber (GLT) columns; all topped by a steel roof system which the group thought would provide added durability assurance for the building's roof structure. All mass timber elements would be encapsulated, except for 10 glulam columns in the 18th floor lounge and the CLT canopy.[1] The building would be enclosed with prefabricated building envelope panels.

1 Encapsulation of the columns is achieved with up to four layers of Type X gypsum board. CLT floor slab encapsulation is achieved by three layers of Type X gypsum board on the underside of the panels. Note: The concrete topping is only used to achieve the required acoustical performance. The concrete topping is not utilized for calculation of the required fire separation rating.

Credit: Acton Ostry Architects

Schematic – Structural rendering

Credit: naturallywood.com. Photographer: KK Law

Structural building details

The typical floor-to-floor height for the mass timber levels was set at 2.81 metres and all would rest on a reinforced concrete transfer slab on the second floor. The ground floor would be 5 metres high. The building's footprint was a simple rectilinear floor plan, approximately 15 metres by 56 metres, for a total gross floor area of 15,200 square metres (162,700 square feet).

The idea of creating a *full-scale mock-up* to evaluate design details and construction processes was also considered during this stage of the design development process.

Once the design approach was set, the next challenge began – the approvals process.

Credit: Urban One Builders

Mock-up – Concept and detail validation

Code Compliance

The University of British Columbia operates much like a small municipality, with jurisdiction in regulating building and development on its campus property, as granted by the *University Act*. Building projects on the UBC campus are governed by several overlapping policies, codes, standards and regulations that are established at local, provincial and national levels.

The primary regulation governing the construction of tall wood buildings on campus is the BC Building Code 2012. With the 6-storey height and 1,200 m^2 maximum building area restrictions, it was necessary to submit a proposal under the *British Columbia Building Act* to develop a Site-Specific Regulation (SSR) for the 18-storey hybrid mass timber project.

The University brought in and deferred to the British Columbia Building and Safety Standards Branch (BSSB) to manage the process of developing the SSR, in conjunction with the project team and the UBC Chief Building Official.

The BSSB management process included structural peer reviews by two third-party engineers and design reviews by two expert panels. The expert panels, one with structural oversight and one with fire safety oversight, were comprised of architects, engineers, fire and code officials, building scientists, advanced wood construction research organizations and UBC engineering and building science faculty.

The expert panels and the University's Chief Building Official reviewed the proposed text developed by the project consultant team for various sections of the SSR.

The design team developed design concepts, proposing strategies for mitigating the key areas of technical risk, and using tried and tested solutions that were already code compliant and in accordance with CSA O86-14 *Engineering Design in Wood* or other recognized standards.

Budget cost targets and time constraints precluded the degree of fire testing that could be expected to demonstrate that an exposed hybrid mass timber design could meet or exceed the level of performance expected by the Code for tall buildings with respect to fire safety objectives, as attributed to the applicable acceptable noncombustible construction solution prescribed in the Code. As a result, the design team opted for a conservative design approach from a fire safety perspective by encapsulating mass timber with a minimum of three layers of Type X gypsum boards. Had the design team not gone in that direction, the construction of an 18-storey hybrid mass timber structure might have been a hard sell not only with the innately conservative code officials, but also with the public, based on perceptions of fire risk associated with any kind of combustible construction. The encapsulation strategy created the opening needed for consideration by the decision makers and expedited the approvals process. As an added bonus, with no exposed

BC's Building Regulatory System

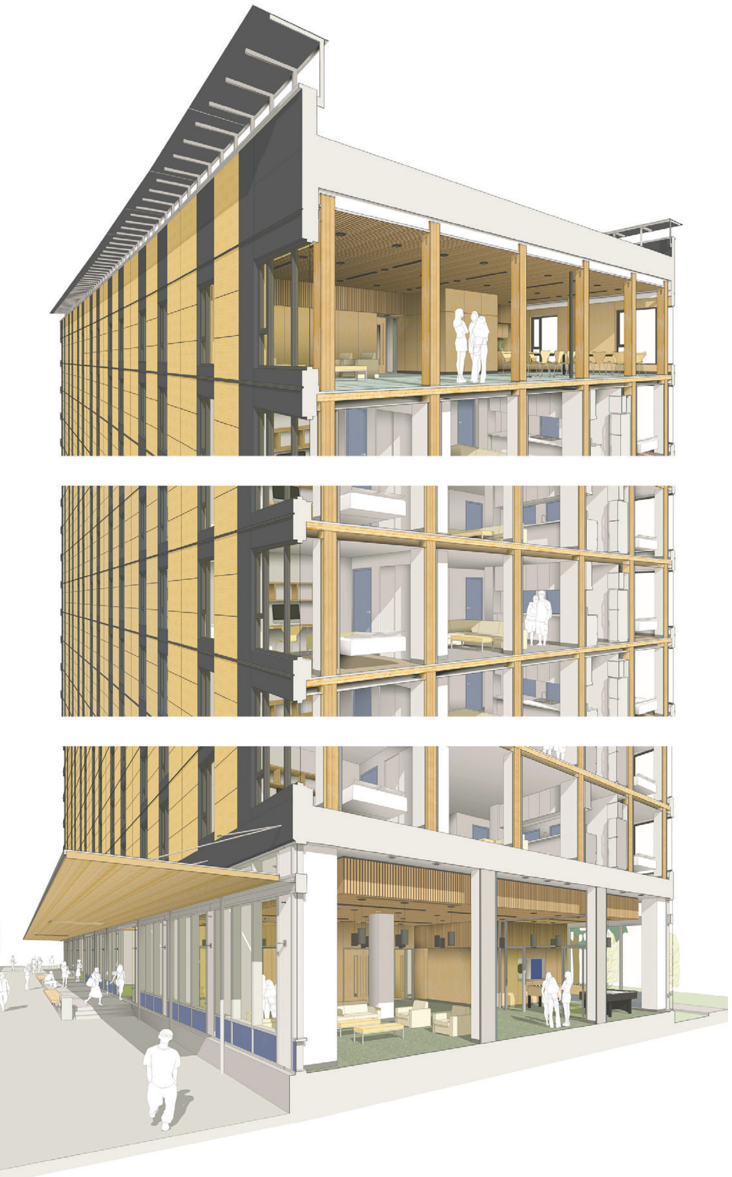
The *Building Act*, introduced by the Province of BC in February of 2015, made it possible to submit innovative proposals to a review process for buildings that use materials or construction methods that do not meet the current requirements of the BC Building Code (BCBC). The process includes technical reviews for adequate safety levels, replacing BCBC building requirements that aren't applicable with substitute requirements giving the same level of performance.

– taken from *A Guide to the Building Act: Modernizing BC's Building Regulatory System, June 2015 – BC Office of Housing and Construction Standards*

Fire Engineering

"80 per cent of the work for this project was pre-construction, 70 per cent alone was gaining code approval."

Andrew Harmsworth
Fire Protection Engineer
GHL Consultants Ltd.



Credit: Acton Ostry Architects

Project – Structure rendering

structural wood except for a few columns on the 18th floor, a non-visual grade could be used. Also, the cross-section of each element could be smaller since there was no provision needed to accommodate charring.[2]

The building was designed according to the not-yet-adopted 2015 NBCC rather than the prevailing 2012 BCBC, which significantly increased applicable seismic acceleration values. Peer reviews were obtained from two third-party structural engineering teams, one local and one international. Additionally, an in-house structural engineering peer review was also undertaken by the project engineers, Fast + Epp.

The local peer review team, which had an expertise in local and provincial building codes, focused its efforts on the structural concept and code issues, looking at strategies for addressing gravity and lateral loads of individual elements and connections, as well as the hybrid construction system as a whole. The international peer review team, which had an expertise in the construction of mass timber buildings, primarily focused its efforts on the mass timber components with respect to gravity loads and ultimate and serviceability limit states.

The analyses of the peer reviewers validated the designers' applications of the codes and reference standards and provided recommendations for areas of further analysis. They also validated flexural, shear and fire safety designs; deflections; vibrations of the CLT panels; and stability and fire design of the GLT and PSL columns, along with their differential movement and settling, all of which were based on the structural engineer's load assumptions.

Key presentations on the technical aspects of the hybrid structure were made in March 2015.

The project team had to expound on the mandate they had been given by UBC PT. UBC wanted a successful project that provides quality housing for its students, that met the budget and would spur the development industry to consider mass timber as a viable construction alternative. A modest project was seen as a way to achieve this, and ensure the actual construction of a mass timber building, whether the wood was exposed or not.

In April 2015, once members of the expert panels were convinced that the proposed design solution would meet or exceed the requirements of the building code and that the idea was not to create a showpiece for wood, but rather to create a structure demonstrating wood as a viable structural alternative in high-rise construction, they gave their unanimous support. Work was ready to start in earnest on a SSR.[3]

2 Heavy timbers, wood elements meeting minimum thickness requirements, have an inherent fire resistance, with a slow and predictable burning rate of approximately 0.6 mm/minute under standard fire test conditions. The resultant char layer protects the unburned portion of the wood. The NBCC and BCBC recognize this characteristic and allow for unprotected heavy timber elements with certain minimum dimensions in combustible construction requiring a 45-minute fire resistance rating as well as in some noncombustible construction applications. It also permits unprotected mass timber elements designed for fire-resistance ratings of one hour or greater using test data or empirical calculation methodologies in combustible construction.

3 For unprotected heavy timber elements with certain minimum dimensions in combustible construction requiring a 45-minute fire resistance rating as well as in some noncombustible construction applications. It also permits unprotected mass timber elements designed for fire-resistance ratings of one hour or greater using test data or empirical calculation methodologies in combustible construction.

The site-specific *UBC Tallwood Building Regulation* was approved by the BC Minister Responsible for Housing on September 29, 2015. The regulation, which applies solely to the Brock Commons building site and does not serve as a precedent for future projects per se, exempts the Brock Commons project from the height restrictions for combustible construction. It substitutes other specific technical requirements that ensure occupant health and safety protection as equivalent to or better than what is provided in the BCBC for a similar-sized building of noncombustible construction. The structural and fire safety of the final hybrid mass timber design achieved a level of safety that was evaluated by the expert panels as being the same or better than that for a building of noncombustible construction, such as a concrete or steel building, notwithstanding the use of mass timber elements. For this reason, the Brock Commons design was accepted as being code compliant.

Following the approval of the *UBC Tallwood Building Regulation*, the BSSB and the project team solicited feedback from the expert panels on specific design strategies and decisions. The review process resulted in agreements on technical requirements specific to the site; it transferred the monitoring and oversight for certain aspects to the University's Chief Building Official, and other aspects to the discretion of the project team who were charged with following principles agreed to during the development of the site-specific regulation.

Fire protection features

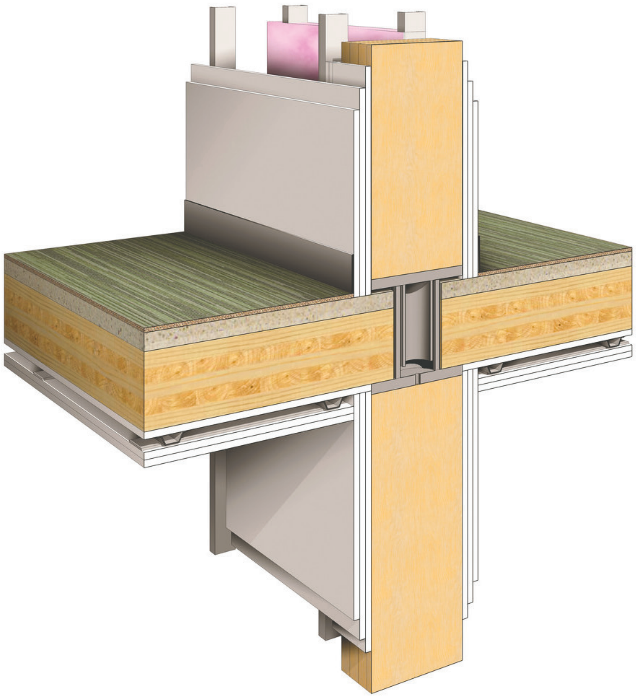
Passive fire protection techniques, as well as active fire detection and suppression systems were used to achieve a level of occupant health and safety protection that is equivalent to or better than that afforded by the BCBC for a similar-sized building of noncombustible construction. Additional measures were put into place for protection during the construction phase.[4]

Passive fire protection strategies employed are a direct result of the design philosophy adopted at the very beginning of the project to *keep it simple*. These strategies included the decision to use a noncombustible structural system for the ground level and noncombustible stair/elevator cores, along with the full encapsulation of the mass timber structure. Multiple layers of Type X gypsum board were used to provide a two-hour fire-resistance rating (2HR FRR) for all mass timber structural assemblies (GLT and PSL columns, and CLT panels).[5] There are no interconnected floor spaces and a 2HR FRR separates each floor level as well as all vertical shafts.

As a result of the multiple layers of gypsum board used for the typical wall assemblies, the demising walls between units provide a 2HR FRR, even though a 1HR FRR would meet code requirements. The corridors are pressurized and the walls separating units from the corridor afford a 1HR FRR.

4 Strategies put in place during construction are discussed in the Construction section of this document.

5 GLT columns are exposed in the student study and social space at the 18th floor.

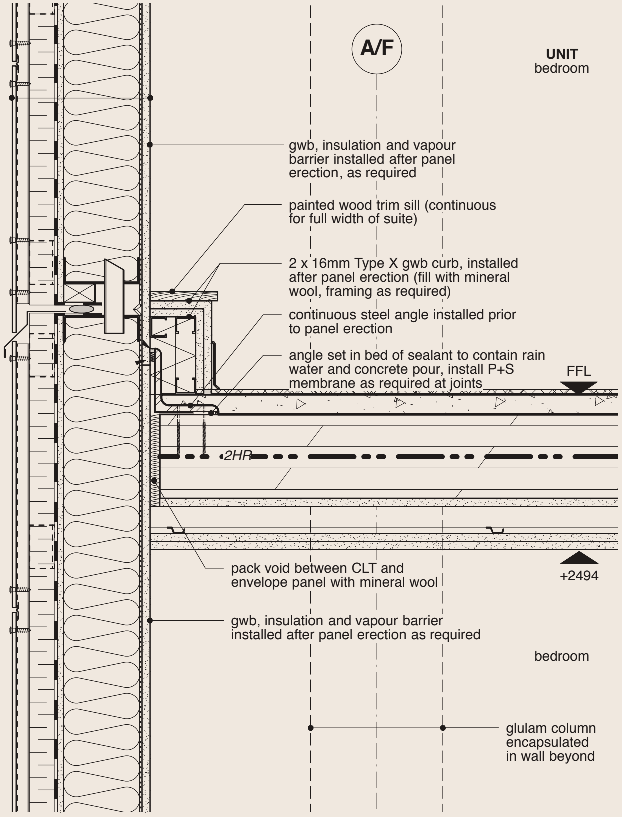


Credit: Acton Ostry Architects

Typical floor and column cross-section

Encapsulation

GLT and PSL columns, as well as the underside of the CLT panels, were encapsulated with three layers of gypsum board; a concrete topping was applied to the upper side of the CLT panels to improve the acoustic performance of the floor assembly.



Credit: Acton Ostry Architects Inc.

Exterior wall and floor plate – Typical cross-section

Fire-stopping tests were carried out for various penetrations through the CLT panels to determine the best approach for a 90-minute fire-protection rating (FPR). Copper, cast iron and PEX piping were all tested. Two hours into the testing demonstrated that protection was still intact at all penetrations, with minimal gypsum board loss and 0-1/4 in. of char at the underside of the CLT panel.

FPR separations are common to noncombustible residential high-rise buildings as well as to many low-rise and mid-rise buildings of combustible and noncombustible construction in BC. They help maintain structural integrity to ensure adequate time for occupant egress and first responder access, as well as limit fire propagation between storeys in the event of a sprinkler system failure.

Active fire protection strategies employed throughout the building include sprinklers on all floors. A single stage and addressable fire alarm system is installed, which includes audible as well as visual signal devices. The alarm and sprinkler systems are monitored and electrically supervised with signals going directly to the Vancouver Fire Department.

The automatic sprinkler system and standpipe system are connected to the municipal water supply. In addition, a fire pump and a 20,000 litre backup water supply tank are located below the ground floor slab. They are run by an independent emergency power source and provide 30 minutes of water. Expansion joints are installed where sprinkler risers exit the concrete core at each level to ensure the integrity of the sprinkler system's operation in case of building movement.

There are fire extinguisher stations at each level and sprinkler heads in the residential units are recessed to limit potential accidental damage. A sprinkler system is installed under the exterior CLT canopy at the ground floor level as well.

Water curtains are used for areas with non-fire-protection rated openings, found on the ground level public spaces in proximity to an adjacent parkade structure.

3D Virtual Modelling

The virtual design and construction (VDC) modeller, added to the design team early in the design process, was tasked with developing and maintaining a single comprehensive 3D virtual model of Brock Commons. The 3D virtual model was used to assist in design development and decision-making as well as fabrication and construction.

The most effective VDC modeller is one with a knowledge of relevant construction processes and methods, as well as an understanding of systems installation. The design-assist trades worked with the modeller to ensure a working knowledge of sequencing and constructability. The modeller then collected all relevant project information from 2D drawings and 3D design models to create a singular comprehensive virtual model of the building with a high degree of detail. The process freed the design consultants to focus on developing their individual designs, using their familiar modelling and drafting tools, without concern for interoperability of the various consultants' software programs.

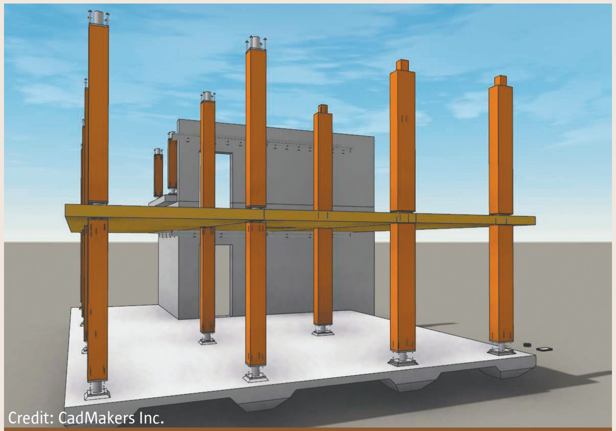
Having been brought on board in the early stages, the VDC modeller was prepared and able to provide rapid feedback during the three-day integrated design workshop to inform the decision-making process of the design team and key specialty trades. The modeller worked closely with the structural engineers to export detailed 2D structural CAD drawings from the 3D model. As the team assessed and refined options for the structural systems, and estimated costs and impacts of various engineering systems, the VDC modeller updated changes in real time. Three structural solutions were modelled and the quantities of timber implicit to each were extracted, along with construction sequencing, thereby providing valuable information during the selection process.

The coordination of building systems design was greatly facilitated with the work of the VDC modeller. The design team defined the routes for utilities and services, and as design iterations and updates were reflected in the virtual model, the modeller identified conflicts between different system layouts, resulting in a higher level of coordination for the building systems design before construction.

At the direction of the design team, the VDC modeller helped to place and size penetrations in each of the prefabricated CLT panels to accommodate the required pipes, shafts and cabling, and ensured the appropriate clearances and spatial requirements.[6]

A simulation of the installation sequence, developed for the 3D virtual model, provided an overview of the assembly of various building elements. This allowed for a visualization of the construction process by members of the project team, who were then able to identify and pre-emptively resolve some of the constructability issues that would have otherwise

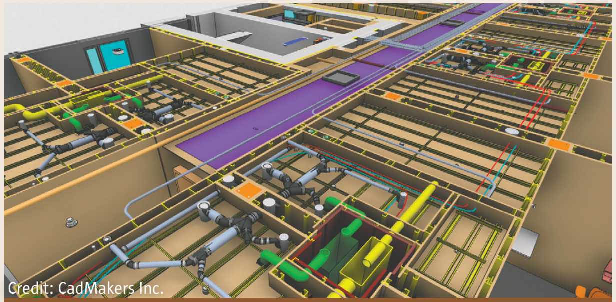
6 Since the mechanical trades were not brought onto the initial design team, routes for utilities and services had to be refined once they were brought on board.


Credit: CadMakers Inc.
Virtual design – Mock-up

Credit: CadMakers Inc.
Virtual design – Core formwork

Professional Responsibility

Professional responsibility and liability were maintained with the registered coordinating design professional and with the professionals-of-record in each discipline. The contract documents are the 2D drawings and specifications produced by the architects and engineers.



Virtual design – Typical floor/ceiling MEP system

Virtual Design – Positive Outcomes

The time spent on planning utilities layouts and building sequencing in the virtual model saved time on the actual build. Issues that arose were much less costly to correct, both in a monetary sense and in terms of lost time.

Virtual Design – Benefit

"The virtual model allowed everyone to see the same thing at the same time, without having to rely on imagination; it even identified critical paths to meet the schedule. It was such a huge help in coordinating work on site that it is now in the budget for all future Urban One high-risk projects."

Karla Fraser
Project Manager
Urban One Builders

caused on-site delays. The trades worked with the modeller, explaining specific processes, helping the modeller's understanding so that sequencing could be optimized.

When incongruities were identified, or constructability compromised, the modeller would go back to the project team for resolution. In this way, many constructability issues that typically arise were "virtually" eliminated.

Having already worked with the design team to locate and coordinate penetrations and connections in the various elements, the VDC modeller subsequently worked with the mass timber supplier to develop the approval and fabrication protocols for the shop drawings. The design model was eventually transferred directly to the fabricator for use during the construction phase for the fabrication of the structural elements. This information transfer was put to the test during the full-scale mock-up of a portion of the building, which was developed during the design phase. (Please refer to the next section.)

Due to its high degree of accuracy, the virtual model was also used for quantity takeoffs of materials throughout the design and pre-construction phases. Removing the guess work permitted many aspects of the project to be modelled in exacting detail, sometimes down to the individual nuts, bolts and screws.

The 3D virtual model and simulation demonstrated their usefulness beyond the design and pre-construction phase. During the tender process, they assisted in the generation of more accurate bids. They helped the trades understand the scope of their work relative to the project and demonstrated that innovation does not necessarily imply complexity or risk. The practical fallout: trades were able to reduce their contingency and risk allocation costs.

The daily construction sequencing process developed using the virtual model was paramount in maximizing the efficiency of the project's crane. The modeller assisted the construction manager and developed videos that establish the methodology and sequencing for construction that could be viewed by the sub-trades.

Virtual modelling assisted with identifying a specific location on the working platform for every formwork component used in the construction of the concrete cores. Every step of the installation and removal process was optimized for efficiency (read "speed") and safety. Workers accessed the animated videos from their cell phones on site to ensure adherence to the established protocols.

Dassault Systèmes'® Catia software was used to assess constructability and optimization throughout the design and construction process. The Brock Commons hybrid mass timber building was virtually constructed numerous times by the modeller, thereby greatly facilitating the coordination of assembly and construction sequencing. The virtual model helped to reduce requests for information and change orders during construction, which in turn reduced paperwork and costs. In the final analysis, virtual modelling turned out to be a very important aspect of the design process.

Full Scale Mock-Up

A full-scale, 2-storey proof-of-concept mock-up was constructed by the construction management team and design-assist trades in July 2015 to test and validate the design's viability and constructability. The virtual model was used as a template for the 3-bay by 3-bay mock-up (approximately 8 metres by 12 metres). All mass timber products were digitally fabricated using the VDC model.

The mock-up assisted in testing various interfaces and included the primary elements and connections that were to be used in the final building. It included a cast-in-place concrete core wall, concrete footings to mimic the second floor concrete transfer slab, the CLT floor plate assembly and GLT columns, all relevant connections, different finishes and various prefabricated building envelope panels. With the participation of the design-assist trades, the team was able to obtain feedback on the erection process.

The constructability of connections, column-to-column, column-to-floor assembly, CLT panel-to-concrete core, and CLT panels-to-building envelope panel, were also evaluated. Construction of the mock-up permitted a realistic assessment of the constructability for the various connection details, as well as the protective coatings and cladding options. The best type of concrete topping and wood sealer to be used to protect exposed wood during construction was determined during the mock-up as well.

Three different column-to-column connections were tested, two wood-to-wood connections and one steel HSS column-to-column connection. The latter connection was selected for the Brock Commons building as it proved to be the easiest to erect and shim, and provided the tightest tolerances. It also allowed for the smallest column size.

Building envelope panel installation was optimized with the work done during the proof-of-concept mock-up, in conjunction with additional in-lab testing. Laboratory testing helped to arrive at a full understanding of building movement tolerances and weather tightness.

When University representatives saw the originally specified metal cladding go up on the mock-up, they instead opted for a wood-fibre laminate cladding which complemented the building. Final installation time for the 8-metre-long building envelope panels of floor-to-floor height was approximately 10 minutes per panel.

The virtual model helped optimize construction sequencing through lessons learned during the construction of the mock-up.

Moisture monitoring of the proposed floor system was also undertaken at the mock-up.

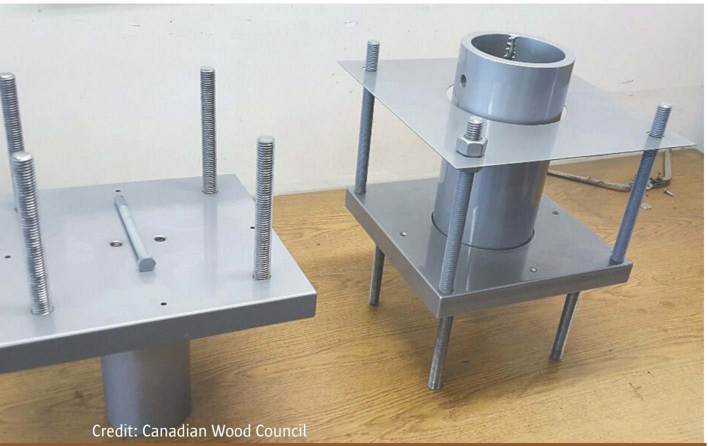
Post-and-Panel Mass Timber System

In addition to accommodating the 404 beds and specifications requested by the University and fitting the 18 storeys within the building height limit on the campus, the benefits from the elimination of beams in the two-way CLT flat-plate floor system were:

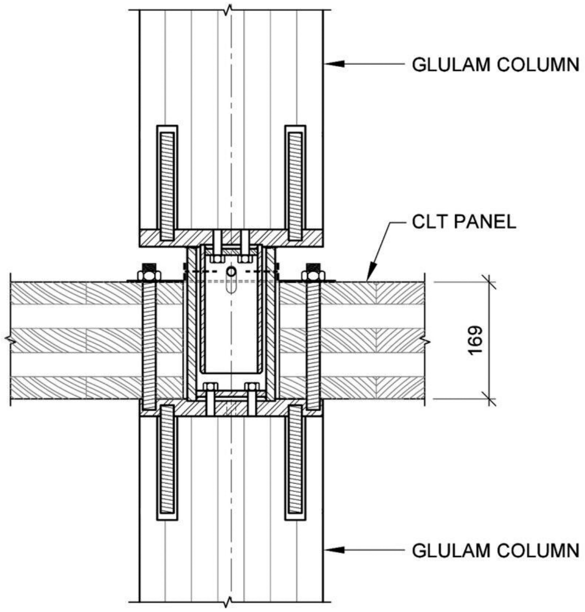
- no horizontal restrictions for the distribution of the buildings' MEP systems;
- optimization of the volume of wood utilized to build the structure;
- reduced number of crane lifts;
- quicker construction schedule; and
- lower overall costs.

Credit: naturallywood.com. Photographer: KK Law

Mass timber – Post-and-panel system



Column-to-column connector parts



Adapted from Fast + Epp

Column-to-column detail

Structural Engineering

What sets the Brock Commons building apart from other mass timber structures that have come before it is the use of CLT panels in their inherent two-way spanning capability throughout, thereby eliminating the need for beams and significantly reducing the structural depth of the building. This, coupled with the adjustment of the column grid and architectural program to suit the maximum available panel size, permitted the design team to minimize the overall number of panels required per floor, while maximizing the structural efficiency of the system.

The hybrid structure uses a dual-pronged approach for managing gravity and lateral loads. The mass timber floor plates (CLT), located on levels 3 to 18 are point-supported by GLT and PSL columns, which carry the gravity load of the upper floors and transfer it to the second floor concrete transfer slab, and down through its support structure – concrete columns, foundations walls and spread, and perimeter footings and raft slabs (referred to collectively in this text as the reinforced concrete foundation and podium). Crushing of the CLT floor plates was prevented by directly transferring loads from upper columns to lower columns through the HSS steel connectors.

Lateral loads are carried through the CLT floor plate diaphragms at levels 3 through 18 and transferred to the concrete cores through steel drag straps and ledge angles, then down to the reinforced concrete foundation and podium. The floor plate diaphragms are achieved by joining the CLT panels together with plywood splines that are screwed and nailed to each panel on site.

The hybrid mass timber structure is significantly lighter than a comparably sized concrete structure. The lower mass, and hence lower inertia, results in a reduced resistance to overturning forces during a seismic event, which is counterbalanced by the concrete stair and elevator shafts through the height of the building.

Addressing gravity loads

Evaluation of moment and deflection demands on the two-way-spanning CLT panels, using finite-element analysis, pointed to the need for a custom layup of the panels, as existing standard layups in the western Canadian market could not meet the required performance.

Stiffness and bending requirements notwithstanding, what really controlled the design for the point-supported system were the rolling shear stresses at the supports of the two-way, point-supported CLT floor plates.[7] Rolling shear stresses

7 The CLT fabrication standard ANSI/APA/PRG 320 specifies rolling shear resistance values for CLT panels at approximately one-third that of longitudinal shear resistance values.

in point-supported panels can be approximated using tributary area and panel geometry (including distance to critical section and panel depth). With 78 columns per floor, there are 1,248 CLT panel nodes in the building where rolling shear stresses could be the controlling design factor.

Several full-scale load tests were undertaken on panels from prospective suppliers (at the FPInnovations laboratory in Vancouver, BC). Two CLT panel configurations were used; one with mechanical service penetrations and one without. Loading results demonstrated two things:

- rolling shear capacities are in fact higher than the values published in ANSI/APA/PRG 320; and
- panels without service holes controlled the panel design as they were subjected to heavier corridor loading.

Addressing lateral loads

Two concrete cores, designed as ductile concrete shear walls in the shorter, north/south direction, and partially coupled ductile concrete shear walls in the longer, east/west direction, provide the primary lateral support for earthquake and wind loading in the building.

The floor diaphragms are a critical part of the lateral support system. The CLT panels and connections for the structure had to be designed to remain elastic for energy dissipation when the cores yield in flexure.

Continuous Douglas fir plywood splines, nailed into CLT dadoes with ring shank nails, transfer in-plane diaphragm shear forces between panels. Partially threaded screws transfer vertical shear across panel joints and ensure a flush panel-to-panel fit.

Steel straps, fastened to the CLT floor plates with partially threaded screws and bolted to cast-in embed plates, drag diaphragm forces into the cores.

As with the CLT floor plate diaphragms, the reinforced concrete foundation and podium was designed as a "capacity-protected" element to resist overturning moments equal to the probable flexural capacity of the cores.[8]

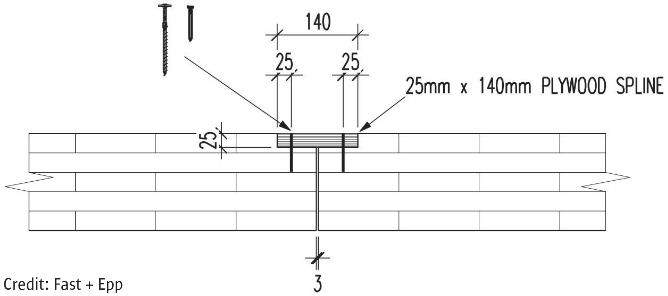
Specific factors also addressed in the design of the Brock Commons hybrid mass timber structure were axial column shortening, dynamic and wind-induced vibrations, and progressive collapse.

8 The probable capacity of the cores is calculated by removing material safety factors and increasing yield strength of reinforcing by 25 per cent, resulting in a calculated capacity of approximately two times the design value.


Credit: naturallywood.com. Photographer: KK Law
Drag strap and angle iron connection to the reinforced concrete core


Credit: naturallywood.com. Photographer: KK Law
Column-to-CLT slab detail before concrete topping


Credit: naturallywood.com. Photographer: KK Law
Plywood spline fastened to the CLT floor panels



Credit: Fast + Epp
Typical plywood spline detail

Mass timber and reinforced concrete hybrid system

Axial column shortening and shrinkage

Several factors contribute to axial shortening of GLT and PSL columns, including dead and live loads, shrinkage parallel to the grain, joint settlement, column length tolerances and wood creep. When properly addressed during the design phase, however, axial shortening and shrinkage should not negatively impact construction or long-term performance of a tall wood building.

Consideration was given to the impact of deformations on vertical mechanical services and elevation tolerances between the wood super-structure and the stiff concrete cores. The cumulative effect of the potential deformations for all columns would be most important at the roof level; if left unchecked, axial shortening could have resulted in nearly 50 mm of estimated deflection.

The strategy for mitigating the axial column shortening and shrinkage was to add a series of 1.6-mm-thick steel shim plates at the column-to-column connections at three strategic levels: floors 7, 11 and 15. Due to expected variations in elastic modulus and a degree of uncertainty surrounding anticipated shortening values, only 50 per cent of the calculated deformations were shimmed to avoid overcompensation. Continuous mechanical stacks and HVAC services were designed to accommodate up to 32 mm of deflection.

Ongoing monitoring of the permanent sensors embedded in the building will be managed by UBC.

The practical vertical tolerance of the cast-in-place concrete door and elevator sills is fairly significant at +/- 19 mm. Details were created to accommodate axial shortening of the adjacent timber structure at these locations. The dimension between the core ledger angle, welded to concrete wall embeds for the CLT panel edges, and the cast-in-place concrete door and elevator sills was measured at each level to identify if discrepancies between actual and theoretical measurements could be corrected by sloping the concrete topping within allowable dead load limitations, or chipping of the cast-in-place sills if necessary.

Dynamic wind-induced vibrations

Wind-induced vibrations are a controlling factor in tall buildings, and in tall wood buildings due to the reduced weight of the structure. The NBCC 2015 requires a dynamic wind load analysis for structures taller than 120 metres, those with a height-to-width ratio greater than 4.0, or those with natural frequencies of less than 1.0 Hz. As the Brock Commons building had a first mode frequency of 0.5 Hz, in part because of the reduced weight of the structure, a dynamic wind load analysis was undertaken using a finite-element model to study a 10-year return period for wind loading.

The Brock Commons building was designed to limit wind-induced accelerations to 1.5 per cent of gravity at level 18. A value for damping needed to be assumed during analysis to arrive at this determination since limited research exists for tall wood buildings. A recent FPInnovations paper suggests, however, that in-situ damping ratios for mid-rise mass timber buildings with varying lateral force-resisting systems is increased with the additional mass of non-structural components such as partitions, finishes and furniture. The assumptions used to determine a damping value of 1.5 per cent for the Brock Commons building will be monitored for validation during the life of the building.

Progressive collapse

The mitigation strategy employed to address progressive collapse in the Brock Commons project is the column tie method as outlined in EN 1991-1-7. In the event of a column failure, tension ties will suspend the floor below to prevent the sequential spread of local damage from element to element, thereby preventing the collapse of the building or a portion thereof.

The tension ties are created by installing bolts and cotter pins through the steel tube sections at the column-to-column connections and epoxying the threaded vertical rods from the plates into the column ends.

Connections

Steel connectors used in the hybrid mass timber building meet several ASTM standards, including standards for coatings, bolts, studs, threaded rods, carbon and alloy steel nuts, rolled or welded structural quality steel, certification of companies providing the fusion welding, and metal arc welding.

Credit: naturallywood.com. Photographer: KK Law

Drag stap connecting CLT floor panels and reinforced concrete core

Credit: Canadian Wood Council

Placing the first columns on the transfer slab

Construction

Pre-construction planning

Key strategies were developed during the pre-construction planning phase to address primary challenges during construction: construction scheduling, possible fire events and possible water events.

Construction scheduling was identified as a challenge early in the process. With practically no available storage on the narrow site, just-in-time delivery would be in order. This necessitated input and buy-in from all the major trades and a strict understanding of construction timing requirements. A proactive procurement process was used for the delivery of all major materials, systems and equipment, tracking availability prior to their need on site.

The fabrication of elements was arranged in a linear process to coincide with the construction schedule. Prefabricated elements were loaded onto trucks in reverse order of installation, which permitted installation directly from the flat-bed of the truck onto the building.

The tight physical constraints of the site also restricted the number of cranes and construction crews that could be practically accommodated. To address this, the decision was made to completely separate concrete works from the mass timber assembly. In this way, once all 18 storeys of the concrete cores were fully erected, the site's single crane could be dedicated to the erection of the mass timber super-structure and the installation of the building envelope panels.

Concrete works were scheduled during the winter months. Erection of the wood super-structure took place in spring and summer to reduce weather-related delays. Components for the mass timber structure and building envelope panels were prefabricated and stored off site. VDC modelling helped to coordinate crane lifts so that building envelope panel installation could follow shortly after the erection of the super-structure elements, thereby closing and protecting the structure as soon as possible.

Possible fire events were curtailed during construction through the requirement of permits for any hot work, along with the posting of fire watch personnel during all such works. Detailing of the wood structure was approached with the goal of eliminating, or at least minimizing the need for on-site welding, thereby reducing the amount of necessary hot work.

The installation of fire standpipes kept pace with the erection of the mass timber super-structure to within four storeys. These installations included temporary Siamese connections for fire department use should the need arise.

On-site personnel received fire prevention and fire response training, and a fire safety plan was created for the project, then reviewed and approved by the Vancouver Fire Department.

Encapsulation of the mass timber structure also kept pace with its erection, to within six storeys. For the CLT floor panels, this meant the installation of Type X gypsum board on their underside; for the GLT/PSL columns, this meant installation of Type X gypsum board on all sides.

Possible water events were minimized during construction by scheduling the erection of the mass timber super-structure during the drier summer season. Water-resistant coatings were applied to wood elements at the manufacturing facilities to minimize water absorption on site.[9] The concrete topping of the CLT flat-plates was sloped to direct drainage, and temporary rain protection screening was erected as needed.

The installation of building envelope panels kept pace with the mass timber super-structure erection to within three storeys of the active CLT installation level. This timeline was shaved to within one storey once the installation technique was mastered. Main water lines to the building were shut off after normal working hours when water flow alarms were activated.

At the roof level, to minimize water damage to the mass timber structure from potential leaks after occupancy, the decision was made NOT to go with a wood-based roof structure assembly. Larger panelized and prefabricated wood systems would have created some logistical as well as safety challenges for the existing crane, along with concomitant time and cost implications.

The build

The site for the new Brock Commons building was cleared in November 2015.

Reinforced concrete works started after eight soil anchors were positioned, with the pouring of foundations footings in December 2015.[10] By January 2016, the installation of steel reinforcement for the concrete columns on the ground floor had begun and by February, with some columns already poured, work started on the ground floor concrete core walls.

9 An extra water-resistant coating applied on site proved to be unnecessary as the curing process for the concrete floor topping was sufficient to control CLT floor panel moisture content.

10 The concrete podium and stair/elevator cores are reinforced cast-in-place concrete.

Credit: naturallywood.com. Photographer: KK Law

CLT panel installation


Credit: naturallywood.com. Photographer: KK Law
CLT panel installation

In March 2016, the second floor 600-mm transfer slab was formed and poured. The VDC model was used to specify the exact locations of mechanical, electrical and plumbing (MEP) penetrations in the transfer slab to ensure that MEP penetrations aligned from floor to floor and did not interfere with reinforcement steel.

Once the transfer slab was poured and sufficiently cured, the reinforced concrete was drilled and steel anchors were inserted and epoxied in preparation for the connection of the first level of mass timber columns. At this point, work on the concrete cores commenced in earnest.

A specially designed lifting formwork system was used for construction of the cores, which included a safety platform for the workers and “outside and inside form boxes” that were two storeys in height. Pouring two storeys at a time enabled tighter controls, as much for the lateral tolerances of the freestanding cores as for the internal tolerances of the elevator shafts themselves. A more conventional slipform system could have been used for the cores but was unavailable for the project.

The symmetrical nature of the concrete cores permitted re-use of the formwork not only from one level to the other, but also between cores. VDC modelling optimized every step of the formwork installation and removal process for speed and safety. The cores were completed by the end of May 2016.

The effectiveness of the virtual model as a communication tool was brought home during the construction of the concrete cores. The 3D model allowed trades to see and understand their role, identifying access routes for emergency evacuation during construction, and even critical egress paths for the finished building.

The virtual model was essential in determining the dance of the formwork as panels were transferred from one core to the other, sequencing their erection and dismantling with the available deck space around the cores, all the while coordinating the crane lifts and even identifying the position of workers throughout the process.

Once work on the concrete cores was completed, the focus was shifted to the erection of the mass timber super-structure.

Mass timber super-structure erection commenced in June 2016. Delivery and sequencing for the erection of the mass timber super-structure were developed and optimized by the construction team with assistance from the virtual model, as was the case with the concrete works that came before.

The first level of GLT and PSL columns was erected at the second storey transfer slab onto the pre-installed steel anchors and connections. Once the columns were in place, the first CLT floor level was installed, starting at the concrete cores. The erection of subsequent floors of mass timber elements took place as follows:

- GLT and PSL columns were lifted onto the active level in bundles where they were installed and braced in their prescribed locations. All but the perimeter columns were manually installed; perimeter columns were lifted using a special rigging developed by the erectors. Steel tube connections at the top of each column were aligned and fitted inside the bottom column connection and fixed with a steel pin.
- Before CLT panel installation on the subsequent level commenced, horizontal spreader braces were placed at the column caps to set the grid and temporary diagonal bracing was installed to keep the columns from tilting and rotating.
- CLT panels were installed on the uppermost deck, angling them into position and "stitching" panels together with plywood splines nailed and screwed into place once all the 29 CLT panels were installed, connecting them into a single diaphragm. The balanced lift of each CLT panel was afforded by a four-point custom-engineered lifting hardware that was developed by the timber erector and installed in the pre-grooved rigging placement on site.
- Steel drag plates and straps were then installed at the concrete cores, and perimeter angles were installed at floor plate edges for support of the curtain wall system.
- Fall protection was installed.

And so up it went, floor upon floor. As construction progressed, the trades familiarized themselves with the processes and techniques, which resulted in increased efficiencies. Laser measurements used to ensure accuracy of the mass timber component installation helped to tighten tolerances even further. Eventually, they were erecting one floor of the mass timber structure every three days, including CLT panels and GLT columns. Only nine workers were needed to rig components off the delivery trucks and on the active level for the installation of the mass timber components.

The highly coordinated process of erecting the mass timber CLT panels and GLT/PSL columns, including the installation of building envelope panels, was completed two months ahead of the initial schedule laid out by the construction manager for the project.


Credit: naturallywood.com. Photographer: KK Law

Pumping concrete – Stairs and landings

Credit: naturallywood.com. Photographer: KK Law

Glulam column installation

Building envelope panel installation was also optimized by the virtual model which helped identify delivery and sequencing schedules for these prefabricated elements.

A steel I-beam spreader bar was used to rig each panel from the lifting points identified during manufacturing. The crane lifted and held panels in position while workers at the lower edge fitted alignment pins at the base of the panel into the header keyway connections. Workers at the upper edge then fastened the bolts to the steel perimeter L angles. Tolerances built into the envelope panel connections allowed wiggle room to permit manual positioning of the panels with the use of shims to ensure accuracy and proper alignment. Once the panels were in the right position, they were unhooked from the crane and the bolts were fully tightened.

Following installation of the building envelope panels, backer rods, caulking and fibreglass batt insulation, along with the vapour barrier and interior wall finishes were added on site. (The final insulated envelope panels achieve an effective thermal resistance of R-16.)

The prefabricated building envelope panel system facilitated closing in the building as the mass timber structure was going up, thus providing protection from wind and rain and reducing the risk of damage during construction. Initially, building envelope panels were installed three levels below the active deck, but that was eventually optimized to only one level below. Envelope panels and panel connections were tested for weather tightness after installation.

Encapsulation of the mass timber floor structure followed five floors below the active CLT installation level.

Encapsulation included one layer of Type X drywall on the underside of the CLT panels. The concrete topping of the CLT panels, primarily designed for acoustical purposes in the finished building and not calculated or required for the floor assembly fire rating, pulled double duty by acting as part of the water-protection strategy during construction.

The concrete topping used is a free-flowing, pump-applied cement-based screed. It provides a smooth level surface to receive floor finishes and has low shrinkage values, thereby requiring fewer construction joints. It could receive foot traffic in 48 hours, so demising wall partitions and rough-ins were able to be installed in a week.

With a floor going up every three days, only four levels were ever left fully exposed at any given time.

The traditional steel roofing system, comprised of steel beams and decking, had to be held to a higher standard than the industry norm when considering construction tolerances. The inherently tighter tolerances of the prefabricated elements, that is of the mass timber super-structure and of the building envelope panels, meant that close consideration was needed to marry the two systems at the roof level to ensure tight interfaces and secure connections.

Interior construction activities, including the installation and finishing of partitions and services, required the use of a cantilevered loading platform for the delivery of materials as there was no construction lift on site and the installation of the permanent elevator was delayed. The crane was used to assist in bringing materials to the upper floors, moving the loading platform between floors as needed. Because worker movement up and down through the building was limited to the stairs, work in some areas of the building actually progressed faster than expected.

The design had prioritized the consolidation of vertical mechanical shafts and had limited penetrations through the CLT floor panels and envelope panels, all in an effort to mitigate the risks associated with water events both during and post construction. Drains were added in each bathroom to minimize water accumulation in case of plumbing fixture overflows or leaks.[11]

The tight tolerances afforded by detailed VDC modelling, in conjunction with the tight tolerances of the prefabricated mass timber structural elements, resulted in on-site dimensions of systems and interior components that were very close to the designed dimensions. As the accuracy of the dimensions became apparent, much cutting-to-size of MEP components was moved back to manufacturing facilities; ducts, pipes and other components, and even the welding of certain assemblies, was done off site, along with some pre-assembly. Consequently, the timeline was compressed and installation of the mechanical room, which would typically take three to four months of on-site work, was completed much more quickly.

The need for on-site adjustments to interior framing and millwork was also minimized, such that installation of the steel stud partitions, gypsum board, and laminate particleboard cabinetry and millwork moved forward in an organized fashion, with minimal impact between trades to affect the sequencing of interior construction activities.

A benefit to the accuracy of dimensions was the reduction of construction-related noise and disturbances from the site. Normally, reinforced concrete sites the size and scale of the Brock Commons project are much noisier. Little or no concrete jackhammering or cutting occurred. The tight tolerances of the prefabricated mass timber elements and the quick installation of the building envelope panels, and even the precutting and partial pre-assembly of certain services off site, meant less need for those activities on site, all of which contributed to reducing site-related disruptions in the vicinity.

The number of trucks required to deliver materials for the construction of the structure, specifically ready-mix concrete and reinforcing steel (rebar) shipments, was easily one-third of that for a similarly-sized conventional Vancouver high-rise.

11 It may be pertinent to consider adding drains to kitchen areas in future projects.

Credit: naturallywood.com. Photographer: KK Law

Building envelope panel installation

Credit: Canadian Wood Council

Detailed CLT panels

Manufacturing

The ability to off-site prefabricate structural components and building envelope panels was key to the successful construction of the project. The manufacture of mass timber components and building envelope panels began three months before the concrete cores were completed. Most mass timber elements were manufactured by the first week in June, when work on the concrete cores was completed.

All CLT, GLT and PSL elements were CNC-machined (computer numerical control) in plant. Virtual modelling assisted in developing erection and shop drawings, refining the routes for utilities initially defined by the design team, and determining the precise placement and size of penetrations to accommodate pipes, shafts and cabling. All the GLT and PSL column-to-column connectors were pre-installed at the manufacturing facility.

Each mass timber component received a unique identifier to assist in tracking and to facilitate assembly on site.

GLT and PSL columns – manufacturing plant preparation:

- Connection holes in both ends of the mass timber columns were CNC'd in plant.
- Steel connections were fabricated separately and installed on the columns during the prefabrication process.

CLT panels – manufacturing plant preparation and site-applied treatments:

- Plumbing line panel penetrations were CNC-routered into the components; peel-and-stick membranes were installed to protect holes during transit and were removed only when services were installed.
- Plywood inserts were installed to protect shaft openings. They were sealed into place with peel-and-stick membranes. Temporary drains were added at the shaft locations on site to help collect, control and divert rainwater during construction.
- Miralite Side Sealer, a clear, penetrating sealer for use as a temporary protectant on laminated or other wooden beams and timbers, was applied on panel surfaces at the plant to help keep the moisture content of the panels below 20 per cent, the threshold for potential mould growth. Another sealing coat was applied on site, but this only led to adhesion challenges for the concrete topping, which had to be screwed down in places. After placement, it was observed that the concrete curing process pulled enough moisture out of the CLT panels to keep the moisture content within an acceptable range.
- Peel-and-stick membranes were installed along the splines at CLT panel edge connections on site to stop water from penetrating to the floor below.[12]
- Grooves were machined into the panels to identify rigging placement for on-site delivery and installation.

12 The peel-and-stick membranes applied to the CLT splines later proved ineffective in stopping the flow of water through the panels on site. The concrete topping became the preferred method of stopping water flow through the panels.

Building envelope panels

The exterior walls of the building are a partially prefabricated steel-stud panel system with the following in-plant layup:

- 16-mm-thick exterior, weather-proof gypsum sheathing panels, applied to the exterior of the steel studs;
- resistive liquid-silicon air and water membrane, applied to the exterior gypsum sheathing panels to act as a sealant;
- exterior high-density semi-rigid stone-wool weather and thermal insulation board, applied to the sealed gypsum sheathing panels; and
- CSA-approved high-pressure laminate panel cladding, consisting of 70 per cent wood-based fibres and resin (Trespa® panels), applied to the insulation board as the finished cladding.

Windows were installed before delivery to the site. Caulking was applied in plant to the interior side of the envelope panels to reduce future failure from weathering.

Each floor of the building has a total of 22 envelope panels – four corner panels (two types) and 18 flat panels (12 types). The parapet also comprises of 22 panels but only comprises of two corner panel types and two flat panel types. Rigging points to facilitate lifting into place on site were identified during the manufacturing process.

Credit: naturallywood.com. Photographer: KK Law

Building envelope fabrication

Credit: University of British Columbia. Photographer: Azadeh Fallahi

Glulam columns

Building Envelope Installation

During manual column installation, and prior to the CLT panel installation on the next level, the crane could be used to lift building enclosure panels for installation on the levels below.

British Columbia Building Safety Standard Branch (BCBSSB)

Site Specific Regulation (SSR) – requirements and adjustments that impacted project costs. Information provided by Urban One Builders.

- Acoustic concrete topping.
- Temporary riser for fire protection during construction.
- 10,000 gallon emergency water tank.
- Gypsum wall board (GWB) fire-rated and acoustical assembly.
- Additional fire system pump, sprinkler heads and flex connectors.
- Additional floor drains, flex connectors, expansion and contraction loops and copper piping to en-suite bathrooms.
- Additional HVAC system requirements pressurized stairs expansion/contraction segments and flex connectors.

Mass Timber Elements

Cross-laminated timber (CLT) panels

CLT is an engineered wood panel made by arranging and gluing up layers of dimension lumber. Each layer is typically perpendicular to the next. The layered stacks of wood are pressed in hydraulic or vacuum presses to form interlocked panels using structural waterproof adhesives. CLT panels are most suitable for dry service conditions in protected or interior applications.

CLT panels typically consist of three, five or seven layers. The dimensions of CLT panels are limited only by transportation constraints but they are typically manufactured up to 19.5 metres long by 3 metres wide (10' x 60'). CLT panels are typically used for floors, walls and roofs, and are also applicable for lateral force-resisting systems, such as sheer walls, timber-braced frames, or post-tensioned/self-centering systems. Custom layup, 5-ply, 169-mm-thick CLT panels were used in the Brock Commons building. They are comprised of machine stress-rated spruce laminations for the outer layers, and No.1/No.2 spruce-pine-fir (SPF) lumber for the inner layers. They meet ANSI/APA PRG 320-2012 *American National Standard for Performance-Rated Cross-Laminated Timber.*

5-Ply CLT 169 E1M3 (ANSI/APA PRG 320)				
Ply #	Direction Length/Cross	Species	Grade	Depth (mm)
1	L	SPF	1650f-1.5E MSR	32
2	C	SPF	No. 2	35
3	L	SPF	No. 2	35
4	C	SPF	No. 2	35
5	L	SPF	1650f-1.5E MSR	32

The CLT panels in the Brock Commons building are used in a two-way spanning capacity, connected to act as flat-plate diaphragms for levels 3 through 17. Two-way spanning eliminates the need for beams and significantly reduces the structural depth of the building. It also provides a clean, flat, point-supported surface for unobstructed service distribution, much like what is found in flat-plate concrete construction.

There are four CLT panel sizes in the Brock Commons building: 2.85 by 6-metre panels which span 1 and ½ bays; 2.85 by 8-metre panels which span 2 bays; 2.85 by 10-metre panels which span 2 and ½ bays; and 2.85 by 12-metre panels which span 3 bays. The different sized panels allow for staggering of the panel layouts between floors.

CLT canopy

The Brock Commons project also features a CLT canopy that is hung off the second level transfer slab. The canopy covers the walkway adjacent to the building on the north and west side.

Glued-laminated timber (GLT) columns

GLT (glued-laminated timber, also called "glulam") is made by gluing together laminations of solid-sawn lumber that are specifically selected and positioned in parallel layers based on their structural strength and appearance characteristics. Waterproof adhesives are used, making them equally suitable for interior and exterior applications. GLT is typically used for beams and columns and is frequently manufactured in curved sections that can be loaded in combined bending and compression.

Pound for pound, GLT is stronger than steel in compression and has greater strength and stiffness than comparably sized solid-sawn timber.

In the Brock Commons building, GLT columns with a 265 by 265-mm cross-section were used on levels 2 through 9; GLT columns with a 265 by 215-mm cross-section were used on levels 10 and above, including the sky-lounge level where they were left exposed for added aesthetics and as a reminder that part of the building's structure is built of mass timber. They meet CSA O122-06 (R2011) – *Structural Glued-Laminated Timber*, CSA O80 Series 08 (R2012) – *Wood* Preservation, and CSA O177-06 (R2011) – *Qualification Code for Manufacturers of Structural Glued-Laminated Timber.*

Parallel strand lumber (PSL) columns

Parallel strand lumber (PSL) is a high-strength structural composite lumber product manufactured by gluing strands of wood together to form a continuous billet under heat and pressure. Growth imperfections are removed from the strands during the manufacturing process, resulting in a strong, consistent material that is resistant to seasonal stresses. An exterior-type structural adhesive is used.

Credit: Canadian Wood Council

Exterior canopy picture – Note highlighted sprinkler heads (circled in red)

Credit: naturallywood.com. Photographer: KK Law

Column and building envelope connection detail at transfer slab

PSL can be machined, stained and finished using the same techniques as for solid-sawn timber. PSL is well suited for post-and-beam construction in both residential and commercial building construction. When laminated into deep sections, PSL can be used in long-span beam or header applications where high bending strength is required; PSL can also be used in column applications where columns are subjected to heavy loading conditions. Engineering analysis showed that under certain conditions, heavier loads could be experienced adjacent to the core on the lower levels of the Brock Commons structure. The PSL columns provided the additional strength properties required to meet the design considerations. PSL columns with a 265 by 265-mm cross-section were used at high-stress positions on levels 2 through 5.

Wood adhesives

Layup of all mass timber elements uses structural waterproof adhesives meeting CSA O112 Series (R2013), *CSA Standards for Wood Adhesives.*

Credit: Seagate Structures. Photographer: Pollux Chung

Balanced CLT panel lift

Monitoring During and Post Construction

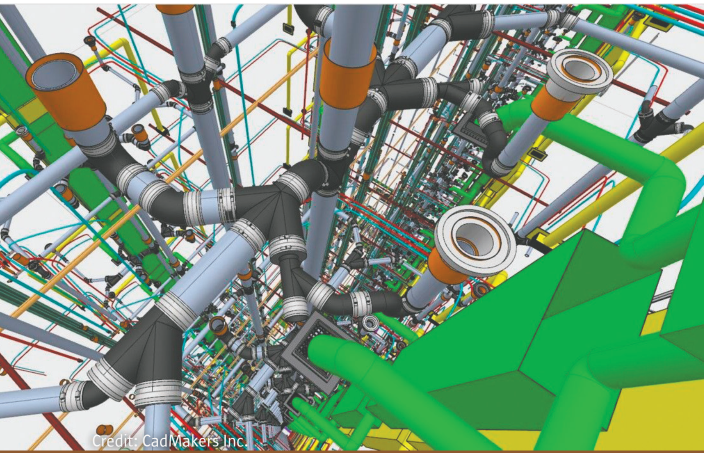
Monitoring systems were put in place to collect data and information on three variables even before construction started, and monitoring continued throughout the construction process. The variables evaluated include: moisture content; vertical building movement and settlement; and horizontal vibration due to wind and seismic movement.

- Sensors that record moisture content and temperature data were installed on five CLT panels per level. They monitored the panels' moisture content from the manufacturing facility, during transport to the UBC campus, through to the final installed condition. The sensors will continue to monitor CLT panel moisture content throughout the service life of the building and will help in identifying an effective moisture content timeline from fabrication to moisture equilibrium.
- Eight vertical shortening string-pot sensors, attached with non-stretch cables that run through four floors of the building, are wired to data acquisition units for analysis of vertical settlement, including elastic shortening, moisture-related shrinkage, and creep. They will measure floor-to-floor axial column shortening in highly loaded GLT and PSL columns.
- Accelerometers installed beneath the CLT plates at numerous levels and locations, and at the second level concrete transfer slab, will help in the determination of in-situ damping values from ambient vibration testing (AVT). Inclination gauges placed on the concrete cores will record the building's angle of inclination during a seismic event. Both accelerometers and inclination gauges will help to verify horizontal vibration due to wind along with the building's performance in a significant seismic event.

As a "living laboratory", Brock Commons will continue to be a source of learning through interdisciplinary research and educational projects. UBC researchers, staff and students will work with industry and government partners to continue monitoring the building throughout its lifetime. Evaluation of the data from these monitoring efforts will provide reference knowledge to support future changes to the NBCC for mass timber and hybrid buildings.

Credit: naturallywood.com. Photographer: KK Law

Typical panel edge envelope connection details and drag straps



Virtual design – M & P systems

Lessons Learned

The lessons learned from the unique experiences and innovative aspects of the Brock Commons project will provide long-term benefits to the North American design and construction industries. The project is being viewed as pivotal in the ongoing development of mass timber technologies and related structural wood systems, construction methodologies and the advancement of tall replicable and viable wood buildings in Canada and around the world.

Integrated design and construction strategy

- An integrated design and construction strategy works very well. The strategy employed for the Brock Commons project ensured the successful implementation of realistic, innovative solutions and optimized construction processes that not only met but also exceeded aggressive timelines.
  - The project benefited greatly from a fully integrated design team approach, including identifying and bringing together the right team members.
  - Constant and frequent communication encouraged the entire Brock Commons project team of design consultants, construction and project managers, and trades to take ownership of and actively contribute to the success of the project.
  - The third party experts who participated in the design process supported the design and construction team by providing additional advice and guidance on specific technical issues.
- The code approval process for tall wood buildings is complex and should be fully understood.
  - The involvement of fire protection engineers as part of the integrated design team approach was important to address the building regulation requirements of the innovative structure. They provided a high level of oversight to ensure building code compliance, site safety and performance standards for the project were met or exceeded.
  - The up-front scrutiny of each design proposition allowed for the early identification of potential pitfalls.
  - The early involvement of the project team with the authority-having-jurisdiction (AHJ) resulted in the timely acceptance and approval by the AHJ of the final design.
- Early involvement by a mass timber supplier that can provide design assistance services can further reduce manufacturing costs by optimizing the entire building system and not just individual elements.
  - Even small contributions, in connection designs for example, can make a difference to the speed of erection and overall cost.

- Mechanical and electrical trades should be invited in to a design-assist role at the outset of the project.
  - Doing so allows for a more complete virtual model, additional off-site prefabrication opportunities and quicker on-site installation time.

Design

- Elegance in simplicity was the very essence of Brock Commons from both architectural and structural design standpoints. The approach was *"simple is better"*.
  - To facilitate the use of wood in the high-rise, a deliberate decision was made to limit the areas of innovation to the structural system.
    - The flat slab concept for the CLT panels greatly helped to reduce the volume of wood used.
    - The elimination of beams and optimization of the column grid helped to reduce the number of pieces and crane lifts required.

Both considerations were key and helped lower project cost.

- Encapsulating mass timber and reducing the component cross-section profile also reduced overall costs (inclusive of additional gypsum cost).
  - The need for additional wood volumes to account for charring to meet fire and structural performance requirements was examined from an economic perspective and was traded off.
- By opting for the concentric HSS tube column connections, smaller cross-sections were required for structural purposes than would have been required for wood-to-wood connections.
  - This approach resulted in lower column component weight and the opportunity for many columns on each level to be installed manually.
- Simplified floor plans, with stacked units, studios over studios and quads over quads, created many cost-related efficiencies.

Prefabrication

Several and previously well-understood lessons learned from other innovative projects were reinforced during the construction of the Brock Commons project.

Mass timber

- Prefabrication produces higher quality and more precise components resulting in:
  - Reduced on-site installation time and overall schedule.
  - Reduced site deliveries.


Credit: naturallywood.com. Photographer: KK Law

Envelope panel prefabrication – Attention to detail

Credit: naturallywood.com. Photographer: KK Law

Concrete topping and water management

Acoustics

A 52 to 54 STC (sound transmission class) rating is achieved for floor assemblies, and a 50 to 62 STC rating is achieved for wall assemblies. The concrete topping on the CLT floor panels increases the weight and stiffness of the floor assembly. The concrete topping, in combination with the air space incorporated into the ceiling assembly, and the carpeting and resilient flooring finishes, reduce the overall floor hardness and the impact sound transmission.

- Reduced on-site waste and related disposal costs.
- Opportunities for other complementary products and concurrent off-site work to take place in controlled conditions.
- Fewer change orders being issued and information or clarifications being requested.
- Reduced schedule time and on-site labour costs for follow-up trades from:
  - mass panel penetrations accurately aligned between floors making the installation of vertical Mechanical Electrical Plumbing (MEP) runs easier;
  - negligible shimming and furring of demising walls;
  - negligible shimming and furring of ceilings, ceiling drops and horizontal chases; and
  - negligible adjustments or re-fitting of cabinetry and millwork.

Building envelope

- An efficient design and prefabrication of panels for the building envelope can dramatically reduce the number of fastening steps required on site, and allows the structure to be enclosed quickly.

Future opportunities

- Additional prefabrication opportunities exist in tall wood buildings that are designed with repetitious layouts. These might include framing for demising walls, bathroom units, electrical cabinets, roof systems, and core walls.

Virtual design and construction modelling (VDC)

- The importance of a virtual model as a communication tool cannot be underestimated. The use of comprehensive VDC and visualization helped identify constructability issues and cost implications, which in turn reduced the number of changes and unforeseen outcomes during the construction phase, making it possible to meet the aggressive construction schedule.
- Virtual modelling is a form of quality control. It addresses timing, scheduling, coordination, potential fine detail requirements and safety factors. It creates a clarity that has tangible results.
- The virtual model and 4D simulation use in the process of designing and construction of the Brock Commons project was instrumental in:
  - developing sequencing for all major site activities and crane lifts thereby providing the site managers with the ability to better anticipate and deal with potential site bottlenecks or conflicts;
  - developing a comprehensive design of the MEP systems that provided exact locations for penetrations required to be precut in the CLT panels;

- enabling the accurate off-site cutting of several MEP system components – ducts and pipes, and partial off-site assembly time needed to complete the building's mechanical room;
- identifying envelope panel installation procedures;
- identifying how, when, and where to coordinate material deliveries;
- assisting drywall and finishing trades schedule site installations;
- reducing requests for information; and
- reducing the number of change orders and an overall reduction in paperwork.


Credit: naturallywood.com. Photographer: KK Law
Strategic construction planning and innovation

Water mitigation

The Brock Commons project and construction managers expected the wood elements of the building to be erected during the drier summer months of 2016. The weather didn't co-operate, and the building was frequently impacted by heavy rain.

- The initial water management plan which included pre-applying peel-and-stick membranes to the CLT panel penetrations proved inadequate. The plan was revised to make the acoustical concrete topping the primary shield to control rain water from migrating down through to lower levels during construction of the upper floors.
- The concrete topping curing process and the judicious placement of fans was used successfully to expel excessive moisture absorbed by the structure during heavy rain events.
- As the project manager realized, the best solution to control water coming into the building is to erect the structure rapidly and to install the building envelope as soon as possible, which is one of the benefits of using mass timber such as CLT.

Mass panel installation

The full-scale mock-up was of significant benefit to the timber erectors as it created the opportunity to develop best practices and solutions prior to construction.

- Key take-aways included:
  - Install prefabricated guardrail systems between columns on the perimeter and pre-determine tie-off points for worker safety.
  - Communicate the importance and request the manufacturer of mass timber components to clearly identify and accurately locate balanced panel lifting points.

- Work closely with the construction management team, the mass timber component manufacturers and the virtual design modeller to pre-plan and optimize truck load stacks, delivery schedules and erection sequencing.

Funding innovation

- Funding innovation provides significant returns when the recipients have strong management skills, support innovation, are ready to explore new solutions and have established clear project objectives.

Communications and innovation

- A well-developed “Project Communication Plan” that incorporates key messaging, inter-related activities and several communication phases is essential to promote the replicability and the lessons learned from a demonstration project.

Credit: naturallywood.com. Photographer: KK Law

A project that was delivered with quality, speed and cost-effectiveness

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Abbreviations Used in this Document

AHJ	Authority having jurisdiction
ANSI	American National Standards Institute
APA PRG320	American Panel Association–Rated CLT Performance Std.
AVT	Ambient vibration testing
BCBC	British Columbia Building Code
BSSB	Building and Safety Standards Branch
CAD	Computer-aided design
CLT	Cross-laminated timber
CNC	Computer numerical control
CSA	Canadian Standards Association
EOI	Expression of Interest
GLT	Glued-laminated timber
HSS	Hollow steel section
Hz	Hertz
LEED	Leadership in Energy and Environmental Design
MEP	Mechanical, electrical, plumbing
MSR	Machine stress-rated
NBCC	National Building Code of Canada
NRCan	Natural Resources Canada
PSL	Parallel strand lumber
SPF	Spruce-pine-fir
SSR	Site Specific Regulation
STC	Sound Transmission Class
TWBDI	Tall Wood Building Demonstration Initiative
UBC	University of British Columbia
UBC PT	University of British Columbia Properties Trust
VDC	Virtual design and construction

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