



ORIGINE

POINTE-AUX-LIÈVRES ECOCONDOS
QUEBEC CITY

© Photo : Stéphane Groleau

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Over the last couple of years Quebec City has witnessed significant population growth and there has been a construction boom to meet the ever-growing demand for housing. In 2003, Quebec City became interested in the land of the Pointe-aux-Lièvres area for new real estate development. This vacant land on the banks of the Saint Charles River and just North of « Nouvo St-Roch » was deemed an ideal location for building a new neighborhood. Poised between nature and the city, the spot was coveted by many who wanted to create a dynamic living environment. The Quebec City council saw the opportunity to create a new neighborhood that would showcase sustainable development. The land developers selected by the city were tasked with developing the area sustainably and offering eco-responsible solutions. Therefore, using wood in the structures was natural.

Development has begun. Three projects were launched in the eco-district, in which Origine is the signature building of this new neighbourhood. This 13-storey, 92-unit building stands out thanks to its architecture, as well as its engineering prowess. The NEB Group, which consists of Nordic Structures, EBC, and Synchro Immobilier, wanted to push the boundaries of wood materials. Origine's great innovation resides in its lateral resistance system made entirely of wood. It is actually thanks to this innovation that the 41-meter high building can boast about being the highest modern building with a 100% solid wood structure.

The NEB Group hopes Origine will pave the way for other similar structures. Forest resources are abundant in Quebec, and design professionals' expertise in wood construction is developing to use them in large-scale structures. Origine has proven the feasibility and safety of using wood in this type of building.

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.

In 2013, NRCan announced a program that would provide 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 GCWood Tall Wood Program Expression of Interest will help Canadian developers, building officials, and industry stakeholders resolve some of the design and construction challenges unique to tall wood structures.

Following the submission and due diligence evaluation exercise, the Origine project was selected as one of two projects to receive federal funding through the TWBDI. These funds were essential in bridging the innovation funding gap during the preliminary design, approval, and construction phases of the project. The resulting technical knowledge gained on this project will benefit future teams designing and building mass timber structures and will support the adoption and advancement of tall wood building in Canada.

In Quebec City's up-and-coming Pointe-aux-Lièvres ecodistrict, one building stands taller than the rest. Origine is 13 storeys high, a remarkable landmark for the green neighbourhood. It is also the tallest wood building in eastern North America. While there are certainly other buildings taller than 41 metres (134 ft) elsewhere in Canada and around the world, Origine is the tallest building with a structure made entirely in wood.

This world first is the work of the NEB group, a consortium made up of Nordic Structures, EBC, and Synchro Immobilier, with architecture by Yvan Blouin Architecte. The building is aiming for a Silver LEED certification.

A quick tour of the site

Standing on the banks of the Saint-Charles River, just a stone's throw away from Autoroute Laurentienne, Origine is a residential building that's close to all the services one could wish for. The Stade Canac baseball stadium, the Fleur de Lys mall, and the Vidéotron Centre are all less than 1.5 km away. Origine boasts 92 housing units, ranging from high-end studio apartments to three-bedroom units, each with its own layout and furnishings. Every unit also has a private terrace or balcony with spectacular views of Quebec City and the neighbouring parks. A bike path cuts through the adjacent Pointe-aux-Lièvres park and runs all along the Saint-Charles River.

The 13-storey building has an area of 890 m² (9,580 ft²) and stands out from the rest of the neighbourhood, not only in terms of height, but also due to its striking appearance. Exterior finishing on the ground floor is brick, and white steel cladding is used on subsequent floors. Red-coloured aluminum architectural features bring the building to life, adding volume and providing a contrast in colour. The basement and ground floor, which are the only parts of the building made from reinforced concrete, house a parking lot, lobby, and other conveniences.

Wood is used from the first floor all the way up to the thirteenth. Load-bearing walls, shear walls, floors, and the roof are all made from cross-laminated timber (CLT), with glue-laminated (glulam) timber posts and beams rounding out the structural system. All these engineered wood products are manufactured from FSC-certified black spruce at the Chantiers Chibougamau plant in Northern Quebec. The roof is covered with a white waterproofing membrane to better reflect the sun and reduce the heat island effect. Each storey is 3 m (10 ft) high from floor to floor for a clear height of 2.6 m (8 ft 6 in).

The building has a gas central heating system that provides domestic hot water and feeds the network of pipes for the radiant floors. In addition to providing comfort, the gas-heated floors will result in savings of up to 30% over regular electric heating. Air conditioning is optional and supplied by individual units in each apartment. The electricity supply and pipes in each housing unit were designed so that air conditioning can be easily installed if required in the future.

The building has been fitted with efficient, easy-to-use recycling and waste elimination systems, such as a double chute separates garbage from recyclables. Thanks to financial support from the City for innovative buildings and wood solutions (*Programme de vitrine*



Typical high-end studio
© Yvan Blouin Architecte



Typical one-bedroom unit
© Yvan Blouin Architecte



Typical two-bedroom unit
© Yvan Blouin Architecte

technologique pour les bâtiments et les solutions innovantes en bois), each unit has a Solucycle system for organic waste. Kitchen sinks have a garbage disposal unit that shreds table scraps and sucks them into a tank in the basement, where, after decanting, the liquid part is sent to a water treatment plant and solids are converted into compost using biomethanization.

Excavation work on the building began in June 2016 and the structure was erected from December 2016 to April 2017. The first housing units were delivered in October 2017 as the finishing touches were being done to the top floors.

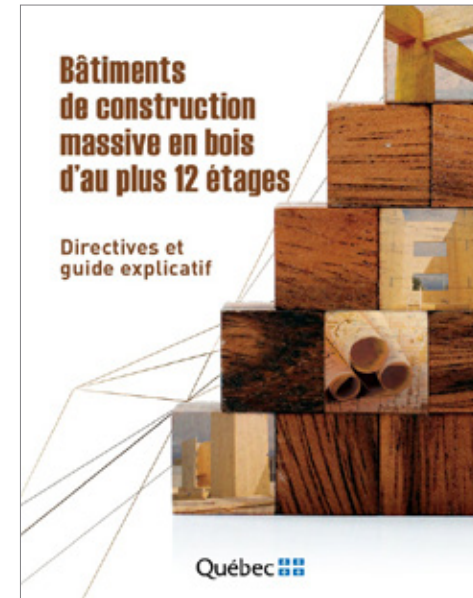
Before the project was launched, and before NEB could receive its construction permit, building with wood still had to prove itself.

Breaking new ground for tall wood buildings

To build 12 wood storeys, the designers behind the project first had to find a way to work around the Quebec Construction Code. When the project began in 2014, the Code stipulated that buildings of more than four storeys had to ensure that the construction was fire resistive. Consequently, this constraint ruled out wood.

An alternative solution—known as “equivalent measures”— was required to show that the Code’s performance goals and functional statements were being respected. An equivalent measures request then had to be approved by Régie du bâtiment du Québec (RBQ). This had already been done for wood buildings of 5 or 6 storeys, and RBQ had published a set of guidelines to this effect in 2013.¹ Origine’s 12 wood storeys meant going through the whole process again, this time on a grander scale. The process tends to be long and costly, discouraging designers and preventing wood from being widely used for tall buildings. To encourage the development of innovative uses for wood and to show that taller projects are technically feasible, Natural Resources Canada and the Canadian Wood Council launched the Tall Wood Building Demonstration Initiative in 2011. They issued a call for projects that came with a budget to support developers and other professionals. Origine was one of two projects selected from across Canada; the second was the Brock Commons project from the University of British Columbia campus in Vancouver.

Thanks to government support, the project designers were able to carry out research and testing in the lab to come up with solutions for building with wood and show that a 12-storey wood building would meet the Code’s objectives. To this end, Origine’s designers worked with Technorm and GHL Consultants, performing tests at FPInnovations’ and the National Research Council of Canada’s labs.



© Régie du bâtiment du Québec

The aim was to show that a 12-storey wood building could be just as safe and functional as one built according to Code requirements (i.e., for fire resistive buildings), providing the same level of safety in the event of a fire. The wood building also had to be comfortable for the people who lived there, provide soundproofing between units, and limit vibrations caused by occupants and wind. After successful trials, the designers submitted the equivalent measures request to RBQ and it was accepted. RBQ set out many of these new measures in a guide titled *Mass Timber Buildings of up to 12 Storeys*.² It provides guidelines for building with wood in accordance with the Quebec Construction Code. Provided they follow these guidelines in their entirety, designers no longer had to come up with equivalent measures to be approved by RBQ. The guide is essentially a province-wide alternative solution that comes preapproved.

¹ *Construction d'habitations en bois de 5 ou 6 étages. Directives et guide explicatif*, Régie du bâtiment du Québec, 2013.

² *Instructions and Explanatory Guide for Mass Timber Buildings of up to 12 Storeys*, Régie du bâtiment du Québec, 2015.

Why build with wood?

It took the project team two years of research and development to show that Origine would be just as safe built from wood as it would be if it had been of fire resistive construction. Why then invest time and money to build with wood when a reinforced-concrete or a steel structure would be less work?

One reason is wood's environmental properties. In addition to being a local, renewable resource, wood helps reduce greenhouse gas emissions. Manufacturing engineered wood products uses less energy than manufacturing other building materials, and wood also traps carbon dioxide (CO₂) through the process of photosynthesis as the tree grows. This means that the 3,111 m³ (109,864 ft³) of wood that make up Origine's structure capture 2,295 tons of CO₂. Using wood instead of other materials also avoided the equivalent of

1,000 tons of CO₂ emissions. Chantiers Chibougamau is able to use the tops of the spruce trees they harvest in the manufacture of their engineered wood products, effectively utilizing the entire tree. This portion of the tree is not usually used in traditional dimensional lumber products. By using this part of the tree, Chantiers Chibougamau optimizes the forest resources of Northern Quebec and adds value to a previously under-utilized wood resource.

A second, more technical, reason to build with wood comes from constraints imposed by the soil at the building site. The ground on the banks of the Saint-Charles River has low bearing capacity. Since wood is lighter than concrete, it was possible to build Origine on a one-metre-thick floating concrete foundation that was poured directly at water table level without having to employ an expensive system of piles. The wood

building weighs the same amount as the volume of earth that was excavated for construction, so the local load borne by the floating concrete foundation did not change. Had Origine been built entirely from concrete, the floating foundation would not have been able to support the structure because it would have been almost twice as heavy. The same building in concrete could only have been 6 storeys high and therefore less profitable. On soil with low bearing capacity, wood construction makes it possible to build higher and thereby provide more housing units at less cost.

A third reason to build with wood is the speed of installation and the reduction in subsequent costs. Wood elements arrive on the building site pre-cut and ready to install; there's no need to wait for concrete to cure before letting in other trades to install windows, partitions, and service equipment on lower



The use of CLT panels enables taller construction

© Photo : Stéphane Groleau

floors. It took only four months, from December 2016 to April 2017, to erect the wooden structure. A total of 16 months was spent on site, from excavation to the finished project. According to architect Yvan Blouin, a similarly sized project would have taken four to six months longer to complete using concrete.

The project's innovative nature meant that the partners had to learn as they went along. It took three months to put up the first seven floors and just one month to put up the remaining five floors and the roof. The knowledge acquired on the job and occasional adjustments helped speed things up considerably.

The experience gained by the project team, and the research carried out for this innovative building are paving the way for other designers to realize the many benefits of using wood as a building material.



© Photo : Stéphane Groleau

Twelve unshakable wood storeys

Origine's key innovation resides in its lateral load resisting system for wind and earthquakes. The system is entirely provided by mass timber, unlike other tall wood buildings that rely on reinforced concrete for lateral resistance. Just like the lateral load resisting system, the gravity resisting system that bears the building's weight, live loads and snow loads is also in mass timber. The innovative approach to lateral resistance makes Origine the world's tallest building with a structural system made entirely of wood (40,9 m (134 ft) including the last 36.6 m (118 ft) of the structural system made entirely of wood).

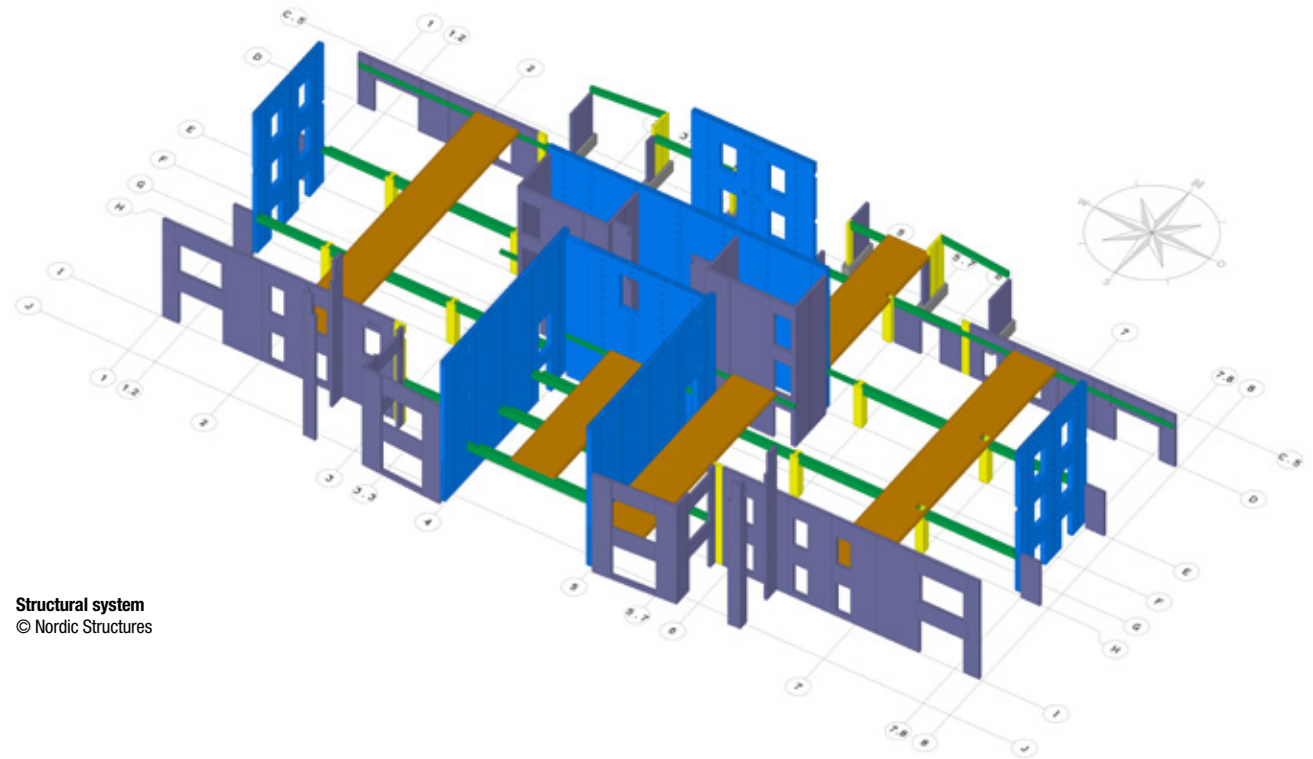
When working on Origine's structure, engineers used the latest version of the Engineering Design in Wood Standard (CSA O86), which they used to calculate the dimensions of wood elements according to resistance required, including fire resistance. They then conducted trials, some of which took place at FPInnovations' labs in Quebec City, to confirm resistance levels (for instance: bending, in-plane shear, shear walls and fasteners).

Overview

The lateral load resisting system is comprised of seven main shear walls made from CLT (in blue in the illustration below): the three walls in the lobby, the back-wall in the emergency exit staircases and elevator shafts, the central portion of the north wall, and the central portion of the east and west walls. The floors (shown partially in brown) act like a diaphragm to transfer lateral loads toward the shear walls.

The gravity load resisting system is made up of CLT load-bearing walls (in purple) and two glulam post and beam axes (in yellow and green) that run east to west through the building. Wall plates are attached to the load-bearing walls and the shear walls to support the floor slabs and complete the gravity load resisting system.

The sides of the east and west walls (not shown) are also CLT and serve only to transfer the wind load to the diaphragm, thereby playing a secondary role in the structural system.



Structural system
© Nordic Structures

Gravity load resisting system

The seven shear walls (that also serve as load-bearing walls) are composed of CLT panels that are 2.44 m (8 ft) wide and 9 m (29 ft 6 in) high, equivalent to the height of three floors. Since the lateral and gravity loads that the shear walls must resist diminish with height, they become thinner with each storey. The CLT walls are capped by glulam elements of the same thickness to increase compressive strength and give the wall added rigidity.

Floors	Layers	Thickness
1 à 3	9	291 mm (11½ po)
4 à 6	7	245 mm (9 5/8 po)
7 à 12	5	175 mm (6 7/8 po)

CLT panel thickness in shear walls by floor

The other load-bearing walls are made up of 5-layer (175 mm, 6 7/8 in thick) CLT panels that are 2.4 m (8 ft) wide and 6 m (19 ft 8 in) high. Unlike the shear walls, their thickness remains constant throughout the building. The thickness of 175 mm that ensures gravity resistance at the base of the building must be maintained on every floor to ensure 2-hour fire resistance. The portions of the east and west exterior walls that play a secondary structural role are also in CLT but only 3 layers thick (78 mm, 3 1/8 in).

Inside the building, the gravity load is supported by a glulam post and beam structure. The posts are one storey high and dimensions vary depending on load. Lower posts have a greater load to bear and measure 456 mm x 456 mm (18 in x 18 in). Dimensions diminish gradually over the height of the building to 279 mm x 279 mm (11 in x 11 in) on the top floor.

On the first floor, the first wood posts are secured to the reinforced-concrete floor using steel plates that are anchored in the concrete with 3.6 m (12 ft)-long steel rods.



Resistance tests on CLT elements at FPIinnovations
© Photo: FPIinnovations

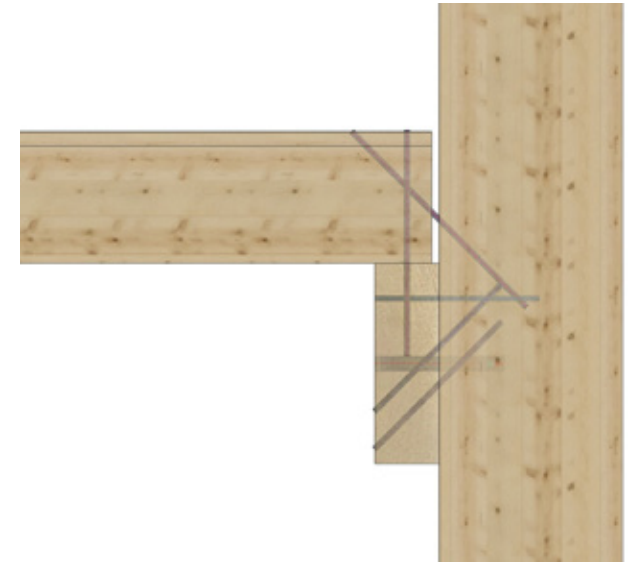
The beams have an average section of 279 mm x 502 mm (11 in x 19 ¾ in) and a span of 4.1 m (13 ft 6 in) to 7 m (22 ft 10 in) depending on where they are in the building. They are inserted and screwed into notches in the posts without metal plates using threaded self-tapping rods. Following this configuration, posts are continuous over the building's 12 storeys and transfer the gravity loads of the posts by themselves without impacting the beams. The continuity of the posts therefore limits compressive stress perpendicular to the grain and, consequently, the structure's vertical movement.

Wood plates attached to the wall to support the floor slabs play the same role. They ensure the walls' continuity so that they can transfer their own load without impacting the floor slabs and restricting the structure's vertical movement.

The beam grid and wall plates support a floor made up of 5-layer CLT panels (175 mm, 6⁷/₈ in) that are 2.4 m (8 ft) wide by 19.5 m (64 ft) long and run through the whole building from north to south.

Instead of using half-lap joints, CLT panels are assembled using plywood strips. This strategy accelerated the cutting process by eliminating the need to turn the panels over to cut the joint on the other side.

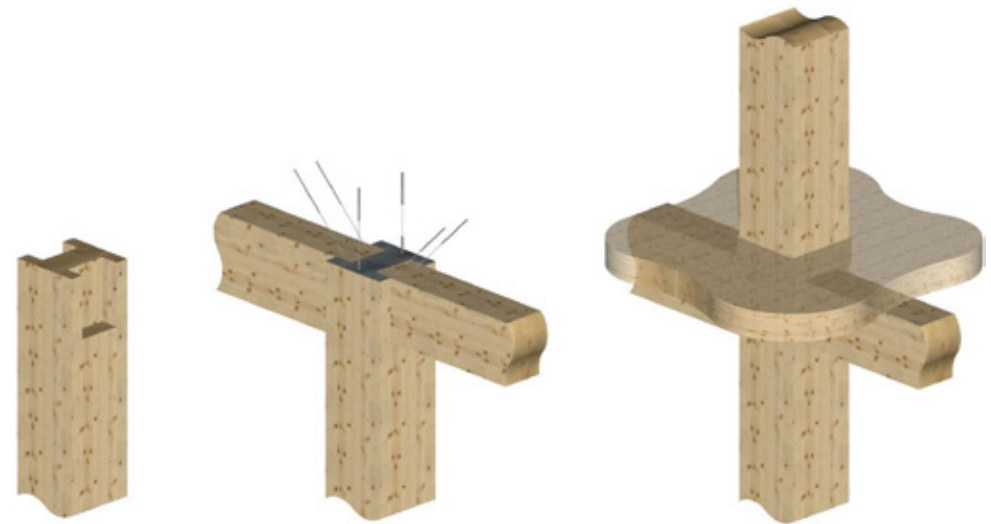
The panels are supported by the beams in the building's centre and by the glulam wall plates screwed to the exterior walls. The floor span is 5.7 m (18 ft 10 in) between beam and wall, and 5.5 m (18 ft 2 in) between beams.



Floor assembly supported by a wood plate attached to the exterior walls
© Nordic Structures



Post and beam assembly
© Photo: Stéphane Groleau



Continuity in posts from storey to storey
© Nordic Structures

Challenges	Innovative Solutions
Dimensioning of elements	Back in the early days of Origine's design, the CSA 086 Standard did not yet include CLT for new wood buildings. This meant that designers had to refer to the FPIInnovations CLT Handbook, international standards, and the results of experimental studies.
Fabrication	Fabrication of 9-layer CLT was a first for Chantiers Chibougamau. The challenge was to complete the assembly in the specified glue "open time". By optimizing the assembly sequence, technicians reduced the assembly time for a CLT panel by 40% to meet the glue restriction.
Compressive strength perpendicular to the grain	To limit the structure's vertical movement caused by compression perpendicular to the grain, the designers came up with fasteners that ensured continuity of the vertical elements. For example, beams are joined to the posts with notches, meaning that the posts transfer the gravity load of the upper floor instead of the beam. Similarly, floors are supported on wall plates fixed to the load-bearing walls and not on the top of the wall.



Computer numerically controlled machinery at Chantiers Chibougamau plant
© Nordic Structures

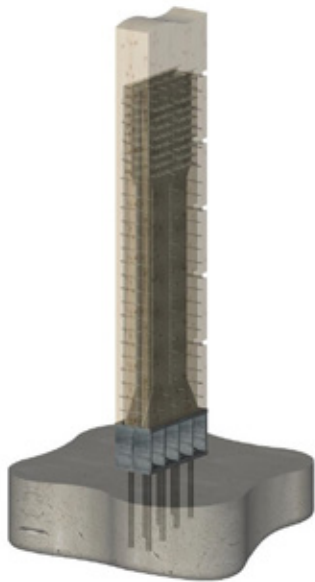


Installing a floor slab, a small portion of which will come to rest on the wall plate attached to the left wall
© Photo: Stéphane Groleau

Lateral load resisting system

The lateral load resisting system used in this project is the balloon-frame type. Walls extend across several storeys (two to three for Origine) and floors are attached to walls by wooden wall plates that are themselves attached to the walls. On the other hand, a platform-type system storeys are put up one at a time.

Shear walls get their name because lateral forces from wind and earthquakes impose compression and tension forces in opposite directions creating shear. CLT panels have to be fastened to the ground and attached to each other in order to counter shear forces. At the same time, connections must provide sufficient flexibility to allow the structure to deform and absorb energy without breaking during an earthquake.



Internal steel plate to transfer lateral charges to reinforced-concrete slab
© Photo : Nordic Structures

Shear walls are held in place on the ground by vertical steel plates welded to a steel beam running the length of the wall. The beam is anchored in the concrete by mechanical anchors and shear keys. The vertical steel plates are embedded in special grooves at the base of the CLT panels and fastened using dowels that go through the panels. The dowels' deformation absorbs most of the energy released by seismic movements. The same plates are also used to assemble panels between storeys.



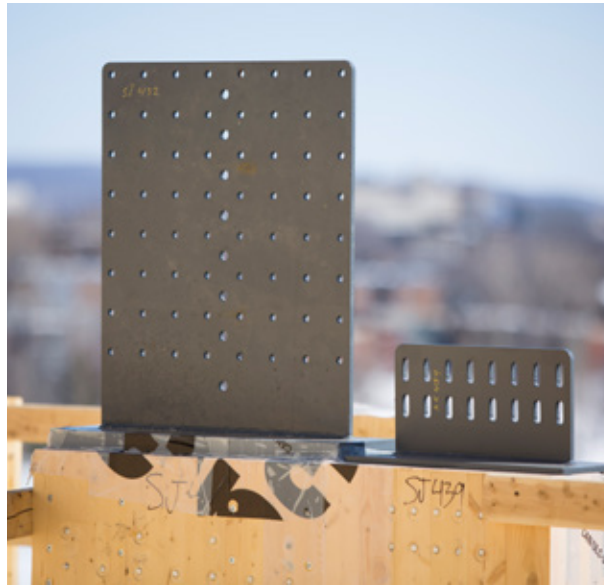
Shear wall testing at FPIinnovations
© Photo: FPIinnovations

When assembling adjacent panels, metal plates are usually nailed on either side of the junction between two panels to transfer shear stresses. In Origine's case, hundreds of nails per plate would have been needed to transfer the significant shear stresses resulting from the building's height. Not only that, but plates can sometimes be hard to reach, particularly inside staircases and elevator shafts, and installing scaffolding for each of the building's 13 storeys would have been complicated. To solve the problem, the designers came up with a system of steel shear keys. The keys passed all the way through the thick panels to prevent them from rubbing against each other when subjected to shear and displacement due to lateral forces. This made assembly considerably easier and faster since one key replaced 400 nails.

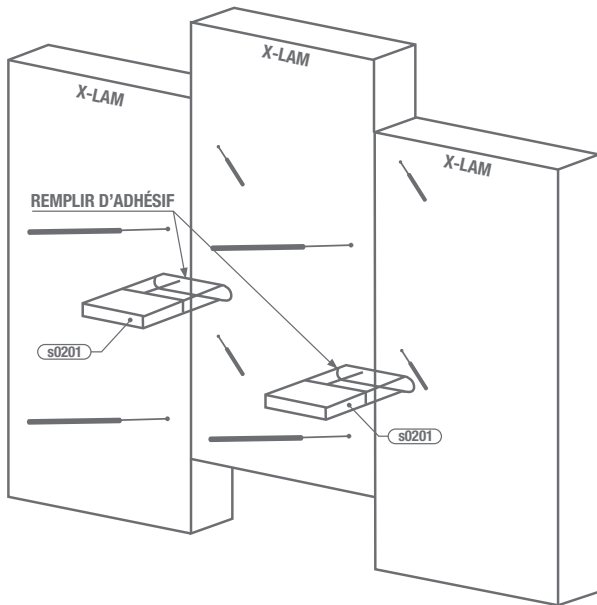


Inserting shear keys in a shear wall and tests at FPIinnovations
© Photo: FPIinnovations

Inside the building, lateral loads are transferred to the shear walls via the floors (diaphragm effect). Along the north-south axis, shear forces are partly transferred between CLT floor panels by way of nailed-down plywood elements 6 to 13 mm (1/4 in to 1/2 in) thick and, at the top of the building, by a 78 mm (3 1/8 in) strip of CLT. Along the east-west axis, the transfer takes place along metal plates that connect the floor slabs to the shear walls.



Junction steel plate to vertically connect the shear wall CLT panels
© Photo: Stéphane Groleau



Inserting shear keys in a shear wall
© Nordic Structures



Junction steel plate
© Nordic Structures

Challenges	Innovative Solutions
Transfer of lateral loads in the floor diaphragm	Lateral loads to be transferred in the diaphragm on the top floor are enormous. A plywood element wouldn't have been enough to transfer the load between the panels running north to south so the designers used CLT strips to transfer the heavy load.
Transfer of shear stresses between shear wall panels	Using shear keys meant there was no need to install large nailed-on metal plates. This reduced installation costs.
Vertical assembly of CLT panels	Metal junction plates with oblong holes allow the building to resist shear stresses without restricting tensile stress.
In-plane resistance of CLT panels	The "true" in-plane shear value for CLT panels was unknown. It had been calculated with a safety margin built in. Following tests carried out at FPInnovations, the factor was reduced by three, providing optimal design for the shear walls.
Fastening to the ground	The designers came up with a system of metal fasteners that worked with shear keys anchored in concrete to transfer forces at the base of the shear walls.
Speed of assembly	Using CLT meant that the wall panels were 3 storeys high, reducing installation time.



© Photo: Stéphane Groleau

Fire safety: naturally safe mass timber

For buildings over six storeys high, Division B of the Quebec Construction Code requires that floors and the elements that support them (walls, posts) be able to resist fire for two hours. The measure seeks to maintain structural integrity, give occupants time to evacuate, and allow emergency services to intervene safely. More specifically, making building elements fire resistant helps prevent structural elements from collapsing and confines fires to their point of origin by using separations such as floors and walls.

Fire resistance is also achieved through compartmentalization; fire separation walls work to prevent flames and smoke from spreading. These walls must also provide insulation to limit temperature increases on both sides of the separation. Depending on where they are in the building, the Code requires fire separation walls to be fire resistant for one to two hours.

This meant that, to realize a successful “alternative solution”, engineers had to develop structural solutions, including the composition of walls, floors and assemblies, that would achieve the required degree of fire resistance. Their proposed solutions then had to be proven efficient using lab tests and structural calculations, all while adhering to the standards set out in the Code.

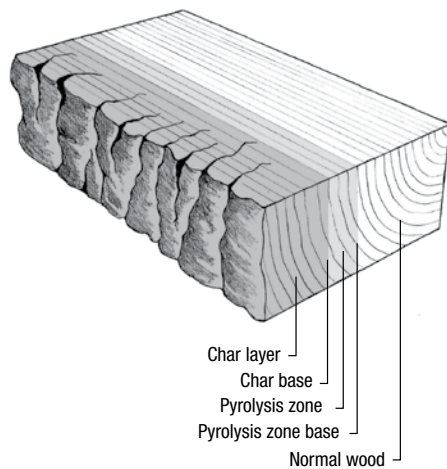
Calculation method and standards

Wood will burn, but when it does, it will produce a thick char layer that for a time provides insulation and protects wood elements from the effects of heat and flame. Wood burns at a predictable speed. Knowing the charring rate, it is possible to calculate and measure the dimensions of a wood element so that, once charred after being exposed for two hours to a CAN/ULC-S101³ standardized fire, the section remaining maintains its structural integrity.

The calculation was performed using the method set out in Annex B of the CSA O86-14 standard. The Annex B method was developed in order to analytically determine the structural resistance of a mass timber element exposed to a standardized fire. It is worth noting that all construction materials that must be fire resistant are calculated or assessed using this standard.

³ ULC, CAN/ULC-S101: “Standard Methods of Fire Endurance Tests of Building Construction and Materials,” Toronto, Ontario: Underwriters Laboratories of Canada, 2014.

It would have been very expensive and inefficient to size all wood elements to include a section that was to be sacrificed in order to provide two hours of fire protection through charring alone, so the project designers opted for a hybrid solution. They sized the wood elements for one hour of fire resistance and protected them with Type X gypsum board. Protecting with gypsum increases the time it takes for CLT to catch fire and consequently limits CLT's contribution to the growth and intensity of a fire over this period. Gypsum increases the fire resistance of the assembly by one hour; the wood and gypsum combined provide the two hours of resistance required.



Char layers
Source : adaptation from CSA 0177

⁴ ULC, CAN/ULC-S115: "Standard Method of Fire Tests of Firestop Systems," Toronto, Ontario: Underwriters Laboratories of Canada, 2011
⁵ Su, Joseph; Roy-Poirier, Audrey; Leroux, Patrice; Lafrance, Pier Simon; Gratton, Karl; Gibbs, Eric; Berzins, Robert, *Fire Endurance of Cross-Laminated Timber Floor and Wall Assemblies for Tall Wood Buildings*, National Research Council Canada, 2014
⁶ L. Osborne, C. Dagenais et N. Bénichou, *Preliminary CLT Fire Resistance Testing Report (Project No. 301006155) – Final Report 2012/13*, Ottawa (Ontario): FPInnovations, 2012.

This means that structural elements can be designed using mass timber (walls, floors, post and beam systems, roofs), all while protecting the connections.

An assembled wall or floor, however, is not limited to a gypsum-covered CLT panel. It also includes insulating material, connectors, interior and exterior sheathing, and other components. Fire resistance must therefore be demonstrated with complete assemblies. What's more, assemblies sometimes contain holes for service equipment to pass through, and junctions between structural elements are not always perfect. In order to prevent smoke and flames from spreading through these gaps and openings, they must be plugged with sleeves or firestop caulk, and the filling and sealing methods of Standard CAN/ULC-S115⁴ must be applied.

Conclusive tests

Engineers carried out tests at Intertek's laboratories to verify whether the building elements behaved as calculated. The test results proved their solutions met the Code's fire safety objectives.

Further tests were performed on a wall and a floor in accordance with Standard CAN/ULC-S101 in order to verify structural resistance and temperature transfer through the materials.⁵ The wall consisted of a 5-layer (175 mm, 6⁷/₈ in) CLT panel protected by two 16 mm (5⁸/₁₆ in) Type X gypsum boards on either side. The floor was also made up of a 5-layer CLT panel covered in glass wool and a 16 mm (5⁸/₁₆ in) Type X gypsum board on the side exposed to the fire, simulating the buildup of walls and floors in the Origine project. Both tests were conclusive. The wall resisted for 3 hours 39 minutes and the floor resisted for 2 hours 8 minutes.⁶

Inside



Outside



Typical wall after two-hour fire resistance test, temperature over 1,000 °C
© Photo: Nordic Structures

Since the proposed building is essentially similar to a fire resistive building, with the exception of structural elements that are made from mass timber, a fire test was carried out on the exterior walls in accordance with Standard CAN/ULC-S134. The test showed that, even though the structural element was made from CLT, using fire resistive materials for insulation and exterior cladding enabled the building to remain within permitted limits for flame spread distance and heat flux above the opening (which represented an exterior window).⁸

The caulk between CLT panels and filling around equipment that passes through walls or floors were tested in accordance with Standard CAN/ULC-S115.⁹ Caulks were given the FT rating required by the Code, signifying that smoke would not pass through the panels (F) and that the temperature on the unexposed side would remain below the level required (T) by Standard CAN/ULC-S115. Filling around equipment was given the required F rating.

The most convincing proof of a CLT building's fire resistance was a demonstration performed by FPIInnovations at the National Research Council Canada that was funded by Quebec's Ministère des Forêts, de la Faune et des Parcs. The demonstration was carried out with an audience of project designers; representatives from the Quebec and Ontario governments; delegates from the cities of Montreal, Ottawa, and Quebec; and professionals from the Quebec City and Montreal fire departments. The goal was to show that if a fire were to break out in the building, the mass timber emergency stair/elevator shaft would remain safe.



Red caulk ensuring the degree of fire separation around equipment passing through a CLT panel
© Photo: Stéphane Groleau



Metal frame to reduce the combustible load
© Photo: Stéphane Groleau

⁷ ULC, CAN/ULC-S134: « Méthode normalisée des essais de comportement au feu des murs extérieurs », Toronto (Ontario): Underwriters Laboratories of Canada, 2013.

⁸ E. Gibbs et J. Su, *Full Scale Exterior Wall Test on Nordic Cross-Laminated Timber System – Client Report A1-006009.1*, Conseil national de recherches du Canada, 2015.

⁹ ITS, *Horizontal Through-Penetration Firestop Systems through Cross Laminated Timber Panels (CLT) – Report No. 102389123COQ-006 Rev.01*, Intertek Testing Services, 2016.

¹⁰ L. Osborne, C. Dagenais, *Full-scale Mass Timber Shaft Demonstration Fire – Final Report*, FPIInnovations, 2015

A studio apartment protected by two layers of 16 mm ($\frac{5}{8}$ in) thick Type X gypsum board and 9 m (29 ft 6 in) high emergency stair/elevator shaft were built using 5-layer (175 mm, $6\frac{7}{8}$ in thick) CLT. The studio apartment was also furnished with a bed, chairs, shelving, a kitchen counter, and other furniture, along with wood cribs for a fire load equivalent to the 95th percentile of residential fire load density, one of the worst for an apartment. The stair/elevator shaft was pressurized to 12 Pa above ambient pressure.

A fire was started in the studio apartment, quickly raising the ambient temperature to 1,100°C (2,012°F). After two hours of this intensity, the CLT inside the stair/elevator shaft remained intact; no smoke had been detected, and the temperature of the surface inside the shaft, still at ambient temperature, had not increased significantly.

In this way it was proven that a stair/elevator shaft made from mass timber is just as safe as one built using fire resistive materials.

The results of this research led to the development of fire safety measures that were implemented in Origine. They were also used to draw up the directives in the RBQ guide Mass Timber Buildings of up to 12 Storeys.¹¹



Assembly for the full scale fire demonstration test
© Photo: Nordic Structures



Fire load equivalent to the 95th percentile of residential fire load density
© Photo: Nordic Structures



Ignition of the combustible load
© Photo: Nordic Structures

¹¹ *Instructions and Explanatory Guide for Mass Timber Buildings of up to 12 Storeys*, Régie du bâtiment du Québec, 2015



Full scale demonstration test after 10 minutes
© Photo: Nordic Structures



Full scale demonstration test minutes before the end
© Photo: Nordic Structures



Stairs/elevator shaft at the end of the large scale demonstration test
© Photo: Nordic Structures

Key fire safety measures implemented in the Origine project

- The load bearing system, including connections and assemblies, provides at least two hours of fire resistance. Wood elements are sized to give the wood one hour of fire resistance, while capping with two layers of Type X gypsum provides one additional hour.
- In the apartments, partitions that are not load-bearing walls have a lightweight metal frame to reduce the fire load inside the building.
- To stop fire spreading, the floors and some non-load-bearing walls provide fire separations of two hours and one hour respectively. Apartments therefore form compartments that will resist fire for one hour.
- The Origine building is 100% protected by an automatic sprinkler system designed and installed in compliance with Standard NFPA 13.¹²
- Service spaces are filled with insulating fire resistive mineral wool.
- Balconies are made from concrete to limit fire spreading outside the building.
- Exterior cladding is made from fire resistive material.

These measures enabled Origine to meet Construction Code requirements for a building of more than six storeys for which fire resistive construction is required. In order to demonstrate fire safety equivalence with a fire resistive building, the designers added the following measures:

- The roof has a fire resistance rating of one hour;
- Plumbing for the sprinkler system is made from fire resistive material;
- Apartment doors have a fire endurance rating of 45 minutes, rather than the 20 minutes usually required by the Code;
- Hallways and emergency exit stairwells and elevator shafts are kept 12 Pa above ambient pressure to prevent smoke spreading through escape routes.

Challenges	Innovative Solutions or Original Features
Demonstrating the mechanical strength of the gravity load resisting system for two hours of fire resistance	Wood elements were sized to provide one hour of fire resistance and the elements were covered with Type X gypsum boards for one additional hour of protection. Fire resistance was also demonstrated in large-scale tests.
Demonstrating the integrity and insulation of floors, load-bearing walls, and other fire separation walls	Fire resistive systems for joints and technical elements passing through fire separation walls were devised and tests were carried out in accordance with Standard CAN/ULC-S115.
Demonstrating fire resistance	Tests were performed in accordance with Standard CAN/ULC-S101, as required by the Building Code. The calculation method (Annex B of the CSA 086 standard) had not yet been published at that time.
Confounding the skeptics	A large-scale demonstration test simulating an extreme case of fire was carried out.

¹² NFPA 13: Standard for the Installation of Sprinkler Systems, National Fire Protection Association, 2016.

Aiming for acoustic comfort

Inside buildings, residents can be disturbed by airborne sounds and impact noises. Airborne sounds come from sources outside the apartment, such as traffic noises or a radio a neighbour is playing too loudly. Impact sounds, as the name indicates, are caused by direct impact against a wall or ceiling, such as a ball bouncing off a wall or footsteps in an upstairs apartment. Both types of noise can, depending on intensity, pass through a wall or ceiling and annoy the neighbours.

A building's acoustic comfort between two apartments is measured in the laboratory in two ways: sound transmission class (STC) for airborne sounds and impact insulation class (IIC) for impact noise. Inside the building, they are measured using ASTC and AIIIC ratings respectively, where "A" stands for "apparent."

The 2015 National Building Code requires, for airborne sounds, an ASTC rating of at least 47 between apartments or, for all separations between two dwellings, an STC of at least 50. A living unit separated by a stair/elevator shaft or a garbage chute must have a separation with an STC of at least 55. The 2015 National Building Code recommends, but does not require, an IIC rating of at least 55 for floors separating two units, tested when bare, without a carpet (NRC, 2015).



© Photo: Stéphane Groleau

To provide the best possible acoustic comfort in a CLT building, the designers went to the National Research Council labs to test various compositions of walls and floors according to standards ASTM E90 (walls) and ASTM E492 (floors).¹³

A number of floor and wall assemblies made up of a 5-layer CLT slab and various combinations of gypsum, concrete topping, plywood, acoustic membrane and floating floor were tested.

However, these were in-laboratory measures for wall elements and floors taken in isolation. In the building itself, sound can travel through any opening: the joint between two CLT panels, between beams and floors, around pipes and electrical ducts, etc. To solve this problem, the designers were careful to seal any gaps that sound might travel through. Openings were filled with acoustic caulk and suspended-ceiling cavities were filled with mineral wool.



Suspended-ceiling cavities are filled with mineral soundproofing wool
© Photo: Stéphane Groleau

Noise can still travel indirectly through the structure; for instance, an object falling on a 5th storey floor would be heard as an impact sound by the neighbours on the 4th floor. The thud might also be transmitted from the floor to the adjacent walls and be heard on upstairs and downstairs floors. To keep this flanking transmission to a minimum, elements must be isolated; in other words, direct contact must be avoided between elements of the structure liable to conduct sound. An acoustic membrane was therefore inserted between the concrete topping and the CLT floor. The membrane extends along the wall CLT to limit sound transmission between the topping and CLT wall.

Once the building was built, in-situ tests confirmed the solid acoustic performance (ASTC and AIIIC) of the apartments.

Challenges	Innovative Solutions or Original Features
Choosing floor and wall assemblies to ensure good acoustic performance	Carrying out tests on assemblies with many variations, to determine optimal solutions.
Ensuring acoustic comfort	Ensuring the quality of implementation and performing in-situ tests to confirm acoustic performance.



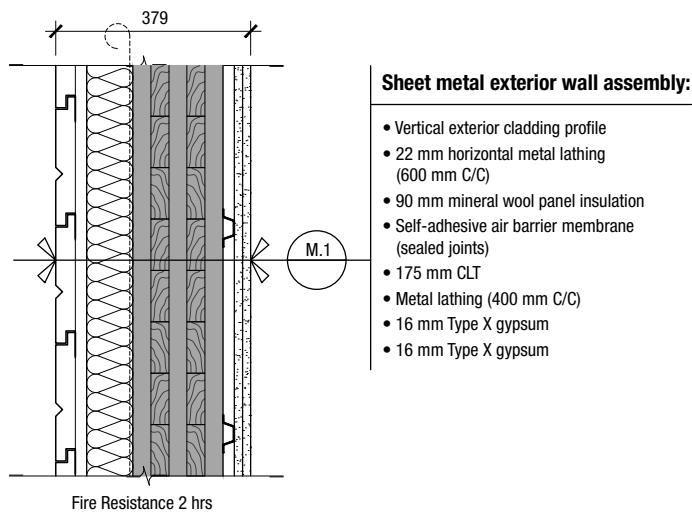
Acoustic seal between CLT panels and soundproofing membrane on the floor
© Photo: Stéphane Groleau

¹³ I. Sabourin, *Measurement of airborne sound insulation of 8 wall assemblies measurement of airborne and impact sound insulation of 29 floor assemblies*, National Research Council Canada, 2015

A closer look at wall and floor compositions

Composition of exterior walls

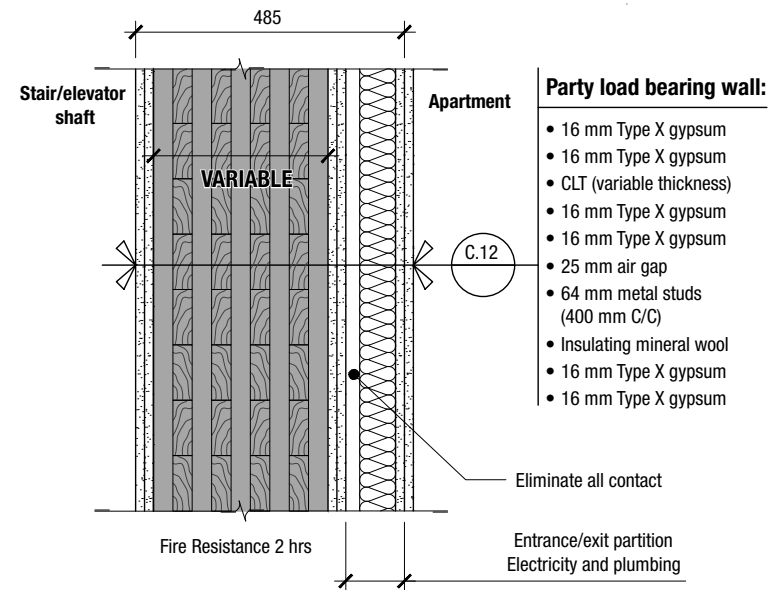
All exterior walls are made from CLT. They are protected by gypsum inside and covered on the outside with insulating mineral wool and steel, aluminum, or stone cladding—all fire resistive materials, as required by the Code. This all adds up to an RSI thermal resistance rating of 4.2 (R 23.9) and severely limits thermal bridges. This is the benefit of using a CLT wall instead of a post and beam system with steel-framed walls where the lightweight steel studs running through the wall act as potential thermal bridges.



© Yvan Blouin Architecte

Composition of stair/elevator shaft walls

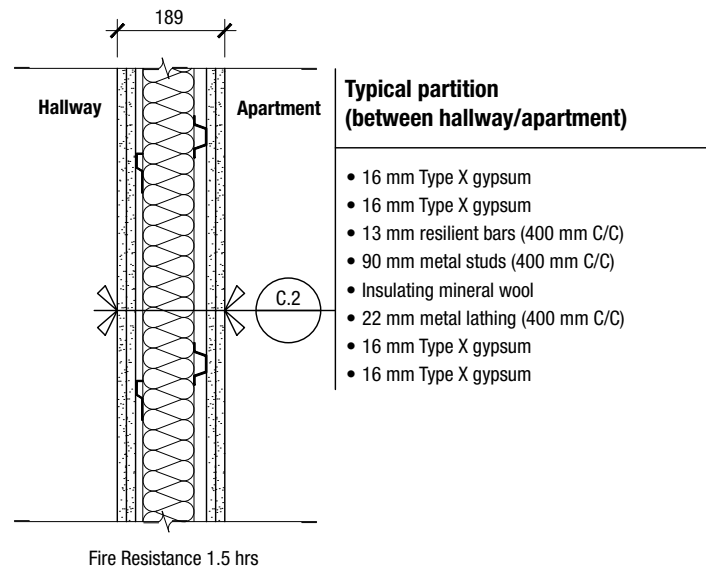
Walls shared by emergency exit stairwells or elevator shafts and an apartment are made up of CLT panels that are 5 to 9 layers thick, depending on the floor, and are protected on either side by two layers of Type X gypsum panels. In order to improve acoustic comfort inside the apartments, party walls also include an air space, acoustic insulation wool, and two other gypsum panels. This assembly ensures two hours of fire resistance and an STC rating of 61.



© Yvan Blouin Architecte

Composition of non-load-bearing interior walls

Non-load-bearing interior walls are not made from CLT, but instead from a metal stud system filled with acoustic wool and protected by two layers of Type X gypsum panels on either side. Walls between apartments and hallways are single, while party walls between apartments have a double layer of acoustic wool on either side of an air space to reduce noise transmission between the two apartments. This configuration exceeds National Building Code's STC requirements.

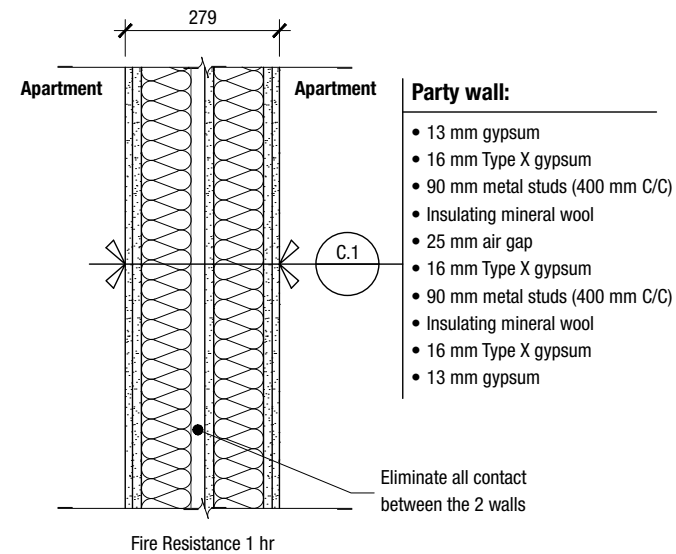


© Yvan Blouin Architecte



Wood elements are protected by Type X gypsum

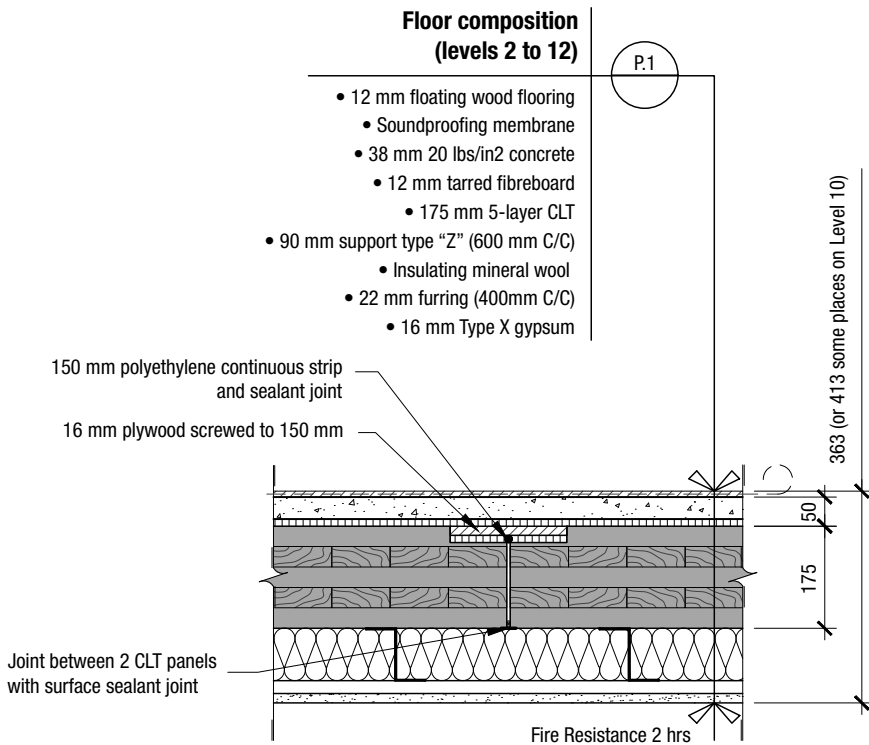
© Photo : Stéphane Groleau



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Composition of floors

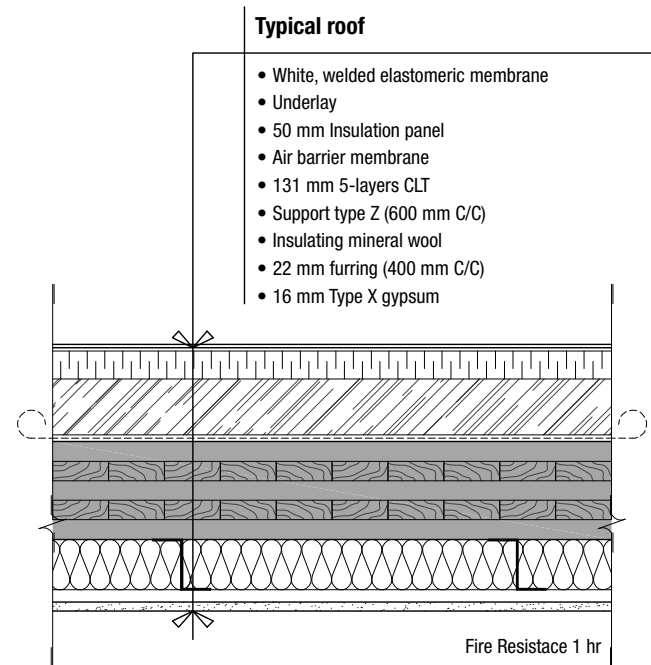
The floor is made up of 5-layer (175 mm, 6⁷/₈ in) CLT slabs joined by a strip of screwed-on plywood. Acoustic wool and a layer of gypsum are attached below the CLT. On the opposite side, the CLT is covered with tarred fibreboard, a non-structural concrete topping that includes radiant heating, and an acoustic membrane. The finish is made up of a floating floor, carpet, or tiles. This assembly provides two hours of fire resistance, an STC rating of 69, and an IIC rating of 58.



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Composition of the roof

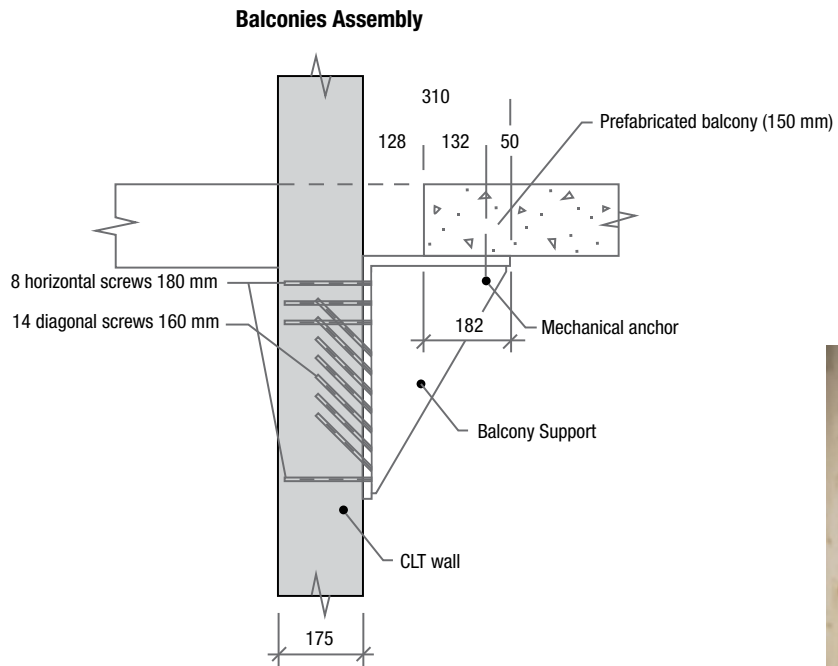
The roof is made up of a 5-layer (175 mm, 6⁷/₈ in) CLT slab. It is insulated using mineral wool and covered with a reflective white waterproofing membrane to reduce the heat island effect. Inside on the ceiling, a gypsum panel is affixed beneath the CLT panel. This assembly provides one hour of fire resistance and an RSI thermal resistance rating of 7.6 (R 43.2).



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Balconies

Balconies are made from precast concrete, but unlike concrete buildings where the balcony would be an extension of the floor to the exterior, resulting in heat loss, Origine balconies do not come into direct contact with the building walls. Rather, they are supported by metal angle sections that maintain a gap between the balcony and the wall.



Balconies connector
© Photo : Stéphane Groleau



Balconies
© Photo : Stéphane Groleau

A look at the worksite

Wood elements are pre-cut to 1 mm precision at the Chantiers Chibougamau plant using 3D files and computer numerically controlled machinery. They arrive on site with openings and cutouts, ready for installation. To facilitate and speed up the assembly of the structure, elements are numbered and stacked on trucks in order of assembly. Posts and beams are unloaded from trailers and stored on site, while the CLT panels are lifted directly off the trailers by crane and erected immediately.



Wood elements arrive on site with all cutouts and openings pre-cut
© Photo: Stéphane Groleau

Assembly sequence of the structure

The sequence starts by erecting the elements that take up the lateral loads: the stairwells and elevator shafts, entrance hall walls, and the eastern and western bearing partition walls. These elements are CLT panels that cover three floors. The bearing walls always cover two floors, except the first northern wall. This first northern wall, which is the height of one level, creates a one-floor gap between the northern and southern walls that is maintained until the top of the building. Next, the columns, beams and wall plates that carry the floor are installed. Every level is completed by installing the floor slabs.



Balloon-frame system allows work to be completed at the height of man
© Photo: Stéphane Groleau

The difference in bearing walls height makes the CLT slab installation easier. Indeed, the CLT slab rests on a half-height wall on one side and on the top of the opposite wall, thus simplifying the lifting operation. This process is repeated until the 12th floor.

To improve the speed and precision of assembly, the designers had holes pre-drilled at exact locations in the walls and wall plates. Once on site, wall plates were temporarily attached to the walls using a dowel system so that screws could later be inserted easily.

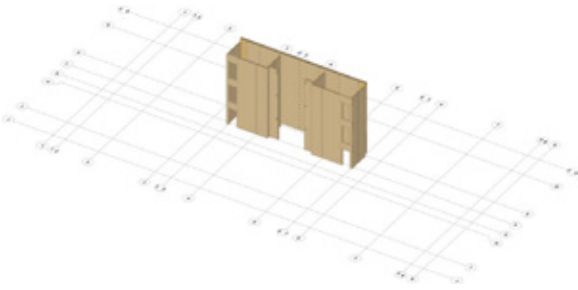
Assembling the floor panels together using plywood strips rather than half-lap joints accelerated assembly. This technique meant the full width of the panels could be used instead of losing a portion to the overlapping half-lap joints. In view of the scale of the Origine project, this optimization has allowed the reduction of the number of panels used and therefore the amount of handling in the factory and on the construction site.



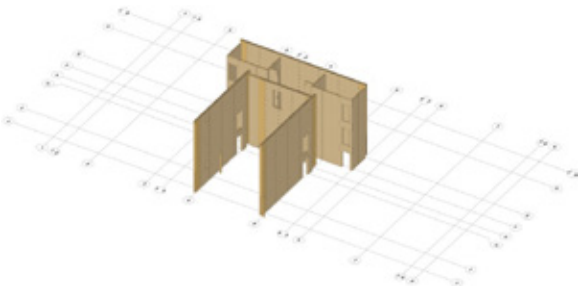
Lifting fitting are removed after the installation of CLT panel
© Photo: Stéphane Groleau

Assembly sequence for the structure

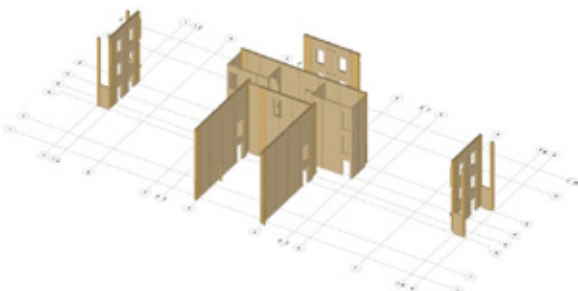
① Emergency exit staircases and elevator shafts



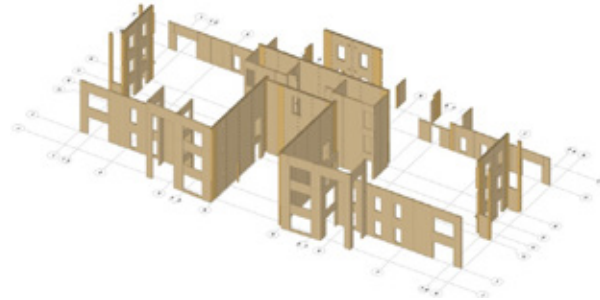
② Lobby walls



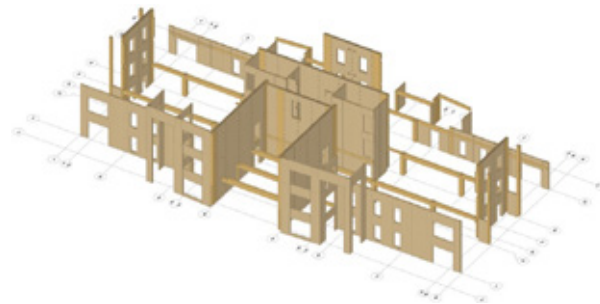
③ East and west shear walls



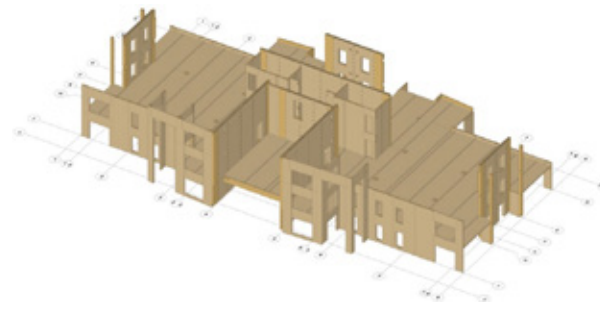
④ Other load-bearing walls, north walls of storey 1, south walls of storeys 1 and 2



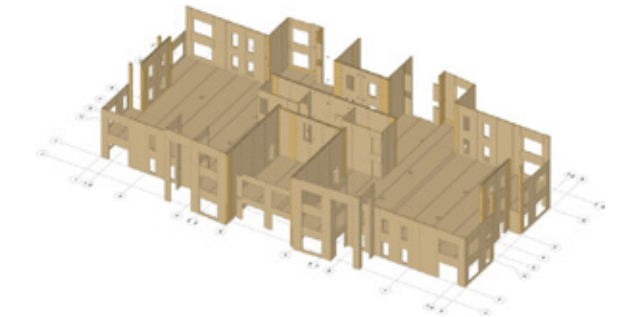
⑤ Posts and beams for the 1st floor



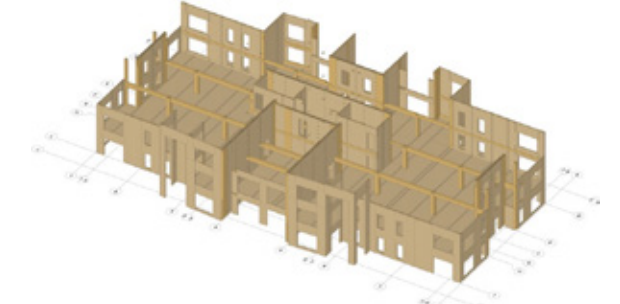
⑥ 1st floor



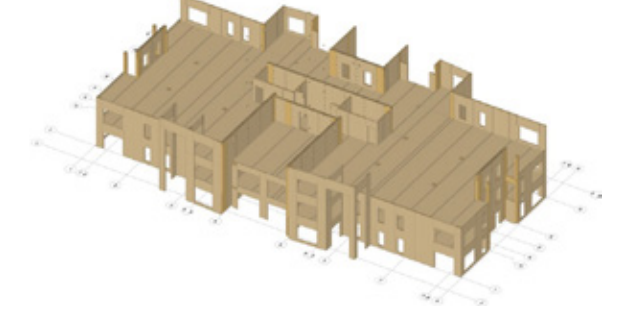
⑦ North load-bearing walls of storeys 2 and 3



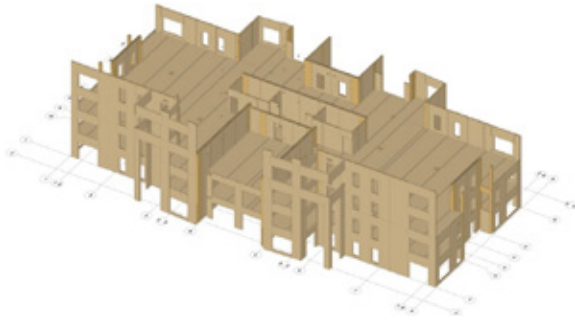
⑧ Posts and beams for the 2nd floor



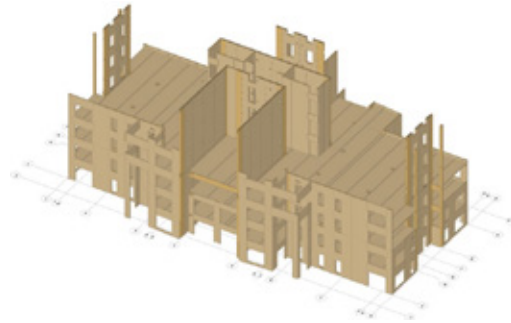
⑨ 2nd floor



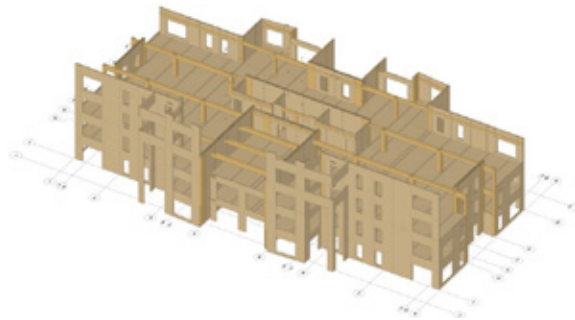
10 South load-bearing walls on storeys 3 and 4



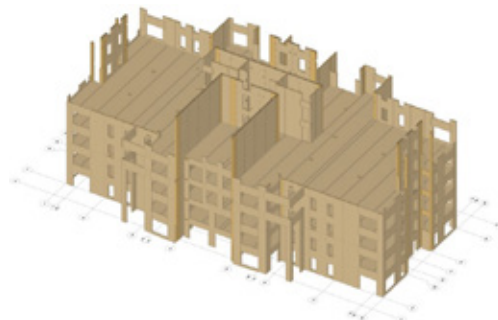
13 Shear walls for storeys 4, 5, and 6



11 Posts and beams for the 3rd floor



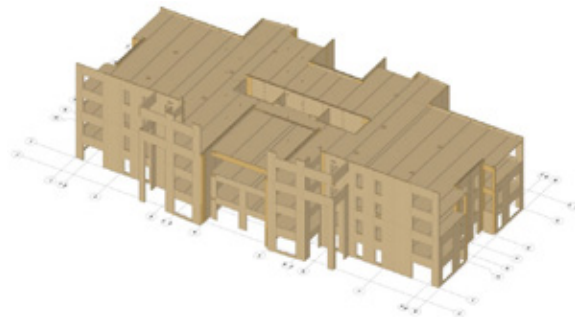
14 North load-bearing walls for storeys 4 and 5, and 4th floor



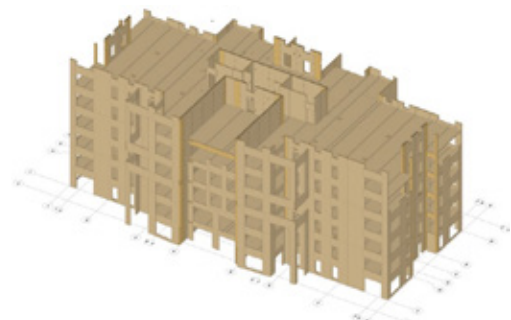
16 Sequence completed



12 3rd floor



15 South load-bearing walls for storey 5 and 6, and 5th floor



Installation sequence for interior finishing

It took only four months, from December 2016 to April 2017, to erect the wooden structure. Tradespeople, however, were able to get to work inside the building long before the roof was set in place, and they proceeded in a sequence that was repeated from floor to floor.



Concrete is poured over the radiant floor
© Photo: Stéphane Groleau

The first tradespeople to work in the building insulated the walls and the pipes for the radiant floor heating and then poured the concrete topping over the floor. Once the concrete had dried, the unit divisions went up and then the plumbers and electricians arrived. When all the pipes and cables were installed, service spaces were filled with insulating wool and gypsum panels were installed on the walls and ceilings.

With that work complete, all that remained was to paint the walls and ceilings and finish the floors. Tiles were used for kitchens and bathrooms, carpet was laid in the building's common hallways, and floating floors were installed elsewhere.

Following this pattern, it took six to eight weeks for all the trades to finish a floor. By the time the final touches had been applied, ten months had passed since the assembly of the wooden structure began.



Lifting the last panels to complete the structure
© Photo: Stéphane Groleau

Close monitoring of the worksite

The safety and quality measures in place were not compromised by the rapid speed of assembly.

Unlike reinforced concrete, which requires formwork and a relatively long time to cure, there is no need to wait for wood to dry before moving ahead with upper storeys. Wood's moisture content must be controlled, however, since wood is a hygroscopic material and, depending on ambient moisture, will absorb or release water. As moisture content changes, wood swells or shrinks, with possible consequences for the structure. In Quebec, wood must have a moisture content of 10 to 12% to keep its shape and remain in equilibrium

with indoor temperature and humidity conditions. The wood was dried to approximately 12% at the Chantiers Chibougamau plant and delivered to the site with the same moisture content. Since the site was not protected from bad weather, the moisture content of the wood elements was measured with a moisture meter.

Specific measures were also taken on site to prevent fire and protect the structure from the risk of fire during construction. A water reservoir was elevated at the same pace as the storeys and was ready to be activated at a moment's notice. Fire extinguishers were also strategically positioned to guard against every eventuality, and all site employees were given safety training, including fire safety training.

Finally, measures put in place to keep workers safe from falls were another noteworthy aspect of the worksite. Under the Safety Code for the Construction Industry, workers must be protected if they are at risk of falling more than three metres (10 ft). One of the proposed prevention measures is to install a guard rail. Origine engineers came up with the innovative idea of designing the wall sections to rise above the floor level. These sections doubled as guard rails so that temporary guard rails only needed to be installed in front of window and door openings. This was another way to optimize the work schedule without compromising safety.

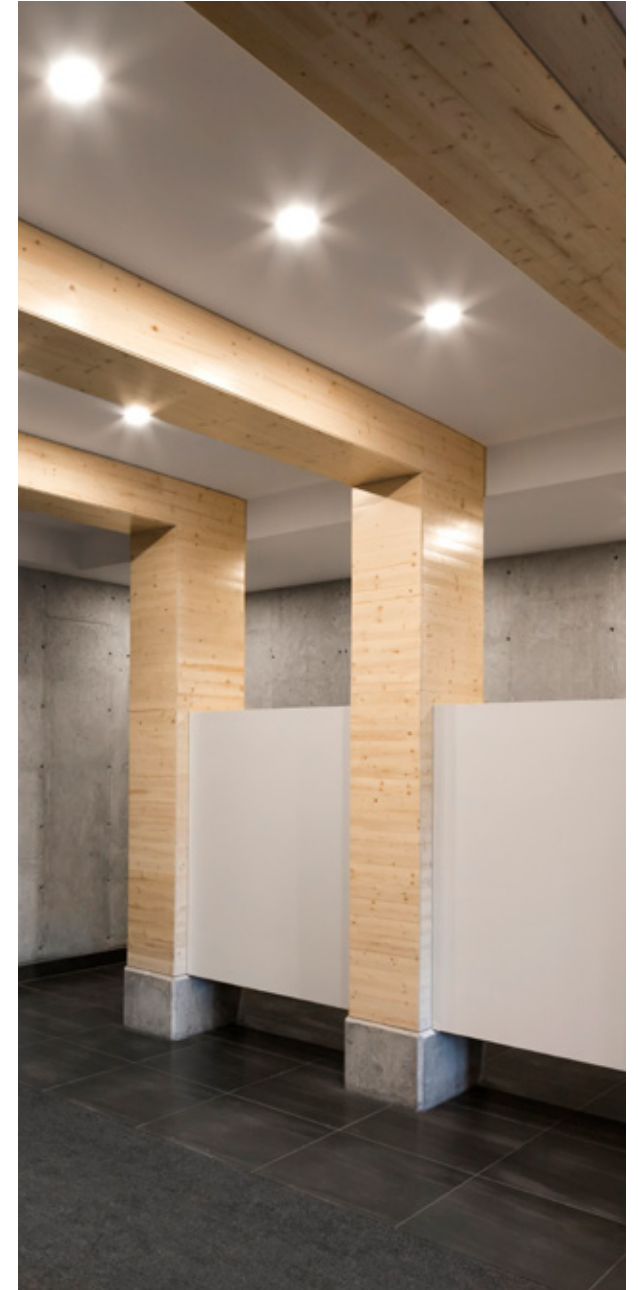


The wall panel rises above the floor level, doubling as a guard rail

© Photo : Stéphane Groleau



View from the terrace of the last floor
© Photo : Stéphane Groleau



Main Lobby
© Photo : Stéphane Groleau



Model apartment
© Photo : Stéphane Groleau

Lessons learned for future buildings

Several innovative ideas were developed regarding the choice of materials and ways to speed up and facilitate assembly of the structure, consequently reducing costs. For example:

- Horizontal sprinkler pipes could be made from combustible materials as permitted by the Code for fire resistive construction;
- Holes were drilled in the floors to allow electrical wiring to pass through. Each hole had to be treated to resist fire. In fire resistive construction, the Code allows all electrical wiring to be fed through a shared mechanical shaft. A mechanical shaft that brings together all or part of the electrical wiring and is then protected against fire, like the garbage disposal chute, reduces the amount of work required

Furthermore, the use of building information modeling (BIM) tools before the project got underway was key to efficiently coordinating all the tradespeople involved.



At a glance

Key environmental protection measures

- 3,111 m³ (110,000 ft³) of FSC-certified Quebec-sourced wood
- Sequestration of 2,295 metric tons of CO₂
- The equivalent of 1,000 metric tons of CO₂ avoided by using wood instead of other materials
- Improved thermal performance by reducing thermal bridges
- Solucycle technology for recovering organic waste
- Reflective roof membrane to reduce the heat island effect

© Photo: Stéphane Groleau



The building

- Building class: Group C
- Height: 40,9 m (134 ft)
- Area of building in wood: 890 m² (9,600 ft²)
- Number of storeys: 13 (12 in wood on a reinforced concrete podium)
- Key wood products:
 - Nordic X-Lam 5-, 7-, and 9-layer (175 to 291 mm; 67/8 in to 11½ in) CLT panels
 - Nordic Lam glulam posts and beams
- Project cost: \$25 million
- Structure erected in 4 months

Team

- Developer: NEB group
- Architect: Yvan Blouin Architect
- Code Consultants: Technorm, GHL Consultants
- Engineering:
 - Timber: Nordic
 - Mechanical: Genecor Experts-Conseils
 - Civil: Groupe conseil SID inc.
- Mass Timber Supplier: Nordic Structures
- General Contractor: EBC
- Erection of the Structure: Les Constructions FGP
- Laboratories: FPInnovations, the National Research Council of Canada

Drafting committee:

Valérie Levée, Gérald Beaulieu, Christian Dagenais, Caroline Frenette, Audrey Latulippe and Simon T. Bellavance

Review committee:

Susa Bernard, Yvan Blouin, François Chaurette, Julie Frappier, Sylvain Gagnon, Simon Gallagher, Kévin Gazeau, Sarah Hicks, Kim Lajoie, Étienne Lalonde, Peter McCambridge and Richard Poirier

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