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ENERGY AND COST IMPACTS OF CLT- CROSS LAMINATED TIMBER TALL WOOD BUILDING CONSTRUCTION. THE CASE OF A 10-STOREY BUILDING IN ALBERTA.

[1] SAIT - Southern Alberta Institute of Technology, Calgary, Canada
[2] azzeddine.oudjehane@sait.ca

Abstract: The use of CLT - Cross Laminated Timber engineered wood product in major construction projects has continuously increased over the past decade and the global market for CLT products estimated at 556 Million USD is expected to grow at a 15% growth rate over the next decade. Market growth of CLT can be linked to increased demand for sustainable building materials with a low carbon footprint. Recent and upcoming updates to building code in Canada recognize the wood design and construction beyond low rise residential, and the race to construct taller wood mass buildings like the 18 storey residence at the University of BC will support the growth in use and application of CLT. This paper and presentation will focus on a construction project management approach to using CLT. A 10 storey building design is considered and a 3D model is designed with two alternatives for the superstructure: reinforced concrete and CLT. Several impact analyses for energy consumption and cost of both alternatives are developed, and a value management approach is used to benchmark the two designs. Review the trends for CLT construction in Canada and globally

1 INTRODUCTION

Wood mass timber construction in North America continues is expected to grow with the recent surge in the manufacturing of Cross Laminated Timber (CLT) accompanied with changes to Building Codes.

In North America, the use of wood products has up until recently been limited to mid rise residential construction. Mass timber on the other hand has the potential to become the core structure for almost every type of building, across all industry segments. That may take several years, perhaps more, as CLT and wood mass construction have to overcome some barriers. Construction of tall mass buildings is at the stage of adoption for high rise concrete buildings in the early 20th century. One of the limitations for CLT market expansion has been the high-investment in the manufacturing process of CLT, hence, limiting the number of suppliers and making the supply of CLT for construction less economic or competitive. An indicator of manufacturing investment costs is the small number of CLT manufacturing firms member of the American Panel Association APA, responsible for standards and certification of engineered wood products. In Canada, there are currently only 3 CLT manufacturing plants located in British Columbia and Quebec.

One can anticipate the supply chain logistics for large construction projects requiring a large volume of CLT floors and panels. For example, the 18 storey tall wood mass building, the Brock Commons at the University of BC, required 29 panels per floor installed over a 3 month period (WoodWorks 2018)

Aside from the challenge with the supply of large volumes of CLT in large buildings, the requirement for prefabricated panel floors and walls CLT panels with pre-cut openings for doors, windows, stairs, service channels and ducts, and shipped directly from requires the manufacturing to include Computer Numerical Controlled - CNC machines capable of delivering panels ready for assembly on site. On the other hand, from a construction management, an integrated design process and collaborative approach to project delivery that includes the manufacturer or supplier may be an important consideration if not a requirement to avoid construction project creep.

Market expansion for the use of CLT in the construction of high rises, i.e. 10 storey and higher, is also dependant on changes to building regulations, standards and codes. However, most studies concur that the concern and issue revolved less about CLT's structural performance and more about its perceived flammability. Hence, to set fire safety requirements and allowable heights, areas and number of stroreys for tall mass timber buildings, the newly proposed building code to be included in the 2021 edition of the International Building Code identified three new types of construction (Wood Business 2018)

- Type IV-A: Maximum 18 stories, with gypsum wallboard on all mass timber elements.
- Type IV-B: Maximum 12 stories, with a limited area of exposed mass timber walls and ceilings allowed.
- Type IV-C: Maximum nine stories, with all exposed mass timber designed for two-hour fire resistance.

All of the above building types of construction are essentially driven by ensuring the fire rating of the building is maintained, despite the fact that CLT has a strong fire resistance through charring. Indeed pending on the panel thickness, CLT can be manufactured with fire resistance up to 90minutes (GreenSpec.com 2018)

Most recently, BC moved towards allowing 12-storey tall wood buildings as part of the new BB Building Code (Construction Canada 2019), whilst the race to build wood mass buildings taller continues as Norway hosts the tallest 18-storey wood mass building in the world at 85.4 meters (Dezeen 2019).

To use a value engineering process for the design and construction of any project, the consideration of alternatives often compares wood and concrete for the building materials. A case study (Mallo 2016) evaluated the economic performance of various construction systems, for a 40,000 square feet performing arts building. The study illustrated that in terms of cost of material, labour and speed of construction, a CLT walls and roof with glulam beams and wood frame system would cost up to 20% less per square foot when compared to the building system option of concrete walls, roof and light steel frame steel. Construction time for CLT systems was also estimated to last up 4 months shorter.

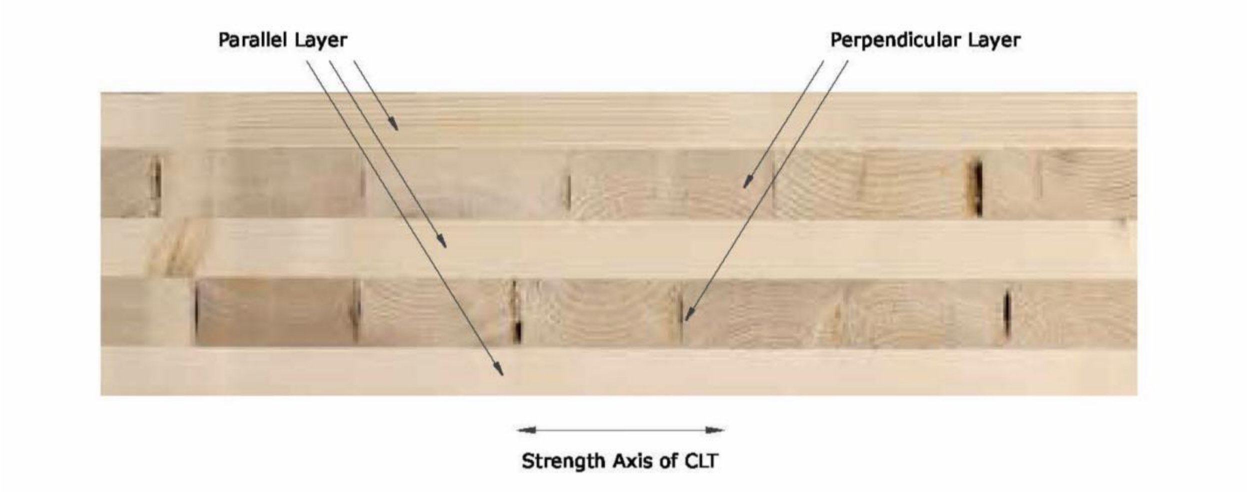
This case study subscribes to the foundations of value analysis principles without the function analysis of a 10-storey building. A benchmark comparison of the same design drawings of a 10-storey building with concrete and a full CLT is conducted in order to evaluate the benefits of CLT from the perspective of construction project management.

2 About CLT- Cross laminated timber

Cross laminated timber CLT is the most recent engineered wood product to enter the construction market in Canada and the US. Up until the construction of what was the tallest wood mass building in the world, Brock Commons building at the University of BC (NaturallyWood 2017) , CLT applications in Canada were limited to heavy duty platform oil rigs and some showcase demo buildings. (NRCan 2019).

According to the definition by the American Panel Association - APA: “A CLT panel consists of several layers of kiln-dried lumber boards stacked in alternating directions, bonded with structural adhesives, and pressed to form a solid, straight, rectangular panel. CLT panels consist of an odd number of layers (usually, three to seven,) and may be sanded before shipping. While at the mill, CLT panels are cut to size, including door and window openings, with state-of-the art CNC (Computer Numerical Controlled) routers, capable of making complex cuts with high precision. Finished CLT pan el s are exceptionally stiff, strong, and stable, handling load transfer on all sides.”(APA 2016). CLT panels be produced in large sizes (up to 0.5 metres (18”) thick, 4 metres (12’) wide and 24 metres (72’) long) into which door, window and service openings can be machined. An odd number of layers is normally used (to decrease warping), and nails or screws may be used for added strength.

Figure 1: Cross section of a a typical 5-ply CLT panel (NRCan 2019)



For the purpose of this case study, the following performance properties were used (StructurLam 2017)

- CLT Wall panels
  - Density: 485 kg/m3(SPF)
  - SpecificHeat Capacity: 1.6kJ/kg K (dependent on moisture content)
  - Thermal Conductivity: RSI Value: 0.84 per 100mm (K·m²/W), R Value: 1.2 per inch (h·ft²·°F/Btu)
  - To convert from (BTU*in)/(hr*ft²*˚F) to W/(m*K) you must divide by 6.933
  - (1.2/6.933) =0.17307 per inch of thickness
  - Exterior wall thermal conductivity = 0.17307*18 = 3.115 W/(m*K)
  - Interior wall thermal conductivity= 0.17307*6=1.0384
- CLT Floors panels
  - Same thickness acting as two way systems.
  - Deflection integrated in long term creep factors associated with wood design in Canadian design standards.

3 The 10 storey building framework

CLT for high rise construction competes directly with the use of other building materials such as reinforced concrete and hybrid steel concrete construction.

In order to undertake a benchmark study, an old existing low income housing 10-storey building was used for this case study. One basic design was made on Autodesk REVIT and the instance properties for materials were then altered afterwards. This allowed for an identical building to be analyzed using the different alternatives of building materials. Below is some basic information about which building material is used for each specific model. Given the emphasis on the superstructure, the building envelope, cladding, the accessories and glazing in this building were identical. Figure 2 illustrates the 2 main alternatives discussed in this paper: one using concrete and steel frame walls; one using CLT over concrete foundation.

Figure 2 Two 10-storey buildings: concrete and steel frame (left) FuLl CLT (right)

In this paper, two types of superstructures of the 10-storey building will be emphasized: full CLT and concrete with steel frame interior walls.

3.1 The Full CLT Building

This model is constructed of CLT and only excludes the foundation walls and slab on grade in the basement. The exterior walls are made of 18 inch thick CLT with the exterior face finished with stucco. The elevator shafts in this building are made of 18 inch thick CLT panels, just as the exterior walls. This allows for an identical wall to be used with similar char ratings and streamlined ordering requirements. Plumbing walls and interior walls are 8 and 6 inches thick respectively. The CLT floors are continuous two-way slabs.

3.2 The Concrete and steel frame building

The concrete building features cast in-situ concrete for the elevator shafts, exterior walls, foundations and slabs (elevated slabs poured on metal decking). The exterior walls have stucco on the exterior finished face and gypsum wall board on the interior finished face. The elevated slabs are concrete poured on metal decking. The interior walls consist of steel studs with gypsum wall board on each finished side. Finally, the foundations, basement slab, stair wells and elevator shafts are made of poured concrete.

3.3 Cost and Energy performance comparison

Cost performance of each building alternative e was estimated on the basis of quantity take-off obtained from the Revit models. The following table summarizes the total area and unit price per area in square feet and m2. For most material prices, an average unit price of the material was used. Labour costs

Building Type	Area (m2)	$/ft2	$/m2
Full CLT building	42,691	$ 7.14	$ 77
Concrete building	43,781	$ 8.11	$ 87

Table 1. Building materials cost-performance comparison.

Cost performance of the 2 building superstructure alternatives indicates slightly higher costs for the concrete building primarily because the CLT alternative did not include drywall to increase the fire rating.

An energy analysis was first performed based on the industry standards of each materials. It is based on the quantity and area of material as estimated from the quantity take-off. The BTU, electrical kWh, and natural gas GJ energy equivalent were calculated to illustrate two energy sources such as gas and natural gas. Overall energy costs could also be considered using average constant rates of 0.11$/kWh and 6.00$/GJ (ATCO 2019) to conduct a full life cycle cost analysis. The results of the energy performance are listed below.

Building Type	BTU Require Per Hour	Energy in kWh	Energy in GJ
Concrete	2,067,167.49	605.85	2.19
Full CLT	1,269,818.21	372.16	1.35

Table 2. Energy performance comparison.

Energy performance was analyzed using the heating degree day (HDD) method where the demand for energy needed to heat a building incorporates the heating degree days, based on Calgary data, the seasonal efficiency of the fuel, heat combustion value and approximate cost of the energy.

In addition to the above calculation solely based on material performances, an energy model of the building design of the 2 alternatives was performed against a NetZero energy benchmarking. The results are shown below. It is to be noted however, that the building design did not include any electrical and mechanical systems.The 2 alternatives used the same type of building envelope and exterior cladding and the EuI is simulated for heating and cooling the building for a Calgary based location.

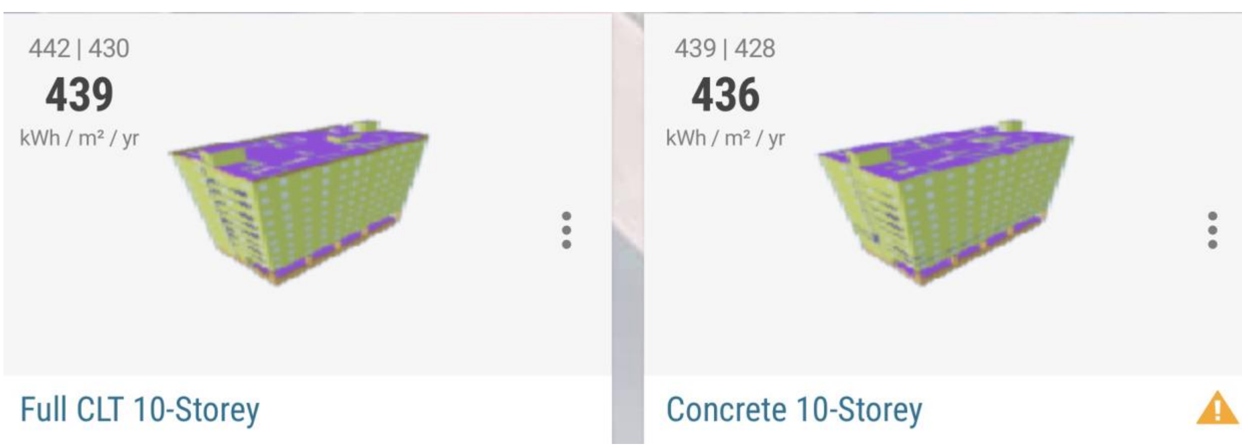


Figure 3. Energy use intensity simulation of the 2 alternatives of the 10-storey building

The benchmark comparison of two alternatives for a 10-storey building using concrete and CLT has indicated limited differences in terms of impacts of cost and energy performances. Nevertheless, we believe that CLT provides slightly more flexibility in terms or energy requirements and thereby a lesser carbon footprint when it comes down to construction. A full life cycle analysis for cost and environmental should be completed and published.

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