A Review on Cross Laminated Timber (CLT) and its Possible Application in North America

Shikai Xu

WOOD 493

A Report Submitted in Partial Fulfillment of the Requirements for the Degree of Bachelor Science in Wood Products Processing

In

Faculty of Forestry

THE UNIVERSITY OF BRITISH COLUMBIA

April 2013

©Shikai Xu, 2013
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>4</td>
</tr>
<tr>
<td>1. INTRODUCTION OF CLT</td>
<td>5</td>
</tr>
<tr>
<td>1.1 DESCRIPTION</td>
<td>5</td>
</tr>
<tr>
<td>1.2 HISTORY</td>
<td>7</td>
</tr>
<tr>
<td>1.3 LEADING COUNTRIES AND MAJOR PRODUCERS</td>
<td>7</td>
</tr>
<tr>
<td>2. CLT MANUFACTURING</td>
<td>8</td>
</tr>
<tr>
<td>2.1 LUMBER DRYING</td>
<td>8</td>
</tr>
<tr>
<td>2.2 ADHESIVE SELECTION</td>
<td>9</td>
</tr>
<tr>
<td>2.3 PRESSING</td>
<td>10</td>
</tr>
<tr>
<td>2.4 PANEL ASSEMBLIES</td>
<td>11</td>
</tr>
<tr>
<td>2.5 CLT CUTTING</td>
<td>12</td>
</tr>
<tr>
<td>3. CLT PERFORMANCE AS A BUILDING MATERIAL</td>
<td>12</td>
</tr>
<tr>
<td>3.1 THERMAL PERFORMANCE</td>
<td>12</td>
</tr>
<tr>
<td>3.2 ACOUSTICAL</td>
<td>13</td>
</tr>
<tr>
<td>3.3 FIRE RESISTANCE</td>
<td>15</td>
</tr>
<tr>
<td>3.4 SEISMIC</td>
<td>16</td>
</tr>
<tr>
<td>4. ADVANTAGES OF USING CLT</td>
<td>17</td>
</tr>
<tr>
<td>4.1 SHORT CONSTRUCTION TIME</td>
<td>17</td>
</tr>
<tr>
<td>4.2 COST COMPETITIVENESS</td>
<td>17</td>
</tr>
<tr>
<td>5. DISADVANTAGES</td>
<td>18</td>
</tr>
<tr>
<td>6. THE NORTH AMERICAN STANDARD</td>
<td>19</td>
</tr>
<tr>
<td>7. THE TREND OF CLT IN NORTH AMERICA</td>
<td>21</td>
</tr>
<tr>
<td>7.1 GOVERNMENT POLICY</td>
<td>21</td>
</tr>
<tr>
<td>7.2 CASE STUDIES</td>
<td>21</td>
</tr>
<tr>
<td>7.2.1 CANADA</td>
<td>24</td>
</tr>
<tr>
<td>7.2.2 OTHER PROJECTS IN CANADA</td>
<td>28</td>
</tr>
<tr>
<td>7.2.3 US</td>
<td>28</td>
</tr>
<tr>
<td>REFERENCE</td>
<td>29</td>
</tr>
<tr>
<td>GLOSSARY</td>
<td>30</td>
</tr>
</tbody>
</table>
A Review on CLT and its Possible Application in North America

LIST OF FIGURES
FIGURE 1 EXAMPLE OF CLT LAYOUT (FPINNOVATIONS, 2011A) 6
FIGURE 2 EXAMPLE OF CLT DIMENSION AND LAYER COMPONENTS (FPINNOVATIONS, 2011A) 6
FIGURE 3 CLT PRESS SYSTEM (SCHICKHOFER, 2011) 11
FIGURE 4 FINGER JOINTING OF CLT PANELS (GOOGLE, 2011) 11
FIGURE 5 GRAIN AND LAYER ARRANGEMENT OF CLT (SCHICKHOFER, 2011) 12
FIGURE 6 COST OF 8 STOREYS APARTMENT, CLT VS NON-WOOD (FII, 2011) 18
FIGURE 7 MURRAY GROVE, LONDON ENGLAND (E-ARCHITECT, 2009) 23
FIGURE 8 INTERIOR LOOK OF MURRAY GROVE (E-ARCHITECT, 2009) 23
FIGURE 9 AUSTRIA HOUSE IN WHISTLER, BC (FPINNOVATIONS, 2011A) 25
FIGURE 10 BIOENERGY RESEARCH AND DEMONSTRATION PROJECT, UNIVERSITY OF BRITISH COLUMBIA (FPINNOVATIONS, 2011A) 26
FIGURE 11 DOWLING RESIDENCE (FPINNOVATIONS, 2011A) 27

LIST OF TABLES
TABLE 1 MAJOR EUROPEAN AND NORTH AMERICAN MANUFACTURERS OF CLT (GAGNON & CRESPPELL, 2010) 7
TABLE 2 THERMAL CONDUCTIVITY OF SOME CANADIAN SOFTWOOD SPECIES (GLASS & ZELINKA, 2010) 13
A Review on CLT and its Possible Application in North America

NOT REGULATED BY NBCC, VALUES ARE SUGGESTED BY BURROWS & CRAIG, 2005) 14

TABLE 4 DESIGN CHARRING RATES OF SOFTWOOD TIMBER (CEN, 2004) 15

TABLE 5 REQUIRED CHARACTERISTIC STRENGTHS AND MODULI OF ELASTICITY FOR PRG 320 CLT LAMINATIONS (YEH ET AL., 2011) 20
Abstract

Cross laminated timber (CLT) is a new building system to North America. Europe is the leading region of applying and manufacturing CLT. European producers stay to a proprietary manufacturing approach as the European (EN) standard is still being developed. This paper provides a general review of the background, process, and performance of CLT. Some case studies of its current applications were summarized. The pros and cons of applying CLT in North America were also discussed.

In North America, CLT standard has been developed as a bi-nation standard for both US and Canada. CLT buildings can perform better than the minimum building code requirements in terms of fire and seismic performance. With additional materials, CLT can be in compliance with acoustic and thermal insulation. In recent years, CLT has been picking up its trend in North America, especially in Canada. Current building codes limitations to wood construction and proper product and design standards are the main obstacles preventing CLT’s wide spread in North America. In conclusion, in order to gain market acceptance, changes to the building codes and development of standards are needed.
1. Introduction of CLT

1.1 Description

Cross Laminated Timber (CLT) is an engineered wood product manufactured by laminating lumber orthogonally with adhesives or fasteners. CLT is a multiple layer panel, typically consisting of three to seven or more in odd numbers, so that the top and bottom layers are symmetrical around the center layer. Dimension lumber is the major material of CLT. According to a recent research by Wood Solutions (2012), it is feasible to use low grade lumber for the interior layers and higher grade lumber for the outside layers during the manufacturing process in the factory. Softwood lumber is currently the dominating material used for CLT, however, hardwood and wood composites are also utilisable. Formaldehyde and solvent free Polyurethane (PUR) adhesives are widely employed for bonding. The dimensions of CLT vary by manufacturers and end users. Typically, the widths, lengths and thicknesses can be up to 3 m x 18 m x 0.5 m. As a building material, CLT panels can be used for interior and exterior walls, floors and roofs.
A Review on CLT and its Possible Application in North America

Figure 1 Example of CLT layout (FPInnovations, 2011a)

Figure 2 Example of CLT dimension and layer components (FPInnovations, 2011a)
1.2 History

CLT was originally invented in Switzerland in the early 1990s (Gagnon & Crespell, 2010). A group of Austrian and German companies developed and tested CLT panels. However, the early production process was a little different from today’s. In 1996, an academic joint research program in Austria came up with the current CLT design. European Technical Approval (ETA) reports allowed the European producers to stay to a proprietary manufacturing approach because the European (EN) standard is still under development.

1.3 Leading countries and major producers

Driven by the green building movement, CLT has gained increasing awareness as a structural and sustainable building material. The demand of CLT had increased dramatically in the 2000s. Europe is the leading region of applying and producing CLT. There are only a few manufacturers in North America as the industry is still fairly new.

Table 1 Major European and North American Manufacturers of CLT (Gagnon & Crespell, 2010)

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Location</th>
<th>Production Volume (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KLH</td>
<td>Austria, UK, Sweden</td>
<td>71,000</td>
</tr>
</tbody>
</table>
### 2. CLT Manufacturing

#### 2.1 Lumber drying

Similar to other engineered wood products, CLT are subject to change in dimension and stability within the hygroscopic range. Gülzow et al. (2010) reported that the stiffness properties of CLT drop with increasing moisture content. Specifically, Gülzow et al. (2010) concluded that modulus of elasticity in the wood grain direction decreases by 1.5% for every percent of moisture content increment within the hygroscopic range. However, if the moisture content of individual timber were below 10%, it would lead to cracking and also decrease in the bending stiffness. Obtaining proper moisture content is crucial not only for properties, but also helpful in eliminating surface cracking which would improve the overall quality. In industry, moisture content
of 12% is considered as a target number with 2% up or down depending on end use location (Gagnon & Crespell, 2010).

It is also very important to have consistent level of moisture content among panel layers. Residual stresses would cause weak bond strength and may develop joint failure, which might cause further cracking of the lamination (Harch, 2010). In 1997, Hernandez and Moody proved that residual stresses could be left behind in the component by bonding layers with various moisture contents.

### 2.2 Adhesive selection

Adhesive is the second largest material of CLT’s components. CLT requires structural adhesive satisfying the requirements of American national Standards Institute and American Institute of Timber Construction (ANSI)/(AITC) 405 in the U.S. and Canadian Standards Association (CSA) O112. Two types of structural adhesives dominating the current industry are polyurethane resins (PUR) and melamine urea formaldehyde resins (MUR). Several tests were conducted by FP Innovations on some Canadian species and glues, where they found that besides those two most dominant resins, phenolic type (PRF) and emulsion polymer isocyanate (EPI) could also be used for CLT (Wang, Pirvu, & Lum, 2011). However, due to concerns with the carcinogenicity of formaldehyde, PUR are still the most popular adhesives used as they are formaldehyde and solvent free (Gagnon & Crespell, 2010).
2.3 Pressing

The two commonly used pressing methods are hydraulic pressing and vacuum pressing (Gagnon & Crespell 2010). Bond pressure and adhesive applications have the most significant influence on CLT properties. In today’s manufacturing process of CLT, the main difference between producers lies in individual gluing. One method is to prepare the layers by edge bonding individual dimension timber. Another method is to only apply adhesive between layers and press all of them together in one step (Gagnon & Crespell, 2010). Hydraulic press system is normally used. The first method requires three axes press system. The three axes are vertical $P_v$, horizontal transverse $P_{h,t}$ and horizontal lengthwise $P_{h,l}$. An adopter of the three axes CLT press system is Minda, a leading German company in the development of press systems for the production of glulam. Minda press system has the ability to apply three directions press in a continuous process line. Figure 3 illustrates the process flow of a CLT press system. Individual panels are fed into vacuum station through two lines, odd layer line and even layer line. Panels handling and alignment are done by a vacuum arm. While the panels are transferring to the gluing station, adhesives are applied. Once the last layer is stacked up, the whole product is fed into press station. The whole cycle takes about 40 minutes.
2.4 Panel Assemblies

Panel dimension can be achieved by trimming and finger jointing lumber (Figure 4). Panels are stack over at right angles and by either using adhesives or nails. The exterior panels are arranged to run parallel to the extending direction. Figure 5 shows an example of CLT wall which is oriented the grain direction of outside layers parallel to the
vertical loads to maximize resistance. The final desired size of CLT can be obtained by jointing individual panels.

![Slab-like Grain and Layer Arrangement of CLT](Schickhofer, 2011)

**Figure 5 Grain and layer arrangement of CLT (Schickhofer, 2011)**

### 2.5 CLT cutting

The final size of a CLT panel is achieved by computer numerical controlled (CNC) routing. CNC machining allows high precision cutting. Panels are also cut out openings for doors, windows and panel-to-panel connections.

### 3. CLT performance as a building material

#### 3.1 Thermal Performance

According to Glass & Zelinka (2010), thermal conductivity is defined as “a measure of the rate of heat flow through a material subjected to unit temperature difference across unit thickness.” Thermal resistivity is the reciprocal of the thermal conductivity. Thermal conductivity of wood is about two to four times greater than common insulating material. The thermal conductivity of CLT is very similar to the wood
species of its raw material. According to Glass & Zelinka, the thermal conductivity of common Canadian softwood species is around R 1.0 to R 1.4 per inch. It is possible to achieve higher thermal resistivity by increase the thickness of CLT panels. A five-inch-thick CLT panel has a thermal resistance of R 5.0 to 6.5. The minimum insulation requirements for Canadian building code vary by locations, but it is common to use thermal resistance of R 20 for residential walls. Therefore, it would not be adequate to meet the minimum insulation requirements level by using the CLT panel itself.

Table 2 Thermal Conductivity of some Canadian softwood species (Glass & Zelinka, 2010)

<table>
<thead>
<tr>
<th>Species</th>
<th>Conductivity</th>
<th>Resistivity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>12% MC (W M(^{-1}) K(^{-1}))</td>
<td>12% MC (R-value)</td>
</tr>
<tr>
<td>Douglas-fir Coast</td>
<td>.14</td>
<td>1.0</td>
</tr>
<tr>
<td>Fir Balsam</td>
<td>.11</td>
<td>1.3</td>
</tr>
<tr>
<td>Pine Lodge pole</td>
<td>.12</td>
<td>1.2</td>
</tr>
<tr>
<td>Spruce White</td>
<td>.11</td>
<td>1.3</td>
</tr>
</tbody>
</table>

### 3.2 Acoustical

In a multi-unit residential construction, sound insulation is particularly important to occupants. Noise from neighbour, can be a negative impact on occupants’ comfort, happiness and satisfaction of the building. Two typical acoustic transmissions are airborne transmission and impact transmission. A sound source in one room sends air pressure and induces vibration in an adjacent room through wall is an airborne sound. An
impact sound transmits through floors being vibrated by direct mechanical contact or impact (Burrows & Craig, 2005). In Canada, sound transmission class (STC) rate is used to measure the average noise reduction in decibels (dB). However, good STC ratings do not guarantee acoustical comfort, impact insulation class (IIC) is another important factor to consider in architects design. The current National Building Code of Canada (NBCC) only regulates airborne transmissions for interior walls and floors in multi-family buildings. On its own, the attenuation of a 5-ply CLT panel is insufficient to meet the NBCC requirements (Table 3). Gagnon & Crespell (2010) believe that by using a combination of CLT, suspended ceiling, fibre glass and gypsum boards, it is possible to achieve a higher degree of acoustic comfort.

Table 3 CLT STC and ICC ratings and minimum requirements (NBCC, 2012, Gagnon & Crespell, 2010 & Burrows & Craig, 2005) (*are not regulated by NBCC, values are suggested by Burrows & Craig, 2005)

<table>
<thead>
<tr>
<th></th>
<th>STC (dB)</th>
<th>IIC (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Party walls</td>
<td>50</td>
<td>-</td>
</tr>
<tr>
<td>Passage walls</td>
<td>50</td>
<td>-</td>
</tr>
<tr>
<td>Inter-unit walls</td>
<td>55</td>
<td>-</td>
</tr>
<tr>
<td>Inter-unit hard floors</td>
<td>50</td>
<td>55*</td>
</tr>
<tr>
<td>Inter-unit carpeted floors</td>
<td>50</td>
<td>65*</td>
</tr>
<tr>
<td>5-ply CLT</td>
<td>38</td>
<td>26</td>
</tr>
<tr>
<td>5-ply CLT+ suspended ceiling + fibre glass insulation 200mm</td>
<td>63</td>
<td>62</td>
</tr>
</tbody>
</table>
3.3 Fire resistance

Table 4 Design charring rates of softwood timber (CEN, 2004)

<table>
<thead>
<tr>
<th>a) Softwood and beech</th>
<th>$\beta_0$ (mm/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glued laminated timber with a</td>
<td>0.65</td>
</tr>
<tr>
<td>characteristic density of ≥ 290</td>
<td></td>
</tr>
<tr>
<td>kg/m³</td>
<td></td>
</tr>
<tr>
<td>Solid timber with a</td>
<td>0.65</td>
</tr>
<tr>
<td>characteristic density of ≥ 290</td>
<td></td>
</tr>
<tr>
<td>kg/m³</td>
<td></td>
</tr>
</tbody>
</table>

Fire is one of the greatest concerns for all wood structural buildings. Nevertheless, CLT panels are usually thicker than most of the traditional wood panels. Therefore, it is relatively hard to ignite. Although CLT panels are flammable and maybe subject to fire contribution under certain situation, solid wood timber still shows higher resistance to fire effect than steel and concrete structure. When exposed to fire, the outer layer of wood member will form a charcoal layer. This charcoal layer acts like insulation and helps to protect the interior wood member from fire.
A study done in Switzerland in 2009 found that the behaviour of CLT panels in the fire test was strongly influenced by the bonding adhesives (Frangi, Fontana, Hugi, & Jübstl, 2009). When PU was used for CLT adhesives, CLT charcoal layers fell off at not constant and higher charring rates than traditional timber products. Charring rates of the layers consistently increased as the later the layer starts charring. It was assumed that the charring rate is doubled for the second layer in comparison to the first layer. Frangi, Fontana, Hugi, & Jübstl also proved that CLT panels with thicker layers had better fire behaviour than those with thin layers. This is because the thicker charcoal layer, the better the insulation it contributes to protecting the interior layers.

### 3.4 Seismic

Considering CLT as a new structural building system, there has not been any verified seismic performance during earthquakes. CLT seismic performance strongly relies on the research projects. A project called SOFIE was undertaken by IVALSA (Trees and Timber Research Institute of Italy) in Japan, where two full scale CLT buildings, 3-storey and 7-storey were tested on the largest shaking table in the world. The 3-storey CLT building survived after 14 tests which had peak ground acceleration (PGA) of 0.5g or higher. The 3-storey reached the collapse state, which was defined to be one or more hold-down failures, when simulated the Nocera Umbra earthquake at a PGA of 1.2g. The director of the SOFIE Ceccotti (2008) concluded that the behavior of CLT walls was not controlled by the CLT panels, but by the connections. A 7-storey building was tested on the shaking table at E-Defense in Japan. After a total of 14 tests, the 7-storey building
showed advantageous performance, with a maximum top displacement of 2.4% (X) and 1.6% (Y) and negligible damage.

4. Advantages of using CLT

4.1 Short Construction Time

There are many advantages of using CLT in constructions. Prefabricated CLT buildings “offers tremendous savings in construction time and cost”, said by Professor Lam at the University of British Columbia. According to a study conducted by FPInnovations (2011), for the same floor area residential, mid-rise and industrial buildings, CLT saved 30% of the construction time compared to concrete, brick and steel buildings. Saving construction time also means saving labor cost. With prefabricated panels, less work is required on construction site. Therefore, less skilled workers are required and the noise during construction is reduced.

4.2 Cost competitiveness

FPInnovations (2011), discovered that the material cost of CLT structure was about 15% less than concrete, steel and masonry mid-rise residential buildings. For non-residential and low-rise buildings, cost of CLT structure can save up to 50% than non-wood buildings (Figure 6).
5. Disadvantages

As discussed in the previous section, CLT is advantageous in many aspects; nonetheless, there are still some raising problems and concerns. First of all, CLT is a solid and dense wood product, which creates certain difficulties in handling and transportation. Moreover, the thermal conductivity property of CLT panel itself is considered to be lower than the building code requirement in North America. Thus, extra insulating materials are still required as in the frame construction. The extra wood material here used in CLT is inefficient for thermal resistance. In a case study of CLT acoustic measurements by Öqvist, Ljunggren, & Ågren (2012) found that CLT system had larger variation in the low frequency range (50-100 Hz) compared to traditional prefabricated volume based building (VBB) system. This alerts that CLT system is lacking the ability to reduce traffic noise so it needs development. A mail survey conducted by Connor, Kozak, Gaston, & Fell in 2004 showed that designers are more
hesitant to use wood for large non-residential buildings because of technical barriers, stringent code limitation of wood and standards gaps. Before the completion of product standard, material design standard and acceptance of building code, CLT is facing challenges and it needs more advertising in order to increase its market share in non-residential buildings.

6. The North American Standard

As a new construction material, a product standard for CLT is necessary to all the manufacturers and certification agencies. In North America, CLT standard was developed as a bi-nation standard to be accepted by both US and Canada. The initial product standards were drafted by FP Innovations. In 2010, FP Innovations passed along the standards to the Engineered Wood Association (APA) for a joint North American CLT standard. The standard was completed after 22 months as ANSI/APA PRG 320 CLT Standard (Yeh, Gagnon, Williamson, & Pirvu, 2011).

Stress classes were based on lumber species and grades:

E1: 1950f-1.7E Spruce-pine-fir MSR lumber in all parallel layers and No. 3 Spruce-pine-fir lumber in all perpendicular layers

E2: 1650f-1.5E Douglas fir-Larch MSR lumber in all parallel layers and No. 3 Douglas fir-Larch lumber in all perpendicular layers

E3: 1200f-1.2E Eastern Softwoods, Northern Species, or Western Woods MSR lumber in all parallel layers and No. 3 Eastern Softwoods, Northern Species, or Western Woods lumber in all perpendicular layers
A Review on CLT and its Possible Application in North America

E4: 1950f-1.7E Southern pine MSR lumber in all parallel layers and No. 3 Southern pine lumber in all perpendicular layers

V1: No. 2 Douglas fir-Larch lumber in all parallel layers and No. 3 Douglas fir-Larch lumber in all perpendicular layers

V2: No. 1/No. 2 Spruce-pine-fir lumber in all parallel layers and No. 3 Spruce-pine-fir lumber in all perpendicular layers

V3: No. 2 Southern pine lumber in all parallel layers and No. 3 Southern pine lumber in all perpendicular layers

Table 5 Required Characteristic Strengths and Moduli of Elasticity for PRG 320 CLT Laminations

(Yeh et al., 2011)

<table>
<thead>
<tr>
<th>CLT Grades</th>
<th>Laminations in the Major Strength Direction of the CLT</th>
<th>Laminations in the Minor Strength Direction of the CLT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$f_{b,0}$ (MPa)</td>
<td>$E_0$ (MPa)</td>
</tr>
<tr>
<td>E1</td>
<td>28.2</td>
<td>11700</td>
</tr>
<tr>
<td>E2</td>
<td>23.9</td>
<td>10300</td>
</tr>
<tr>
<td>E3</td>
<td>17.4</td>
<td>8300</td>
</tr>
<tr>
<td>E4</td>
<td>28.2</td>
<td>11700</td>
</tr>
<tr>
<td>V1</td>
<td>13.0</td>
<td>11000</td>
</tr>
<tr>
<td>V2</td>
<td>12.7</td>
<td>9500</td>
</tr>
<tr>
<td>V3</td>
<td>14.1</td>
<td>11000</td>
</tr>
</tbody>
</table>
7. The trend of CLT in North America

7.1 Government policy

According to the Canadian Wood Council (CWC) 2010, since the first introduction of I-beams 40 years ago, no product has gained so much interest like CLT. In March 2011, Harper Government announced a total of $88 million investments to protect jobs in Canada’s forest industry. Canadian CLT manufacturer Structurlam received a $2.5 million investment for its Okanagan Falls facility. This investment would help to expand the use of engineered wood product such as CLT in order to improve environmental performance. This investment would also jumpstart the production and would allow CLT to gain more public reorganization in commercial and institutional construction. Another advantage of using CLT is to utilize the mountain pine beetle killed wood that is now available.

7.2 Case studies

First developed and already popular in Europe, CLT is picking up its trend in North America. In Europe, it was reported in March 2012 that there were eight CLT manufacturers, with capacities ranging from 4,000 to 71,000 m$^3$ (Table 1). In Canada, two producers were mentioned: Structurlam in Penticton, BC and Nordic Engineered Wood in Quebec (WBPIONLINE, 2012).

Because of the nature of its assembly method, CLT has the strength to bear heavy loads and has the potential to be used both vertically and horizontally. Its fire, acoustical,
A Review on CLT and its Possible Application in North America

and seismic performances, as discussed above, also make CLT preferable over other building materials in many aspects. Due to prefabrication, the efficiency of building walls, floors and roof from CLT is higher than using traditional materials (Frank Lam). In terms of ecological footprint saving and improving aesthetic appearance, CLT has offered great opportunities to North American builders and designers. CLT provides protection to collapse to some extent if it was designed smartly. For example, if one piece fails, other elements could carry the load (Fountain, 2012). In theory, CLT has the potential to replace concrete or steel as structural system in buildings up to 10 storeys, the tallest existing CLT building being the nine-storey Murray Grove residential tower in London, England (FPInnovations, 2011a). In May 2012, a 10-storey CLT apartment tower was started in Melbourne, Australia. Some people optimistically predicted that it would be possible to hit 12, 13, 14 or even 15 storeys in the near future (Fountain, 2012).

By March 2012, there was approximately 0.3 million m$^3$ of CLT existing in constructions globally, and the projected future volume was 0.6 – 1.0 million m$^3$ by 2015 (WBPIONLINE, 2012).
A Review on CLT and its Possible Application in North America

Figure 7 Murray Grove, London England (E-architect, 2009)

Figure 8 Interior look of Murray Grove (E-architect, 2009)
However, the lack of building standards and codes may pose a problem towards the spread of CLT applications in North America. These need to be developed first before the wide utilization of CLT could happen. According to Mr. McCrone, the owner of Innovative Timber Systems, the understanding of such product comes relatively quickly (Fountain, 2012).

7.2.1 Canada

Wood has been traditionally utilized as building materials in Canada and especially in British Columbia. The earliest utilization was Frist Nations longhouse while the latest and possibly the most well-known one is the Richmond Speed Skating Oval in BC England (FPInnovations, 2011).

In BC, by replacing the current concrete and steel used with CLT, it might help reducing the amount of salvage logs and standing dead trees from the mountain pine beetle epidemic (Fountain, 2012).

Austria, as the world’s largest CLT producer by far, built its BC Austria House for the 2010 Winter Olympics in Whistler. As the first Passive House in Canada, it demonstrated CLT role in environmental friendly and sustainable
The University of British Columbia has been developing a Bio-energy Research + Demonstration project since 2011, with CLT walls and roof construction on top of a concrete foundation. Upon completion, it will provide electricity and steam to the campus (FPInnovations, 2011a). This is going to be the first industrial CLT building in North America.
CLT has been recognized by the Canadian and BC government as a new viable building option. More specifically, a two-day symposium on CLT was held in 2011 to promote CLT as a part of the BC’s Wood First Initiative ((WoodWorks, 2012)There, a project studying the feasibility of a 9-12 storey advanced wood hybrid structure was proposed and funded.

In the residential building sector, some projects have taken place in BC. The Dowling Residence built by Greg Dowling from the Vancouver firm of DGBK Architects, is a three-storey hybrid construction built with concrete, steel, and CLT. The walls, floors and roof assemblies were mainly made from CLT. A cantilevered balcony was also made
A Review on CLT and its Possible Application in North America

solely with CLT panels. It is the first permanent residential construction in BC using CLT as main building material (FPInnovations, 2011a).

Figure 11 Dowling Residence (FPInnovations, 2011a)
7.2.2 Other projects in Canada

1. An expansion of the Fort McMurry airport in Western Canada is being carried out, where CLT plays a role in the innovative roof paneling and spandrel panels. This project will be the largest application of CLT in Western Canada when it is completed (Structurlam, 2013).

2. CLT was used for the roofing of the Wayne Gretzky Sport Centre (Structurlam, 2013).

3. Walls and floors made by CLT in the North Shore Credit Union Environmental Learning Centre in Brackendale, near Squamish, BC (Structurlam, 2013).

4. Elkford Community Centre incorporated CLT into an exposed interior wall panels (Structurlam, 2013).

7.2.3 US

There are no CLT producers in the US yet. Nonetheless, there are CLT involved projects already completed and some underway (WBPIONLINE, 2012).

Innovative Timber Systems, based in Whitefish, Montana, was hoping to be the first to produce CLT in the United States. The company previously built a martial arts studio with panels imported from Australia (Fountain, 2012).

Overall, CLT as a novel wood product in North America, from product life cycle analysis point of view, is still going through its introductory/growth phase. Therefore,
there are massive potential markets for it. CLT is generally following the similar evolution trend as LVL, PSL and even OSB (WBPIONLINE, 2012). What is worth mentioning is that the others substituted each other for the existing building system whereas CLT can potentially replace them.

In North America, the CLT standards and certifications are being developed mainly by APA-The engineered Wood Association. This intention of the standard document was to be used bi-nationally in both US and Canada, according to Dr Borjen Yeh, the director of APA’s Technical Services Division (Yeh et al., 2011).

Reference


A Review on CLT and its Possible Application in North America


**Glossary**

\[ A_g \quad \text{Gross cross-sectional area, in in.}^2/\text{ft} \quad (\text{mm}^2/\text{m}) \]
A Review on CLT and its Possible Application in North America

\( A_{\text{net}} \) Net cross-sectional area, in \( \text{in.}^2/\text{ft} \) (\( \text{mm}^2/\text{m} \)) for calculating the compressive stress in the major strength direction

\( E_0 \) Modulus of elasticity in bending parallel to the major strength direction of CLT, in psi (MPa)

\( E_{90} \) Modulus of elasticity in bending perpendicular to the major strength direction of CLT, in psi (MPa)

\( f_{b,0} \) and \( F_{b,0} \) Bending strength and allowable bending stress parallel to the major strength direction of CLT, in psi(MPa)

\( f_{b,90} \) and \( F_{b,90} \) Bending strength and allowable bending stress perpendicular to the major strength direction of CLT, in psi(MPa)

\( f_{c,0} \) and \( F_{c,0} \) Compressive strength and allowable compressive stress parallel to the major strength direction of CLT, in psi(MPa)

\( f_{c,90} \) and \( F_{c,90} \) Compressive strength and allowable compressive stress perpendicular to the major strength direction of CLT, in psi(MPa)

\( f_{t,0} \) and \( F_{t,0} \) Tensile strength and allowable tensile stress parallel to the major strength direction of CLT, in psi(MPa)

\( f_{t,90} \) and \( F_{t,90} \) Tensile strength and allowable tensile stress perpendicular to the major strength direction of CLT, in psi(MPa)

\( f_{v,0} \) and \( F_{v,0} \) Shear strength and allowable shear stress parallel to the major strength direction of CLT, in psi(MPa)
A Review on CLT and its Possible Application in North America

$f_{v,90}$ and $F_{v,90}$  Shear strength and allowable shear stress perpendicular to the major strength direction of CLT, in psi(MPa)

$I_g$  Gross moment of inertia, in in.$^4$/ft (mm$^4$/m)

$I_{\text{eff}}$  Effective moment of inertia, in in.$^4$/ft (mm$^4$/m), of the composite CLT section for calculating the bending stiffness of CLT

$S_{\text{eff}}$  Effective section modules, in in.$^3$/ft (mm$^3$/m), of the composite CLT section for calculating the moment capacity of CLT

$A_{\text{eff}}$  Effective cross-sectional area, in in.$^2$/ft (mm$^2$/m), of the composite CLT section for calculating the interlaminar shear capacity of CLT