CROSS-LAMINATED TIMBER: AN ADVANCED ALTERNATIVE THAT WILL RESHAPE THE INFRASTRUCTURE OF THE WORLD

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Abstract—In today's world, scientists and engineers are searching to design and create the most efficient and cost-effective materials. One of these materials is cross-laminated timber (CLT), built by stacking wood boards at 90-degree angles. This simple design allows the material to be easily manufactured. There are also specific properties that distinguish CLT from other materials, such as the strength, resistance to delamination, fire resistance, and reactions to vibrations. The application of CLT can also be considered quite efficient compared to other common materials. There is a shortened build period, a lower amount of labor required, and a lower amount of material required when using CLT. The fabrication process takes advantage of these characteristics, allowing CLT to be easily designed on a computer before being constructed or simply customized on the spot. CLT is just starting to become popular; several structures have already been constructed using CLT, and future structures are being designed allowing room for improvement in this new building material. CLT also contributes to the sustainability environment by being easily harvested and lacking emissions such as CO₂.

Key Words—Cross-Laminated Timber, Building Materials, Cross-Laminated, Foundations, Infrastructure, Structure, Timber

CURRENT STATUS OF INFRASTRUCTURE

According to the American Society of Civil Engineers, America’s infrastructure ended 2017 with a grade of a D+. This grade was obtained by looking at and evaluating multiple categories of infrastructure—including bridges, roads, and energy [1]. Some of the currently materials include steel, concrete, and wood. This poor grade is partially due to the efficiency of these materials.

Concrete

Concrete is currently one of the most used building materials in the United States, “already produced in over 2 billion tonne quantities per year” [2]. The U.S. Geological Survey government organization found that the production of cement, the main component for concrete, in the U.S. was around 85.4 million tons in 2016 [3]. Cement is popular because of how efficient it is for such a low price. This does not mean that concrete is the strongest material, but instead that it has the most efficient ratio between strength and price. In 2016, the average price per ton was $111.00 [3]. The main problem with concrete that is being acknowledged is the CO₂ emissions.

Steel

Another widely-used material is steel. Just like concrete, steel can be used for a variety of different projects. In 2016, the demand for steel in the U.S. was 78.5 million tons [4]. One issue with steel is the price compared to concrete. The price for steel in 2017 was around $365 per ton [5]. This is significantly larger than the price of concrete, making steel not as appealing. Iron and steel production also account for around 6.5% of CO₂ emissions [6], similar to concrete. Steel has a higher overall strength compared to concrete. The main problem with this is that now both steel and concrete must be paid for.

Wood

Wooden structures also appear frequently, having both benefits and drawbacks. Wood has advantages when it comes to properties such as strength and environmental friendliness, but there are also disadvantages when it comes to reactions to the environment and its deterioration. Deterioration, one of these common disadvantages, can be caused by common agents such as sun, water, fungi, and bacteria [7]. Typically, choosing the right type of wood and properly preparing it can prevent these problems. During the week on January 12th, 2018, the average lumber price was around $458 per thousand board feet [8]. Wood can have a wide range of prices depending on the kind used, so the price depends significantly on the project it is being used for.

Cross-Laminated Timber

Scientists and engineers are working to make the most efficient and least expensive materials. A recently rising
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alternative is called cross-laminated timber (CLT). This material utilizes a certain design of timber to make a more stable material. It is just being recognized as an effective alternative to common building materials and will be further discussed throughout this paper.

**CROSS-LAMINATED TIMBER – THE FUTURE OF INFRASTRUCTURE**

**Brief History of Cross-Laminated Timber**

The early versions of CLT were first produced in the early to mid-1990s in Europe, specifically Switzerland and Austria. Producers and researchers combined to devise a better way to use the outer layers of logs, as they had little value. The researchers discovered that the mechanical properties of these parts of the logs could be utilized in a way that makes them the most useful part of the log [9].

The CLT industry has been a slow moving one throughout the course of its history, but with other innovations and experiments with the material, it is starting to become an increasingly popular choice in the construction industry. Originating in Europe, it has taken around two decades for the material to spread across the world. With more use comes more standards that companies have to follow. In 2015, CLT was added to the International Building Code as a standard material used when designing structures. Along with following the standards set in the International Building Code, the CLT industry has developed its own form of code in the US CLT handbook. This document describes the necessary properties and regulations that buildings need to follow when using CLT in their structures [10]. The process of creating CLT, known as lamination, serves as a crucial aspect of the manufacturing process of the material.

**The Manufacturing Process**

One of the advantages of CLT is its simple manufacturing process. The main material necessary is dried lumber. The lumber must meet specific requirements of around a 12% moisture content and a temperature of around 15° C [11]. These conditions are ideal because they allow for the strongest bonds between the separate pieces. The following picture displays this design of the layers.

![FIGURE 1](image1.png)

**FIGURE 1 [10]**

*Design of CLT*

A layer is created by pieces of the timber being glued together with an adhesive. The direction of each layer is alternated, meaning that the first and last layers are parallel to each other while every other inner layer is perpendicular [11]. This cross-lamination enforces the strength in all directions of the timber. This strength reinforcement is what helps CLT be distinguished from just using timber. There are some standards in the design process, including a minimum and maximum width of 5/8 inch and 2 inches, respectively [10]. These dimensions are issued to make sure that the CLT behaves at its optimal circumstances. The means of construction and materials necessary for CLT allow the material to be beneficial to the environment. Cement production accounts for around 5% of the worldwide CO₂ emissions [2]. CLT’s simple construction process results in little to no CO₂ emission. The developmental impact on the environment is important to consider. This specific way of development is what distinguishes CLT from other common materials given its optimal properties.

**PROPERTIES OF CLT**

**Durability**

One of the reasons that CLT has advantages is because of its strength compared to similar materials such as traditional timber. This strength is advantageous in both perpendicular loads such as force on the floor and wind or parallel loads such as the force imposed on walls and columns. This angle between each of the layers allows the stresses to be distributed more, creating less focused stress on certain parts of the timber. Typically, wood can be around 25 times stronger in terms of stress and strain when applied to the direction of the grain compared to applied perpendicularly. Therefore, having the timber alternate directions will help utilize the area of the most strength. The bending strength is caused both the multiple parallel layers and the perpendicular layers. The parallel layers add to the strength because there is a larger strength at the ends, which are typically where the force is applied to bend the layers. The perpendicular layers also assist by stopping cracks from continuing down the board since the layers are at different directions. Typically, the planes are at 90 degrees angles to each other, but researches have also been testing to see if the layers perform better at ±45 degrees. The reason that this has potential is because the layers are still in alternating directions, but there is also part of the stronger layer in the original perpendicular layers. This inclusion of the stronger layer can potentially boost the performance of CLT even more [12].

![FIGURE 2](image2.png)

**FIGURE 2 [12]**  
*Alternative Layering of CLT*

To test to see if this alternate option was better, researchers at the Technical Research Institute of Sweden put both of the
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options to the test. There were 10 samples of the boards arranged at angles of 0°, 90°, 0°, 90°, and 0°. The other ten samples were arranged at 0°, 45°, 0°, 45°, and 0°. Multiple bending tests were performed on each of the different designs to measure the ultimate load required before the panels broke [12]. The results of the tests are displayed below.

<table>
<thead>
<tr>
<th>Specimen CLT 90°</th>
<th>Ultimate Load (kN)</th>
<th>Specimen CLT ± 45°</th>
<th>Ultimate Load (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>114.0</td>
<td>11</td>
<td>143.6</td>
</tr>
<tr>
<td>2</td>
<td>91.3</td>
<td>12</td>
<td>157.7</td>
</tr>
<tr>
<td>3</td>
<td>90.7</td>
<td>13</td>
<td>162.8</td>
</tr>
<tr>
<td>4</td>
<td>119.1</td>
<td>14</td>
<td>137.2</td>
</tr>
<tr>
<td>5</td>
<td>116.6</td>
<td>15</td>
<td>147.8</td>
</tr>
<tr>
<td>6</td>
<td>119.5</td>
<td>16</td>
<td>139.5</td>
</tr>
<tr>
<td>7</td>
<td>107.8</td>
<td>17</td>
<td>139.9</td>
</tr>
<tr>
<td>8</td>
<td>116.8</td>
<td>18</td>
<td>148.4</td>
</tr>
<tr>
<td>9</td>
<td>108.8</td>
<td>19</td>
<td>155.5</td>
</tr>
<tr>
<td>10</td>
<td>112.5</td>
<td>20</td>
<td>148.0</td>
</tr>
<tr>
<td>Ave.</td>
<td>109.7</td>
<td>Ave.</td>
<td>148.0</td>
</tr>
</tbody>
</table>

**FIGURE 3 [12]**

**Results of 90° vs 45° CLT**

These results show that the 45° alternating angles did improve the strength of the timber, as was suspected. This means that the bonds between the layers are stronger when placed at this angle because there are components from both the perpendicular and parallel layers in the layer. These results display examples of the benefits of this type of design and how it can continue to be improved.

Even though it might not be obvious at first, the strength of a material has an impact on the environment. If the material had to be repeatedly replaced because of its weak strength, the effect that the construction process has on the environment is increased. For example, if the concrete had to be replaced on a repetitive basis, CO₂ would be released every time the replacement set was made. Therefore, the strength of CLT helps make replacement uncommon, resulting in less of a potential negative effect on the environment.

**Seismic Performance**

The way that CLT is designed gives the material a strong resistance to horizontal forces such as earthquakes. This is an important characteristic when choosing a material to use in a building, as even a multi-story building performs remarkably well under intense seismic testing, with little to no lasting deformation. A seven-story CLT building in Japan was tested under the same conditions as a severe earthquake, with a magnitude of 7.2. The structure lasted 14 consecutive seismic events, all with almost no damage [13]. This test shows that CLT has a high resilience, which is critical when choosing a material for structures. High resilience means that the buildings will not suffer as much damage compared to other structures, which is optimal for structures. There are recommendations, such as the following of how to design buildings using CLT that are the most efficient in terms of seismic performance.

**FIGURE 4 [14]**

**Recommended Seismic Design of CLT**

This design is recommended when constructing using CLT to obtain the optimal design strength. The locations (1-4) are where connections are made and correspond to “1 – Vertical joints between perpendicular walls” [14], “2 – Horizontal half-lapped joints between floor panels” [14], “3 – Connections between floor panels to the walls below” [14], and “4 – Vertical half-lapped joints between wall panels” [14]. All of these components help to ensure that each part of the structure is connected to another piece, helping it maintain its structure when affected by a force.

**Fire Protection**

The cross sections that make up the core structure of CLT make the material very impervious to receiving a lot of damage from a fire. While the material is flammable, the thickness and cross-style the boards are created with cause the panels to char slowly, burning much slower than typical wood and other common building materials. As more char forms, the inside of the wood that remains unaffected protects the structure from being degraded further. The wood also serves as an insulator, as it doesn’t allow heat to escape to the unexposed surface. By the standards set by the American Wood Council (AWC), a CLT structure passes their fire resistance test. Their test consists of three parts: structural resistance, integrity, and insulation. A CLT structure is very safe compared to other structures, as it passes all of these tests [13].

**Thermal Performance**

How a material reacts to heat and the energy that it can store is important. The amount of energy that flows through one unit of a certain thickness in a certain time is known as thermal conductivity. Therefore, a smaller number for thermal conductivity results in a more efficient insulator. For CLT, the thermal conductivity is not as small as insulators, but is significantly smaller than other common materials. A case study on CLT written by the AWC provided a report that “the conductivity of structural softwood lumber at 12 percent moisture content, [the required percentage for CLT], is in the range of 0.7 to 1.0 units compared with...310 for steel, 6 for concrete” [13]. The low conductivity value displays that wood is a better insulator than steel or concrete. This more efficient
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insulation provides for less necessary investment in other insulating materials. Other values that display performance are the coefficient of heat transfer (U) and the insulating ability (R). The thickness of the wood panel affects U, decreasing it as the panel gets thicker. The lower U values means that less heat pass through the material. The R value for wood is typically 1.25 per inch. “So a 7-inch-thick CLT panel would have an R-value of 8.75. Softwood in general has about…400 times [the thermal insulating ability] of solid steel” [13]. This low U value and high R value display that CLT has a high insulation, requiring it to not need as much insulation as a structure made of steel, for example.

EFFICIENCY OF C.L.T.

Materials

One efficient quality of CLT is the small amount of material required to produce it. There are two main components: the laminations and the adhesives. The laminations are the boards themselves and are made of lumber which must meet specific requirements. To be approved as eligible lumber, the ratio of density of the lumber to the density of water must be at least 0.35, and both the parallel and perpendicular layers must meet certain visual grades [11]. These light requirements allow for manufacturers to easily find sources of timber for the CLT. This also allows for scientists to research the most efficient combinations between layers. The adhesive materials must also meet certain requirements. Common adhesives are phenol-resorcinol formaldehyde, emulsion polymer isocyanates, and polyurethane. These adhesives must be able to be durable, specifically at different temperatures [11].

Cost

The cost of CLT tends to be lowest compared to some of the other common materials. A report done by a construction company in Seattle stated that CLT tends to cost around 4% less than concrete [15]. Even though the cost is not significantly different, the performance comparison can also convince consumers about what the more efficient investment is. There was a study performed where a project was selected, and a cost analysis was performed, comparing different options. The first option was only concrete, the second and third options replaced the walls and roofs with CLT made by different manufacturers, and the fourth and fifth options replace the concrete with CLT panels [16]. The table displays the results of this study.

<table>
<thead>
<tr>
<th>Element</th>
<th>Concrete/Steel option</th>
<th>CLT options</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Basic CLT option 1</td>
<td>Basic CLT option 2</td>
</tr>
<tr>
<td>(Concrete walls/roof,</td>
<td>($624,417)</td>
<td>($641,901)</td>
</tr>
<tr>
<td>steel beams, light-steel frame)</td>
<td>($625,416)</td>
<td>($625,416)</td>
</tr>
<tr>
<td>Roof System</td>
<td>($289,339)</td>
<td>($289,339)</td>
</tr>
<tr>
<td>Interior Walls*</td>
<td>($155,304)</td>
<td>($155,304)</td>
</tr>
<tr>
<td>Steel Beams</td>
<td>($506,575)</td>
<td>($506,575)</td>
</tr>
<tr>
<td>Glulam Beams</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Extra CLT Walls</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Extras for CLT**</td>
<td>-</td>
<td>$595,241</td>
</tr>
<tr>
<td>TOTAL $</td>
<td>$2,590,950</td>
<td>$2,565,763</td>
</tr>
<tr>
<td>SOFT</td>
<td>40,065</td>
<td>40,065</td>
</tr>
<tr>
<td>Cost per sqft</td>
<td>$64</td>
<td>$64</td>
</tr>
</tbody>
</table>

* Interior walls for concrete and basic CLT options are in light-steel frame construction. Interior walls for CLT Green options are in wood-frame construction.

** Extras for CLT includes labor cost and connectors for CLT

FIGURE 5 [16]
Cost Comparison of CLT

This table displays the individual prices for certain components and the total price in each of the different cases. These results show that the price can vary depending on the source of materials. In three out of the four cases when CLT was used, the cost per square foot did decrease. This decrease ranged from approximately 6% to 22%. For some of the individual elements, there was a large difference. For example, in CLT option 2 for the roof system there was around a 52% decrease in price. Part of this difference in cost comes from the amount of labor necessary for CLT.

Installation

The speed and efficiency of the installation of a material plays a significant role when choosing a material. Most CLT material is made beforehand in different shapes and sizes, already cut in the shape of their use. These pre-made pieces are then sent to the job site where they are needed. Once they arrive, little work to make any changes is necessary so the panels are lifted into place and connected [13]. This simplicity and speed of construction helps prevent any unnecessary delays or complications. “The CLT construction [below] was
completed in 12 weeks, by four skilled laborers and one supervisor” [13].

FABRICATION

Computational Manufacturing

In the wake of today’s rapidly growing digital age, everything is becoming automated. Every industry is taking advantage of this new technology, including the production of CLT. When combining manufacturing with computers, a lot more can be accomplished in a much shorter amount of time. The way that engineers have combined these technologies is through a machine called a Computer Numeric Control (CNC). This technology uses software such as CAD (Computer-Aided Design) to receive instructions inputted by an operator, and performs a specific task, such as printing, or in the case of CLT, cutting, milling, or drilling. Almost any material, including CLT, can be used in and manipulated by a CNC machine. Before the creation of this machine, any manipulation of the structure had to be done by hand, leaving a huge margin of error compared to the error produced by a machine. This type of automation allows companies producing CLT in large quantities to do so at a much more efficient rate. In addition to being more efficient, the addition of computers and the CNC router allows CLT structures to be significantly more customizable [17].

Customization

The incorporation of computational technologies in any process, if used correctly, can be a huge advantage to a producer. In the case of CLT, computers are going to be significantly more accurate in cutting and restructuring of CLT designs, allowing them to be very customizable. Various types of openings, compound angles, and other unique features that involve complex geometries that are challenging to produce by hand can be easily created using the CNC router. Having people that are knowledgeable about the CNC router can be very beneficial to the manufacturing process of CLT, as it is greatly simplified. Fewer workers in general are needed when manipulating the material, minimizing the potential for error.

APPLICATIONS

As a result of CLT’s efficiency and rising approval in the construction market, there have been many construction companies that decided to make use of this material. The number of CLT projects per year has been slowly increasing. The successful results of these projects are what have gotten engineers and construction companies interested in this material. A few examples of projects using CLT include the Long Hall, Forté, and a Candlewood Sweets® hotel.
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The Long Hall (2011)

The Long Hall was the first commercial building project to use CLT in the United States. The building was originally a 60-year-old hut that was not appealing to the eye. In response, there was an effort to design and construct a completely new building in this space. The new building was originally planned to be built with concrete masonry units (CMU). After discussing with their client, the building designer and engineer convinced said client to switch to using CLT instead of CMU [19].

One of the main advantages of CLT that was considered was the difference in cost of the project. There was an initial cost estimation comparing the CMU and CLT, which is displayed below.

<table>
<thead>
<tr>
<th>Item</th>
<th>CMU</th>
<th>CLT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original project size: 5950 sf</td>
<td>CMU walls; stud framing; Trussed rafters to roof;</td>
<td>CLT walls, roof and 2nd floor;</td>
</tr>
<tr>
<td>Initial Cost (Whole Scheme)</td>
<td>$665,000.00</td>
<td>$616,000.00 $40,000.00</td>
</tr>
<tr>
<td>Shipping CLT &amp; CLB from Austria</td>
<td>$7,000.00</td>
<td>INCLUDED</td>
</tr>
<tr>
<td>Structural Engineering/Code</td>
<td>$22 weeks (Minimum)</td>
<td>12 weeks</td>
</tr>
<tr>
<td>Time of closure of Facility</td>
<td>$40,000.00</td>
<td>$15,000.00</td>
</tr>
<tr>
<td>Assumed $2,500 per week</td>
<td>$712,000.00</td>
<td>$671,000.00</td>
</tr>
<tr>
<td>Savings</td>
<td>$41,000.00</td>
<td>6.11%</td>
</tr>
</tbody>
</table>

As shown, the price when using CLT was estimated to be around 12% less than when using CMU. This $76,000 saving is significant in the outcome. This lower price is one of the reasons that CLT is better than other common materials. One of the factors that led to this decrease in the price was the little amount of time and labor required to finish the project.

The ability for the walls to be pre-assembled plays a significant role when considering the factors of time and labor. The panels were ordered from Europe, so their size was 7 feet 4 inches wide and 39 feet long. This caused the contractors to decide to stack the panels vertically. Another problem was that there was very little space between the area for the structure and the adjacent buildings. In response to this, the panels were pre-built and edited using CNC machines at a nearby site.

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The CLT displayed solutions to multiple challenges that appeared during the construction process. One problem was the soil not being as strong as it was at the top as they got deeper. CLT does not weigh as much as the CMU, the alternative option, so the foundation does not need to be as strong. Another reason to use CLT was because of the out-of-plane strength, which is strong enough in the long span between supports. This setup allows all of the forces to be distributed. The fact that CLT is a solid wood panel means that it can be used as an optimal insulator, also improving energy efficiency [19]. These structural performances are important when considering which type is the most efficient.

Candlewood Suites® (2015)

Candlewood Suites® is a hotel chain that has multiple locations around the U.S., but in 2015 they decided to build one of their hotels out of CLT. This decision was innovative, being the first hotel in the U.S. to be made of CLT. The hotel has 92 rooms and was made as a hotel for soldiers and guests on U.S. Army bases. The original plan was to use steel stud framing when building the hotel, but the project managers were convinced that CLT would be the better option [21].
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The biggest difference that CLT made was in terms of speed and difficulty. CLT typically provides an advantage in both fields compared to other materials. The following tables include results of typical hotels made by the company to those of Redstone Arsenal, which is where the hotel was made using CLT.

<table>
<thead>
<tr>
<th>PAL Portfolio</th>
<th>Typical New PAL Hotel (Actual*)</th>
<th>Redstone Arsenal (Actual)</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross square feet (sf)</td>
<td>54,991</td>
<td>62,980</td>
<td>+14%</td>
</tr>
<tr>
<td>Average # of employees</td>
<td>18 (peak 29)</td>
<td>10 (peak 11)</td>
<td>-43%</td>
</tr>
<tr>
<td>Structural duration (days)</td>
<td>123</td>
<td>78</td>
<td>-37%</td>
</tr>
<tr>
<td>Structural person hours</td>
<td>14,735</td>
<td>8,203</td>
<td>-44%</td>
</tr>
<tr>
<td>Structural production rate/day</td>
<td>400 sf</td>
<td>903 sf</td>
<td>+75%</td>
</tr>
<tr>
<td>Overall schedule</td>
<td>16 months</td>
<td>12 months</td>
<td>-20%</td>
</tr>
</tbody>
</table>

* PAL, New Build Hotel Historical Average

FIGURE 11 [21]
Efficiency of Typical Hotel vs. CLT Hotel

As displayed by this table, using CLT resulted in constructing the hotel 37% faster and with 44% less person hours than the typical hotels. This crew consisted of only 11 people, including carpenters and laborers. The crew was able to construct a larger area in less time with less people on site, displaying the difference in efficiency between the projects.

FIGURE 12 [21]
Workers on Site of Redstone Project

The ease of use pertaining to CLT made the construction process efficient. The CLT panels were already premade and were supplied in the order that they were needed, diminishing any confusion. To put the structure together, a crane was used to move the panels, and then the workers locked them in place. Using this efficient approach, three workers were able to install at a rate of 400 square feet every 20 seconds [21].

Cost was another important factor when considering if CLT was the best option for the hotel. In this case, CLT turned out to be more expensive than the metal studs. When comparing theoretical data between the two options, CLT still came out on top because of the difference in time and labor. For labor, the cost of labor happened to be more expensive at the location the hotel was being built. This means that less labor, which is a benefit of CLT, was the optimal choice. The time to construct using CLT is lower compared to using the metal studs; speeding up the construction process results in the ability to make profit sooner [21].

Some of the design characteristics that were made sure to be brought into consideration when using CLT consist of structural integrity and energy efficiency. When working with wood as the construction material, all types of movement must be considered. The environment typically causes shrinkage and swelling in wood, but the drying process and design of CLT prevent the material from shifting significantly. One of the purposes of using CLT is to obtain a tighter fit throughout the structure. This results in less of a need for other materials in terms of insulation. This led the manufacturer to conclude that this hotel will be 31% more energy efficient than their other hotels [21]. This hotel design was a first and has caused other hotel companies to follow similar paths.

FIGURE 13 [21]
Candlewood Suites® During Construction

SUSTAINABILITY

Harvesting

There are several factories around the world that specialize in the sustainable harvesting of timber, with some that focus specifically on CLT. One of these factories, the Nordic Factory, is in Quebec, Canada. The Nordic Factory is one of the leading producers of CLT in the world. In order to minimize waste, the trees that enter the factory are immediately scanned by a 3D scanner, which determines the optimal cutting pattern that maximizes the yield from each individual tree. Once the trees are cut into several strips of timber, they are finger-jointed at the end and glued together, creating massively long pieces of wood. The layers of the CLT structure are assembled from here, with each additional layer perpendicular to the previous.

Factories like Nordic put incredible efforts to be as environmentally-friendly as possible when harvesting this timber. The factory currently grows more than two million acres of black spruce trees, but a measly 1% of the acreage is harvested, with the remaining trees creating a positive cycle of tree growth. These harvested areas then regenerate naturally, and the ecosystem is left in a better state than it was before.
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[22]. As long as other major factories follow the same procedures that the Nordic Factory follows, the ecological effects are minimal, and the environment would remain the same, if not in a better state after the harvesting.

Ecological

When a building is constructed using CLT rather than other common materials, there are multiple ecological benefits hidden. CO₂ emissions are avoided and decreased at the same time. For the Long Hall project, 5,227 cubic feet of CLT and glulam were used in the production. The forests in the U.S. and Canada can produce this same amount of wood in 26 seconds. 104 metric tons of CO₂ were stored in the wood while 59 metric tons of CO₂ were avoided. This results in a total potential carbon benefit of 163 tons of metric tons of CO₂ [19]. These statistics are important to analyze when seeing how beneficial CLT was. The Long Hall was small in size compared to the hotel project. In the Candlewood Suites® project, 935,696 board feet of wood products are used. This amount of wood is grown in a matter of five minutes in Canadian and U.S. forests. By using the wood instead of fossil fuel-intensive materials like concrete, the project avoided emitting 494 metric tons of CO₂ and 1,276 metric tons of CO₂ were stored in this wood, rather than being emitted through burning or other process. This produced a net carbon benefit of 1,770 metric tons of CO₂ for just one project [21]. This low amount of CO₂ emissions with aid in the growing initiative to help protect the environment. To get a clearer picture of what these benefits are equivalent to, the emissions can be compared to everyday activities. For the Long Hall, the carbon benefits are equivalent to 31 cars being off the road for a year and the energy to operate a home for 14 years [19]. For the Candlewood Suites®, the benefits are equivalent to 374 cars being off the road for a year and the energy to operate 187 homes for a year [21]. The difference is these values are apparent between the size of the project. Since both the amount and size of the projects utilizing CLT is increasing, the benefits and equivalent energy will also increase. With a heavier focus on CLT becoming a top of the line building material in the future, these benefits will be recognized even further, and possible regulations for harvesting and CO₂ emissions will be implemented, given the rate of success the material achieves.

WHAT IS NEXT FOR CROSS-LAMINATED TIMBER?

Cross-Laminated Timber (CLT) has been around for over 15 years but has only recently begun to come into the market. The recent induction into the International Building Code has given the material credibility, allowing companies to not be as weary. A more efficient and inexpensive material entering the construction market could significantly shift the market if it continues to be successful.

Whenever considering the optimal material for a project, the material’s properties play a big role. The simplicity and unique properties of CLT are what make it a valid alternative to the commonly used materials. The materials required to make CLT consist of the timber and an adhesive. This simple design can allow for the material to be constructed at a lower price and in a shorter time. The whole reason that CLT is designed the way that it is originates from the fact that wood is typically stronger in the direction of the grain. CLT optimizes this by increasing the area of the material where force will be applied in that direction. The resistance to larger forces also increases the seismic performance, a key aspect for material to be used. Typically, wood is easily flammable, but the thickness and style of CLT prevents the fire from expanding and burning the wood quickly. The thickness also prevents energy and heat from easily flowing through the material. This property can help decide how much other material is needed for cases such as insulation. These properties all make CLT a viable alternative, and scientists are continuing to collect data as well as optimize CLT. This means that in the future, CLT can be designed to have the upper hand in many other properties besides the advantages it already has.

Another important characteristic of a material is the efficiency involved when using the material. Using reports, it was displayed that certain types of products can be up to 50% cheaper when using CLT compared to materials such as concrete. The only concern is that, after the prices of all the materials are added together, the net cost turns out to not be significantly different. The CLT still ends up being slightly cheaper, but it depends significantly on the supplier the CLT is purchased from. This difference in net cost can change in the future as CLT starts to become more popular, giving companies a reason to optimize the production by making the most efficient CLT for the cheapest price. The installation process is also significantly more efficient, and projects can take multiple months less to finish. The lack of workers necessary to put together the preconstructed pieces also have positive and negative results. The positives are that less money needs to spend on workers and other workers can be used to work on other company projects. A negative expectation that can be derived might be that the lack of necessary workers in less open jobs for the unemployed. To see what the full effect is, it will be necessary to wait and see until CLT has been around long enough.

The effect on the environment is a commonly asked question when referring to materials. One of the main reasons for using CLT is its aid to the sustainability of the environment. The plants that manufacture CLT typically challenge the common concern of needing trees to make CLT by having forests dedicated to their supply of CLT and maintaining the state of these forests. The comparison of CO₂ emissions for CLT and its competitors is an obvious advantage. CLT production releases a minimal amount, if any, of CO₂; CLT has become the option for a more environmental friendly building material compared to common options such as steel and concrete.
CLT is a rising construction material that has numerous advantages compared to other commonly used materials. Based on the current research and observations, CLT has the potential to become one of the most popular and effective building material alternatives.

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