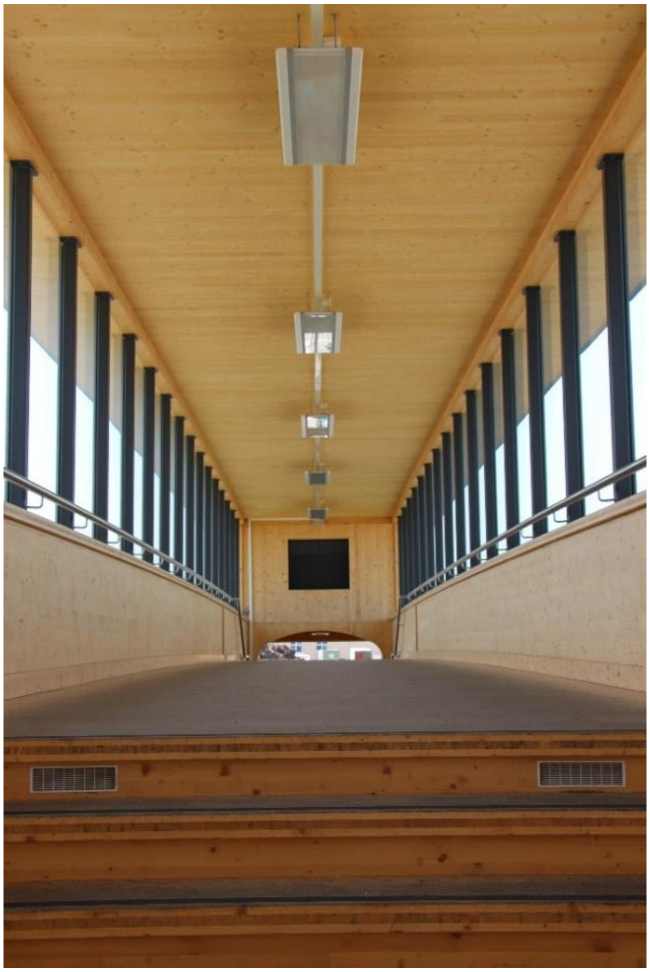

# CROSS-LAMINATED TIMBER

*An analysis of the Austrian industry and ideas for fostering its development in America*

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# ABSTRACT

This research paper was written under the Austrian Marshall Plan Foundation Scholarship at Fachhochschule Salzburg: University of Applied Sciences. The goal of this research was to document the Cross-Laminated Timber (CLT) industry within Austria and discuss how the industry might be fostered within the United States of America.

To accomplish this research, interviews were conducted with individuals of interest groups and manufacturers involved with the Austrian CLT industry. This information was used along with accessible literature to develop the paper. An analysis of the industry's potential in the United States was conducted through resource considerations and market potential.

From my research, I found the CLT industry in Austria as well as the whole of Europe to be continuously growing. Based on the successfulness of CLT in Europe and the availability of timber resources for CLT, the industry can be said to have a promising future within the United States. Although, the success of CLT in the US will be entirely dependent upon market demand.

# OUTLINE

## LIST OF FIGURES

## LIST OF TABLES

# 1. INTRODUCTION

## 1.1 A BRIEF HISTORY

Cross-laminated timber (CLT) was developed in Austria and Germany during the 1990's as a product which could address the amount of waste wood which was being produced by mills. In the mid-1990's, a joint research effort began between the industry and academia of Austria to develop the modern CLT product which is produced throughout Europe today.

The demand of this building product took a few years to become significant due to the lack of knowledge of CLT's performance and capability as a heavy construction material, but along with the green building movement, CLT would soon gain popularity as a construction material choice for residential and non-residential purposes in Europe. CLT is a green building material because the use of wood for larger structured buildings has been found to carry a significant number of benefits including carbon sequestration, reduced emissions (from harvest to construction), and cost effectiveness when compared to concrete and steel (MGB 2012). Now, this product has been found to be an alternative building material which properly combines all the advantages of a solid structure while being produced from a sustainable resource (Binderholz 2010).

CLT can be used for both conventional stick-frame wood construction and larger structures typically constructed with steel, concrete, and masonry. As of now, CLT is only economically advantageous for these larger structures such as mid-rise buildings and possibly high-rise buildings in the near future (Karacabeyli and Douglas 2013).

Michael Green, a Canadian architect, is currently planning a 30 story CLT skyscraper to be built in Vancouver, British Columbia (Michler 2012). Similar plans have been taking place across Europe and even in Australia.  Figure 1 shows one of the tallest buildings of CLT built to date in London, England.

Figure 1: Waugh Thistleton's Timber Tower in Hackney London standing nine-stories tall

Source: http://www.treehugger.com/ sustainable-product-design/waugh-thistletons-timber-tower.html

# 2. CLT: THE DETAILS

## 2.1 PRODUCT DESCRIPTION

Cross-laminated timber is defined as a massive or a mass timber product. Through CLT production, low-grade, waste wood produced by mills can become a product of value and use as a green-building solution. The production of value-added products such as CLT and pellets can result in a nearly, if not entirely, waste-free and efficient facility.

In Austria, CLT is produced largely from Norway spruce (*Picea abies*) timber, but it can also be manufactured from White fir (*Abies alba*), Scots pine (*Pinus sylvestris*), European larch (*Larix decidua*), Douglas fir (*Pseudotsuga menziesii*) and Swiss stone pine (*Pinus cembra*) (Brandner 2013). Austrian manufacturers and both Austrian and American academics have begun to look into the use of hardwood species for CLT purposes (Jeitler 2013). Few structures have been built from hardwood to date. An example of one such project can be seen in Figure 2.

Figure 2: The "Endless Stair" designed by dRMM
Source: http://drmm.co.uk/projects/view.php?p=endless-stair

Additional projects have been completed such as a three story building in Brucknerstrasse, Graz, Austria as part of the "massive_living" project (Brandner 2013). The building was composed of wall elements made from silver birch (*Betula pendula*). The utilization of hardwoods may provide opportunity higher bending stiffness and shear resistance in CLT panels without increasing thickness or possibly, reducing thickness (Brandner 2013). Therefore if not utilized for the entire structure, hardwoods might prove to be useful for transverse layers in CLT panels to provide increased structural dependability.

## 2.2 MANUFACTURING PROCESS

Lumber coming into the mill is typically kiln dried to a standard moisture content of 12% +/- 3% (Karacabeyli 2013). The lumber often times arrives at the mill having already been dried to this specification. The same is the case for grading. In Austria, it is not uncommon for the feedstock to have already been sorted by size and/or grade upon arrival. This is due to the use of visual grading for structural and strength suitability of the lumber at the sawmill (Kraus 2013). Although, grading for appearance purposes is often performed based on a company's standard at the CLT manufacturing plant.

In Europe, the visual grading requirements are that parallel layers must be at least grade 2, but perpendicular layers can be grade 3 (Karacabeyli 2013). Stress grading is the secondary option of grading this lumber and is done in accordance with standards developed by the individual countries. For example, the United States will need to meet grade requirements in accordance with ANSI/APA PRG 320: Standard for Performance-Rated Cross-Laminated Timber (APA 2012).

The production process is similar to that of plywood. The main difference is in the dimensional characteristics of the feedstock. The process of finger jointing and trimming the lumber to obtain the desired lengths for layer construction is the first step in the actual assembly of the panel. Since the use of finger jointing such as that seen in Figure 3 can be used in CLT production, limitations for feedstock dimensions are minimal, and therefore, increasing the product's ability to be an excellent use for waste wood.

Figure 3: Finger joint of two lamellae within a CLT panel (Stauder 2013)

The typical lumber dimensions of the lumber range from 16 to 51 mm thick and 60 to 240 mm wide (Karacabeyli 2013). After the lumber has been planed on four sides, layers are typically formed by surface bonding the narrow faces of the lamellae. The transverse layers do not necessarily need to be adhesively bonded. The layers of lumber are then orthogonally stacked and glued together on the wide faces just as shown in Figure 4.

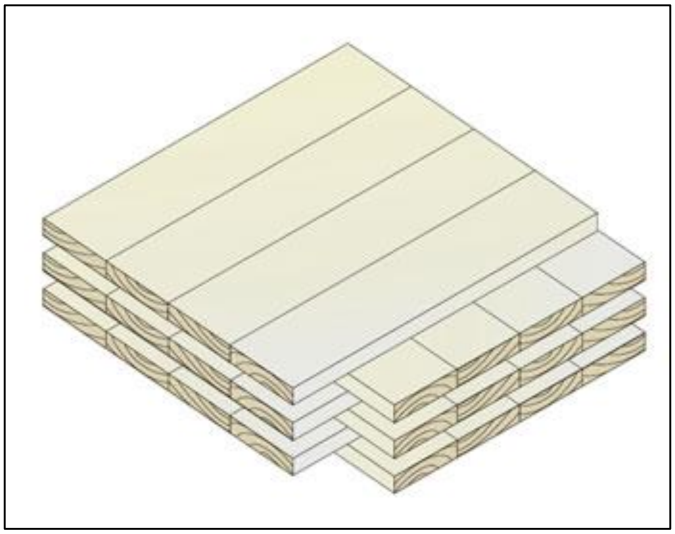

Figure 4: CLT panel of orthogonally stacked layers (Karacabeyli 2013)

By alternating each layer direction by 90 degrees for each lamination, strength is distributed across both panel directions, instead of a single direction as in solid-sawn lumber thus creating a much stronger product. To ensure the outer layers are aligned in the same direction, the number of layers per panel is typically odd. Having the outer layers in the same direction parallel to the vertical load (for walls) or greatest directional span (for floors) will provide maximum strength (Karacabeyli 2013). Typically, a panel will consist of 3 to 7 layers and sometimes more.

CLT panels can be produced in thicknesses from 50 mm up to 500 mm (Mass Timber 2013). The typical maximum panel dimensions for commercial use are 18 meters in length and 3 meters in width, but some companies exceed these dimensions (Dataholz 2012). Overall, panel dimensions are found to differ by manufacturer.

There are two steps in the construction of these panels. First, an adhesive is often added to the layers. Interior/exterior polyurethane (PUR) adhesives are normally used, but melamine urea formaldehyde (MUF) and phenol-resorcinol-formaldehyde (PRF) adhesives may be used as well (Crespell and Gagnon 2010). Alternatively, methods which use nails or wooden dowels can also be utilized.

The second step is the press which is typically hydraulic but can also done with a vacuum or compressed air press. One example is the bladder press (vacuum) which two presses with dimensions of 3.5 by 22 meters can be operated by three laborers (Binderholz 2013). Every press likely carries its own advantages and disadvantages. An issue with bladder presses is the press sheet tearing on the panel's rough edges.

The panels are typically pressed both vertically and horizontally. The pressure required for surface bonding is dependent upon several factors such as the adhesive system, timber species, adhesive quantity and application system, and the surface quality of the layers (Brandner 2013). With PUR adhesives, a surface pressure of 0.6 N/mm is sufficient (Kraus 2013).

An additional requirement of some adhesives is the application of heat and/or climate controlled situations during the pressing process. For example, PUR is a "cold" press adhesive, but the room ambient conditions of the room must be maintained at 45-50% humidity and around 20°C to ensure effective surface bonding (Binderholz 2013).

Figure 5: Finished CLT panel with CNC cutout likely for window installation (Stauder 2013)

Following these steps, the panels can be planed or sanded for a smooth surface. The installation of insulation and drilling for openings can be performed. Any design elements such as openings for doors or windows can be cut out of the panel using CNC operations as seen in Figure 5. By using CNC machining, the entire structure can be prefabricated in the CLT mill before being taken to the construction site.

Prefabrication, aside from windows and doors, also often includes the panel to panel connection elements. This is done by means of creating half-lips and splines which allow for the effective use of metal brackets, hold-downs, and plates to hold the structure together. An example is shown in Figure 6. Once again, innovative methods of connecting panels and the use of wooden dowels and screws can utilized. Therefore, the structure requires minimal effort during construction.

Figure 6: Double internal spline for panel connections

Source: http://www.forintek.ca/public/pdf/Public_Information/presentations/CLT_Symposium_Feb_2011/CLT-Connections.pdf

The panels should then be tested to be in compliance with standard requirements for CLT panels. Tests such as bending strength, shear strength, and delamination must be performed to ensure that the product quality is ensured before leaving the factory. This is often done by a regular sample test during each shift.

Following any final touches, the panels are marked with information such as CLT appearance grade, dimensions, and manufacturer identity. To ensure that the panels maintain the sought after moisture content on arrival of 12% (+/- 2%), the panels are entirely wrapped and sealed in a waterproof tarpaulin before transport. On the construction site, the panels are left in their protective wrapping on lumber skids or something similar to elevate the panels from the ground.

A volume to building comparison of CLT as a final product can be seen in the case study of three buildings by FP Innovations. The following data was reported in their CLT Primer (Crespell 2010):

- Residential: 0.43 cubic meter of wood/square meter floor area |or| 16.8 bdft/sqft
- Educational: 0.38 cubic meter of wood/square meter floor area |or| 14.96 bdft/sqft
- Warehouse: 0.15 cubic meter of wood/square meter floor area |or| 5.96 bdft/sqft

## 2.3 CONSTRUCTION BENEFITS OF CLT

CLT provides the opportunity for a continuous building envelope with a quick erection time and a significantly reduced construction footprint when compared to concrete and steel construction. The panels can be used for the entire building structure (i.e. floor, walls, and roof). The development time is shortened since the panels are manufactured to a design of a prefabricated solid structure. In some cases, the building time for a multistory building can less than one week per level (Naturally Wood 2012). Since the panels can be assembled in such a short time, the building is quickly weatherproof and soon ready to be utilized. An example of a CLT building construction process can be seen in Figure 7.

Further benefits of CLT as a building material include less on site waste, a lower demand for skilled construction labor and less disruption to surrounding neighbors (Crespell 2010). Further, crews can be as little as 2 to 8 carpenters plus one or two mobile crane operators (Crespell 2010). Therefore, a lower capital cost and a faster project completion time give CLT further advantageous benefits over the use of concrete and steel.

Figure 7: CLT construction example

Source: http://lang.clt.info/index.php?id=5

## 2.4 CLT LIMITATIONS

CLT as a building material does carry limits. The versatility of CLT as a building system is due to the change in capabilities as the thickness of the panels vary. For example, with a 230 mm, 7-ply floor, CLT can provide spans of 7.5 m without beams or columns (Crespell 2010). With the addition of concrete as a reinforcement, the span can increase to 10 m without support beams (Karacabeyli 2013). The incorporation of beams and trusses can increase the span to over 20 meters or more (Crespell 2010).

In regards to the vertical direction, TRADA: Timber Research and Development Association has designed a CLT building which reaches 12-stories (Crespell 2010). Following this, it seems that the incorporation of steel or concrete must be used in the design to support higher buildings. With this addition, buildings largely composed of CLT material can feasibly reach levels of 30+ stories (Karacabeyli 2013). As mentioned before, architect Michael Green is developing such a building with minimal incorporation of steel and concrete as seen in Figure 8.

Figure 8: A 30-story wooden tower using building materials such as CLT

Source: http://inhabitat.com/michael-green-unveils-wooden-tallwood-skyscraper-for-vancouver/

## 2.5 CLT PERFORMANCE

The performance of CLT has been extensively tested and proven to provide similar or even better results than concrete and steel. Issues such as seismic performance, sound and thermal insulation, longevity, and fire protection play pertinent roles in the admittance of CLT as a heavy construction material especially for buildings larger than single family homes. Following are the results of CLT performance as a construction material

### Seismic

The seismic performance of CLT has been tested by institutions such as IVALSA (Trees and Timber Research Institute of Italy). FP Innovations reported their findings on the tested 3- and 7- story buildings tested in Japan. The buildings were subjected to earthquake motions at a magnitude of 7.2 with accelerations of 0.8 to 1.2 g (Crespell 2010).

The 7-story building was found to have no residual deformation at the end of the test. Measurements were taken on inter-story drift and maximum lateral deformation at the top of the building. The respective values were 40 mm (1.3%) and 287 mm (Crespell 2010).

### Sound

Sound insulation can be a difficult task with any building material. In the United States, buildings must be constructed properly to ensure they meet the International Building Code (IBC) when required. FP Innovations conducted research on the topic of sound insulation and have found that with proper design and installation CLT buildings can achieve sound insulation levels which meet or exceed IBC standards and provide satisfactory conditions for future occupants.

For the United States, the IBC requires a minimum Sound Transmission Class (STC) and Impact Insulation Class (IIC) 50 for airborne sound between wall and floor elements or 45 for field measurements (Karacabeyli 2013). Through incorporating materials such as gypsum board, mineral wool, air space and other materials into the design, CLT elements were found to meet or exceed the required STC and IIC of 50 (Karacabeyli 2013).

### Fire

While there is a natural inclination to assume a building of wood would carry a higher risk in the event of a fire, buildings built of CLT tend to have excellent fire resistance since they are constructed of such large components. Further, fire tends to burn at a slow and predictable rate (Crespell 2010). An example to consider is how a large log burns much slower and predictably than many twigs and branches which tend to burn fast and hot. In one case, a CLT test specimen burned 3 hours and 6 minutes until it failed (AWC 2012).

FP Innovations reports that full scale fire tests in accordance with ASTM E119 have shown CLT panels to have the potential to provide comparable fire resistance to typical heavy construction assemblies of non-combustible materials (Karacabeyli 2013). Materials such as gypsum board can be used to provide protection for the CLT panels in case of fire. With CLT, the predictability of fire behavior ultimately provides an excellent advantage as a building material.

### Thermal

Being that CLT is composed of solid wood laminations, this building material has an inherent level of thermal resistance. FPInnovations reports that CLT panels provide an R-value of approximately R-1.25 per inch (Karacabeyli 2013). As reported by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, concrete only provides R-0.52 per inch of thermal resistance. Therefore, an airtight building of CLT can easily provide a greater level of thermal resistance (Arch 2013).

Thermal insulation can be added to further minimize heat gain or loss. By installing insulation on the exterior of the building, the thermal resistance is increased by allowing for continuous coverage including areas in which two panels are connected and air leakage is most likely.

## Longevity

The measure of a wooden buildings longevity is quite difficult if not impossible. Instead, a design which is suitable to the location of the building is the determining factor in a CLT building's longevity. Architects must consider the area's climate in the design to ensure there is little to no risk of a dangerous rise in moisture content in the CLT panels. An increase in moisture content can promote fungal levels which will result in the rot and decay of the wood.

Fortunately, there are many design elements which can help to ensure the longevity of these buildings. FP Innovations developed the idea of the four D's of CLT design: Deflection, Drainage, Drying, Durability (Karacabeyli and Douglas 2013). By incorporating design elements such as cladding and providing adequate air space around the CLT panel, rain water can easily be handled and its threat eliminated. Further efforts can be utilized by used wood which has been treated with preservatives or which is naturally durable to reduce any risks.

# 3. THE DEVELOPMENT OF THE CLT INDUSTRY IN AUSTRIA AND EUROPE

## 3.1 CAPACITY TRENDS

Trends for the production capacity of CLT mills in Austria, Germany, and other producing countries can be found in Figure 9. A steady increase in capacity can be found for Austrian manufacturers who as of 2013 produce roughly 71% of CLT products within Europe as shown in Figure 10. From year to year, there is an average percent increase in production capacity of around 17%.

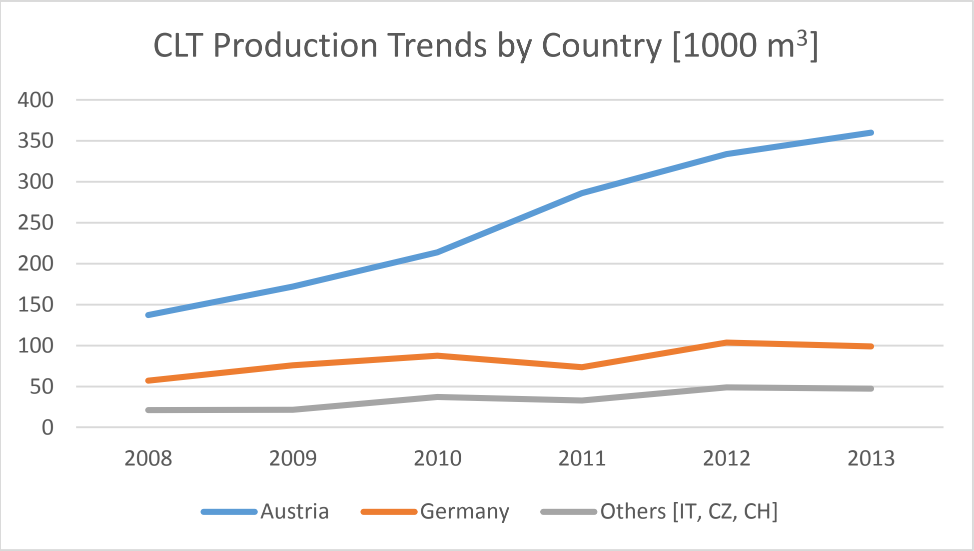

Figure 9: Capacity trends for major CLT producing countries in cubic meters by year [1]

Between the years of 2012 and 2013, there was only a 7.2% change which is half of the 14.4% change from the previous year and drastically smaller than the 25.2% increase from 2010 to 2011. The large increase in production in 2011 was likely due to the introduction two new CLT

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[1] Data extracted from CLT production reports provided on http://www.timber-online.net/

production facilities: a secondary Stora Enso facility and the entrance of Hasslacher into the market.

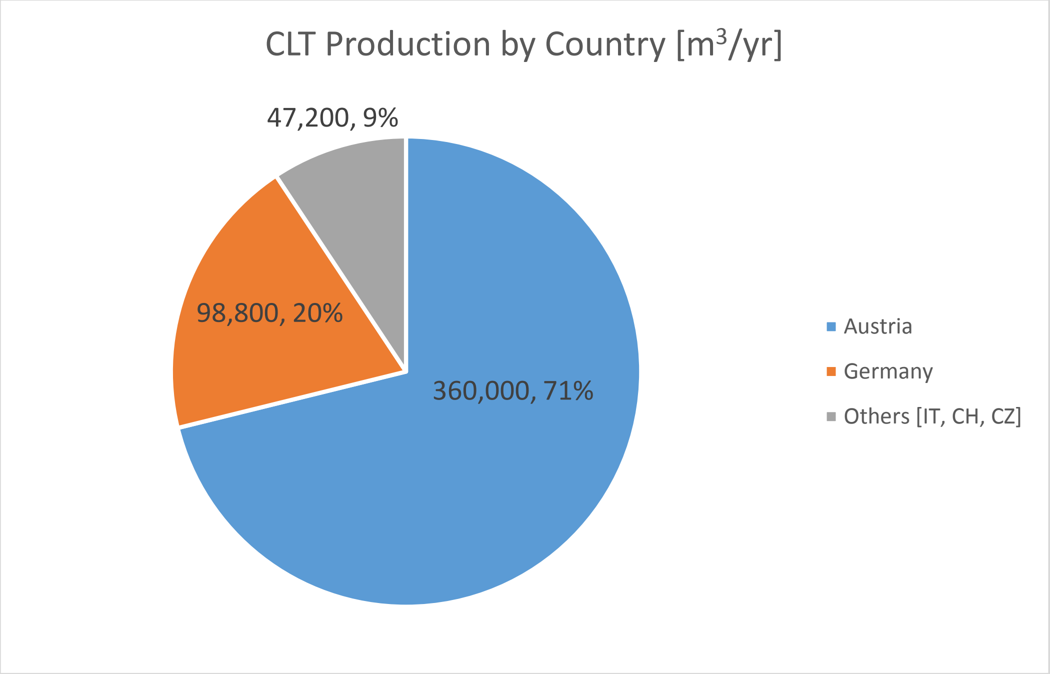

Figure 10: European production breakdown by country [2]

European production has and is expected to continue to steadily increase. Figure 11 shows the general trend of production capacity for Europe over the past 18 years. The future projections for Europe and globally as reported by Dr. Gerhard Schickhofer of Graz University of Technology in Austria are also included. CLT production capacity has increased at an average estimated rate of 11.5% per year over the past 18 years. The future projections suggest an increase of 18.5%/year until 2015 at which production capacity in Europe will have reached 800,000 $m^3$. As for the global projection, there is an estimated 200,000 $m^3$ to be produced by producers in countries outside of Europe which would bring global production up by 25.3% per year from 2013 until 2015.

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[2] Data extracted from CLT production reports provided for 2013 on http://www.timber-online.net/

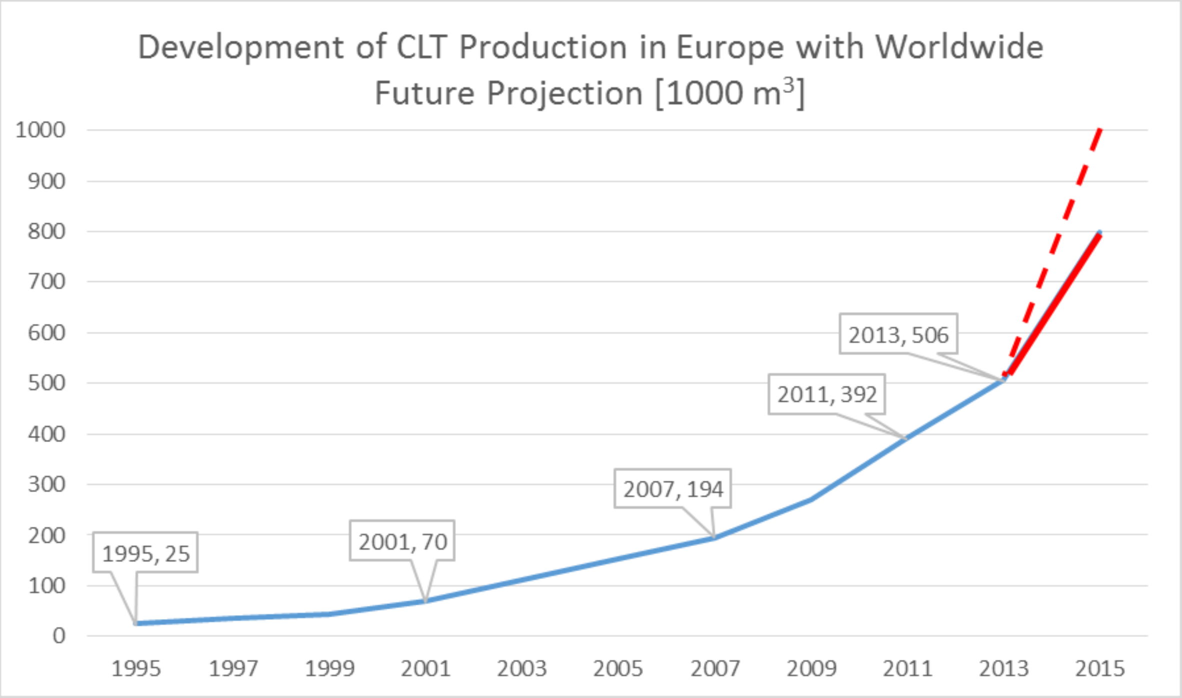

Figure 11: European CLT capacity trend with future projections for Europe and the World [3]

The future of the CLT industry seems quite promising by the production trends over recent years. This is not to suggest that there are not limitations to be faced as market demand and production increases. Within Austria, the price for spruce roundwood is likely increasing due to changes in forest management. Austrian forests are slowly becoming managed or changing through natural succession in the absence of management from pure conifer stands to mixed stands of conifer and deciduous species, although pure spruce species still compose around 40 percent of the total Austrian forest composition (Foglar et al., 2008).

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[3] Data retrieved from Dr. Schickhofer's 2010 presentation titled "Cross Laminated Timber (CLT) in Europe – from Conception to Implementation". Source: http://holzbauforschung.at/fileadmin/user_upload/Intranet/Veroeffentlichungen/Presentations/Canada/Vancouver_2010.pdf.

With an increase in price, the low grade lumber which is used for CLT purposes is more expensive and limited (Jeitler 2013). The limited supply is likely due to the effort to utilize as much of a log as possible for higher valued products. Therefore in the CLT industry, low grade wood is in very high demand.

As for market demand, CLT is becoming a known alternative as a building material throughout Europe. With the ongoing green building movement and other environmental efforts, CLT will remain an attractive material for those individuals and groups with such interests. Further, the cost competitiveness of CLT which can often times be found to be cheaper than concrete and steel in midrise and soon, high-rise buildings further expands its market niche.

## 3.2 TOP 5 PRODUCING COMPANIES

In Table 1, manufacturer specific information can be found. Topics addressed include capacity, layers, wood types, adhesive, and dimensional capabilities for the individual producers. The largest producers of Austria include Stora Enso, KLH, and Binderholz. All information presented can be found in the technical factsheets for each company's CLT product.

Table 1: Manufacturer details for the top 5 producing companies in Austria

| | | Binderholz[4] | | Hasslacher[5] | KLH[6] | Mayr Melnhof Holz[7] | Stora Enso[8] |
|---|---|---|---|---|---|---|---|
| Capacity [cubic meters] | | 80,000 | | 30,000 | 90,000 | 50,000 | 95,000 |
| Product | | BBS 125 | BBS XL | | | | |
| Layers | | 3-,5-,7-ply | 3-,5-ply | 3- , 5- ply | 3,5,7 ply | 3, 5, 7 ply | 3-,5-,7- 8- ply |
| Wood types | | spruce, pine, fir, larch | spruce, pine, fir, larch | spruce, pine, fir, larch | spruce, pine | spruce | spruce, pine |
| Adhesive | | BBS: formaldehyde-free PUR adhesive EN 301\| single ply board: MUF; emissions class E1 | | MUF | polyurethane adhesive (PUR) | Melamine resin-based adhesive, Adhesive Type I acc. to EN 301 approved | polyurethane adhesive (PUR) |
| Dimensional Capabilities | Length | up to 24 m | up to 22 m | up to 20 m | up to 16.5 | to 16.5 m | up to 16 m |
| | Width | 0.625, 1.25 m | max 3.5 m (std 2.4, 2.6, 2.75, 2.95, 3.2, 3.5 m) | 1.49 m to 3.15 m (from 0.5 up to 4 m on request) | 2.4 - 2.95 m (std. 2.4, 2.5, 2.72, 2.95) 2.25 on request | to 3.0 m (std: 2.4, 2.65, 2.75, 2.9, 3.0 m) | to 2.95 m (std. 2.45m, 2.75m, 2.95m) |
| | Thickness | 60 to 280 mm | 60 to 200 mm | 57 mm to 200 mm (up to 400 mm on request) | 57 mm to 500 mm | 57 to 278 mm | 60 to 320 mm |
| | Lamellas | 20, 30, 35, or 40 mm\| kiln dried, quality graded, finger jointed | | 19, 33, 40 mm | 10 to 40 mm \| technically dried, quality graded, finger jointed | 19 to 40 mm kiln dried, quality graded, and finger-jointed (std 20, 30, 40) | 20, 30, and 40 mm kiln dried, quality graded, finger jointed |

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[4] Binderholz "Cross Laminated Timber BBS 125 | BBS XL" Publication Source: http://www.binderholz.com /fileadmin/books/en/Cross_Laminated_Timber_BBS_125_BBS_XL_GB/Cross_Laminated_Timber_BBS_125_BBS_XL_GB/assets/downloads/publication.pdf. Accessed: 9 September 2013.

[5] Hasslacher Norica Timber "CLT Cross Laminated Timber: The ecologically sound building material of the future" Publication Source: http://www.hasslacher.at/uploads/media/MONITOR_BSP_folder_E_2013.pdf. Accessed: 9 September 2013.

[6] KLH "Cross Laminated Timber" Brochure Source: http://www.klh.at/fileadmin/klh/kunde/2011/Kreuzlagenholz /Herstellung/EN/KLH_Cross-laminated%20timber.pdf. Accessed: 9 September 2013.

[7] Mayr Melnhof Kaurfmann "Cross-Laminated Timber Panels: M1 BSP crossplan" Publication Source: http://www. mm-kaufmann.com/fileadmin/ablage/dokumente/dokumente/MMK_M1_BSP_crossplan_En.pdf. Accessed: 9 September 2013.

[8] Stora Enso "Building and Living: Building Solutions" CLT Product Description. Source: http://www.clt.info/en/wp-content/uploads/sites/6/2013/08/01-Technical-folder-Stora-Enso-Building-Solutions-CLT.pdf. 9 September 2013.

# 4. UNITED STATES: RESOURCE, MARKET, AND SUSTAINABILITY ANAYLSIS

## 4.1 THE RESOURCE

In order to begin the CLT industry in the United States tree species would need to be designated as having suitable wood for CLT purposes. Further due to the diversity of the United States' forest composition, many species would need to be declared suitable to ensure the industry to be established across the nation.

Within FP Innovations' CLT Handbook, the current requirements for these selected species are extensively discussed. As of now, a standard has been developed for CLT materials. ANSI/APA PRG 320-2011: Standard for Performance-Rated Cross-Laminated Timber contains the requirements and test methods for CLT qualification while providing quality assurance for production using solid-sawn lumber as well as structural composite lumber (SCL) (APA 2012).

ANSI/APA PRG 320 has been written with considerations of the North American lumber resource, manufacturing preferences, and the expectations of the end-use (Karacabeyli 2013). In regards to the United States, the standard permits softwood lumber species or combination of species which have a minimum specific gravity of 0.35 and have been recognized by the American Lumber Standards Committee (ALSC) under PS 20 to be suitable to be used for CLT purposes (Karacabeyli 2013).

ALSC: PS 20 lists 65 softwood species which are commercially sold as lumber in the United States. Of these 65 species, only four do not meet the minimum specific gravity of 0.35. These species which would therefore be unsuitable are Northern white cedar (*Thuja occidentalis*), Western red cedar (*Thuja plicata*), subalpine fir (*Abies procera*) and Atlantic white cedar (*Chamaecyparis* *thyoids*) (Miles and Smith 2009). A full list of the official species suitable for CLT production can be found in the appendix.

Because species often differ from one another in regards to mechanical and physical properties, the standard requires the same species or species combination to be used within the same layer of CLT (Karacabeyli 2013). Adjacent layers can be composed of different species or species combinations, but within a layer, there must be a uniformity.

Although it is currently not a feasible option, structural composite lumber (SCL) might prove to be an effective option for CLT purposes under certain conditions. As of now, SCL is written in the ANSI/APA PRG 320 standard as an option provided the material meets the qualifications of American Society for Testing and Materials' (ASTM) D5456 (Karacabeyli 2013). SCL is currently not an efficient material to use because the face bonding of SCL billets is a difficult process and can often fail.

Despite these difficulties and increased cost, the ANSI/APA PRG 320 committee found that the use of SCL would produce a very advantageous product since SCL can be produced in a long, wide billet form. Also, SCL is without the natural defects of wood such as shake, wane, and knots, and also, more dimensionally stable and uniform in strength and stiffness (Karacabeyli and Douglas 2013).

In Figure 12, the range of these suitable species can be seen to cover much of the Eastern US while the Western US's coverage is substantial but inconsistent. This would seem to suggest that the Eastern US would hold the highest capacity for CLT production.

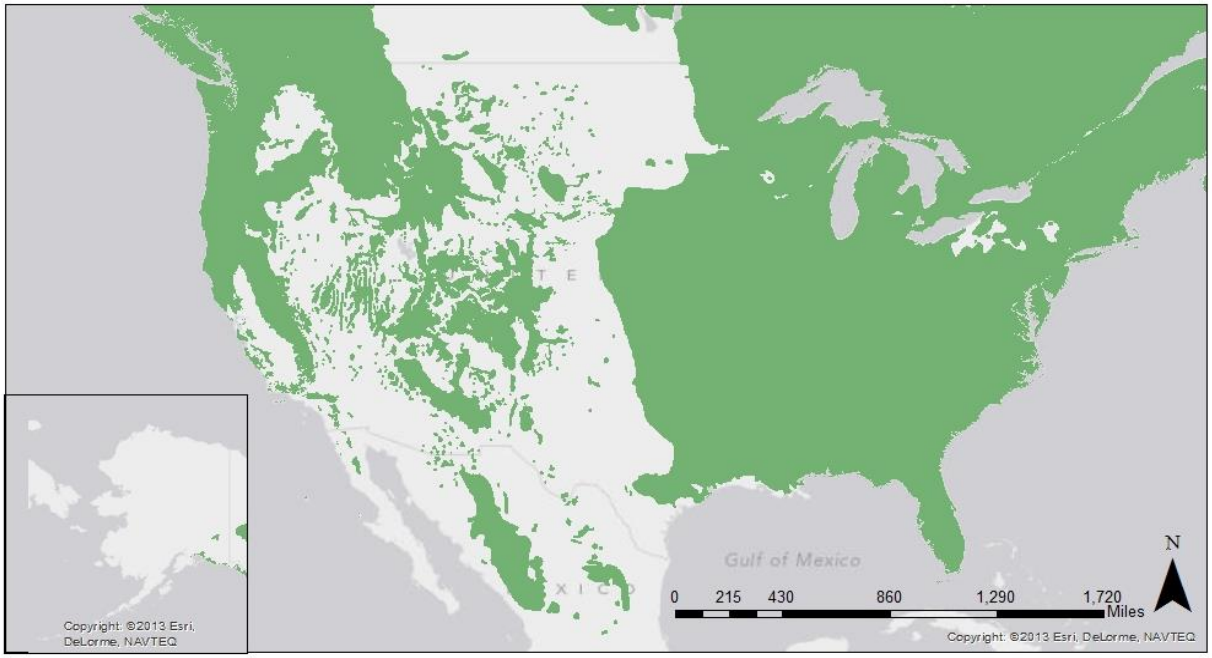

Figure 12: Range coverage for all suitable softwood species for CLT production [9]

The volume per acre by state presented in Table 2 provides for a much more in depth analysis of CLT production potential across the US. Along with all suitable softwood species, yellow poplar (*Liriodendron tulipifera*) was included in these volume estimates to provide a more realistic estimate for the volume available for CLT production. In the event that some hardwoods are accepted as being suitable for CLT purposes, it is quite likely that yellow poplar will be one of the first.

As one might suspect, the Western states contain a significantly larger concentration of softwood volume than Eastern states. With massive timber species such as Douglas fir and the less diverse forest types, the concentration of suitable species and the volumes they present are found to be

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[9] Map created by Cameron Stauder using ESRI ArcGIS and species range data available from the USDA:USFS via http://www.arcgis.com/home/item.html?id=e528d3c1023f477897256ccedacb7700. July 2013.

quite high. Therefore despite the inconsistent coverage of these species in the West, their volumes greatly surpass those of Eastern states. Total volumes by state were also included to provide further analysis, but obviously, the varying sizes of the states and percentage of forest cover have significant influence on these numbers.

Table 2: Volumes for top states in volume concentration of suitable wood species [10]

| State | $m^3$/hectare | bd.ft./ac | million $m^3$ |
|---|---:|---:|---:|
| Washington | 131.76 | 22,597 | 1,225.14 |
| Oregon | 109.55 | 18,787 | 1,355.79 |
| Alaska | 109.03 | 18,699 | 777.24 |
| California | 87.44 | 14,996 | 1,179.05 |
| Idaho | 64.84 | 11,119 | 580.22 |
| Montana | 39.74 | 6,815 | 428.11 |
| Wyoming | 32.58 | 5,587 | 141.64 |
| Colorado | 26.40 | 4,528 | 262.65 |
| North Carolina | 23.25 | 3,987 | 122.02 |
| Maryland | 22.61 | 3,878 | 7.74 |
| Massachusetts | 22.32 | 3,827 | 31.29 |
| South Carolina | 21.56 | 3,698 | 104.29 |
| Virginia | 19.52 | 3,348 | 68.52 |
| Georgia | 19.32 | 3,313 | 168.74 |
| New Hampshire | 18.94 | 3,248 | 42.13 |

The present volume in an area unfortunately does not mean that the needed volumes of low grade lumber will be available for CLT manufacturing. If there is a strong market for CLT, then the allocation of lumber for these purposes will obviously be greater. Therefore, CLT potential is first dependent on the market for CLT in the areas in which the volumes are present. The resource will

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[10] State by state volumes of suitable softwood species and yellow poplar (*Liriodendron tulipifera*) were estimated using USDA:USFS EVALIDator Ver. 1.5.1.05 via http://apps.fs.fed.us/Evalidator/evalidator.jsp

then control the supply and price of the product. If the needed low grade lumber is in low quantity, then the lumber will cost more to acquire.

There is likely a point at which the use of CLT will be more costly than the use of concrete, masonry and steel. Obviously, expenses such as transportation of the CLT panels would need to be weighed by the buyer. Stora Enso of Austria has sent panels all the way to Australia (Kraus 2013). Therefore, it is possible that the transportation of CLT panels from production areas such as the Western states to areas in the Midwest will prove to still be a cost competitive option. Although, this is a topic which would require further study.

## 4.2 MARKET POTENTIAL

The United States market potential has been extensively analyzed by FP Innovations. The following information is strictly based upon their research into CLT's potential on the US market which was based on the construction statistics within the US. Three estimates were made in their analysis; CLT manufacturing costs, the cost competitiveness of the building shell, and market opportunity based on different market penetration scenarios.

### CLT Manufacturing Costs

Based on European manufacturers, small operations (4,000 $m^3$/year, 1 line) was found to cost between \$5 and 6 million, and larger operations (70,000 $m^3$/year, 2 lines) to cost \$20 to 30 million (Crespell 2010).

Within the analysis of manufacturing costs, assembly expenses, profit markup (25%), connections, erection expenses, and engineering and CAD work were considered. The calculated average production cost was $19.20 per cubic foot based on a 300-mile delivery radius with total lumber costs at $400/MBF (Karacabeyli 2013).

### Shell Cost Competitiveness

As expected, light wood frame was found to be the most economical system in low-rise projects and CLT to be more competitive with higher building heights or larger sizes (Karacabeyli 2013). The “best bets” for CLT were found to be parking garages and mid-rise, industrial, retail (1-2 stories) and educational (2-3 stories) buildings (Karacabeyli 2013).

### Market Demand

The market demand was based on penetrations of 5% and 15%, and the market opportunity was found to be at 0.9 to 2.7 BBF or roughly 2.1 to 6.4 million $m^3$ (Karacabeyli 2013). The equates to roughly 2.5% to 7.5% of the 85.4 million $m^3$ of softwood lumber consumed in the United States during 2011 and around two to six billion dollars of CLT shell value (Karacabeyli 2013). FP Innovation also reported the demand concentration to be focused on in California, Texas, the Great Lake States, and the East Coast.

## 4.3 THE SUSTAINABILITY OF THE RESOURCE

Resource sustainability should always be a major consideration when introducing a new product for consumption. By reviewing the figures reported in prior sections, an increase of 2.5% to 7.5% in softwood consumption within the United States seems minimal since yearly forest growth volumes currently continue to exceed the volumes being harvested each year. According to the USFS in their 2010 National Report on Sustainable Forests, “the sheer volume of wood being added to our forests each year through growth well exceeds the amount we are removing, and …

total stocks of standing timber have been increasingly rapidly in almost every region of the country as a result."

Across the US, the average growth is 1.6 cubic meters per acre per year while the average volume annually harvested is roughly 1 cubic meter per acre per year (Robertson et al. 2011). Using 2006 as an example year, softwood growth was roughly 425 million cubic meters across the US, and the harvested volume for that year was roughly 270 million cubic meters (Robertson 2011).

Therefore, softwood harvest and consumption could increase by 37% and still remain sustainable based on these 2006 growth/harvest data. In regards to CLT, the volume needed to meet the market demand only equates roughly 1.5% of the annual growth of softwood across the United States.

# 5. CONCLUSION

This green building product which can serve as an alternative building material for concrete, masonry, and steel construction is one that many countries with adequate wood supply can benefit from. In Europe, the cross-laminated timber industry is steadily growing from year to year. By the end of 2015, CLT production is estimated to hit 800,000 cubic meters. The introduction of additional manufacturers and new mills will likely be found throughout Europe.

In regards to the United States, the market will likely be the limiting factor since wood supply does not seem to be of significant concern. With a product which can make use of low grade wood from many species, the sustainability of the CLT resource is even further ensured.

One large issue to be conquered within the United States is the logistical plan for transporting CLT materials (whether raw lumber or CLT panels) from areas of high resource concentrations to areas without such resources while keeping the product’s costs lower than other alternatives. The industry will likely be concentrated in the Eastern or Western states as the Midwest’s timber supply is practically non-existent in comparison.

In regards to building codes in the United States, the American Wood Council reported on November 12, 2012 that CLT has been approved by the International Code Council as a heavy timber construction material for non-residential purposes. The approved code will be published in the 2015 International Building Code and then be available for jurisdictions to adopt the code (AWC 2012).

There is much to learn from European CLT manufacturers. In efforts to ease the unavoidable growing pains which will likely be experienced in the United States, potential manufacturers would be wise to seek out information or even partnerships with these European manufacturers to better understand how they have become successful in the introduction and increasing utilization of cross-laminated timber products.

The performance and potential of CLT as a heavy construction material begs the question, “Why not wood?” Many comparisons have been completed showing CLT to be an equal or even better material for heavy construction. Further, laws and regulations are being adjusted to incorporate the use of wood for purposes in which concrete and steel are typically used. Therefore just as it likely was in Austria and the whole of Europe, the final trial for CLT in the United States will be its acceptance by the architects, construction community, and the involved public.

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# APPENDIX A: SUITABLE SPECIES FOR CLT PURPOSES IN THE UNITED STATES

Suitable species for CLT purposes under the requirements of ANSI/APA PRG 320 and ALSC: American Softwood Lumber Standard PS-20-05. All species confirmed to have minimum specific gravity of 0.35 based on findings of United States Forest Service representatives Patrick D. Miles and W. Brad Smith in NRS-38.

| Commerical Species or Species Group Names | Scientific/Botanical Names |
|---|---|
| Alaska cedar | *Chamaecyparis nootkatensis* |
| incense cedar | *Libocdrus decurrens* |
| Port Orford cedar | *Chamaecyparis lawsoniana* |
| Eastern Red cedar | *Juniperus virginiana* |
| baldcypress | *Taxodium distichum* |
| pond cypress | *Taxodium distichum var. nutans* |
| balsam fir | *Abies balsamea* |
| Fraser fir | *Abies fraseri* |
| Douglas fir | *Pseudotsuga menziesii* |
| Bigcone Douglas fir | *Pseudotsuga menziesii* |
| noble fir | *Abies procera* |
| California red fir | *Abies magnifica* |
| grand fir | *Abies grandis* |
| Pacific silver fir | *Abies amabilis* |
| white fir | *Abies concolor* |
| Carolina hemlock | *Tsuga caroliniana* |
| eastern hemlock | *Tsuga Canadensis* |
| mountain hemlock | *Tsuga mertensiana* |
| western hemlock | *Tsuga heterophylla* |
| western juniper | *Juniperus deppeana; J. scopulorum; J. osteosperma; J. occidentalis* |
| western larch | *Larix occidentalis* |
| Bishop pine | *Pinus muricata* |
| Digger pine | *Pinus sabiniana* |
| knobcone pine | *Pinus attenuata* |
| Coulter pine | *Pinus coulteri* |

| Commerical Species or Species Group Names | Scientific/Botanical Names |
|---|---|
| Jeffrey pine | *Pinus jeffreyi* |
| jack pine | *Pinus banksiana* |
| limber pine | *Pinus flexilis* |
| lodgepole pine | *Pinus contorta* |
| red pine | *Pinus resinosa* |
| pitch pine | *Pinus rigida* |
| ponderosa pine | *Pinus ponderosa* |
| Monterey pine | *Pinus radiata* |
| sugar pine | *Pinus lambertiana* |
| whitebark pine | *Pinus albicaulis* |
| western white pine | *Pinus monticola* |
| eastern white pine | *Pinus strobus* |
| longleaf pine | *Pinus palustris* |
| slash pine | *Pinus elliottii* |
| loblolly pine | *Pinus taeda* |
| shortleaf pine | *Pinus echinata* |
| pond pine | *Pinus serotina* |
| Virginia pine | *Pinus virginiana* |
| sand pine | *Pinus clausa* |
| spruce pine | *Pinus glabra* |
| redwood | *Sequoia sempervirens* |
| black spruce | *Picea mariana* |
| red spruce | *Picea rubens* |
| white spruce | *Picea glauca* |
| blue spruce | *Picea pungens* |
| Engelmann spruce | *Picea engelmannii* |
| Sitka spruce | *Picea sitchensis* |
| Norway spruce | *Picea abies* |
| Tamarack | *Larix laricina* |
| Pacific yew | *Taxus brevifolia* |