Drivers and Barriers of Cross-Laminated Timber (CLT) Production and Commercialization: A Case Study of Western Europe's CLT Industry

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Abstract

According to several sources, CLT construction systems are an excellent structural choice for tall commercial and residential buildings, have excellent environmental performance, and provide an additional market for softwood and hardwood lumber. Besides and because of its engineered nature, CLT panels can be an excellent market for low value timber (lesser known species, diseased trees, infested trees, and low-grade timber). However, the US construction industry is not yet taking full advantage of the benefits of CLT construction systems due to several limiting factors including market and code acceptance, lack of knowledge, and local CLT panel manufacturing capacity. This last limiting factor is considered critical for the expansion of the US CLT market. Therefore, this research aims to investigate through a case study methodology the main challenges and barriers that CLT panel manufacturers in Western Europe had to overcome to successfully manufacture and commercialize CLT panels. It is expected that current engineered wood products firms, investors, and policy-makers will benefit from these results. Learning from failures, successes, and best practices of leading CLT companies in Western Europe can help support the potential development of CLT manufacturing capacity elsewhere.

Keywords: CLT, building construction, CLT production, CLT drivers and barriers

1.0 Introduction

The sustainable use of timber in the United States (US) for the manufacturing of value-added products has positive social, economic, and environmental impacts (Lippke et al. 2004, Lippke et al. 2011). Currently in the US, the paper and forest products industry employs more than 1.1 million people and generates more than US$355 billion in value added per year (USCB 2017). The timber industry is a critical generator of employment in rural areas in the US where otherwise there would be very limited opportunity to create jobs and valuable social impacts.

The ideation and commercialization of cross-laminated timber (CLT) systems was developed in Germany and Austria around the year 1996 (KLH 2017). A CLT system is defined as a set of CLT panels, joinery, other necessary ancillaries, logistics, transportation, and assembly instructions. Different from a commodity wood product, such as structural lumber, a CLT solution requires a great level of collaboration between the customer, architect, building engineer, CLT manufacturer, logistics company, and builder during the whole execution of the construction project. Today, European CLT manufacturing companies have developed the most respected global reputation in the design and delivery of CLT system solutions and provide over 80% of current CLT production in the world (UNECE 2015) and it is important for potential CLT manufacturers in other regions in the World to learn from their failures, successes, and best practices.

The significance and impact of CLT systems in the forest, forest products industries, the general public, and the natural environment has been addressed by many authors (APA 2012, Brandner 2013, Laguarda Mallo & Espinoza 2014, Pei et al. 2016). As of 2018, there are over 15 CLT structures that have been completed in

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Figure 1. CLT building at the University of British Columbia in Vancouver, Canada.

North America (ThinkWood 2018), with many more in the planning stages. As an example, Figure 1 shows the tallest (18 stories) CLT building in North America on the University of British Columbia campus in Vancouver, Canada, with a cost of CAD$51.5 million.

It has been demonstrated that the use of renewable materials for the construction of residential and commercial buildings such as CLT systems is an important strategy to support global efforts to develop more sustainable construction systems (Lippke et al. 2004, Crespell & Gagnon 2010, Lippke et al. 2010, Lippke et al. 2011, Green 2012). However, current limitations on the manufacturing capacity of CLT systems in the US are limiting the development and expansion of such building solutions.

This article aims to provide an overview of the main drivers and barriers that CLT manufacturers in Western Europe had to overcome to streamline production of CLT systems. A case study methodology was used to collect data through semi-structured interviews and observation of the CLT panel production facilities. In addition, suppliers of CLT manufacturing equipment were asked about the main challenges to begin CLT production to triangulate the data obtained from the interviews at the CLT production facilities. Interviews with suppliers were conducted during the 2017 LIGNA trade fair in Hannover, Germany. The results are useful for investors and policymakers who are interested in adding CLT manufacturing capacity in the US and other countries as a way to increase markets for hardwood and softwood lumber.

2.0 Literature Review

2.1 Potential New Markets for Timber in the US

As indicated by the US Forest Service, less than 1% of harvested timber in the US comes from state and federally owned forests (Oswalt et al. 2014). Little has been implemented by state and federal agencies to increase the consumption of timber from publicly owned forests. In many cases, the extraction of low value timber (e.g., lesser known species, diseased or infected trees, or invasive species) is considered a good strategy to increase the value and health of the forest (Potter & Conkling 2014). In the U.S., privately-owned forest harvesting operations focus on recovering as much timber as possible from operations, including low value timber (Jefferies 2016). However, there are significant factors such as regulations, logistical and harvesting conditions, as well as harvesting costs that impede similar harvesting strategies in national and state forests.

In the last 8 years, there has been an increase in the use of forest biomass for bioenergy markets. The bioenergy market feeds primarily on wood residues produced in sawmills and other forestry operations. In addition, many logging companies have invested in chipping equipment to produce wood chips directly from low value timber in the forest that are used for bioenergy production (Ekstrom 2017). This new market has been critical to support not only logging operations but also to create new outlets for forest and wood product residues (Qian & McDow 2013). Sawmills and primary wood products industries that previously faced challenges in selling their residues are now seeing an important revenue stream from wood waste. However, other traditional industries that have relied on wood residues, such as the paper industry, are seeing an increase in biomass prices due to the rise of bioenergy markets (DraxBiomass 2017). A critical aspect that drives a big part of the bioenergy market is the demand in Europe for US wood pellets, which is mostly being driven by policy and environmental regulations. This could change at any time depending on the current political environment. In addition, the import of US wood pellets into the European Union has been scrutinized by the general public and non-profit organizations due to its overall environmental impact not only on US forests but also because of the impact of logistics and transportation across the Atlantic (Drouin 2017).

An alternative market for increasing the consumption of timber involves recent developments in wood nano-composites. By using new processing methods, woody biomass can be broken into cellulose, lignin and hemicellulose in a faster and more efficient way (Lee et al. 2014) and incorporated into wood composite products for different industries including automotive and medical. However, the potential demand of cellulose, lignin and hemicellulose in these alternative markets is currently very low compared to traditional woody biomass markets such as paper, bioenergy, solid wood products, and wood composite products (Sadhukhan et al. 2014).

In the US southeast region, the most significant use of timber other than pulpwood involves the production of solid and composite wood products. The US softwood and hardwood lumber industries were able to survive the economic downturn of 2009 and beyond. Over the last 6 years, both industries are enjoying a period of increased demand for their products (Luppold & Bumgardner 2016, Howard & McKeever 2015) in local and international markets. New developments in the engineered timber construction industry, such as cross-laminated timber (CLT), could provide a new market for both softwood and hardwood industries. Current construction codes in the US vary by state, where in some cases no more than three stories are allowed and in others no more than six (Torgelson 2017) when using solid softwood conventional timber. However, with the use of CLT systems combined with glued laminated beams (a.k.a. 'mass timber'), tall buildings made from engineered timber are now a reality (Brandner 2013).

2.2 Impacts of Using Wood Products

Previous research have demonstrated that the use of timber for value-added products is a critical strategy to positively impact the environment (Lippke et al. 2004, Oliver et al. 2014, Popovski & Gavric 2016). Studies conducted by CORRIM have shown that when comparing different construction systems with the same functional unit (e.g., area, timeframe, volume, etc.), the impacts on energy and global warming potential is 16% and 31% less when using timber instead of concrete. The same analysis revealed that when comparing steel construction against timber, energy and global warming the potential is 17% and 26% less for timber when compared to steel structures (Lippke et al. 2004). Other studies in the bioenergy sector indicate that the use of forest biomass to produce wood pellets has a lower environmental impact than using fossil fuels, even when accounting for transportation, logistics, and the actual burning of biomass (Dwivedi et al. 2014).

By implementing sustainable practices to manage, harvest, and manufacture forest products, the timber industry not only positively impacts human lives but also ecosystems and other natural resources that are interconnected with forests (Lippke et al. 2011). In all cases, natural and planted forests need to be properly managed to avoid low timber yields, wildfires, water scarcity, and negative wildlife impacts. In the U.S., forest certification schemes such as the Forest Stewardship Council (FSC) and Program for the Endorsement of Forest Certification (PEFC) are recognized as effective strategies to incentivize the private sector to implement effective sustainable forestry practices. However, the impacts have not been the same in public forests and private forests. With over 400 million acres owned by the state and the federal government (USDA 2015), a different approach might be necessary in the U.S. to reduce the negative impacts of diseases, infestations, and an increase in wildfires.

2.3 CLT Construction Systems

The ANSI/APA PRG 320-2012 (APA 2012) defines CLT as "*a prefabricated solid engineered wood panel made of at least three orthogonally bonded layers of solid-sawn lumber or structural composite lumber (SCL) that are laminated by gluing of longitudinal and transverse layers with structural adhesives to form a solid rectangular-shaped, straight, and plane timber intended for roof, floor, or wall applications.*" Figure 2 shows a picture of a three-layer CLT made of Southern Yellow Pine (SYP) at the Department of Sustainable Biomaterials at Virginia Tech.

The PRG 320-2012 only accepts softwood lumber species that are recognized by the American Lumber Standards Committee (ALSC) under PS 20 or Canadian Lumber Standards Accreditation Board (CLSAB). The

Figure 2. CLT panel made of Southern Yellow Pine (Hindman et al. 2012).

minimum grade lumber in parallel layers should be at a 1200f-12E machine stress rated (MSR) or visual grade No. 2 and in the perpendicular layers should be graded at a minimum No. 3. (APA 2012). Moisture content of the lumber at the time of CLT production should be 12±3%. The adhesives used in the manufacturing of CLT panels must meet the requirements of AITC 405 for bonding, strength, and moisture durability (Evans 2014). In addition, adhesives must be evaluated for heat performance in accordance with section 6.1.3.4 of DOC PSI (APA 2012).

According to the Wood Products Council, CLT construction systems are designed to complement light and heavy-timber framing options (Woodworks 2017). Because of CLT's high strength and dimensional stability, CLT can be used as an alternative to concrete, masonry, and steel in many building types. According to Evans (2014), CLT construction systems offer the following benefits:

- Speed and efficiency of installation
- Design flexibility
- Cost competitiveness
- Fire protection
- Thermal performance and energy efficiency
- Environmental performance
- Resource efficiency

In contrast with Evans (2014), Pei et al. (2016) indicate that CLT construction systems face critical challenges that need to be overcome, including:

- Coordination of CLT research across multiple organizations in North America
- Training of future leaders to advance a new generation of mass timber construction
- CLT panels resistance to lateral loads
- Building performance
- Fire safety
- Raw material sourcing

Even though CLT technology has some unresolved critical challenges, the adoption of CLT panels is showing an upward trend in North America. More CLT-related construction projects are being considered, reaffirming that the benefits of CLT technology may outweigh the potential challenges.

3.0 Methods

A multiple case study methodology was used in this research to collect and analyze data because the authors wanted to get a deeper perspective of the selected CLT manufacturers. Case study is a research methodology used to deeply investigate a subject or group of subjects using observation, semi-structured interviews, and document analysis (Yin 2013). Case studies allow a researcher to investigate a topic in far more detail than when dealing with a large number of subjects. The data collected can be analyzed using different methods including grounded theory, text interpretation or even quantitative techniques. For this particular study, the researchers formulated the following questions:

- What were the barriers that impacted the initial production and commercialization of CLT systems in Western European companies?
- What are the more significant current drivers for the commercialization of CLT systems?

Three CLT manufacturers in Western Europe were selected to conduct the case studies. The reason that European CLT companies were selected is because they have been pioneers in the manufacture of CLT systems. In addition, CLT equipment suppliers attending the 2017 LIGNA trade fair in Hannover, Germany were also asked about challenges and barriers to begin CLT manufacturing. Table 1 shows the main demographic aspects of the selected CLT manufacturing companies.

Each company was contacted by one of the researchers who had worked with the company in another research project. In order to compare and conduct further analysis, the same questions were asked to each case study company and companies were told that their name would be kept confidential. The positions of the interviewees at companies 1, 2 and 3 were Project Manager, International Product Management, and Managing Director, respectively.

The interviewees were told that the researchers would visit the production site to conduct a semi-structured interview and to observe the CLT production facility. The observation of the CLT production process was critical to better understand the responses and to make sure there was consistency in responses. As a strategy to triangulate the data obtained from the CLT manufacturers, interviews were also conducted at the 2017 LIGNA trade fair in Hannover, Germany. The CLT production equipment suppliers were selected for convenience by the researchers. Each supplier was asked if they were willing to participate in the study and told that their name would remain confidential. A total of seven suppliers of CLT equipment production were asked one question: *What are the main challenges and drivers to start out production of CLT panels*?

4.0 Results

4.1 Major challenges to start CLT production

Companies were asked how long it took to get to the production stage after deciding to move into CLT systems production. One company indicated that it took from one and a half to two years. The other companies indicated three and two years, respectively. This time included the construction of the facility, purchasing and installation of the production technology, the product testing, and the fine-tuning of the CLT operation.

When the case study companies were asked about the main challenges or barriers to start CLT production, several aspects were mentioned. Three companies indi-

Table 1. Main demographic aspects of selected companies.

Demographic Aspect	Company 1	Company 2	Company 3
CLT production capacity	65-75 thousand m^3/year	65-80 thousand m^3/year	95,000 m^3/year
Species	Spruce and Fir	Spruce	Spruce
Geographic markets	Europe, Australia and the USA	Global	Austria, Germany, France, UK, Italy, Sweden, Norway and the USA
Number of employees	50	40	175
Year began producing CLT systems	Since 2008	Since 2012	Since 1999
Produced products before CLT	Lumber and engineered wood products	Lumber and glulams	None

cated that the most difficult challenge to overcome was the lack of markets for CLT systems. Specifically, architects and engineers did not know about the product, so different strategies needed to be conducted to educate these two groups. For example, one of the case study companies started a pilot CLT project to show potential customers the advantages of CLT systems.

Two of the companies mentioned that finding a source near (20 miles or closer) the required raw material was also a challenge, as CLT manufacturing requires specific sizes, quality, and species for the panels. Related to this, another company mentioned that not having glued-laminated timber (glulams) production was a critical challenge, as the company had to partner with other companies to incorporate glulams into the CLT projects.

One company mentioned that another challenge was the certification process for the acceptance of CLT systems in the construction industry. Even today, there is not a common standard but just general quality guidelines included in the European Union agreements that all companies must follow.

Finally, one of the companies mentioned that staff and production workers did not know anything about CLT systems production, therefore, they needed to train their employees in order to start CLT production.

4.2 Current CLT Commercialization Barriers

The case study companies were also asked about current barriers preventing the expansion and acceptance of CLT systems in Europe and in global markets. Two companies mentioned that building regulations are different in each country and that in most cases, the large majority of architects, engineers and builders do not have CLT experience. It was also mentioned by these two companies that there is still a large number of fire science engineers in Europe that do not support wood as a construction material. Another company mentioned that transportation outside of the European market is very challenging because CLT elements must be containerized.

The companies in the study were asked about specific strategies they have formulated to overcome barriers for expansion of CLT systems. Two companies indicated that they need to increase CLT production capacity as current capacity is booked for several months. For example, one company indicated that the lead-time for an average size CLT project is 8 weeks. It was also indicated by one of these two companies that advantages of the CLT system are not very well known yet. For instance, most of the current use of CLT is for commercial applications and little CLT production goes into residential construction. A reason for this could be the need to improve the transition process from the architect to the design and manufacturing stages.

In terms of support from local government and from the European Union to overcome current barriers, two companies indicated that more should be done to increase awareness of using wood as a construction material for residential and commercial buildings. For example, one company indicated that tax breaks could be implemented and that it should be mandatory that a new construction project should include at least 20 to 30% of wood in the mix of construction materials. Another company suggested that the local governments should do more to promote the use of CLT and wood products in general in public buildings, such as schools.

4.3 Drivers for CLT Production

Companies were asked about their motivation to start CLT production. Two companies indicated that they saw an opportunity to increase revenue and profits. For example, one company had been manufacturing glulams before introducing CLT production, so they thought both products would complement each other very well. For the third company, CLT production was their first product (this company is a pioneer in CLT production) and the plan to start CLT production was supported through a collaboration with a university in Germany.

When the companies were asked about the drivers that have led to their success in the CLT market, several reasons were mentioned. Company 1 indicated that the uniqueness of the production process is a key competitive advantage as this company glues the layers (edge glue) before the panel itself is constructed. In addition, this company can provide very good CLT prices, as they have a large transportation network and infrastructure that can handle very competitive shipping rates compared to their competitors.

Company 2 mentioned that their main drivers involves the integration they have with their lumber, glulam and CLT manufacturing. In addition, this company indicated they have created a smooth and highly integrated collaboration process with their customers (architects and engineers). A complete CLT project (including glulams) can be shipped together decreasing the project time and complexity but also ensuring standardization and ease of assembly at the construction site.

Similar to Company 2, Company 3 indicated that owning and controlling a nearby sawmill operation guarantees the supply of a consistent and high quality raw material. Additionally, this company provides excellent support to CLT projects including technical and educational support to their customers. But perhaps the most important competitive advantage is the fact that this is the pioneer company in the CLT market. The company started in 1999 and has delivered more than 20,000 CLT projects around the world.

4.4 Perception of CLT production equipment suppliers about challenges and barriers

A total of seven suppliers of CLT equipment production were also interviewed during the 2017 LIGNA trade fair in Hannover, Germany. These suppliers were asked the following question: *What are the main challenges and drivers to start out production of CLT panels*? The answers can be found below in Table 2.

From Table 2, it can be seen that 6 out of 7 suppliers indicated that raw material supply (in terms of quality and availability) is the main issue impacting CLT manufacturing. Other important challenges that emerge more than once include the integration with glulam production and the financial aspects of the project. For example, one supplier indicated that a 50,000 m^3/year capacity CLT plant requires an investment in the range of US$10-US$15 million. The results of the interviews with the CLT equipment suppliers were very useful to validate the answers from the CLT manufacturers.

5.0 Discussion

It has been more than 17 years since the first CLT panels were produced and commercialized in Germany and Austria and the product, the information flow, the production technology, the logistic and building operations, and yet the market continues to evolve. The acceptance and potential of CLT construction systems around the world continues to grow as more projects are completed and introduced to the public opinion.

The cases studies conducted in Western Europe and the interviews of CLT manufacturing equipment suppliers in the LIGNA trade fair in Germany helped to understand the main challenges, barriers, and current drivers of the manufacturing and commercialization of CLT construction systems. The interviews of suppliers during the LIGNA trade fair were important to triangulate the main challenges indicated by the manufacturers.

Figure 3 summarizes the main challenges and barriers that the case study companies had to overcome to successfully commercialize CLT construction systems. Following, a detailed explanation of each factor is discussed.

Markets: When the product was introduced in 1999, there was some familiarity with engineered products such as glulams in Europe. This knowledge could have helped the European market to slowly accept CLT construction systems. In the US, the situation is very similar to what it was in Europe 15 years ago. The construction community in the US is familiar with massive timber products, such as solid timber, glulams and laminated-veneer lumber (LVL). This could be used as a strategy to

Table 2. Challenges and barriers to start out CLT manufacturing

Supplier number	Equipment	Main Challenges
1	Finger jointing	High quality lumber, availability of raw material, market for CLT products
2	Pressing equipment for CLT production	Lumber supply, integration with glulam production, financial and marketing aspects
3	Integrated CLT production systems	Integration of different production processes with architects and builders, savings in raw material is critical, high quality lumber supply
4	Material handling systems for CLT production	Press needs including size, type cost. Also raw material supply
5	Pressing equipment for CLT production	Layout configuration
6	Material handling equipment for CLT production	Financial aspects, standardization vs customization, integration with glulam, and nearby availability of lumber supply
7	CNC equipment	Lead times from planning to production

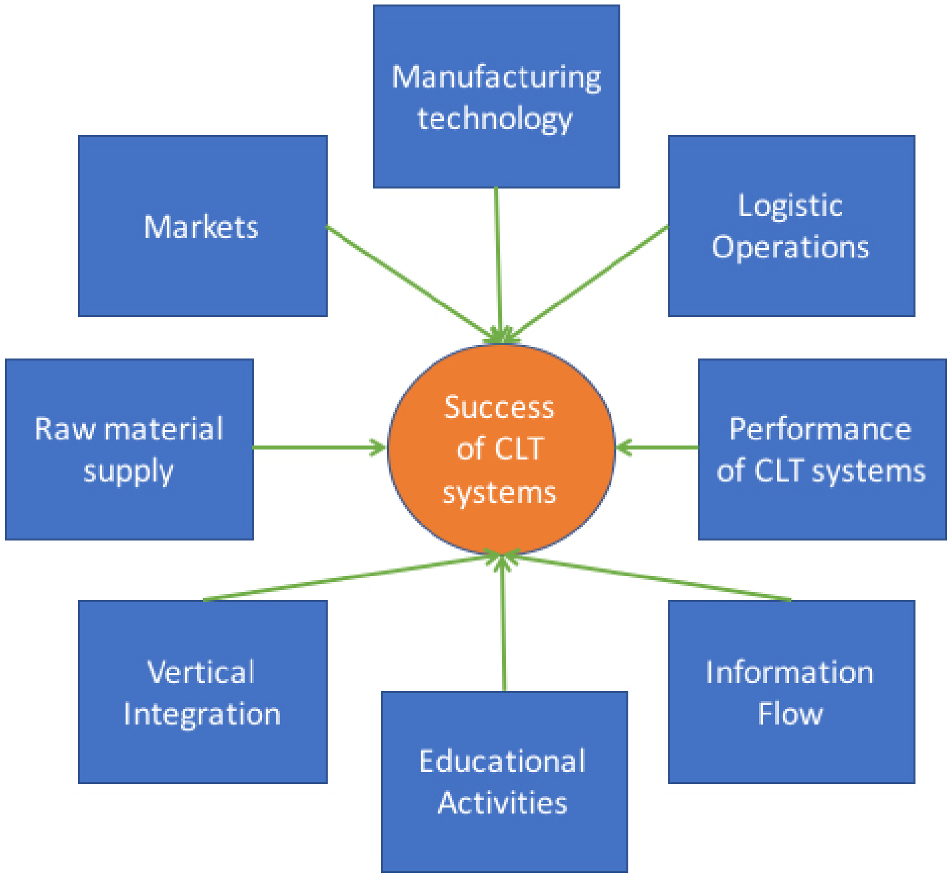

Figure 3. Barriers and challenges impacting the success of CLT manufacturing and commercialization.

promote the advantages of CLT as many construction projects will need both (i.e. CLT panels and glulams).

Information flow: Because CLT construction projects must be customized, the level of communication and integration among customer, architect, CLT manufacturer, glulam manufacturer, raw materials supplier, CLT logistics companies, and builders must be at the highest level. Even for the case study companies, this is still an issue that could prevent a project from becoming successful.

Performance of CLT systems: Even though wood and wood products are highly accepted in Europe, there is still a concern about the performance of wood construction products against fire, decay, and earthquake resistance. Private and public institutions such as universities have conducted numerous independent studies to measure the performance of CLT construction systems against different building codes and it has been proven that these systems meet or exceed requirements (Hindman et al 2012, Popovski & Gavric 2016). As the case study companies indicated, there are some construction industry groups that resist the idea of using CLT construction systems over traditional construction materials, such as steel and concrete.

Manufacturing technology: Case study firms indicated that it took from 1.5 to 3 years to move from CLT planning to production. The required technology to produce CLT panels has a price tag that varies from US$10 to US$18 million for a 50,000 m^3/year capacity production plant. Production equipment includes sophisticated machinery to inspect dimensions, defects and moisture content of lumber, finger jointing equipment, massive presses to form panels, computer numerical control (CNC) machines to cut the panels, and massive material handling capabilities. In addition, final inspection and repair of the CLT panels still requires a lot of manual labor involvement.

Raw material supply and vertical integration: All case study firms indicated that a consistent and high quality supply of lumber is required for the successful production of CLT panels. In all cases, the case study firms owned a sawmill located within 20 miles of the CLT production facility. As indicated earlier, incoming lumber is checked for the proper dimensions, grade, and moisture content. In the case of installing CLT manufacturing capacity in the US, this could be very challenging if lumber is coming from different suppliers. The amount of raw material required to produce 50,000 m3/year of CLT panels is equivalent to 25 million board feet (at 80% yield), whichwill require strong business relationships with several suppliers if the CLT production mill needs to buy their raw material. All three case study companies mentioned that having some level of vertical integration is a key success factor for them.

Logistic operations: All case study companies have worked very hard to develop a proper logistics system for the packing, loading, transportation, unloading, and installation of CLT panels. Keeping track of every panel could be a challenging task that requires an efficient use of information technologies, as well as strong project management skills. A CLT construction project will most likely require extensive planning to coordinate manufacturing, logistics, and assembly of the panels. Each project will need to have clear instructions on how to packed, shipped, and assembled each panel.

Education activities: A key challenge that impacts the consumption of CLT construction systems is the lack of knowledge by architects, civil engineers and builders related to the advantages and disadvantages of wood products in construction. At higher education institutions, there is a belief that the proportion of courses that emphasizes the use of wood for residential and commercial construction is minimal compared to steel and concrete. As the CLT manufacturers and suppliers indicated, much more must be done to elevate the awareness level of using wood as a construction material. The more knowledge these professionals have, the better the chances the market could increase consumption of wood products and especially of CLT construction systems.

6.0 Conclusions

The results of this research indicate that current challenges for CLT panel manufacturing are related to the following factors: consistent supply of high quality raw material, vertical integration with lumber suppliers and glulam producers, efficient and effective management of the information flow, and proper logistic and transportation operations. These results were validated by CLT equipment and materials suppliers at the LIGNA trade fair.

The acceptance of wood and wood products such as CLT as safe and high-performance construction material is still rejected by many groups in Europe. Organizations supporting wood products such as Universities still need to continue to educate architects, the general public, and policy groups to fully embrace CLT construction systems as a construction material that performs equally or better than steel and concrete. It was mentioned by the case study companies that government support of CLT construction systems could be significant in incorporating wood products in new or the remodeling of public buildings, such as hospitals, schools, fire stations, windmills, towers, etc. These projects could serve as case studies and demonstrations to showcase the advantages of CLT construction systems

The potential installation of manufacturing capacity of CLT panels in other regions of the World such as in North America could be translated into an additional market for hardwood and softwood lumber in the North America. However, the current CLT code only accepts some softwood species and hardwood species are still not accepted as a CLT panel raw material. Another entry barrier is the capital investment required to install CLT manufacturing capacity where according to one CLT equipment supplier, the cost of a CLT production line ranges from US$10 to US$ 15 million for a 50,000 m3/year CLT mill.

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