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Cross-laminated Timber in North America: What can we learn?

BIOPRODUCTS BUSINESS

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Abstract

Cross-laminated timber (CLT) is becoming global. New countries and regions increasingly realize its potential. As an example of a new market, this study analyses the current characteristics of the North American market, as well as its resident companies. Additionally, the historic development of the product is studied. There is the unique opportunity to learn from the existing Original Market in Europe and the companies that have been successful there for many years. The German-speaking alpine region of Europe is the cradle of CLT innovation. Using qualitative methods, specific lessons learned are identified. The combined findings give an enhanced understanding of what can be done to effectively foster and fast-track implementation of CLT in North America. This study also aims to provide interested parties, such as architects, engineers, owners, developers and academics with insights regarding the development of CLT in North America, while also providing a foundation for future academic research.

Keywords: Digitalization; digital transformation; wood products industry; customer value; service logic

1. Introduction

In recent years, cross-laminated timber (CLT) has experienced huge growth in international awareness and interest. North America, for example, is veritably booming, where CLT is a trendy topic in the construction industry and even, at times, in public discourse. But what role does CLT really play in North America?

Architects and engineers, as well as interested parties like developers and owners often encounter uncertainties and false expectations concerning the use of CLT. There is much more to a market than excitement and publicity; there is a highly complex process of producing CLT, realizing projects, and establishing the product as a competitive building solution. Gathering information about the situation can be a long and wearying process for new market players. Our results provide lessons learned from Alpine Europe relevant to advancing the North American CLT market. In doing so, we provide information and insights for professionals with an interest in becoming involved with CLT in the US or Canada. This information can facilitate implementation and growth of the market compared with historical development in Europe.

Considerable work exists documenting the views of US architects and engineers regarding CLT, including opportunities and barriers in the market (Mallo and Espinosa, 2014, 2015) and the characterization of global manufacturer characteristics and capabilities (Muszyński et al., 2017). Thus far in the development of CLT, no work has considered the development of the marketplace from the perspectives of both experts in the marketplace and manufacturers in both Europe and North America. Considering this, our study provides lessons learned from more experienced markets, especially in the German speaking alpine region of Europe. Market

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characteristics and lessons learned are placed into the context of the North American industry. Specifically, we focus this study on the following two objectives:

1. Identify how threats and weaknesses can be dealt with, and opportunities and strengths can be used to foster the implementation of CLT in the North American market.
2. Identify lessons, especially from the development of CLT in the Original Market of the German-speaking alpine region in Europe, that North America can benefit from.

2. Theoretical Background

In order to develop a comprehensive overview of the two CLT markets, data collection in this research relies on a framework of categories, based on theoretical models from the literature. One of the most common is the PEST model (i.e., *political, economic, social* and *technological* factors). Together, these categories describe important external influences affecting a company (Yüksel, 2012). Hansen and Juslin (2011) adapt this concept specifically to forest products marketing and create a structure to guide information gathering, using the *Information Environment Model*. The authors divide all aspects that influence a company into two main areas, the *macro environment* and the *micro environment*. The *macro environment* includes *Demand*, *Supply* and "*Other"*, primarily describing impacts on the firm from the context of the economy or marketplace. The *micro environment,* on the other hand, contains aspects that describe the behaviors or context of customers, competitors, and systems of distribution (Hansen and Juslin, 2011). In this research, we make use of the categorizations of *PEST analysis,* with the addition of the *Information Environment Model* to guide the process of gathering information for drawing a comprehensive understanding of the context surrounding the CLT marketplace. An additional category is introduced, *Existing CLT Structures*, which captures projects that have already utilized CLT within a certain market.

A second framework of categories was used to collect comprehensive information about the business models of individual companies, relying on the *Nine Building Blocks* by Osterwalder and Pigneur (2010), including the additional category *Strategies*. Osterwalder and Pigneur developed the *Business Model Canvas* with its nine categories as a "*shared language*", which can be used to describe virtually any company and its business model. Because of its universal and complete nature, this system can be used effectively to collect information as a basis to describe and analyze companies within the CLT industry.

The last framework we utilized is concerned with the results, dividing them into two stages, each following one of the research objectives. The first is concerned with the current status of the North American CLT market, compared to the Original market, and is structured around the four pillars of a *SWOT analysis*. This widely used theoretical model describes external *opportunities* and *threats*, giving information about what is happening within a market, as well as internal *strengths* and *weaknesses* of each company, in this case, CLT manufacturers. The second stage contains all results concerning *lessons* that can be *learned* from the development of CLT especially, but not exclusively, in the Original Market.

3. Data and Analysis

The data collection process is focused first on CLT markets themselves (including everything but CLT manufacturers), and second on companies that manufacture CLT. *Figure 1* shows the conceptual framework with a *market* side (green) and a *business* side (blue) that was used to guide data collection and presentation of results.

Muszyński et al. (2017) refer to the alpine cluster in Europe as the Original Market. We divided our study area into the "O*riginal Market*", the geographic region where CLT was initially developed and implemented, and North America. Within this research, however, the term "*German-Speaking Alpine Region*" was used to define this area. *Figure 2* shows the approximate area of the *Original Market*.

Within these two regions, personal interviews were conducted as a primary source of information. Following the overarching research structure, informants were divided into two groups. *Experts* were defined as individuals with a high level of knowledge about a certain CLT market (external), and *manufacturers* as companies that produce CLT (internal).

When selecting experts we attempted to engage a large variety of participants. The first few interviewees were chosen through convenience sampling. Subsequently, snowball sampling was used, where every interviewed person was asked for references of other potential informants (Patton, 2002). Following

these methods, a large variety of CLT experts, such as university professors, trade journal editors, architects, engineers, etc., were identified and interviewed. Secondary research showed that North America has only seven operating CLT manufacturers. Therefore, we invited all of them to participate. The Original Market has more manufacturers and was approached with criterion sampling, where manufacturers had to be in operation for at least 5 years to be considered. Following that, convenience and snowball sampling were also used.

Our sample size was not defined in advance. Instead, we stopped interviewing when *data saturation* was reached, which means that new interviews no longer provided significantly new information. In total, we conducted 19 interviews, including six experts in North America, five experts in the Original Market, three manufacturers in North America, and five manufacturers in the Original Market.

Personal interviews were conducted using a semi-structured approach. We used four open-ended questions, closely arranged around the two study objectives (see Appendix). Two interviews were conducted by telephone, while all others were conducted in person. The length varied between 45 and 210 minutes. To make sure interviews covered the most important topics, the research framework categories were utilized as a guide for additional probing questions. Every time quotation marks and italics are used in the results, the quote comes directly from an interviewee.

According to Gillham (2007), transcribing and analyzing recorded interviews are the most time-consuming steps of qualitative research. Clausen (2012) sees a significant disadvantage in the time-consuming nature of traditional techniques, as they limit the researcher to a smaller number of interviews. Also, if a long time passes between data collection and analysis, the quality of analysis of written transcripts suffers since the researcher's memory of the interview will fade over time. Another significant threat of having a large number of pages of transcriptions is that the researcher might fail to see the forest through the trees and consequently miss or overlook important findings. Addressing these issues, Clausen (2012) developed *The Individually Focused Interview* (TIFI). The TIFI methodology omits the need for the widely-used audio transcription process by relying on verified field notes, allowing a larger number of interviews to be conducted. After the interview, the field notes are shared with the respective interviewee to ask for comments or changes. All verified field notes are then combined to a data set, which is used for data

Figure 1: Conceptual framework

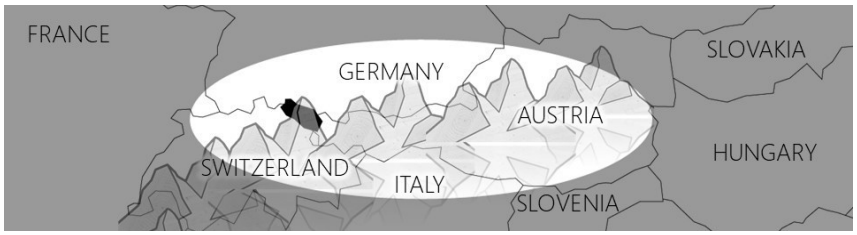

Figure 2: The German-Speaking Alpine Region of Europe

analysis. Considering its advantages, we chose the *TIFI* methodology for this study and adapted the process to ensure data reliability. Instead of only relying on verified field notes, every interview, with the permission of the informant, was audio recorded. Afterwards, we listened to the recordings and created an additional set of *audio notes*, which we then compared and merged with the *field notes* to create a set of *final notes*.

For data analysis, we took a simple structured approach. At first, all information gained through data collection was combined to a complete database by distilling all *final notes* down to individual *information blocks*, where each block contained a specific theme. In the subsequent data analysis, the *market characteristics* stage and the *lessons learned* stage make use of slightly different approaches. The first divides the respective *information blocks* into the categories of the SWOT analysis. Within them, the Original Market and the North American market are compared to each other to create awareness about the differences between them. This builds the basis for the *lessons learned* stage. To help assure reliability only those *information blocks* that are mentioned by more than one independent source (*number of occurrences* >1) are included in the results.

4. Results

4.1 The North American Market in Context

The culture around construction and building differs from North America to Europe. CLT as a product, system, and global industry is more developed now than it was in its early days in Europe. Because of this, the development of CLT in North America will likely differ from the example in Europe. The following four points illustrate the differences between the two markets, to put the lessons learned into context.

4.1.1 Strengths

We discovered that many companies consider similar virtues to be their strengths. For example, most companies in North America as well as in the Original Market say that providing additional services is very important to their success. This is because nearly all manufactured CLT is part of a custom order (Muszyński et al., 2017). Therefore, companies must support customers with design capabilities and custom fabrication of raw CLT panels. Muszyński et al. (2017) also found that manufacturers see their additional services as the second most important competitive advantage, after high quality. Very few companies produce commodity-type panels that are subsequently customized by carpenters or specialty firms.

Almost all large manufacturers in the Original Market, and about half of North America's producers, are vertically integrated in production. Interviewed companies consider this to be one of their biggest strengths and state: "*You can only provide price stability, in combination with your own saw mill. Then you can set average prices for the next year or so*." This is a great advantage for both the manufacturer and the customer, because the cost of a project can be held stable in the time between the offer and production. In the Original Market it is common to provide annual cost sheets for CLT, whereas in North America, prices are as volatile as the lumber market.

4.1.2 Weaknesses

Since the North American market is comparably young and still in its development stage, the local industry tends to be less efficient. In particular, the standards of production facilities could be greatly improved, compared to the Original Market. Most manufacturers: "*add on there, and add on here, and it's just never gonna be efficient.*" Therefore, workflows are less lean or quick and more human input is required. This increases the costs of the final product significantly. Also, the degree of accuracy and precision, and therefore the quality of CLT is lower in North America. The load carrying capacity is not compromised, but for special applications, like visual surfaces, special surface finishes, or art projects, this is an issue. Currently, CLT producers from the Original Market can offer cost-competitive and superior quality CLT in the US and Canada, even with shipping costs included.

Post production and CNC machining of CLT is particularly affected by this prevalent lack of efficiency. The less work input that must be done to a panel in production, the cheaper it can be sold. Consequently, CLT in North America is currently used primarily for ceilings and not so much as wall elements, because cutting out doors and windows requires more effort and cost.

4.1.3 Opportunities

Globally, population and resource depletion are increasing (WWF 2016). This creates an opportunity for CLT construction, as its high degree of prefabrication can provide fast and efficient housing, its good strength-to-weight ratio makes it possible to densify urban landscapes even

more, and being made from wood, CLT is renewable and even sequesters CO_2. Despite recent political events, there is an increasing awareness of climate change, also in North America.

From a practical point of view, CLT is very versatile. Experts know that it can be used for public buildings, schools, gyms, hospitals, hotels, apartment buildings, office space, industrial buildings, high-rises, multi-family housing, single-family homes, boutique projects (beautiful buildings), tornado shelters, wind turbines, bridges, as T-beams or plate-beams or free-forms (e.g. artwork), etc. One often-overlooked application involves utilizing CLT as access mats, which are used to build temporary roads on otherwise inaccessible terrain, without overly impacting the landscape. CLT maintains its structural integrity considerably longer than, e.g., conventional non-laminated hardwood mats. Therefore, CLT mats can be used much longer. The oil, utility, and forestry industries in North America use huge volumes of access mats, which provides an opportunity for large production volumes of CLT. Forest Economic Advisors (Schmon et al., 2017) found in their study that the North American CLT access mat market is growing more rapidly than architectural CLT. According to their study, North America consumes 45,000 m^3 of CLT for buildings, and 118,000 m^3 for access mats, which is only about 3% of their potential market.

Speaking of market potential, in North America "*the chances for CLT are huge*". An especially promising area is repetitive projects. If, for example, McDonalds decided to make even a canopy for their restaurants out of CLT, or if an insurance company would promote discounts for customers who have a CLT garage in tornado-prone areas, very large demand volume could result. Even modular single-family housing could find large scale application for CLT, due to the high degree of prefabrication.

It is understood that the North American market is growing faster than the Original Market did in its beginning. There is considerable excitement around the product. In 2011, a standard for CLT (PRG320 APA/ANSI) was created, and the International Building Code (IBC) of 2015 in the US (must be adopted by every state individually) prescriptively allows mass timber and CLT. In Quebec, Canada, the office of the local building code, the RBQ (Régie du bâtiment du Québec), even made an official design guide for mass timber projects up to 13 stories, making the code approval process much easier and faster. A "CLT Handbook" was created by FPInnovations in Canada, which is a comprehensive guide on how to build with CLT. Before 2015, Mallo and Espinosa (2014) found that the fact that CLT was missing in the IBC was the main barrier to the adoption of CLT in the US.

4.1.4 Threats

In North America, wood as a building material has an equivocal image. In the US, more than 90% of single-family houses are made with timber-framing (U.S. Census Bureau, 2016). However, experts also explain that there is a preconception that the use of wood harms forests. Apart from the public, even many architects and engineers have the perception that only certified wood is sustainable, thinking that is influenced by Leadership in Energy and Environmental Design (LEED) building certification. According to our respondents, LEED tends to discriminate against uncertified wood, whereas Environmental Product Declarations (EDPs) can provide a more comprehensive examination and show different results.

The current design processes in North America are inflexible and old-fashioned. Very popular is the Design-Bid-Build process, because it is seen as a tool to control the price of a project. However, it is a threat for CLT, because manufacturers must bid on a pre-made design, which often forces a non-efficient use of CLT and mass timber. This process also favors decisions mostly based on cost-per-square-foot calculations, which do not consider the savings that CLT provides through its speed of installation. Architects say that within the current stiff planning processes in North America, "*collaborating with manufacturers isn't very easy*". Further, the IBC of 2015 is using safety mechanisms around CLT that are very conservative, which limits mass timber design and makes CLT less efficient and cost-effective.

The mass timber industry in North America is not yet using its full potential of efficiency and know-how. There is existing knowledge and skill in more experienced CLT markets that can be learned from, but the North American industry tends to ignore these existing sources of knowledge. Many mistakes and experiences would not need to be repeated in North America if more cooperation was pursued. Most publications around CLT and mass timber in the Old Market are also available in English, and many European manufacturers are willing to start collaborations internationally, some are even actively looking for partners.

4.2 Lessons Learned

4.2.1 Wood Education

Experts mutually agree that it is highly important for CLT, and mass timber construction as a whole, to foster education since it is a great point for new professionals to enter the industry. Aside from that, the related research increases knowledge and fosters new developments. Most needed is education for professionals that work with CLT, something well-documented in previous work (Oregon BEST, 2017; Mallo and Espinoza, 2015; Hemström, et al., 2011; Kozak and Cohen, 2007). Firstly, architects must be instructed on how to safely, efficiently and sustainably design CLT buildings. They have the power to choose one material over another, so the more they are comfortable with CLT, the more demand can be created. In the Original Market, architects created the largest demand for CLT in the beginning. Manufacturers know: "*If you can't convince architects, you don't have projects!*". Also, engineers must fully understand the properties and characteristics of CLT so that they can plan efficiently and safely. The more engineers that know about mass timber, the more they can increase the efficiency, flexibility and longevity of a building. The importance of educating architects about CLT is consistent with Mallo and Espinoza (2014). They identify a lack of education about CLT as a barrier to the adoption of CLT in the US. In the Original Market, education about wood construction is provided on many levels, including high schools, apprenticeships, trainings, and universities. There even are universities that teach in English language and have comparably low costs of tuition, however, very few North Americans take advantage of these study opportunities.

After the planning stage, a CLT structure must be installed, which also requires trained labor. In the Original Market, carpenters find it very easy to adapt to CLT, but in North America this expertise is still scarce. Even though assembling a CLT building is very straightforward, if someone has not done it before, there is a sizeable learning curve.

4.2.2 Water-Related Building Services

Experts in the Original Market say, "*the only big weakness*" that is left in the development of CLT and mass timber construction, are water-related building services. Accordingly, new optimized solutions for building services in CLT and mass timber buildings are needed. Experts agree that design of mass timber buildings must carefully consider the potential for moisture intrusion (Wang et al., 2018).

Currently, it is common practice to use standard details and designs from other building technologies like concrete, brick or steel in mass timber projects. It is, for example, typical to route water-carrying pipes within or underneath the screed of a floor construction. By doing so, the biggest vulnerability of wood is ignored; wood will decay when exposed to moisture over time. If these pipes start leaking, water invades the structure and it may be some time before the issue becomes visible on the surface. If it goes unnoticed for an extended period of time, there is potential for significant damage, especially compared to a concrete or steel structure. This is why it is very important to develop and use building services that are designed for wood construction so that any kind of abnormal moisture concentration can be detected right away, and damage prevented. For that reason, experts in the Original Market ultimately demand: "*No single water-carrying pipe should be routed inside of the floor construction. No fresh water, no warm water, no coils for floor heating. All water-carrying pipes have to be accessible!*" One alternative solution could be the proactive use of moisture detectors. These could function like smoke detectors, announcing when an abnormally high concentration of moisture is detected in a mass timber building.

4.2.3 Tall Wood Illusion

There is an unofficial ongoing race within the global mass timber scene to build the tallest buildings in wood. Even public media sometimes reports on the latest achievements in wood construction and big plans for the future. However, experts have mixed feelings about this tall wood hype. The enormous publicity that tall buildings in wood are generating is a benefit for the industry. Many people get excited about these projects and even the general public occasionally shows interest. It creates excitement to watch taller and taller wood buildings go up. However, the real drivers that are needed to advance the industry at this point are: a reliable and increasing demand, higher efficiency, and diverse market penetration with large volumes of CLT. Tall wood projects do not provide these hard benefits, simply because the demand for high-rises, in general, is comparatively low.

In North America, the term *'mid-rise gap'* refers to the situation in Canada and the US where wood frame

construction is only allowed up to 5-6 stories, depending on the regional code. Everything taller must be built in concrete or steel. However, experts say that concrete is not very efficient below about 10 stories. This opens up an area between 6 and 10 stories, where an efficient building material is needed. This offers a great opportunity for CLT and mass timber construction, because in that height range, they can be very efficient.

As a conclusion, the "*sweet spot*" for CLT and mass timber construction in North America, lies in the mid-rise gap, between 6 and 10, or optimistically 4 and 12 stories. North America's commercial building sector carries a lot of potential for CLT and mass timber. Potential projects incluede warehouses, retail stores, large schools, hotels, etc.

4.2.4 Holistic Design

CLT is not just another building material; it is a concept which requires adapting conventional planning processes accordingly. Due to the nature of CLT and its high degree of prefabrication, the design process must start very early to be cost-efficient. Since CLT is a panel, forces are conducted differently, and the structure must be designed differently. In addition, different manufacturers produce different products with different properties and dimensions. Therefore, "*With CLT, working with the manufacturer from the beginning, is really important!*". If this is not the case, plans and 3D models, and structural calculations must be changed to incorporate differing new panel dimensions and performance characteristics. A good design team, where architects, engineers, builders and manufacturers work together early on in the design phase, is key.

With CLT, "*You have to go slow to go fast!*", meaning more time must be spent on the planning phase, so that the construction phase can be expedited. The more planning effort that is invested beforehand, the higher the degree of prefabrication, and the faster the installation will be, which increases time and cost efficiency. In the existing planning traditions in the Original Market, this approach can be pursued more easily than in North America. Processes beyond "*design-bid-build*" are needed, and owners must be made aware that with prefabrication a design must be final when entering the production and installation stage. Architects in North America see CLT and mass timber as a potential catalyst for modernizing their existing old-fashioned planning processes. More collaboration and more comprehensive planning are needed.

4.2.5 Automation

CLT is a panel that can easily be machined and transported, which makes it possible to produce housing quickly and efficiently with much less skilled labor in the factory as well as on the building site. Our informants say this provides potential opportunity to modernize the entire construction industry. This is precisely the business model currently pursued by Katerra in the US (Katerra, 2018).

Common practice in the Original Market and in North America involves using a CNC to fabricate all CLT panels individually off-site, turning a construction site into an assembly or installation site. However, state-of-the-art in prefabrication is already much further along. Instead of transporting individual panels, entire cubicles and modules can be preassembled in the factory. Modularization even makes it possible to preinstall interior construction and facades so that an installation site can consequently become a mere delivery site. The more that is done in advance, the more efficient and therefore cost-competitive a CLT project can be.

Comparing the construction industry with, e.g., the automotive sector shows that modern production standards could take efficiency to an even higher level. In a car factory, the human component is eliminated as much as possible. CLT provides an opportunity to bring this technology to the construction industry, taking it beyond prefabrication, towards automation. Currently, almost every CLT panel is custom-made. By increasing the level of standardization, this could be changed. A company could offer a few box types and a range of interior features to choose from, similar to car models and their optional features. Business models like this can allow mass production of CLT. At present, at least two companies are establishing large-scale production facilities, planning to mass-produce modularized CLT housing. If they succeed, this concept is very likely to spread globally (Schmon et al., 2017).

The study from FEA (Schmon, et al., 2017) predicts that decreasing skill levels and increasing productivity are keys for the future of the construction industry because affordable housing is in high demand worldwide and skilled labor is hard to find.

4.2.6 Establishing new Production Facilities

Contemplating market entry as a CLT manufacturer requires careful decision-making. Two things are essential: having good production know-how about CLT

and knowing the construction industry within a market. Wood products companies have an edge in terms of technical understanding, however, glulam manufacturers that have expanded to CLT production say it was still challenging. One challenge documented in the literature is the cultural gap that exists between wood products manufacturers and specifiers (Fernando et al., 2018). In addition, glulam is often produced as a commodity type product, or with low amounts of customization. With CLT, nearly every panel is 100% custom-made and a CNC panel machine is needed to be competitive. Glulam-based CNC machines are unlikely suitable for panels. Additionally, CLT manufacturers must do a lot of planning work up front. They typically provide pre-static calculations, technical detailing, 3D modeling, design assist and optimization.

For a current glulam producer interested in entering the market, the options are to extend current production or invest in a new CLT production line. Experts are fairly clear that a green-field investment is the better choice. A clean start allows use of state-of-the-art technology, which is much more competitive than a patchwork of old and new. A large manufacturer said: "*If the decision is made to invest, why not invest into a proper production right away*?" Machine producers offer pre-planned CLT production lines, however, launching and running a production line successfully also requires skill. There is a lot of fine tuning to be done and additional planning services must be established. A potential slow progression for a glulam producer that mostly does commodity production could be starting to provide additional services, like planning and engineering, first. This intermediary step can help to get to know the regional construction industry in detail. Once this is second nature, the stretch to manufacturing CLT is no longer overwhelming. Despite the challenges, there have been numerous announcements of new facilities and high interest within the general wood products industry (Oregon BEST, 2017).

5. Summary and Conclusions

The North American CLT industry has already made considerable progress, but the market is in its early development. Manufacturers have room for improvement in their operations. For example, planning and customization services must be improved, as well as the overall levels of production efficiency. The newly created product standard in North America, something that does not exist in Europe, is likely beneficial for development of the market. Also, the International Building Code prescriptively allows CLT; however, the current codes are quite conservative, making it hard for CLT to be used efficiently and cost-competitively. The competitiveness of CLT against other building materials in general is of significant interest (MacDonald, 2017) in the marketplace and deserves the focus of future research. How much does it cost, in comparison to light-frame, concrete and steel construction? Current planning processes are old-fashioned and mostly based on *cost-per-square-foot* values. More interactive processes are needed. Another barrier, especially on the west coast, is the belief that using wood harms the forest and is only sustainable when certified. Even within the construction industry, this prejudice is an issue.

In terms of how wood construction professionals are trained and educated, a lot can be learned from the Original Market. However, reproducing the extensive coverage that exists there is likely not feasible in North America. Perhaps the best place to invest in the North American education system is at the university level, with a special focus on architects and engineers, via close industry cooperation. This is an area that the American Wood Council and the WoodWorks™ program are currently active.

Global research must further focus on two other aspects. Production, design, and use of CLT must be more efficient, using less material for the same functionality and performance. Also, its highly important to develop new solutions for all water-carrying building systems in wood buildings, so that "*the only big weakness*" of mass timber construction can be eliminated. Related to that is the controversial nature of the ongoing tall wood hype. High-rises in wood fascinate people, but they do not keep production lines running across a market. They are still too inefficient, and demand is too little. The '*mid-rise gap*' carries much more potential for CLT in Canada and the US. To increase the competitiveness of CLT, construction planning processes must be adapted and made much more interactive, incorporating all parties that are involved in a project early in the design phase. In the Original Market, the level of cooperation is traditionally much higher, and projects are more individual.

Automation may play an important role in the development of the North American CLT market. Standardizing and modularizing CLT construction can translate to

very efficient production and facilitate direct interaction between manufacturers and customers/owners/developers. This approach can allow mass production of CLT and take the product to the next level of cost-competitiveness. When establishing new CLT production this must be taken in to account and a decision must be made to either produce regionally and small, or large and with a high degree of automation. Opposed to Europe, the North American construction industry is traditionally focused on standardization, repetitiveness, and large scale, which suggests that CLT production and planning are more likely to follow that path in North America as the market develops.

A solid foundation for CLT is being established in North America. Within the next few years, strong growth is expected in the industry, especially once larger manufacturers begin producing. In Europe, there is a strong regional concentration with Austria alone manufacturing about 500,000 m^3 annually, or around 65% of global CLT production (Schickhofer et al., 2017). A similar trend is described for North America by Schmon et al., (2017). They claim the demand and supply of CLT will initially grow in the "*greenest*" US states. Lastly, new business models are likely to emerge and CLT might help to modernize the processes of how architecture is designed and built in North America.

6. Limitations

Our results and conclusions are derived from personal interviews and are based on verified knowledge from the CLT industry in North America and the Original Market. We chose a qualitative approach for this research, so that a great variety of topics could be covered, which is needed to provide a broad overview. While we are confident that our results provide a good snapshot of the industry, the reader should keep in mind the fast-paced change happening in this market and that we were only able to interview a relatively small number of experts and manufacturers in the overall industry.

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Appendix

Interview Guide

1. Giving informant an overview about research

2. Informing informant that interview is confidential and depersonalized

3. Asking informant for permission to audio record

4. Interview Questions

4.1 Questions for Experts in Original Market/North America

ICEBREAKER: How did your organization become an expert in CLT?

Q1: In your organization's opinion, what are the main drivers and opportunities for CLT manufacturers in the Greater German-speaking Alpine Region/North America?

Q2: In your organization's opinion, what are the main challenges and threats for CLT manufacturers in the Greater German-speaking Alpine Region/North America?

Q3: In your organization's opinion, what developments and dynamics are to be expected within the North American CLT market in the next years?

Q4: In your organization's opinion, what lessons can be learned from the original European market to help the North American CLT market to develop fast and efficient?

SNOWBALL SAMPLING:

- What other CLT experts could be helpful to this research?

- What important CLT companies could be helpful to this research?

4.2 Probing Categories for Expert Interviews

Political/Legal: building codes, environmental, regulations, standards, governmental subsidies

Economic: GDP, raw material costs, housing starts, square meter prices

Social: awareness/perception, environmental awareness, relationship to house, CLT education

Technological: IT adaption, construction methods, inventions, R&D, Health, Sustainability

Demand: advertising, growth, population, annual newbuilds, user trends

Supply: products types, additional services, raw material, value chain

Competition: big players, Importers/Exporters, Channel Power

Distribution: Sales, communication, marketing & advertising, transportation, value chain

Customers: Industrial customers, end-users, general contractors, value chain

Existing CLT Structures: residential, public, multi-family, multi-story

4.3 Questions for Manufacturers in Original Market/North America

ICEBREAKER: How did your company get into producing CLT?

Q1: What are the strengths and the USP (unique selling proposition) of your company and how did these aspects develop over time?

Q2: What are the most significant weaknesses and challenges your company had to overcome?

Q3: In your company's opinion, what developments and dynamics are to be expected within the North American CLT market in the next years?

Q4: In your company's opinion, what lessons can be learned from the original European market to help the North American CLT market to develop fast and efficient?

SNOWBALL SAMPLING:

- What CLT experts could be helpful to this research?

- What other important CLT companies could be helpful to this research?

4.4 Probing Categories for Manufacturer Interviews

Customer Segments: mass-customized, private-industrial customers, import-export

Value Proposition: customer needs, planning, design, prefabrication, R&D, brands

Channels: marketing, sale platforms, awareness, communication, transport

Customer Relationships: personal assistance, co-creation, customer/end-user

Revenue Streams: incoming-outgoing, CLT, additional services, licensing, advertising

Key Resources: physical (Raw material, production line, assembly equipment, trucks) intellectual/human (formulas, parameters, assembly team), financial

Key Activities: purchasing, production, customization, prefabrication, transport, quality control, R&D, site assembly, planning, static calculation

Key Partnerships: suppliers, third party certification, private customers, general contractors, architects, carpenters, structural engineers

Cost Structure: cost-driven, value-driven, fixed costs, variable costs

Strategies: additional services, vertical/horizontal