Lumber Supply-Chain Practice in Cross-Laminated Timber Industries in the United States: A Comparison with Austrian Producers

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Abstract

Lumber is the main raw material for cross-laminated timber (CLT) production, accounting for up to 80 percent of the cost. The availability, quality, and price of lumber are critical factors that influence the completion of CLT projects in the United States. Although structural-rated CLTs are made from structural-grade lumber available in the commodities market, CLT mills have additional requirements to process the lumber more efficiently. These requirements increase production costs, affecting the supply chain, delaying production schedules, and increasing project completion times. This study aims to identify the differences in the lumber supply-chain practices for CLT manufacturing in the United States and Austria. The authors used the case-study survey with convenience sampling method to describe how CLT mills work with suppliers, their delivery preferences, quality-control practices, and current critical issues in each country. The study shows significant differences in lumber procurement and quality monitoring between CLT mills in the United States and Austria. Although the quality of lumber supplied to Austrian CLT mills does not require additional preparation, the quality of lumber in the United States significantly affects production efficiency and cost. To address the lumber supply-chain problems in the United States for CLT production, the authors recommend sorting lumber from the current market to meet minimum requirements and introducing a new lumber grade specifically for CLT mills. Furthermore, adopting the Austrian practice of mass-producing blank CLTs can provide a continuous supply of lumber from sawmills or distributors and increase collaboration opportunities with suppliers and producers.

Cross-laminated timbers (CLTs) are wood panels made of lamellae of lumber or composites stacked at 90-degree angles. In the United States, an odd number of layers, three to seven per panel, are common in fabricating approved CLT panels (APA-PRG 320 2018), whereas European companies often manufacture up to nine layers (Grasser 2015). Glue, nails, or wooden dowels fasten the lamellae to form the composite product. CLT was invented early in the 1990s in central Europe and is now considered an alternative construction material to steel and concrete for mid- and high-rise buildings across the globe. CLTs are typically classified as structural or nonstructural based on the standard followed for manufacture or use. Structural CLTs are used in construction and manufactured under the criteria specified by APA-PRG 320 standards in North America. Nonstructural CLTs are manufactured in the United States from many different lumber species that satisfy the user requirements and are commonly used as access mats.

In the United States, CLT industries are not major consumers of lumber, and no sawmills produce lumber that matches all of

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Forest Prod. J. 73(4):370–377.
doi:10.13073/FPJ-D-23-00018

the CLT mills' raw material quality requirements. Currently, CLTs are manufactured primarily using softwood lumber graded as structural. For structural CLT panels, each lumber must meet the APA-PRG 320 requirements. The standard requires that lumber meets a specific moisture content (MC), is surfaced to the required thickness, and is accurate in dimension and grade. These technical requirements are critical and influence the productivity and cost of the manufacturing process (Adhikari et al. 2021). Currently, a larger volume of nonstructural CLTs is produced in the United States (Adhikari et al. 2020).

CLT mills in the United States consume lumber available in the market for structural purposes and are graded to meet the American Softwood Lumber Committee (ALSC) standards. Although the ALSC standard meets the current structural uses of lumber, CLT is a new product with additional quality requirements on lumber to avoid interruptions in production. These additional requirements include inconsistencies in the lumber dimensions, which complicates the layup procedure. Lumber used in the perpendicular direction is cut to press width. CLT mills equipped with side presses need lumber to have accurate dimensions when received; otherwise, the lumber needs to be trimmed to the exact width of the CLT press before use, adding more time, labor and cost to the production process. In addition, the lumber used in the parallel layer has an allowable length variation that is not greater than one-eighth inch. When the length of the lumber is greater than one-eight inches, many finger-jointing systems have operational difficulty, halting overall production. Further, variation in thickness and width causes gaps and problems in symmetrical layups across the surface that may compromise the structural integrity of the panel. Thus, the minimum requirements for lumber used in CLT layup are more accurate dimensions at 9 to 15 percent MC and produced to avoid end defects.

CLT construction in the United States was first recognized and accepted by the International Building Code in 2015. Continuous updates have been made to increase the use of CLT for high-rise construction with added safety (Stegner and Fotheringham, 2022); since this acceptance and recognition, the market has grown steadily. It is expected to continue growing in the coming years. More than 10 companies are producing CLTs, and more will be in production soon. As the CLT industry grows, issues related to the raw material supply chain are identified as major hindrances (Adhikari 2020). CLT industries are not treated as major consumers of lumber as they consume less than 1 percent of lumber by volume compared with annual production. However, the situation is changing as CLT production and consumption continuously increase. It is projected that CLT production will be increased in North America at a compounded annual growth rate of 16.2 percent from 2017 to reach a market value of $1.833 billion by 2024 (Energies Market Research 2018). The demand for lumber in CLT industries is estimated to reach 3.9 billion nominal board feet by 2025, accounting for 17 percent of the total lumber production in the United States in 2017 (Anderson 2018; The Beck Group 2018; Adhikari et al. 2020).

As the US CLT market grows, CLT manufacturers will continue experiencing significant issues with the lumber supply chain. Identifying the problems and solutions to support the CLT industry's growth is necessary. Thus, to compare the current practices, it is necessary to reference well-established industries. CLT was developed in Austria, and the industries there pioneer efficient and effective practices, so Austrian companies were the best choice to compare the current practices in the United States. Therefore, this study investigated how lumber supply-chain issues in the United States affected the CLT mass timber industry and compared these issues with those experienced by CLT producers in Austria, where the manufacture and market for CLT are more mature.

Methods

A case-study survey methodology was used to collect information regarding raw material supply-chain differences between the CLT industries in the United States and Austria. CLT is a new industry with less information and higher variation in production practice, so to understand the current situation, exploratory research is an appropriate strategy (Galloway 2005). A case-study survey method was chosen as it is considered a robust method for identifying patterns across studies (Lucas 1974; Widdowson 2011) and developing an initial understanding of the research issues when a broad range of conditions is of interest (Jauch et al. 1980; Larsson 1989, 1993). Case-study surveys are self-reported information indicating what responders think they should report at that time (Mills et al. 2010), so it is the perfect method to capture the perspective and practice of the CLT industries on the lumber supply chain. A convenience sampling method (CSM) was used for data collection in which industries that fit the study's criteria were identified, informed, and requested for participation (Emerson 2015). Thus, the total sample for this case-study survey is the number of participants who agreed to participate, and responded. CSM can collect data easily from geographically spread-out populations for initial research at a low cost and can be designed to compare the responses (Qualtrics 2022); thus, CSM was chosen as a data collection method because this study was designed to measure the existing practice of new industries in two different countries and compare.

A list of CLT manufacturers from the United States and Austria was gathered based on the publicly available information from web pages of CLT manufacturing companies in production in 2021. We gathered information on 13 CLT mills from Austria and 11 from the United States. Fifteen CLT industries were identified for the study with phone and e-mail contact information and contacted to determine their interest in participating. Among the 15 companies contacted for the study, 10 were from the United States, and 5 were from Austria. A mass timber consulting firm working with CLT industries in the United States and Europe was also contacted to gain their perspective from working with companies in different regions. Austria was selected as a country for comparison since CLT was initially developed there, and most CLT produced in Europe is from there.

First, all manufacturers were contacted and asked for voluntary participation through e-mail or phone. All companies were given 4 weeks to respond after the first week of November 2021. Six of the 10 US companies agreed to participate; however, only four responded during the assigned data collection period. One mill chose to participate by phone, and three others responded by e-mail. Of the five companies contacted in Austria, only two participated and did so by e-mail. One mass timber consulting firm responded by e-mail based on their experiences with US and Austrian

Table 1.—Cross-laminated timber (CLT) mills' response to their relationship with lumber suppliers.

Industries[a]	Company response
A	We are partnering with sawmills to integrate the upstream process vertically
B	We establish a long-term relationship and continue with the same suppliers
C	We choose the suppliers based on the quality and quantity of lumber needed for the project
D	Supplier selection for us is aligned with the type of lumber or quality of lumber
E	We have need-based relations with suppliers
F	We have contractual relationships with suppliers; we return the product that does not meet our need
G	Most suppliers deal with CLT industries as secondary customers because they are not the major consumer of their products

[a] A and B are Austrian companies; C through F are US companies. G is a US-based consulting firm.

mills. As data were collected using the CSM method, of 16 participants contacted, 7 responded, so the sample size for this case-study survey is 7.

Ten different open-ended questions were developed to capture the experience and practice of the CLT industries with their lumber supply; questionnaires were sent before the meeting for those who wished to participate by phone. It was believed that sending questionnaires before the meeting would help prepare the participants and capture more accurate information. Participants were asked about their experience, practice, or opinions on selection and relationship with the suppliers, delivery requirements, lumber cost, payments, transportation preferences, quality of lumber, used metrics to monitor the quality of the lumber, and the impact of these factors on the lumber supply chain. The next section summarizes the collected responses. The responses are presented with coded names to protect the identity of the participating mills.

Results and Discussion

This study was designed as exploratory research, and a nonprobability sampling method—selecting a sample from a population without using random sampling where the probability of selecting any specific member cannot be measured—was used to collect the response. The major limitation of the nonprobability sampling method is the sampling bias, so the results should be understood as specific to participating companies and may fail to represent the total population. Thus, we caution all readers to understand the limitation of a convenient sampling method to interpret the results and generalize our findings.

In this study, companies A and B represent the two responders from Austria, whereas companies C to F are the four manufacturers from the United States. Company G is a US-based mass timber consulting firm with US and Austrian companies. Responses from each company were summarized into single sentences. In most cases, concluding statements from participants were used to summarize the responses. The observed results from this study are summarized in the section below.

Selection, relationships, and experiences with current suppliers

All mills in the United States and Austria focused on the consumption of local resources, thus prioritizing local suppliers and developing long-term relationships with them. Mills used no specific methods in either country to select suppliers. However, all CLT mills prioritize resource and time optimization, so they choose their major suppliers based on hauling distance, the value provided, and the quality of lumber. In the United States, one mill receives lumber from within a 200-mile radius, but all others receive lumber from a $<$100-mile radius. In Austria, both mills receive the lumber within 50 miles of the mill location. We found no significant differences in the selection of lumber distributors in both countries.

Strong relationships with suppliers are crucial for industries to ensure a consistent supply of high-quality raw materials on time (Mwikali and Kavale 2012), which is also true for CLT industries. For this study, we define a relationship between a CLT mill and a sawmill or lumber distributor as the ease of working on necessary changes in product quality, quantity, and delivery based on current practice. Respondents were asked to comment on current relationships and experiences with their suppliers; all mills have different practices to maintain this relationship. The summarized response of CLT mills is presented in Table 1.

Both companies from Austria have dedicated lumber suppliers. One mill has formed a partnership with sawmills and has a vertically integrated production line, resulting in an efficient supply chain as both the sawmills and the CLT mill work together to meet the required quality and quantity of lumber delivered on schedule. The second Austrian mill has a long-term contract with lumber suppliers and distributors and has been sharing information and continuously improving to meet each other's needs. Most importantly, CLTs are not only produced as customized products but promoted as commodity products (commonly known as blank CLTs) in Austria, so mass production is possible, which is significantly different from the United States. The opportunity for mass production needs continuous lumber supply and guarantees the market for CLT-grade lumber, which invites collaboration with lumber producers and distributors.

In the United States, many CLT mills have short-term project-based relationships with sawmills and distributors to fulfill their yearly lumber needs. These relationships are only established to meet specific project requirements. Most of them place lumber orders based on the project on hand and market value. CLT mills indicated that the current lumber production and distribution system used in the United States and the low consumption capacity of mills relative to other markets make it harder to develop long-term relationships with suppliers. The production of structural- and nonstructural-rated CLTs leads to changing requirements for specific lumber types. Only structural-rated CLT production requires lumber to meet minimum quality as stated in PRG 320 standard in the United States; nonstructural-rated CLTs can be manufactured from any species with lumber that matches the end-user requirements and can be produced on the current mills' setup. All responding CLT mills in the United States understood that to receive excellent quality material, long-term relationships between lumber suppliers

Table 2.—Cross-laminated timber 'mills' response to weather protection requirements on lumber deliveries.

Industries[a]	Company response
A	Important as we brought higher-quality lumber
B	Necessary for us as we get higher-quality lumber directly for our mill
C	Packing is minimum
D	It must be for us
E	It must be for us
F	It depends on the time of year, but lumber cannot be exposed to a wet environment
G	It mostly depends on suppliers

[a] A and B are Austrian companies; C through F are US companies. G is a US-based consulting firm.

and CLT mills are necessary, which is the key to improving the lumber supply chain. These findings indicate that CLT millshave a limited marketability to influence lumber production and quality. CLT mills in the United States also mentioned that it is not practical to share the information with all sawmills and distributors they work with or to ask for improvements to match their requirements because CLT industries are not their primary consumers.

Delivery requirements

Lumber supplied to CLT mills must have 12 ± 3 percent MC (EN 16351 2015; APA-PRG 320 2018). Lumber can be exposed to harsh weather in storage or transportation, causing the MC to fall outside specifications, thus leading to a shortage of inventory and delays in scheduled production. All CLT mills responded that they needed weather-protected deliveries to ensure that the quality of the lumber they received was acceptable. The summarized responses from each company are presented in Table 2.

This study finds that CLT mills required some types of weather-protected packaging in the United States and Austria. In the United States, weather-protected packaging is more important to a mill that receives quality lumber specified on PRG 320 and practices smaller inventory because the CLT mills responded that if they receive nonconformity lumber, it may delay or stop the production line.

Payment terms

The authors hypothesized that payment terms might affect the performance of the lumber supply chain and that suppliers may hold lumber or delay deliveries because of payment issues. N-30 is a common business practice (and the authors also assumed it to be the common practice for CLT industries) that refers to standard payment terms in which payment is due within 30 days of the invoice date. However, CLT mills reported having some practices in place to deal with their suppliers and prevent negative impacts on the supply-chain system. The responses from the CLT mills in both countries indicated no problems with the suppliers' payment terms. The summarized responses of CLT mills are presented in Table 3.

Lumber prices

Lumber price is another factor influencing the CLT industry's raw material supply, as CLT mills' responses indicate. All mills responded that the lumber price affects their raw material supply. Mills with larger inventories acknowledged that short-term lumber price increases have a minimal impact, but when the lumber prices are stable at a higher price for longer periods, the impact is similar to that of other mills. One mill from Austria reported that when lumber prices went up, they struggled to find the right grade and quality, affecting the production schedule. When the prices started to increase in the United States, some mills received a higher percentage of nonconformity lumber, which affected the production schedule and the company's strategy to acquire raw materials. Thus, all mills not vertically integrated with sawmills had trouble finding the right grade and quality of lumber when the price increased. These findings suggest that lumber price is important in maintaining a healthy supply-chain line for CLT mills regardless of country. The summarized responses are included in Table 4.

Delivery frequency

In general, companies with smaller inventory capacities may prefer to receive inventory more frequently in smaller quantities to reduce their holding and storage costs, whereas companies with larger inventory capacities may opt for less frequent deliveries of larger volumes to minimize transportation and administrative costs. This principle is known as "economies of scale" in supply-chain management. It often optimizes the balance between inventory carrying costs and supply-chain efficiency. It is also true for CLT mills. Thus, CLT mills with smaller inventories prefer to receive lumber at a shorter frequency, and those with larger inventory capacity prefer bulk volume and a longer lead time. The mills' summarized responses to delivery frequency are presented in Table 5.

Austrian mills that receive higher-quality lumber practiced minimum inventory, promoting regular deliveries with minimum lead time. US mills receiving mixed-grade lumber that includes lower-grade lumber and needs quality

Table 3.—Cross-laminated timber mills' response on the impact of the supply chain based on payment terms.

Industries[a]	Company response
A	It is not relevant to us
B	It does not affect us much as we pay them right after deliveries
C	We practice N-10 standard
D	We practice the N-30 standard with a 30–50% deposit to lock the price based on the project
E	It has never been an issue for us. We have developed good relationships with suppliers on payment terms
F	Not answered
G	Not answered

[a] A and B are Austrian companies; C through F are US companies. G is a US-based consulting firm.

Table 4.—Cross-laminated timber mills' response to the impact of lumber prices on the supply chain.

Industries[a]	Company response
A	Price is always a crucial factor but has minimal impact on our supply chain
B	It is like we must pay the prices, and if not, we do not get the needed goods
C	We have a big inventory of more than 1 million board feet, so we have a minimal impact for the short term, but eventually, it is a critical problem
D	The cost of lumber is about 60%, so it has adversely affected us; second, the price hike is also related to the shortage of lumber
E	It is critical and significant to our supply chain
F	We used to have significant inventory, but now we are running weekly. We are using each lumber delivered by the current week for next week's use
G	During the price increase, we saw a lumber shortage as well

[a] A and B are Austrian companies; C through F are US companies. G is a US-based consulting firm.

checks on all the boards prefer to receive deliveries with longer lead times and order bulk volume.

Delivery times

Mills that practice small inventory have short lead times and need delivery at a specified time compared with mills with long lead times. Both Austrian mills need the delivery on a specified timeline to avoid interrupting their production. CLT mills in the United States utilize longer lead times to adapt for potential delivery delays; even the mills that practice minimal inventory are scheduled to get material delivery 1 week before the production schedule. Mills that practice larger inventory have minimal impact on delivery time and vice versa. Thus, the mills in Austria have numerous deliveries within a week, but in the United States, mills receive sporadic deliveries; some receive once-a-week or twice-a-week deliveries and even some even practice biweekly deliveries. The summarized mills' responses are presented in Table 6.

Transportation mode

CLT mills were asked about transportation methods and their impact on the supply chain. Participating mills from both countries preferred consuming local resources, so trucking was the first choice for mills. One CLT mill in Austria, vertically integrated with sawmills, prefers to transport lumber by truck and has reported no opportunity to use rail. Another mill uses both modes of transportation. All CLT mills from the United States had opportunities to use trucks and rail, but none has used rail for lumber transportation, and some are willing to use rail soon. The summarized responses of mills to transportation modes are presented in Table 7.

Lumber quality

Lumber quality for a CLT mill is defined based on dimensional accuracy, required grade, MC, and the presence of end defects. US mills have mixed responses on the quality of lumber received. In Austria, both mills received lumber specifically produced for CLT industries to meet the mills' requirements.

Austrian mills responded that they receive accurate-dimension lumber of the right grade mix based on project needs. None of the Austrian mills reported issues with end defects with their lumber suppliers. In Austria, one mill that is not vertically integrated also had issues with the MC of incoming lumber, but they routed it to other products, minimizing its impact on CLT production unless the whole batch of the lumber has a higher MC.

The dimensional accuracy of the lumber delivered to the mills' inventory is within acceptable limits for all CLT mills in the United States. However, some of them defined their acceptable limits as 5 percent nonconformity, and some defined it as 10 percent nonconformity per truckload. Hence, no standard practice was identified for mills. In the United States, mills received lumber mixed with below-minimum requirements and good quality. When the price and demand are high, some mills receive a higher percentage of below-minimum-requirements lumber. One mill reported that up to 15 percent of lower-grade lumber in each bundle is a good delivery with their suppliers. Increased volume of lower-grade lumber will add to the CLT panel's raw material and production costs, making it harder to compete with other producers. Mills' response to their experience in the supply chain with various technical aspects of lumber is summarized in Table 8.

Additionally, US mills reported a higher percentage of lumber with end defects in each delivery. Each mill in the

Table 5.—Cross-laminated timber mills' response to the lumber delivery frequency and its impact on the supply chain.

Industries[a]	Company response
A	We prefer constant material flow, so we mostly receive lumber each day
B	Our frequency of lumber deliveries is weekly
C	As required, we prefer to stock significant inventory based on inventory level
D	It all depends on the size of the mass timber order. Currently, we practice minimum inventory
E	We need deliveries weekly, or we must suspend production
F	Mostly two times a week
G	We buy lumber for the project, so it is based on demand at the time

[a] A and B are Austrian companies; C through F are US companies. G is a US-based consulting firm.

Table 6.—Cross-laminated timber mills' response on the impact of delivery times on the supply chain.

Industries[a]	Company response
A	We must need delivery in time as we have limited inventory capacity
B	We practice 3–4 wk of lead time to deliver lumber, which reduces the impact due to lumber shortage in our inventory
C	We are open to delivery time as we have enough inventory to continue production
D	From time to time, delays in the delivery time of lumber hurt us and delayed the project
E	When delivery time differs, it affects our production schedule, negatively affecting efficacy
F	When lumber is not delivered to us on time, we must switch our production schedule
G	It is particularly important, but mills must increase the lead time to get material in the required time

[a] A and B are Austrian companies; C through F are US companies. G is a US-based consulting firm.

United States received lumber 8, 10, 12, 14, and 16 feet in length for CLT production and used mostly 8-foot lengths of lumber in the crosswise direction. Eight-foot lumber with end defects had minimal or no impact as it can be used in the transverse direction. For example, if the lumber was 10 feet or longer and had an end defect, the lumber needed to be trimmed to a lower standard length because of the requirement of defect-free ends for each piece of lumber for finger jointing. Trimming a single piece of lumber requires a minimum of 2 feet to be trimmed, so a higher percentage of end defects on lumber leads to a larger volume of wood waste and increases material cost. MC was an issue for all mills in the United States because structural-grade lumber production is standardized with a maximum allowable MC of 19 percent, 4 percent more than the upper limits defined by the APA-PRG-320 standard. Mills with larger lumber inventory currently practice air drying while it remains in the inventory. They are used in production after the lumber reaches the required MC. After receiving the lumber with higher MC, mills must dry them to optimize the production and CLT performance on the structure. All responding mills from the United States and Austria are satisfied with the lumber species available to them. Two mills from the United States are trying to add more species to add variation to the product.

Monitoring the lumber quality

All responding mills must receive the right quality of lumber and maintain its quality throughout the production process. However, each mill practices a different method to measure and monitor the lumber quality. Failing to comply with the minimum lumber quality leads to product rejection, causing a delay in the project completion and loss of resources. Thus, the quality-control department has the significant role of keeping up with the production schedule and maintaining the external and internal lumber supply chain.

Table 7.—Cross-laminated timber mills' response on primary modes of transportation for lumber.

Industries[a]	Company response
A	Trucks
B	Eighty percent by truck and 20% by rail
C	Rail and trucks
D	Now truck only but has a rail depot we plan to use in future
E	Only truck now but can use rail in future
F	Only truck
G	Not responded

[a] A and B are Austrian companies; C through F are US companies. G is a US-based consulting firm.

Each mill was asked about its specific actions to monitor the quality of the lumber. All responding mills performed quality checks of the purchased lumber, but some chose random samples, and others checked each board. Both mills from Austria practiced random quality checks because they received quality lumber as the project required. In the United States, mills received a mixture of quality and below-minimum-quality lumber and practiced quality checks on each lumber for minimum qualifications except one mill. One mill in the United States also did random sampling for lumber quality confirmation. However, when they found nonconformity in a delivered batch of lumber, they then extensively checked each lumber for minimum requirements. The responses from participating mills to monitor the quality of the lumber are summarized in Table 9.

Summary and recommendation

This study describes the significant differences in the lumber supply chain between the United States and Austria. Austrian CLT manufacturers have been in business for over 20 years and have well-established relationships with lumber suppliers. Lumber suppliers to Austrian mills know the quality of lumber needed for the industry. They sort lumber only for CLT use and deliver it regularly, which helps reduce the impact on the supply-chain system. CLT mills in the United States are newer and consume lumber manufactured from the structural lumber market with different specifications and requirements than those needed by CLT mills. This lumber needs additional sorting and preparation to meet the minimum requirements for CLT manufacturing. Additional sorting and preparation can be avoided if the suppliers deliver quality lumber to match the mill's needs to maintain an efficient supply chain. The major findings of this study are summarized in the following points.

1. CLT mills in both the United States and Austria prioritize local suppliers and focus on optimizing resources and time in selecting suppliers. They choose suppliers based on hauling distance, value, and quality of lumber supplied. All mills have different practices for maintaining these relationships with suppliers.
2. CLT products are promoted as customized and commodity products in Austria as project-based specific panels and blank CLTs, allowing for mass production, which differs from the United States, as all structural-rated CLTs are produced as customized products only.
3. Most CLT mills in the United States have short-term, project-based relationships with sawmills and distributors to meet their annual lumber demand. The current US

Table 8.—Cross-laminated timber mills' response to their experience in the supply chain with various technical aspects of lumber.

Industries[a]	Company response			
	Dimensional accuracy	Lumber grade	Moisture content (MC)	Species
A	We have no problems	A well-established system, so there are no issues	No issues: we always get the required moisture in lumber	Spruce only
B	Always get accurate-dimension lumber	We get the right quality product based on our project's need	The second main factor for us and we route nonconformity to other product	Spruce/fir and pine
C	It varies with suppliers but is within limits	We get a good mixture of lumber grade	Sometimes, we receive high-MC lumber and manually dry it in our inventory	Mostly southern yellow pine (SYP)
D	It varies with suppliers but is within limits	Suppliers tend to put a little lower grade in a hot market	Most suppliers push the lumber with a higher MC, which is an issue for pressing	Douglas fir/larch and spruce–pine–fir lumber
E	In acceptable limits	In acceptable limits	We receive it within acceptable limits, but sometimes it must be manually dried, leaving it in the inventory	Mostly SYP
F	Fairly steady, within ⅛" on a variation of the length	Up to 5% below-grade lumber in the bundles	Lumber from sawmills is typically stamped KD19, so we need additional drying unless we ask the specific MC on the lumber	Only SYP
G	Acceptable	Some issues are there to match the mass timber industry needs properly	There is a need for secondary drying for most of the lumber	Most softwood species

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lumber production and distribution system and the low consumption capacity of mills make it difficult to develop long-term relationships.

4. Lumber prices affect the CLT industry's raw material supply chain in the United States and Austria. When lumber prices increase for a prolonged period, it affects the mills' ability to find the right grade and quality, affecting production schedules. The response of mills suggests that lumber prices are crucial in maintaining a stable supply chain for CLT mills because as the lumber price goes up, lumber shortage becomes an issue for most mills.
5. Austrian mills receive the required quality of lumber; thus, they maintain minimum inventory and prefer regular deliveries with minimum lead time. In the United States, mills receive mixed-grade lumber; most need quality checks on all boards, so most mills prefer deliveries with longer lead times and order bulk volume.
6. Dimensional accuracy, grade, MC, and end defects determine the quality of lumber for CLT mills. Austrian mills receive lumber specifically produced for CLT industries, with accurate dimensions, the right grade mix, and no reported issues with end defects. US mills have mixed responses on lumber quality; most receive a mix of lower and minimum required quality lumber with a higher percentage of end defects. MC is also an issue for all US mills; most use air drying in the inventory to optimize production.

From this study, we can conclude that Austria's best practices could be adopted to improve the US-based CLT mills supply chain. CLT mills and lumber suppliers from the United States must work together to minimize the impact of the lumber supply chain on CLT production. Recommendations would include collaborating or establishing a long-term contract to share product information. Mills could share the specific requirements of the lumber for their project, and suppliers could only supply the lumber that matches it. Collaboration with sawmills would have a significant impact on improving the quality of the lumber and increasing productivity. Suppose sawmills knew the product specifications for the CLT industries; in that case, they ced saw, trim, and dry the lumber to match the required specifications and schedule it to be delivered on time to avoid additional work on the lumber. Such practices reduce the lumber supply chain's impact on production, helping improve resource management and saving lumber supply costs.

To improve the lumber supply chain in the United States, sawmills or suppliers could sort the lumber to match the

Table 9.—Cross-laminated timber mills' response to their practice and experiences in monitoring the quality of the lumber.

Industries[a]	Company response
A	We randomly check the dimensions and moisture for each delivery
B	We asked the supplier to send the specific quality of the lumber based on project needs and check for the same specification randomly
C	We conduct an incoming inspection of lumber and reject all nonconformity
D	We have a random sampling procedure for all lumber we receive to confirm the minimum requirements
E	We always monitor the quality of each lumber throughout the process
F	We always sort lumber after we receive it based on the dimension and moisture content
G	All the mills perform a quality inspection at the receiving dock

[a] A and B are Austrian companies; C through F are US companies. G is a US-based consulting firm.

minimum requirements of the CLT mills and deliver the lumber to mills within a specified period. Second, CLT industries could benefit from adopting the Austrian mass production of structural-rated CLTs by producing blank CLTs, which could be the best opportunity to develop a more efficient lumber supply-chain system as it provides continuous production of CLTs as well as consolidated collaboration opportunities with suppliers and producers. Vertical integration is not likely to occur based on current practice to produce and supply structural-grade lumber in the United States, so the authors suggest that a good alternative would be to introduce a new lumber grade specific to CLT mills' requirements and promote collaboration between sawmills, lumber suppliers, and CLT mills.

Acknowledgments

Softwood Export Council funded and supported this research, which was completed on January 31, 2022.

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