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Abstract

Cross laminated timber (CLT) has, in recent years, grown from an invention to a much celebrated product and building technology revolutionizing the use of massive timber in construction. The CLT industry is concentrated in Alpine Europe, where the technology was originally developed and where most CLT is still produced. Despite great interest, the rate of adoption of CLT technology in the US is slow, reflecting uncertainty with regard to whether the European models can be successfully transplanted to the business environment of the USA. The goal of this project was to assist development of the CLT industry by providing insights into the global sector's structure, output potential, production profile, internal diversity, competitiveness, innovativeness, and perceived barriers to further expansion. Survey data collected from 21 CLT manufacturers was supplemented with information obtained from other sources. The primary finding is that the CLT manufacturing industry is unique in the commodity-oriented forest sector in that most of its production is custom-made for specific projects. While much of the hype surrounding CLT is focused on tall buildings, most of the CLT is produced for small to medium-size multi-family housing, public, and industrial structures. There is a high level of collaboration along the CLT supply chain, including vertical integration. Nearly one-third of respondents are involved in building construction. This first of its kind comprehensive review of the global CLT industry provides insights for potential entrants into the CLT manufacturing sector including businesses along its extensive supply chain.

Keywords: Cross-Laminated Timber, innovativeness, manufacturing firms

1.0 Introduction

Cross-laminated timber (CLT) is a relatively new product and building system originally developed in central Europe during the early 1990s. It is a massive composite panel product comprised of cross-layered pieces of dimension lumber bound together in a way that the whole panel is acting as a single load bearing element for wall, roof, and floor assemblies. The importance of CLT is that this new engineered composite product is enabling entirely new building technology, revolution-

izing the use of timber in construction. The rise of CLT technology from concept to a viable industry has taken about 20 years of high growth, mostly concentrated in the Alpine region of Europe. For example, Austria, Germany, and Switzerland together held just under 80% of global production capacity in 2015, with 60% attributed to Austria alone (Plackner 2015a).

Although the adoption of the technology outside of the Alpine cluster has been relatively slow to date, CLT plants now operate in a number of other European countries, as well as in Canada, the US, New Zealand, and Japan. The first CLT line in New Zealand was built in 2010 and started commercial operation in 2012 (XLam 2017). In 2014, three new CLT lines were launched in Japan (Figure 1). As of 2015, the nation's manufacturing output was approximately 10,000 m³ of CLT annually, expected to grow to 50,000 m³ in 2016 and up to 500,000 m³ by 2024 (Plackner 2015d, Grasser 2015). In Australia, at least two companies announced plans to build CLT

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Figure 1. Global distribution of CLT manufacturing plants in 2015/2016 (graphics by GoogleMaps).

production lines which could dramatically increase the production capacity in that region.

In North America, the adoption of CLT technology was first championed by Canada, where the first two production lines were founded: Nordic in Chibogameau, Quebec and Structurlam in Penticton, British Columbia. In recent study the total production capacity of Canadian companies for 2015 was estimated at 110,000 m³ (Espinoza et al. 2016). Canada's FP Innovations committed itself to CLT-related research and an information campaign, which resulted in two *CLT Handbooks* published for Canada in 2010 and for the US in 2013, followed by an ANSI/APA PRG320 CLT product standard in 2011, which was subsequently updated in 2012. These developments eventually led to the adoption of CLT in the International Building Code 2015 (ICC 2015).

While non-structural CLT panels were produced in the US as early as 2010, the first structural grade CLT products were offered in 2015 by DR Johnson Lumber Co., located in Riddle, Oregon, and in 2016 by Smartlam, located in Whitefish, Montana (Espinoza et al. 2016).

Estimates made for the global annual production of CLT in 2013 were between 600,000 m³ and one million m³ by 2015. (Plackner 2013, Stauder 2013). Later, expected new growth of operations in France, the UK, Finland, Latvia, Japan, and the US (Espinoza et al. 2016) gave grounds for a projection of global production to reach three million m³ by 2025 (Plackner 2015a). These estimates should be considered in the perspective of the annual consumption of softwood sawnwood in North America, which was nearly 91 million m³ in 2015 (UNECE 2016).

Historically, the primary market for CLT has been residential construction, driven particularly by demand in Central Europe. By 2015, Germany, Austria, Switzerland, Italy and the UK were still identified as the biggest consumer markets for CLT, absorbing 70% of European CLT production output (Grasser 2015). As users and producers gained a better understanding of the material, more multi-family units, larger public buildings, and office spaces are being built with CLT. In recent years, the technology of tall wood buildings has been developed so that CLT is being used to build mid-rise buildings (more than 9 storeys) in London; Melbourne; Vancouver, British Columbia; and Trondheim, Norway (Lanz 2016, Espinoza et al. 2016).

Despite great interest on behalf of architects, investors, and increasing excitement in the forest sector, the rate of adoption of the new technology in the US is slow, reflecting uncertainty whether industry models developed in Europe can be successfully transplanted to the business environment of the USA.

Existing CLT operations, especially those in the Alpine cluster, provide a living laboratory for understanding how the CLT industry and its related supply chain may develop in the future in other regions of the globe. Understanding the global development of the industry can provide many lessons for companies that may be contemplating manufacturing and marketing this new product. This understanding can also help identify key success factors and impediments affecting the growth of a robust and competitive CLT industry and the related CLT market, as well as identify and/or define conditions for replication of past success.

With this in mind, the main objective of this paper is to capture a comprehensive snapshot of the nature of the global CLT industry covering the sector's structure, output potential, production profile, internal diversity, competitive advantages, approaches to innovativeness, and perceived barriers to further expansion. These insights are intended as assistance for potential entrants into the CLT manufacturing sector, including businesses along its extensive supply chain.

Information was collected primarily through a 2016 industry survey sent to companies believed to operate CLT manufacturing lines in 2015, and supported by secondary sources. The approach and the data sources are described in detail in the following sections.

2.0 Methods

The findings presented in this paper have been compiled from three principle sources: (1) the primary data source is an industry survey conducted in 2016 which aimed to canvas the global industry, and provide a snapshot of its mode of operation, capacity and innovativeness; (2) the secondary source, used to supplement and fill in blanks in the data collected through the survey, comprises three comprehensive reviews from Austrian trade journal *Holzkurier* on the Alpine CLT industry in 2011, 2013 and 2015 (Plackner 2011, 2013, 2015c), as well as other market reports related to CLT industry published in the journal (Plackner 2014a, 2014b, 2015b, 2015c and 2015d); (3) when possible, data obtained from the two primary sources were supplemented with information collected by the primary author via interviews and participant observation during visits to 22 CLT operations in Europe and North America over the past six years.

There are substantial differences in the modalities, geographical coverage, scope of information covered, as well as unique challenges and limitations related to each of these three data sources that must be discussed.

Data source #1: The questionnaire was developed in the beginning of 2016. It consisted of 20 questions covering topics of current ownership structure, output potential, production profile, internal diversity, competitive advantages, approaches to innovativeness, and perceived barriers to further expansion. The questionnaire was originally developed in English and subsequently translated into Japanese, French, and German by native speakers of respective languages familiar with the forest sector and its terminology. Each translation to a foreign language was then translated back to English by another native speaker familiar with the field. Divergences between original and back-translated version were then discussed and corrected.

Conscious of the small and diverse nature of the CLT industry, a substantial effort was invested in obtaining as high of a response rate as possible. The list of companies and contacts was derived from a database compiled gradually in 2010-2015 to guide the plant tours and was augmented by additional contacts provided by the surveyed companies. The interaction with the companies was conducted in 3 stages.

Stage 1: The first contacts were made via English or bilingual (English and either French, German, Italian or Japanese) invitation emails in early February 2016. In this invitation email, the companies were introduced to the premise of the study, were inquired about their interest to participate, and asked to provide direct contact information of the employee most qualified to answer the questionnaire.

Stage 2: The following procedure depended on the reaction to the invitation. In case of a positive response, questionnaires in English and, when needed, in French, German, Italian, or Japanese were sent to the indicated contact in the company via email, with instructions to print, fill in, scan and email the questionnaire within four weeks. When companies did not respond, another email was sent and followed up by a direct phone call. Companies indicating unwillingness to participate were excluded from further consideration.

Stage 3: Companies that did not return the questionnaires within four weeks were sent email reminders once or twice a month. In July 2016, a summary of preliminary results of the survey (based on 21 responses) published as a research brief (Muszyński et al. 2016) was attached to the communication to encourage participation. Towards the end of the data collection period, attempts were made to contact persons in the non-responding companies by telephone. These efforts, however, did not bring any additional responses.

Reception of completed questionnaires was immediately acknowledged in a confirmation email in which the company contacts were asked to list all other CLT companies known to them. This, as well as parallel online research, added several companies to our database.

Data collection began in early March and ended in late November with 21 responses out of the 47 companies (45% response rate) identified as producing CLT or closely related panel products. It is important to note that some respondents selected to skip certain questions. Consequently, item response varies from one question to another and is indicated in the results.

Data source #2: *Holzkurier* (HK) is an influential Austrian (German language) *trade journal* distributed weekly in paper form since 1952 by *Agraverlag*, a large publisher in the country, claiming 16,000 readers of its B2B content, primarily from Austria, Germany, Switzerland, and Italy (G. Ebner, personal communica-

tion, December 16, 2016). It is also offered online via *timber-online.net* in German, English, and Italian. A knowledgeable group of editorial staff is working in parallel on a handful of wood and timber related journals and magazines, *Holzkurier* being just one of them. *Holzkurier* has been tracing the progress of the CLT industry in the Alpine Region of Europe (*Alpenraum*) since 2008, providing news on line openings and closings, as well as CLT industry production capacity summaries and predictions. *Holzkurier* also informed its readers on the development of the CLT industry in other regions of Europe and overseas. To date, *Holzkurier* has published three reviews covering various numbers of CLT plants operating in Central Europe (Figure 2; Plackner 2011, 2013, 2015c).

The 2011 summary (Plackner 2011) covered 16 companies operating within the loosely defined Alpine Region, including companies in Austria, Switzerland, the Italian Southern Tyrol region, Germany, and the Czech Republic, but leaving out two other Italian companies operating at that time. The 2013 summary (Plackner 2013) covered 24 companies from roughly the same region, this time including all known Italian manufacturers, plus some Italian companies that were known to build with CLT but did not manufacture CLT. The 2015 summary (Plackner 2015c) covered 17 companies in the Alpine Region. Another summary published in the same year (Plackner 2015a) listed 37 CLT companies worldwide, but did not include the usual details regarding line parameters and capacities. The differences in the number of companies included in the three summaries with production data result mostly from new production line launches and a few closures, however, comparing the summaries, we were able to identify a few clear omissions. It is important to stress that this type of publication (e.g., trade journal) is not expected to meet the high standards of a refereed scientific publication regarding detailed characterization or assessment of the sources.

The production data included actual output volumes (in m³ of finished CLT) for the year of publication and one year preceding the publication attributed to each company (Plackner 2011, 2013, 2015c), the maximum per-shift production volume, adhesive system and wood species used in production (Plackner 2013, 2015c), maximum panel in-plane size (Plackner 2013, 2015c), and additional comments (Plackner 2011, 2013, 2015c). Volumes for companies operating two lines or

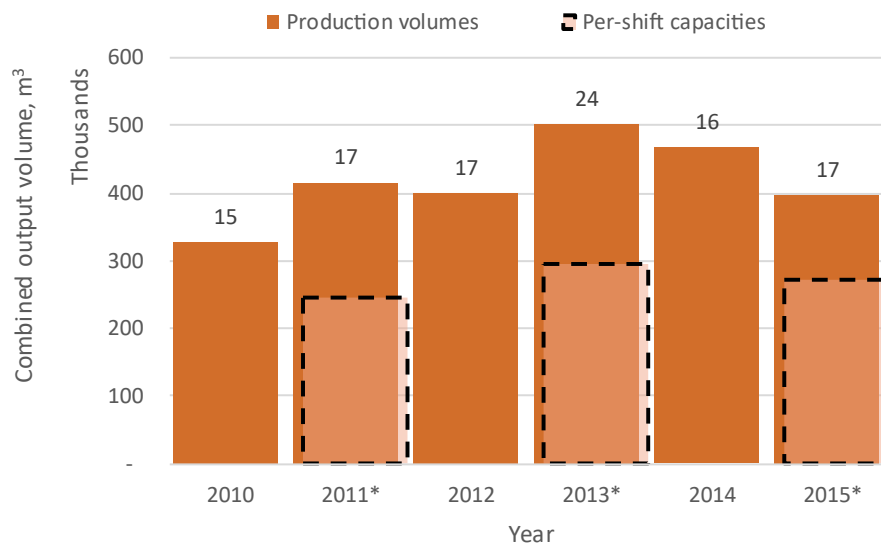


Figure 2. Summary of output volumes and per-shift capacities of CLT in the loosely defined Alpine Region reported by HK in three reviews published in 2011, 2013 and 2015 (* denotes the publication years). Captions on top of the bars mark the number of companies listed for each year (Plackner 2011, 2013, 2015c)

plants in two different locations were summed up and reported jointly.

Data source #3: Site visits including interviews and participant observation by the primary author constitute the final data source. Six site visits were undertaken by the primary author in 2011/2012, with the goal of gaining a basic understanding of the industry and were continued only when the diversity of the CLT industry in terms of mode of operation, scale, ownership and market strategies became clear. In addition to these initial tours, two more sites were visited in 2012, four in 2013, seven in 2014, and two in 2015. It was only with time that a relatively uniform template of questions were developed and an effort made to collect the data according to that template. It should also be stressed that due to the extended period of time in which these tours took place, the data in some cases is dated.

2.1 Source overlaps

There is substantial overlap among the three data sources. Only five of the companies have been covered by all three data sources; 16 by the survey and *Holzkurier* publications; 19 by *Holzkurier* and site visits; and seven by site visits and by the survey. Interpreting results is somewhat complicated when the overlap in the output volumes represented by the companies covered by each source is considered.

Relative volumes and volume overlaps in production output volume data attributed to plants covered by the data sources discussed above are presented in Figure 3. The areas of the rectangles in the top section of Figure 3 represent relative volumes in the same scale. The top left square representing 1 million m³ of the estimated global CLT output in 2015 (Plackner 2013) serves as a convenient scale reference. It should be noted that Plackner's 2013 projection of the one million m³ of global CLT output by 2015 proved to be quite accurate when compared with all data available to the authors to date and considering the number of existing plants for which no specific output volumes could be attributed.

The dark orange square in the top center represents the total output volume (397,500 m³) attributed to 17 CLT companies operating in Central Europe, as reported in *Holzkurier's* 2015 summary (Plackner 2015c). It is important to keep in mind, however, that the volumes published in *Holzkurier* summaries are affected by inconsistent definition of the geographical region being covered, resulting in arbitrary omissions (compare Figure 2).

The smaller yellow square in the top right part of the diagram represents the output volumes reported by responding companies (148,203 m³). It should be noted, however, that a number of companies did not provide any information on their output volumes, even though output volume data that could be specifically

attributed to these companies had already been available in the public domain (Plackner 2015c). When this published data is substituted, the total output volume represented by responding companies reaches 421,203 m³, about three times the volume specifically declared by responding companies. This volume is represented by the light orange external square in the top right portion of the diagram in Figure 3.

The overlap of the annual output volumes attributed to the CLT companies in 2015 covered by the sources discussed above is presented in the lower part of Figure 3. A square representing the output volumes attributed to all specific plants known to be in operation in 2015 obtained from all available sources was added. In this

estimate, the latest published volume is used whenever data for an existing plant is not available in the Holzkurier 2015 summary, and the output volume information obtained during a site visit is used when no published data is available. Using this approach, the total output volume that could be attributed to all companies comes to about 660,000 m³ in 2015. This scheme still leaves a number of companies for which no plant-specific data could be attributed.

2.2 Data treatment and presentation

While the default mode of presenting the survey data is by number of respondents selecting individual response options, the relevance of such a presentation must be

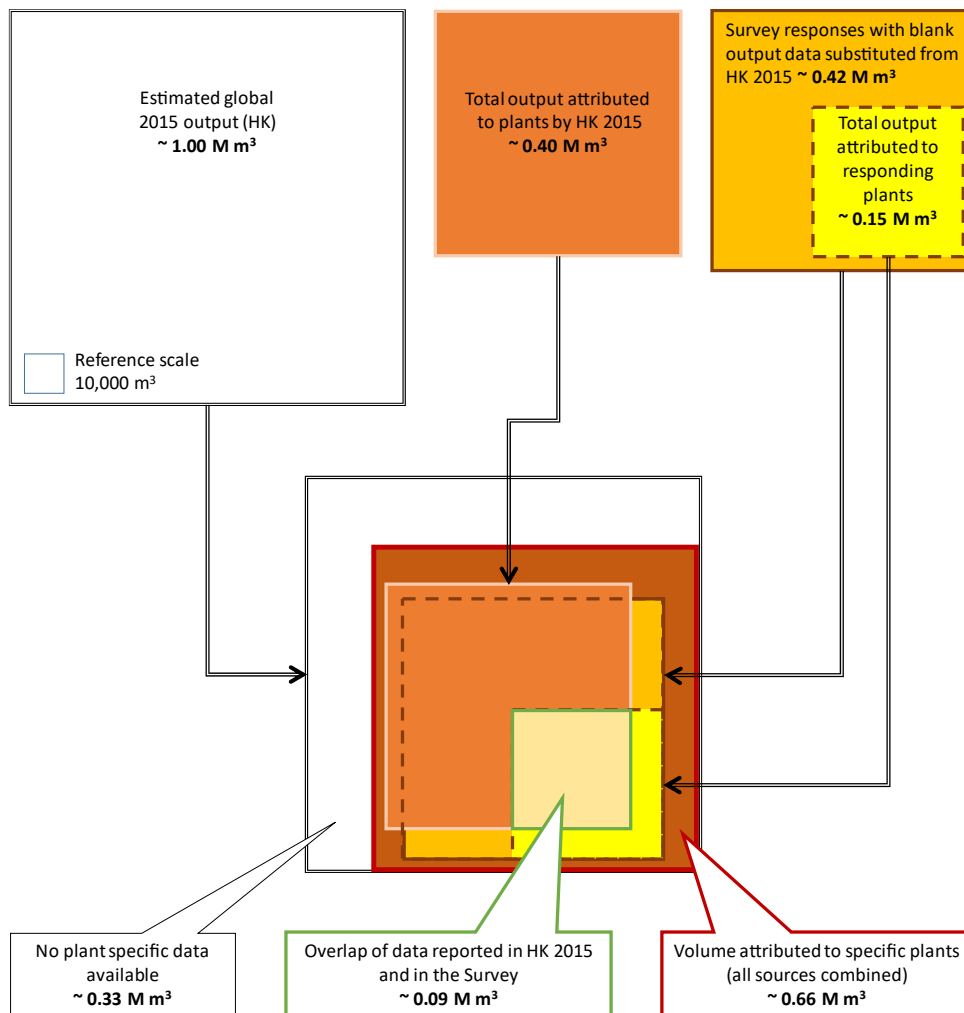


Figure 3. Relative volumes and volume overlaps in data attributed to plants covered by the data sources characterized above (the areas of the rectangles represent relative volumes in the same scale, compared to the square representing 1 million m³ of the estimated global CLT output in 2015).

critically assessed where the self-reported annual output volumes for 2015 range from 500 m³ to 45,000 m³, and up to 100,000 m³ when the blank responses are substituted with data available in the public domain. For some responses, it is important to qualify the responses by the scale of the operation of the respondent. This has been achieved by reporting aggregate production volumes represented by specific response options, or by weighing some responses by the output volumes attributed to the companies. Such data treatments can significantly affect the general profile of the response. An extreme example of such differences is presented in Figure 4, where simplified versions of the responses to one of the survey questions are presented a) by the number of respondents, b) by the production volume self-reported by the respondents, and c) by the production volumes attributed to the respondents from external sources (e.g., Plackner 2015c). Note that the bars in option (a) represent the number of respondents, but in options (b) and (c) they represent combined volumes, while the numbers of respondents for each response option are shown in labels on top of the bars. Note also that in option (b) the number of respondents shown at the top of the bars reflects the numbers of non-blank responses to the question at hand and to the self-reported output volume estimate. In option (c) an output volume is attributed to all respondents, and thus, the numbers on top of the bars coincide with the number of respondents shown in graph (a).

The comparison presented in Figure 4 is also important for understanding that weighting the data based

on the self-reported output volumes alone brings substantial risks of distorting the conclusions. Therefore, the responses scaled exclusively by the survey reported output volumes are not used for presentation and analysis below. Decisions on selection between presenting the data in the form of number of respondents and volumes represented by respondents (as in option c) have been made by the authors on a case-by-case basis, taking into account the nature of the presented data. The selections are noted in captions and in the description of each graph presented in the Results section. In one case, both modes of presentation are included and the differences are discussed.

Finally, in some cases, such as when the authors felt that the diversity of the industry was not fully represented by the survey respondents, the combined data from all sources are presented, in which priority is given to the survey data, followed by the Holzkurier summary data, beginning with the 2015 review (Plackner 2015c), and the information obtained during a site visit is used when no published data is available.

3.0 Results and Discussion

The overall findings indicate an industry with a substantial level of diversity in terms of the ownership structure, level of vertical integration, scale of operation and production profile.

Ownership and scale of operation: Ownership ranges from privately held (12 respondents), cooperative (1), to parts of large, publicly traded companies (5).

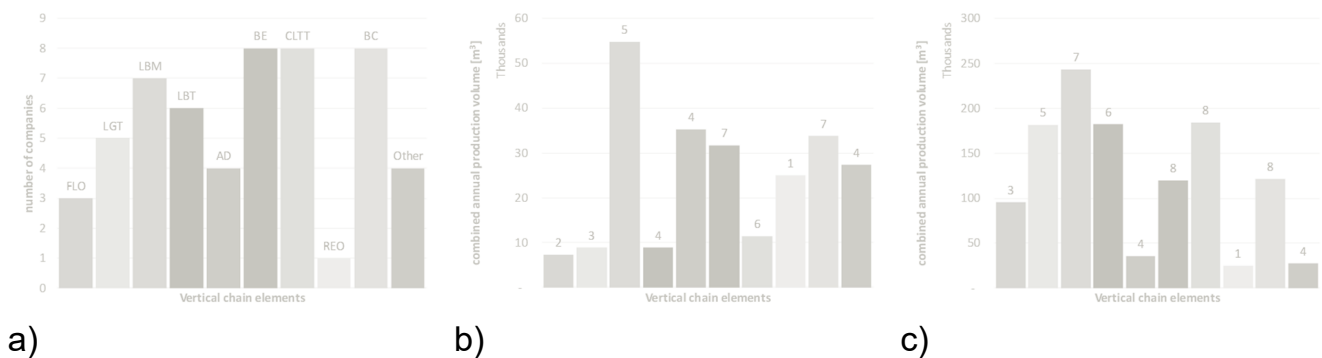


Figure 4. An extreme example of the effect of data treatment on the summary survey outcome: a) responses summarized by number of respondents, b) responses summarized by number of respondents and weighed by output volumes attributed in the survey, and c) responses summarized by number of respondents and weighed by output volumes attributed to the respondents from combined sources.

The information in Figure 5 is derived from all three sources and represents all CLT lines known to the authors, to which annual production volumes can be attributed from any available source. As evident from the bar labels representing the number of companies in each of the four scale categories, most of the manufacturing plants are on the small end of the scale.

Out of 31 lines for which the annual output capacity could be assessed, 22 fall below 10,000 m³ per shift, contributing less than 12% of current global capacity. By contrast, the six largest, highly automated plants with an annual capacity over 30,000 m³ represent more than 35% of the estimated global capacity and often secure projects executed overseas.

Discussion: Observations collected during the site visits indicate that smaller companies can afford a relatively low level of automation, typically rely on manual labor, and mainly serve local markets. Larger operations require a high level of automation for handling large volumes of raw material in tight press cycles. Just three companies in the category between 20 and 30 thousand m³ capacity may indicate the watershed limit for transition from manual labor to full automation.

Apparent coexistence of companies of remarkably different sizes is one of the interesting characteristics of the cluster of CLT plants concentrated in the Alpine Region. Little is known about the markets served by companies of different sizes, specifics of their marketing strategies, and how much they compete in the same space. Better understanding on how this coexistence is possible may shed light on whether the coexistence of large and small players is critical for overall market development.

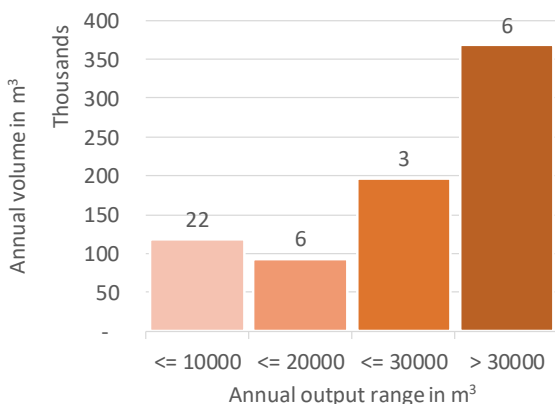


Figure 5. Cumulative output of CLT companies by size of operation (combined sources). Labels above the bars designate number of companies in given operation size category.

Most of the responding companies plan to increase their production capacity within two years (12 respondents) and one plans a major expansion within 5 years (Figure 6).

Figure 7 summarizes survey responses regarding the methods to be employed towards increasing production volume. Most companies (10/13) focus their attention on line efficiency. The second most popular option (8/13) involves adding shifts. In fact, the responding companies indicated that in 2015 they worked, on average, 1.12 shifts, so there is a substantial incremental capacity reserve in the industry. Other options include installing new equipment (7/13) and adding another line in the current plant location (6/13). One company plans to build another complete CLT plant.

Discussion: This summary, naturally, does not reflect production capacity to be brought in by new entrants to the industry. It should also be stressed that currently, from the global forest products perspective, the CLT industry with projected annual capacity of about 1 million m³ (Plackner 2013) is still boutique size. Holzkurier projected a production size of as much as 3 million m³ by 2024 (Plackner 2015a).

Production profile: Survey respondents identified over 96% of production volume as manufactured for custom orders (Figure 8). In fact, only one of the respondents indicated production of 100% blank, non-machined panels to be sold as generic CLT products. This matches observations made during site visits, but sharply contrasts with much of the forest industry, which generally focuses on highly productive, commodity-focused operations (e.g., Crespell et al. 2006). Forest

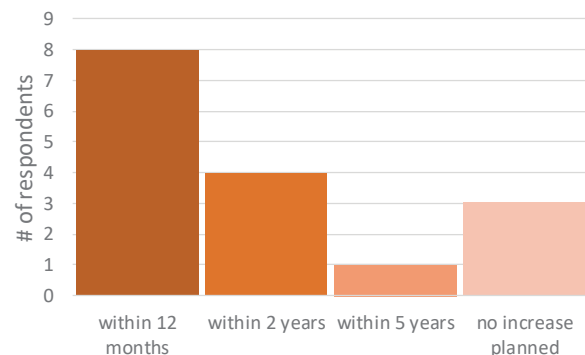


Figure 6. Survey responses on plans to increase production volume (n=16/21).

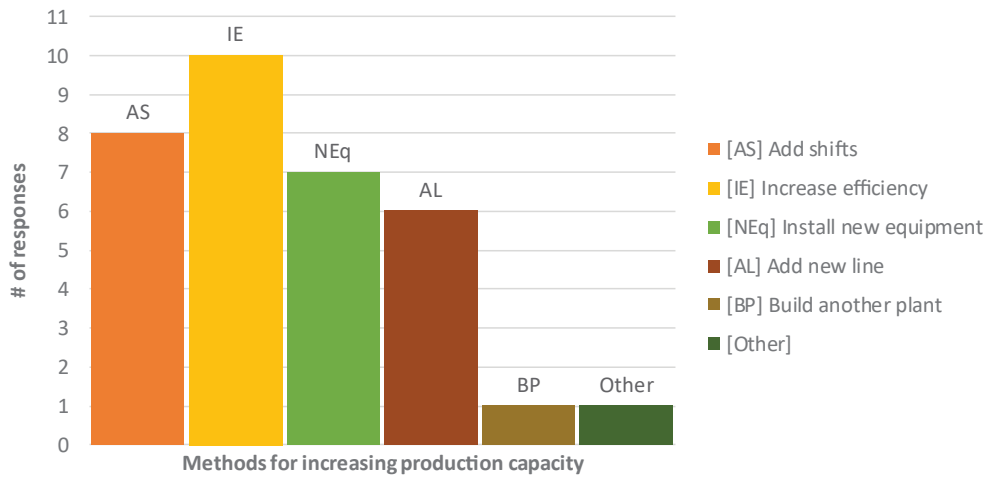


Figure 7. Planned modes for increasing production capacity (n=13/21)

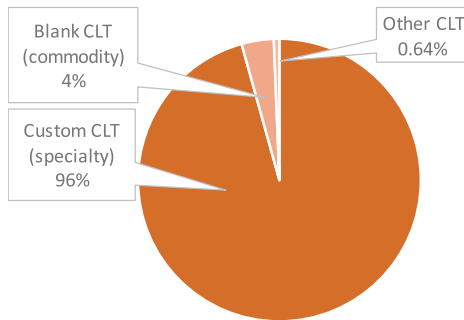


Figure 8. Production profile in terms of custom vs. commodity products by output volume (n=18/21)

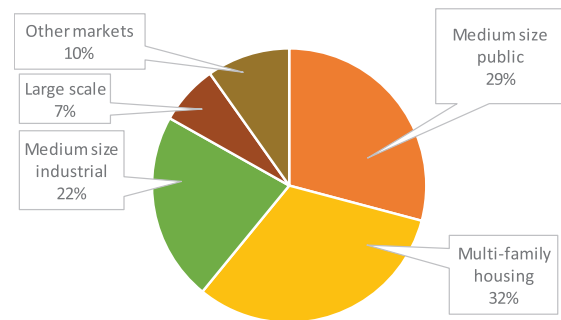


Figure 9. Production profile in terms of the market segment by output volume (n=18/21)

products manufacturing used to be focused either on manual crafting of unique objects or on mass production of repeatable elements. In the CLT industry, a creative merging of digital design and fabrication substantially expands the range of manufacturing options and offers more freedom for developing innovative, adaptive, and material-oriented construction systems (R. De Amicis, personal communication, March 28, 2017).

With respect to market segments, respondents were focused primarily on multi-family housing, at nearly one-third of the attributed production volume (Figure 9). Medium-size public buildings was the second largest segment. Large-scale buildings represent only seven percent of the market for responding companies.

Discussion: This small share of large projects in the global CLT output is easily corroborated by the still small number of CLT buildings over 10 storeys completed worldwide. What is fueling the industry are small- to medium-size

projects within the specifications allowed under current building codes.

The focus on custom projects is a result of the complex circumstances of the evolution of the CLT industry in Europe. The first circumstance involves the fact that CLT technology has been a disruption in the building environment in Europe. Wood as a structural material has been suppressed to the margins of European building industries for over two centuries. In order to propose a revolutionary building technology that did not rely on technologies, practices, experiences, or skill sets existing in concrete, steel, brick and mortar or even in the traditional timber structure technologies, proponents were compelled to offer a finished package: CLT-specific architectural design, engineering specifications, building materials, and a CLT-conscious construction crew. This created a strong incentive for close collaboration. In fact, close collaboration among the architects, engineers, contractors and manufacturers is still commonplace today,

and these functions are often vertically integrated within one company. This means that architects and engineers design with intimate knowledge of the intrinsic flexibilities of the specific manufacturing process, which allows the manufacturer to carefully optimize the product for a specific project (beyond just cutting to specified dimensions).

In fact, many companies also integrate other elements of the extended CLT supply chain incorporating transportation, lumber processing, and other functions typical to their forest products roots (Figure 10).

Figure 11 provides an overview of vertical integration reported by the companies responding to the survey. Interpretation of responses to this question is complicated by the great diversity in scale of operation between the respondents (up to 20 times between the smallest and the largest respondents), as discussed in the Methods section above. Analyzing by the number of responses

alone (Figure 11a), it can be said that nearly one-quarter of respondents are involved with architectural design, half of the respondents with building engineering, and just over half with building construction.

When the responses are presented in the context of the attributed output volumes of the respondents (Figure 11c), the overall importance of the vertical integration is confirmed, however, the priorities are somewhat shifted, suggesting the importance of integrated lumber manufacturing, log and lumber transportation for large players in the CLT industry. The dimmed graph representing responses scaled by self-declared volumes illustrates the danger of reliance on the incomplete output volume data from the survey alone (see discussion in the Methods section).

Discussion: While the graphic does not depict a highly integrated industry sector, relative to much of the forest

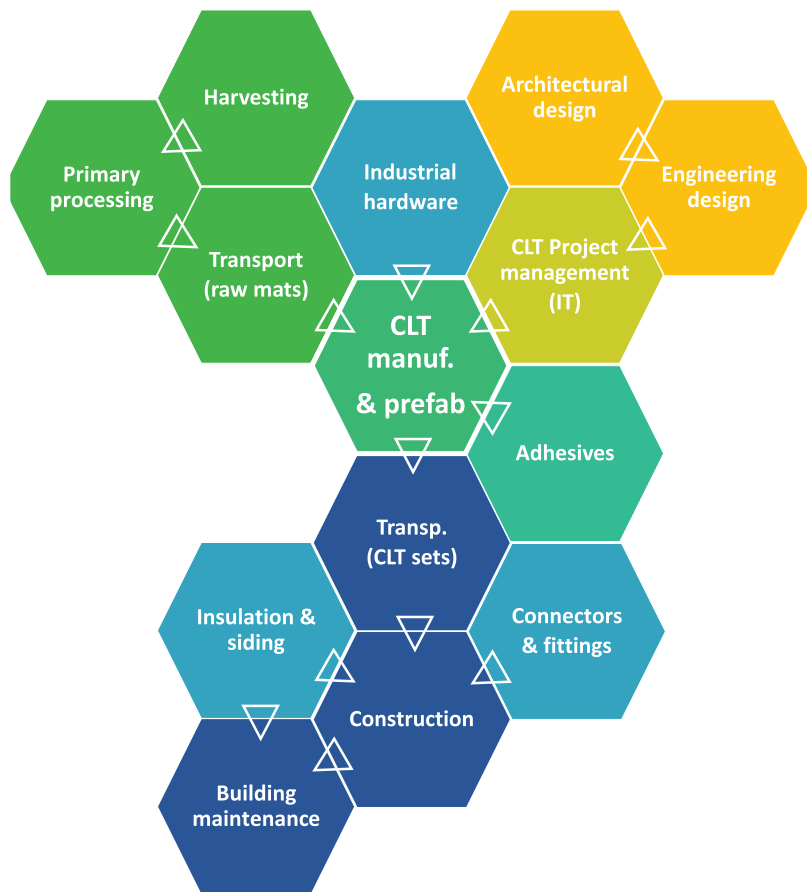


Figure 10. CLT extended supply chain (based on site visit experiences)

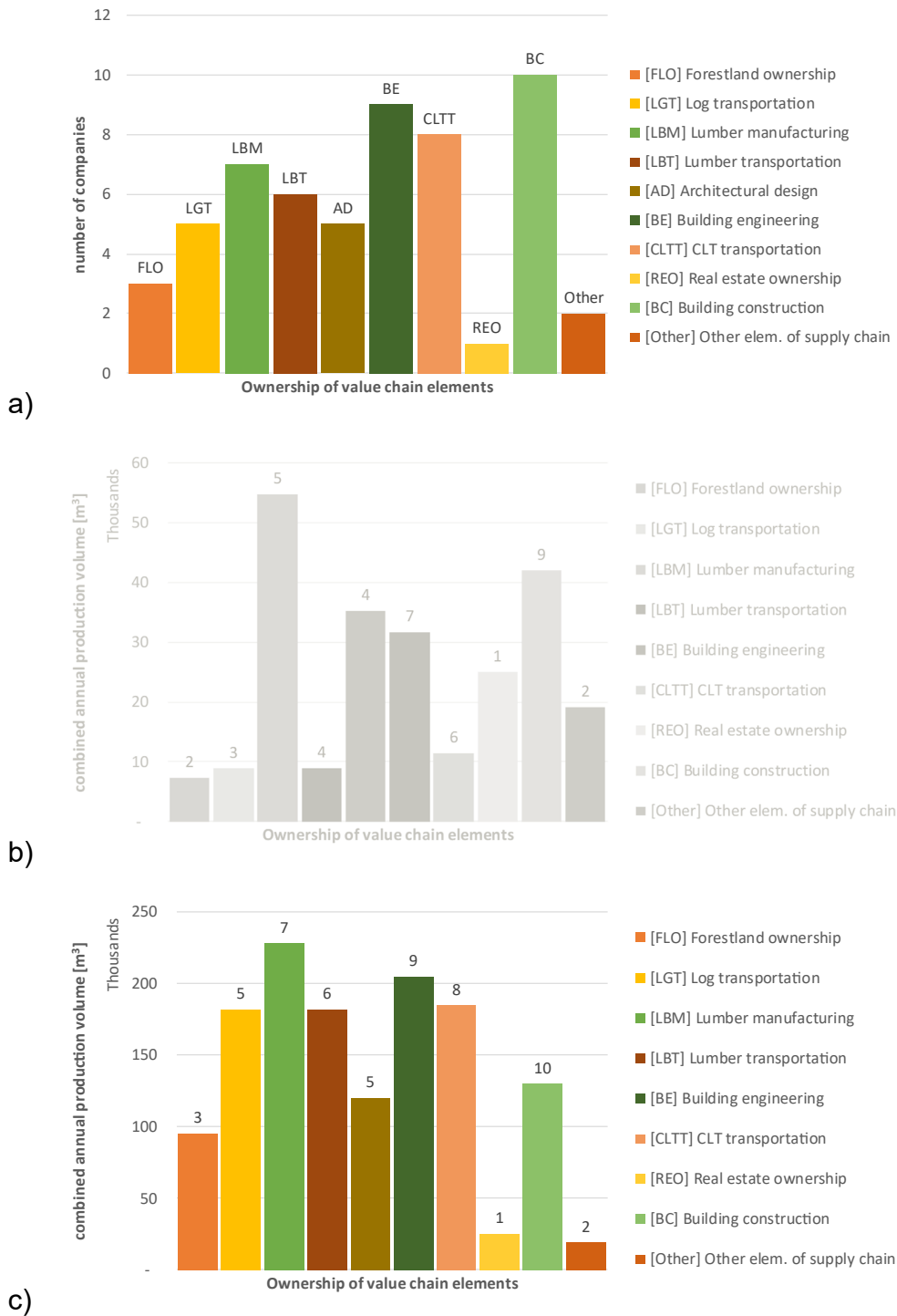


Figure 11. Level of vertical integration reported by responding companies (n=18/21)

industry, multiple respondents are heavily involved in downstream integration.

Diversity: The organic growth of the industry in Europe resulted in striking diversity not only in the scale of operation but also in the selection of manufacturing

options, such as press types and sizes (Figure 12) as well as adhesive or mechanical binder selection (Figure 13).

While large-area hydraulic presses are used in most of the plants, about 22% of CLT lines (for which such information could be obtained from the combined

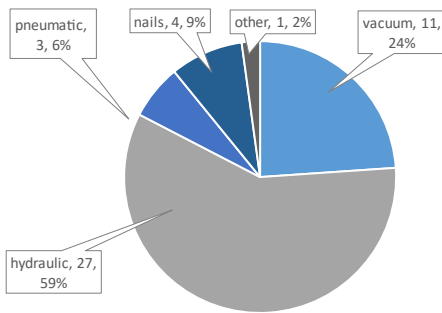


Figure 12. Press technologies employed in CLT plants (combined sources, by number of known companies)

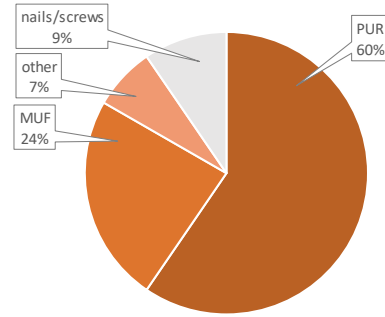


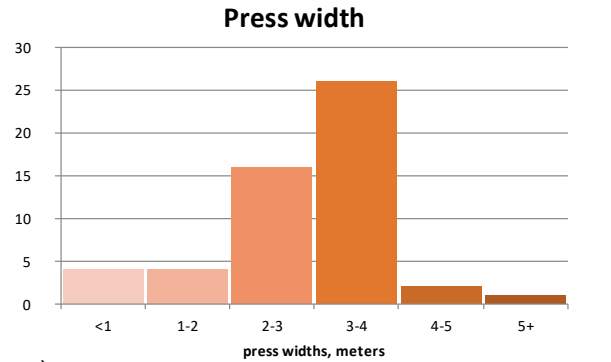
Figure 13. Adhesive systems and other types of binders (combined sources, by number of known companies)

sources) used vacuum presses and at least 9% used nails or other mechanical binders (Figure 13). Almost all vacuum presses are produced by a single company, which is a rare case of relatively standard equipment being used by a large group of companies.

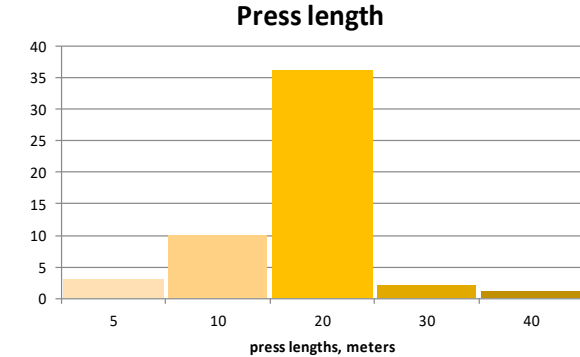
It should be stressed that nailed CLT panels are different from traditional nail laminated timber (NLT), i.e., massive timber panels produced by arranging all layers in the same direction. These are obviously not cross-laminated, but unidirectional panels, and have not been targeted in this investigation.

Compared to traditional adhesive bonded wood composites, the adhesive selection for binding large area panels is limited to cold setting structural adhesive systems, because of the difficulty and expense of using heat to cure resins in a massive panel. Of companies producing adhesive bonded CLT, 25 (over 65%) run lines relying on polyurethane (PUR) adhesives and 10 (about 26%) have lines using melamine urea-formaldehyde systems (MUF). These numbers include one company that uses both systems on parallel lines. Of the lines using MUF systems, at least three use radio frequency presses to heat-cure the resin.

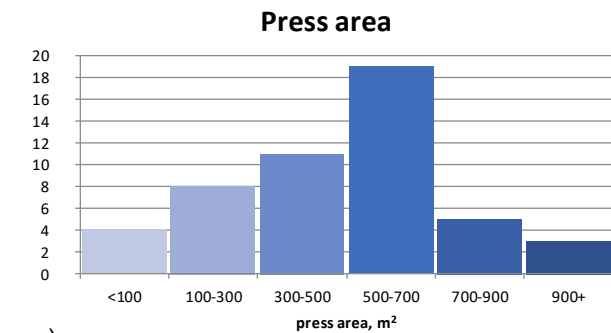
In line with the custom nature of the global CLT industry, to date, there is no standard regulating the in-plane dimensions of the massive panels. Accordingly, the sizes of the presses vary widely. Graphs in Figure 14 illustrate the diversity of press sizes installed in CLT manufacturing plants broken down by a) press width, b) press length and c) press area. The graphs represent either the dimensions of presses (known from Plackner 2011, 2013 and 2015c, or from notes from site visits) or the largest in-plane dimensions of CLT panels offered via the companies' web-catalogues, considered a reliable



a)



b)



c)

Figure 14. Diversity of press sizes installed in CLT manufacturing plants broken by a) press widths (b) press lengths (c) and press areas. Note that some plants operate more than one press on the same site (based on combined sources).

proxy for the press size. Note that some plants operate more than one press on the same site.

Most of the surveyed plants use spruce as their primary raw material (88% of reported production volume) with smaller shares of pine (just over 6%) and fir (5%). The survey responses weighted by volumes attributed to the respondents are summarized in the pie chart in Figure 15.

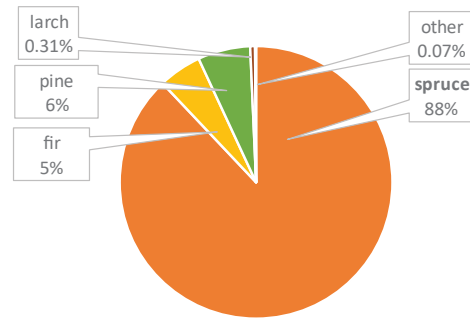


Figure 15. Wood species used in CLT products by output volume (n=19/21)

Competitive Advantage: Similar to many forest industry companies, survey respondents claimed quality as their primary competitive advantage (Wagner et al. 2007). In Figure 16, the responses reflect on the importance of items using a scale from 1 (low importance) to 5 (high importance). Quality was closely followed by services they provide, offering custom products, and skill of their workforce. Somewhat surprising is the lower importance attributed to processing and information technology.

Innovativeness: Innovativeness was measured using the Likert scale developed by Knowles et al. (2008) and we average the four items in each dimension. Although there were no major differences in the type of innovativeness respondents claimed with regard to their firm, it is interesting to note that product innovativeness was

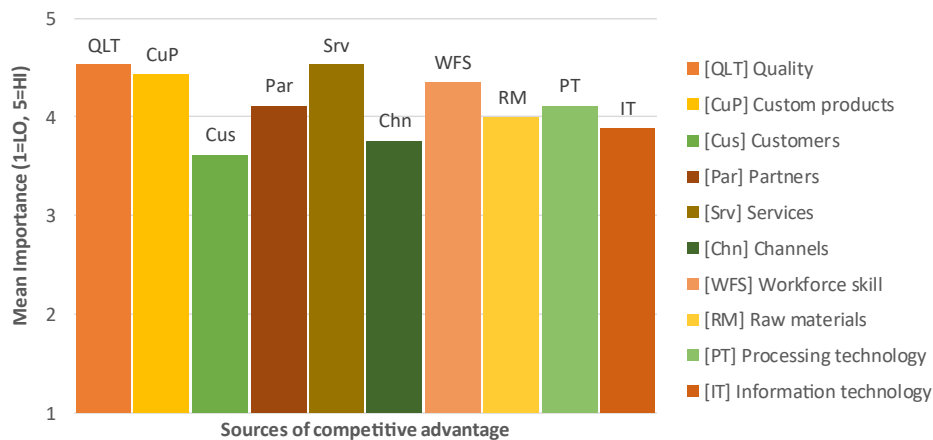


Figure 16. Perceived importance of factors of companies' competitive advantage (n=19/21)

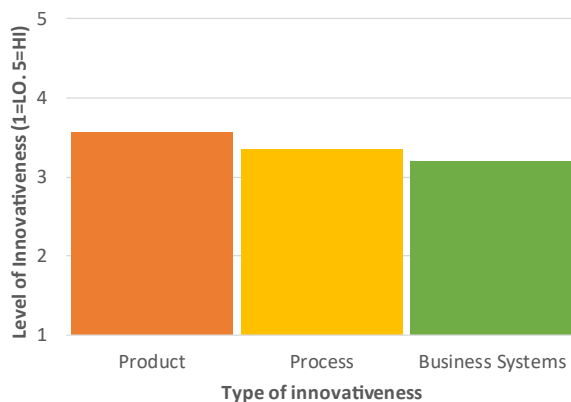


Figure 17. Innovativeness focus of responding CLT manufacturers (n=17/21)

rated highest (Figure 17). Weighting the responses by the attributed output volumes produced very similar results.

Discussion: The level of product innovativeness among our respondents contrasts with other sectors of the forest industry where process innovativeness tends to dominate (Hansen and Nybakk 2016). This likely reflects the custom-made nature of CLT production among respondents (Figure 8). It is also consistent with theory espoused by Utterback (1994) regarding the evolution of the innovation focus within an industry. According to Utterback, product innovation receives the most attention in the early stages of an industry. Once a generally accepted design for the product is accepted in the marketplace, the focus tends to shift toward process innovation.

Barriers: Figure 18 summarizes responses concerned with perceived barriers to the further growth of the CLT industry. The original responses scaled 1 (low concern) to 5 (high concern) were weighted by reported output volumes. Building codes were seen to be, by far, the biggest barrier, followed by the architectural community's unfamiliarity with CLT technology. Costs, both raw material and production, were seen as rather low barriers, rated below the midpoint (3) of the scale. Finally, lack of demand was seen as the least significant barrier to further growth of the industry, reflecting the prevailing optimism among manufacturers.

4.0 Limitations

The number of companies using nails and other mechanical binders in their products is certainly underrepresented

in this study. As said earlier, nailed CLT panels are different from traditional nail laminated timber (NLT), i.e., massive timber panels produced by arranging all layers in the same direction. These non-cross-laminated, unidirectional panels have not been targeted in this investigation.

However, due to the unspoken assumption that CLT is predominantly bonded with adhesives, many companies using alternative binders like nails, screws, or hardwood dowels do not advertise their products as CLT and are often inconsistently represented, or not represented at all in CLT tallies and surveys. Unfortunately, our study was no exception. Late in the process, the authors discovered at least 30 European companies operating under the same franchise, using specialized robotic equipment to bond massive cross laminated panels with aluminum nails. Only a few of them were invited to participate in this study based on their self-identification as CLT manufacturers or coverage in other reviews. Although the output volume of plants producing the nailed CLT is small when compared to plants producing adhesive bonded CLT products, their actual contribution to the CLT industry remains unknown due to inconsistent coverage.

5.0 Conclusions

Despite its 20-plus year history, the global CLT manufacturing industry can still be considered young and in the process of development, sending to the market relatively small volumes of products (compared to the commodity-oriented, traditional forest products industry). The highly custom nature of CLT production is noteworthy

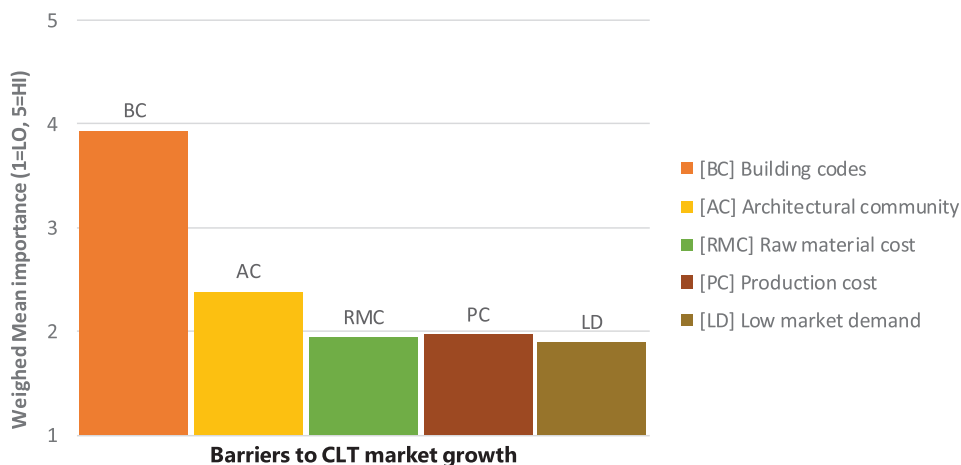


Figure 18. Perceived barriers to CLT industry growth ($n_{BC}=18/21$; $n_{other}=17/21$)

as being different than much of the traditional forest sector. Only one responding company was producing “blanks” rather than custom panels. Creative merging of digital design and fabrication substantially expands the range of manufacturing options of the CLT industry and offers more freedom for developing innovative, adaptive, and material-oriented construction systems.

The industry is remarkably diverse in terms of mode of operation, scale of production, level of automation, ownership, and business models. The range in size of facilities by annual output volume is enormous (the largest produce about 20 times as much as the smallest). The ownership ranges from family to corporate.

In contrast to the CLT hype currently fixated almost exclusively on tall buildings, responding companies reported that most buildings constructed with their CLT are small to medium-size multi-family housing, public, and industrial structures within the limits of current building codes. This is expected to remain the norm since this is the easiest route through existing building codes.

An especially interesting aspect of the CLT sector is the level of collaboration along the supply chain that takes place in order to realize successful construction projects. The summary of the survey responses and the observations from the site visits suggest that many companies have internalized key steps in the supply chain and have, for example, in-house engineers/designers. Nearly a third of our respondents are directly involved in building construction, showing downstream vertical integration. A high level of collaboration and/or ownership of downstream steps in the supply chain appear to be important elements of a successful CLT operation.

Most respondents indicated plans for expansion in the next two years. Collectively, responding firms are not fully utilizing existing capacity at all times, which may be expected for an industry occupied with custom projects. These responses combined with plans to open new CLT plants reported in the trade press suggest that the global sector is poised for significant growth. Still, the hype around CLT must be tempered by remembering that despite high levels of growth, it still represents a relatively tiny fraction of the global wood consumption (just over one percent of softwood sawnwood consumed in North America alone). The development of the sector is a rich laboratory that deserves further study to inform both theory and practice. New entrants to the CLT sector, especially existing forest industry firms, are

advised to carefully consider the unique character of the CLT sector where success appears to require extensive involvement along the value chain and primarily custom-made products.

Future work: There is still very little research characterizing the CLT industry. While this paper provides a static snapshot of the status quo for 2015 with limited context of historic data, only a well-designed series of such snapshots over an extended period of time can reveal the dynamic changes in the vital metrics of the CLT industry, short-term trends, and early warning of potential issues. Of interest are 1) changes in production capacity and dominant technologies in global CLT production; 2) key success factors and constraints determining the emergence and growth of the contemporary CLT industry; 3) differences in the perceptions of opportunities, risks, challenges, constraints, related business models, strategies, and contextual policies; and 4) the role of innovation systems in these strategies. More work is needed for insights regarding the businesses positioned within the existing or potential value chains of the CLT industries in various regions.

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