SOCIETY OF WOOD SCIENCE & TECHNOLOGY

Awareness, Perceptions and Willingness to Adopt CLT by U.S. Engineering Firms

BIOPRODUCTS BUSINESS

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Abstract

Developed in the early 1990s, Cross-Laminated Timber (CLT) is an engineered wood product that consists of multiple layers of dimension lumber oriented perpendicular to one another and glued together to create structural panels. CLT has been used successfully in Europe for over 20 years and it is now entering the Canadian and Australian markets. It has also been gaining momentum in the U.S., particularly in the Pacific Northwest. This paper presents the results of a survey conducted to evaluate familiarity and perceptions of U.S. engineering firms about CLT, as well as their willingness to adopt it. Results indicate that the level of awareness of CLT is low to moderate. Highest ranked characteristics of CLT were its environmental and structural performance and its aesthetic properties, while lowest ranked characteristics were vibration and acoustic performance and lack of availability in the market. Influential barriers to the successful adoption of CLT involve building code compatibility, high material and construction costs, and a rather limited availability in the U.S. Most respondents indicated willingness to adopt CLT in the near future. Based on these results, this paper concludes that a successful market adoption of CLT in the U.S. will greatly depend on the familiarity of the CLT system and its advantages among construction professionals. This familiarity can be enhanced through promotional activities, educational initiatives, and successful demonstration projects.

Keywords: adoption, cross-laminated timber, mass timber, perceptions, willingness, wood construction

1.0 Introduction

Construction professionals today cannot afford to follow old models of design and construction (Bernheimer 2015a). Two major issues that will require firms to take a new approach involve climate change and a growing world population. The construction of buildings across the world is currently dominated by concrete (Bernheimer 2015b), but production of cement, a primary ingredient in concrete, is a major source of pollution, producing a ton of CO_2 for every ton of cement (Hanle 2013). One method of reducing the environmental impacts of construction involves increasing the use of materials with lower environmental footprints, such as wood. Approximately half of wood is carbon, effectively turning wood, either as growing stock or as end products, into "carbon sinks" (Lehmann 2011, Oneil & Lippke 2010).

Wood's natural heterogeneity, unpredictable defects, and variation of properties have been timber's greatest disadvantages in the market of structural products. Engineered Wood Products were initially developed in order to account for this heterogeneity, more efficiently utilize the raw material and expand the uses of wood products in construction (Forest Products Laboratory 2010, MacKeever 1997). In EWPs manufacturing, wood boards, chips, or particles are assembled using adhesives and/or pressure to create a product with less variability, enhanced design characteristics, and more consistency and reliability than the original material (APA 2015, Forest Products Laboratory 2011). Thus, the production of EWPs can make use of small diameter trees, lower grade lumber, and a wider variety of tree species

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Acknowledgements: The authors would like to gratefully acknowledge the assistance of Tony Staeger and John Ellingson from HGA Architects and Engineers; Doug Steimle from Schaefer; David Barber, Hans-Eric Blomgren and Michelle Roelofs from ARUP; and Benton Johnson from Skidmore, Owings and Merrill. The research discussed in this paper forms the basis of a PhD Dissertation and was funded through the Department of Bioproducts and Biosystems Engineering Graduate Research Fellowship from the University of Minnesota.

BioProducts Business 3(1), 2018, pp. 1-14. http://biobus.swst.org.
https://doi.org/10.22382/bpb-2018-001

(Paun & Jackson 2000). The development of EWPs, such as Glulam, I-joists, and strand and particle boards, has established new uses for wood in construction (CWC 2014, Paun & Jackson 2000).

A recent innovation in EWPs was the development of CLT in Austria in the 1990s (Lehmann 2012). CLT is a building system (Chen 2012, Lehmann 2012, Oqvist, Ljunggren, & Agren 2012, Zumbrunnen & Fovargue 2012) composed of large-format solid timber panels that developed as an extension of the technology that began with plywood (Crespell & Gagnon 2011, FPInnovations 2013, Lehmann 2012). CLT panels are composed of lumber boards that are glued together, alternating the direction of their fibers for each layer. The cross-lamination of layers translates into panels that are monolithic, experience minimal shrinkage (both longitudinal and transversal), and can carry forces in all directions (Evans 2013). This stability can result in very small tolerances for prefabricated buildings.

Developed in Europe over 20 years ago in the 1990s, CLT has been used as a structural system for various types of buildings, from residences and offices, to barns, power lines, schools, churches, bridges and mixed-use mid and high-rise buildings (CWC 2015). This versatility has added visibility and reputation to the system (Evans 2013, Sanders 2011). In Europe, the use of CLT has become very popular. More recently, it has been introduced in North American and Australian markets; more than fifty buildings have been built using this building system (Crespell 2015). Yet, the U.S. market for CLT is still in its embryonic stage (Laguarda-Mallo 2014). So far, only a handful of projects have been built using CLT, most of them with imported panels.

1.1 Product Adoption

Rogers (2003) defines adoption as *"a decision to make full use of an innovation as the best course of action available."* Therefore, the adoption of an innovation relates to consumers' individual decision-making processes regarding the full use of new products. This complex process involves multiple stages, which will be described in the following sections.

1.1.1 New product adoption process

The successful introduction of a new product in the market carries significant economic risk for a firm (Armstrong, Kotler, & He 2013). A number of authors have addressed the process of product adoption (Harvey 1979, Urban & Gilbert 1971) and several models have been proposed (Beal, Rogers, & Bohlen 1957, King 1966, Rogers 2003). Beal et al. (1957), for example, propose the five-stage product adoption process, as shown in Figure 1.

Awareness is defined in the marketing literature as the moment a consumer learns about a new product, service or brand and starts forming the first perceptions about its benefits and disadvantages (Armstrong et al. 2013). During this stage the individual usually has very limited information about the product. According to several authors, the level of awareness largely influenced by how and how much information about the product is getting to the potential consumer (Beal et al. 1957, King 1966, Rogers 2003). The second step in the adoption process relates to how attracted the consumer is to said product. At this point in time, the individual usually conducts a more in-depth research about the features and the performance characteristics of the product (Armstrong et al. 2013). It is not until the *application* stage, that the individual evaluates the new product and considers its advantages and disadvantages (Armstrong et al. 2013). During this stage, the potential consumer arrives to the conclusion of whether or not the new product should be tried out. A positive application leads to a *trial* period. Finally, the *adoption* of the product (King 1966). During the adoption the consumer starts using the new product. According to Gayle (2008), during this final stage, the individual often becomes an advocate for the product in their community. The role of these early adopters is essential in transferring product knowledge to other potential adopters.

1.1.2 Innovation adoption in the construction industry

The construction industry has often been described as laggards with regard to the adoption of new technologies (Ganguly, Koebel, & Cantrel 2010, Tangkar & Arditi 2004, Tatum 1987). Innovation is seen by (Wagner & Hansen 2005) as a source of competitive advantage that can benefit the construction industry, providing the critical component of a firm's long-term competitive strategy (Slaughter 2000). However, the adoption of innovations is a highly complex process, where scarce research has been conducted.

The risk associated with the adoption of an innovative material or process has been recognized by Slaughter (2000) as one of the most significant factors affecting the rate of adoption of a new product. Specific to the

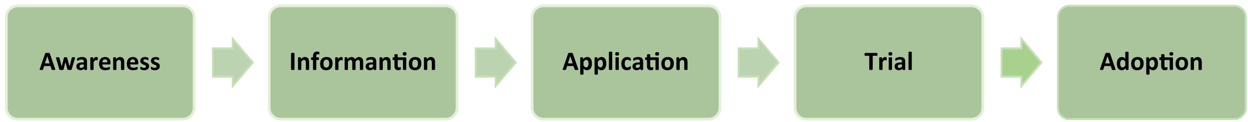


Figure 1. Stages of the adoption process, according to Beal et al. (1957).

construction industry, liability risk is considered one of the largest barriers to the adoption of new materials and technologies (U.S. Department of Housing and Urban Development (HUD) 2005). Design professionals, such as architects, engineers, and contractors, are often responsible for the performance of their buildings, including the specification of the materials used, and can face severe penalties when building components fail to perform as expected (Sido 2006). This liability is frequently shared with product manufacturers (U.S. Department of Housing and Urban Development (HUD) 2005).

According to McCoy, Thabet, & Badinelli (2009), a complexity of the adoption process in the construction industry is caused by the large number of actors (e.g. suppliers, manufacturers, design professionals, and final users) involved in the decision-making process regarding the adoption of an innovation. Although design professionals comprise only one group of actors involved in the decision-making process, their decisive role in the supply chain, as the specifiers of building requirements and materials, makes them essential to the success of the adoption of an innovative material or technology (McCoy et al. 2009).

1.2 Objectives

Extensive research has been carried out to evaluate CLT performance as a structural system, including studies on CLT's mechanical properties, fire and thermal performance, and seismic behavior (Harris et al. 2013, Karacabeyli & Douglas 2013, Kuilen et al. 2011). However, market research related to CLT is scarce. To address this gap in the literature, this study seeks to assess the market potential for CLT in the U.S. by investigating the level of awareness, perceptions, and willingness to adopt CLT by U.S. structural engineering firms, considered one of the key actors in the structural material decision-making process. The research presented here is part of a larger effort by the authors to study the adoption of innovative wood products, specifically CLT, by construction professionals.

2.0 Methodology

A nation-wide survey of U.S. structural engineering firms was carried out with the purpose of learning about the community's awareness and perceptions regarding CLT. The survey was conducted online, which provided a cost-effective approach to reaching a large geographic area (Dillman 2011, Sue & Ritter 2012). Qualtrics software was used in the development of the design, implementation, and data analysis of this study (Qualtrics 2016).

Given the importance of engineers in the material selection process, engineers comprised the population of interest in this study. Based on information from prior interviews (Laguarda-Mallo & Espinoza 2014) and preliminary economic analysis conducted by FPInnovations (FPInnovations 2011), which concluded that commercial buildings represent a likely market for CLT, a decision was made to focus on U.S. civil engineering firms that work primarily with commercial (which includes office buildings, retail, hospitals, restaurants, and hotels), industrial, institutional, and educational buildings.

As a first step in the survey process, a list of U.S. structural engineering firms was compiled using an online database managed by the American Council of Engineering Companies (ACEC 2016). According to personal communications with the Chair of Membership of the ACEC, this association represents licensed engineers of all fields, including civil structural engineering firms. The ACEC's member directory provides search tools to generate lists of firms using criteria such as geographic location, type of engineering firm, and zip code. There are currently more than 5,000 firms listed in the ACEC's database, representing more than 500,000 employees throughout the country (ACEC 2016). As there are approximately 94,500 engineering firms operating in the U.S. (U.S. Census Bureau 2016), the ACEC database represents approximately 5.3% of all engineering firms in the U.S.

2.1 Sample Size Determination

Choosing the sample size is a critical decision in any survey research. The objective involves selecting the smallest sample size that allows for an adequate confidence level and margin of error. An appropriate sample size will help decrease the occurrence of sampling error and sampling bias (Dillman 2011). Sample size was calculated with a desired level of confidence of 95%, a confidence interval of 5%, and a standard deviation of 0.5 (Dillman 2011). Assuming an expected response rate of approximately 25%, an initial sample of 1,600 firms was determined to be sufficient. The number of firms from each state to be included in the sample was calculated as a proportion of each state's population.

2.2 Survey Development

The first draft of the survey was created taking into consideration a previous survey to U.S. architecture firms conducted in 2015 (Laguarda-Mallo & Espinoza 2015). This questionnaire contained a total 15 questions, including 6 multiple-choice questions, 8 Likert-type items, and one open-ended question. The questionnaire covered the following topics:

- Firm demographic information, including the location and size of the firm.
- Sources of information used to investigate new structural materials, firms' perceived innovativeness, and types of buildings and structural materials firms typically work with.
- Awareness of CLT in the Engineering Community, including familiarity with CLT and how respondents learned about the system.
- Perceptions about CLT, including how participants perceive the environmental, structural and economic benefits of the system.
- Willingness to adopt the CLT building system.

The survey questionnaire was then sent to two university professors with extensive knowledge in conducting surveys and two professional engineers. These individuals provided detailed feedback about the questionnaire. Based on this feedback, changes were made to the questionnaire.

The survey instrument included an introductory email to inform participants about the study and ask for their participation, including a link to access the web-based survey. The questionnaire started with a welcome page, information about the study, and a confidentiality statement. Questions were grouped according to the topics mentioned above. A final "thank you" message was presented to those respondents who completed the questionnaire. Participants were also asked whether they were interested in receiving a summary of the survey results; those who answered positively were asked to provide an email address to which the summary would be sent.

2.3 Survey Pretest

A pretest was conducted by sending the survey to seven U.S. structural engineering firms. These firms were asked to provide feedback on the survey's clarity and potential errors. After one week, a reminder was sent to participants who had not yet responded. All seven firms' representatives responded to the pretest. A preliminary analysis of the pretest responses did not show any problems completing the survey.

2.4 Survey Implementation

An initial email was sent to all firms on the distribution list in February 2016. Three reminder emails were sent to those participants that did not complete the questionnaire, one, two and three weeks after the initial email. Thus, the online survey was closed four weeks after the initial email was sent. Due to the low response rate obtained during the first iteration of the study, personal phone calls to all non-respondents were conducted over the course of the three weeks following the first reminder to obtain more responses.

2.5 Data Analysis

Responses obtained from the survey were analyzed using similar data analysis techniques as the ones used in a previous study by the authors (Laguarda Mallo & Espinoza 2015). Descriptive statistics were calculated using Excel spreadsheets (Microsoft 2017). Chi-square tests were evaluated using IBM SPSS software at a 0.05 alpha level.

2.6 Limitations

Authors recognize that as with any survey, there are many limitations that could arise (Dillman 2011, Laguarda Mallo & Espinoza 2015, Sue & Ritter 2012). The most important are listed below:

- Measurement error: survey questions and answers could lead to inaccurate analysis because question and answer options may be interpreted differently by different respondents. Measurement error was minimized by the authors by seeking the input and feedback from experts and by conducting a pretest.

- Non-response bias: this bias could occur when respondents and non-respondents are significantly different (Berg 2005). In order to evaluate existence of any issues, non-response bias was calculated with early and late respondents. Results are presented in the results section of this manuscript.
- Coverage error: using the ACEC database to compile the mailing list for this survey could introduce a source of coverage error, as not all U.S. structural engineering firms are associated with the ACEC (only 5.3% of all engineering firms in the U.S. are part of the ACEC), and some differences may exist between firms that belong to this association and firms that do not.
- Similarly to what was done by the authors in a previous study (Laguarda Mallo & Espinoza 2015), a "multi-region" category was created, grouping those engineering firms that indicated to work in more than one region. Even though this helped the authors simplify the data analysis and make inferences, it is possible that some region-specific information was lost from after this regrouping (Laguarda Mallo & Espinoza 2015).
- As with any internet-based survey, connection problems could have affected the completion of the survey (Laguarda Mallo & Espinoza 2015).
- It is important to mention that responses from the survey represent the insights of only one of many professionals of the participating firms (Laguarda Mallo & Espinoza 2015).
- Due to our sampling criteria of selecting engineering firms that work mainly with commercial projects, generalizations to the entire engineering community cannot be made.
- Due to our low response rate (see next section "Results and Discussion"), generalizations to the population of interest are also difficult to make.

3.0 Results and Discussion

3.1 Response Rate

The questionnaire was sent to a total of 1,601 U.S. structural engineering firms. A total of 113 usable responses were received. Accounting for 110 firms that declined to participate or were not part of our target population (e.g., bridge engineering firms, consultants, etc.), 202 undeliverable emails, 1 duplicate address, and 12 incomplete (unusable) responses, the adjusted response rate was 8.8%.

3.2 Non-Response Bias Assessment

Non-response bias refers to error in estimating a population characteristic based on a sample in which, due to non-response, certain types of respondents are under or not represented (Berg 2005). To assess non-response bias, respondents included in this study were separated in two groups, or "waves": The first group corresponds to the early respondents and the second group corresponds to the late respondents (Laguarda Mallo & Espinoza 2015). Late respondents were used as a proxy for non-respondents. Early and late respondents were compared using three demographic questions from the survey: location and size of the size, and level of awareness about CLT.

Early and late respondents were compared using Pearson's chi-squared tests with a significance value of 0.05. The test performed using the location criteria resulted in a chi-squared value of X^2=0.997 and a p-value of 0.348 ($p>0.05$), indicating that there is no relationship between the time of response and the location of the firm. The association between the time of response and the size of the firm also shows that there is no statistically significant relationship between these two variables (X^2=0.937 and p-value =0.812). Similarly, no statistically significant relationship was found between the timing of the response and the familiarity with CLT (X^2=0.669 and p-value of 0.556). Based on these analyses, we concluded that no significant bias existed between respondents and non-respondents.

3.3 Firm Demographics

In order to gain further insights about respondents, authors asked participants in in which U.S. region their firm operated. Multiple responses were possible. Firms working in more than one region were grouped into a "Multi-region." Table 1 displays the counts and percentages of respondents for each region as well as firm size.

3.4 Sources of Information

Findings about the most commonly used sources of information (Table 2) indicate that most engineering firms gather information about new materials from the web (93.8%), industry events, such as meetings with suppliers (78.8%), and design and construction-themed magazines (64.6%). The least mentioned media included webinars, with only 19.5% of respondents indicating

Table 1. Location and firm size, as reported by survey respondents. N=113.

Firm Characteristic	Count of Respondents	Percentage
— Firm Location (U.S. Region) —		
Multi-region	38	33.6%
Midwest	24	21.2%
West	21	18.6%
South	20	17.7%
Northeast	10	8.8%
Alaska/Hawaii	0	0.0%
Total	113	100.0%
— Firm Size (Number of Employees) —		
1 to 4 employees	18	15.9%
5 to 9 employees	14	12.4%
10 to 19 employees	25	22.1%
20 to 99 employees	28	24.8%
100 employees or more	28	24.8%
Total	113	100.0%

Table 2. Sources of information used to learn about new building materials. N=113.

Source of information	Count of respondents	Percentage*
Internet	106	93.8%
Industry Events	89	78.8%
Magazines	73	64.6%
Academic Journals	70	61.9%
Research Academics	61	54.0%
Seminars	60	53.1%
Books	58	51.3%
Expos	42	37.2%
Workshops	41	36.3%
Conferences	39	34.5%
Manufacturer's Websites	37	32.7%
Webinars	22	19.5%
Unanswered	3	2.7%

* Multiple responses were possible.

that they use this source to learn about new materials. These results show an opportunity to promote innovative materials through articles and reports published on the internet and in magazines, as well as by introducing them at industry related events.

3.5 Innovativeness

Over the past three decades, many studies have been conducted to evaluate factors that influence the adoption of new materials by consumers (Gatignon H. 2002, Gronross 1997, Rogers 2003). A wide range of factors have been discussed, of which "innovation characteristics" and "adopter's characteristics" stand out. In regard to "adopter's characteristics," the most common criteria include age, education, and income (Arts 2008, Gronross 1997). Hirschman (1980) stated that "psychographic characteristics" are part of "adopter's characteristics," and include innovativeness, defined by the author as *"a driver of adoption intention and adoption behavior as it captures the propensity of consumers to adopt new products."*

To better understand how structural engineering firms perceive their own innovativeness and investigate the willingness of firms to adopt innovative wood-based materials, survey respondents were asked to rate their agreement with several statements related to employee training, the incorporation of innovation in the firm's competitive strategy, and the openness to collaboration between the firm and other organizations. Results for these questions are shown in Figure 2. Research conducted on organizational innovativeness indicates that encouraging employee freedom to explore and innovate positively influences innovative behavior at the individual, team, and organizational levels (Anderson 2014, Shalley & Gilson 2004). Results from our survey indicate that the majority of respondent firms invest in the training of their employees, with 93.8% of firms agreeing or strongly agreeing with the related statement. This is not surprising, given that professional engineers must fulfil continuing education requirements. Similarly, 92.0% of respondents indicated that their firms encourage employees to research new materials. The inclusion of innovation in the corporate strategy seems to also apply to the majority of firms, as 84.1% of respondents agreed or strongly agree with the related statement. Statements with which respondents indicated the most disagreement were those related to collaboration with other firms or institutions; 66.3% of respondents stated they "strongly disagreed" or "disagreed" with the related statement. We hypothesize that the lack of collaboration relates to the market-driven nature of the engineering industry, where opportunities related to the research and development of new technologies or materials are scarce and the primary objective of firms is to deliver the final product, based on the clients' specifications, within the stipulated amount of time and cost, all while minimizing the risk for the firm.

A Pearson's chi-squared test (α=0.05) was performed to determine whether there was a significant relationship between innovativeness and other demographic factors.

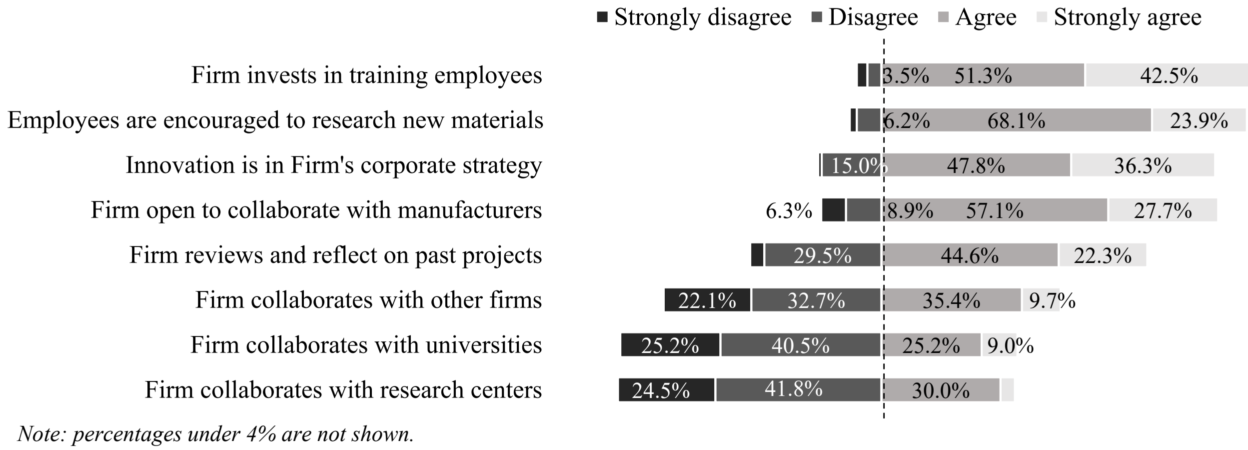


Figure 2. Level of agreement with statements about firm innovativeness. N=113.

No statistical difference was found between location and innovativeness. However, a significant relationship was found between innovativeness and the size of the firm. Table 3 lists criteria for which a statistical difference was found. In the engineering community, innovation is seen as a competitive advantage. However, as in any sector, the successful introduction of an innovation usually requires an upfront investment and carries significant economic risk (Armstrong et al. 2013). Our results indicate that larger firms tend to invest more in innovation than smaller firms. It may be that larger firms have greater financial resources, thus allowing them to be more open to collaboration and innovation. In contrast, collaboration and innovation could be perceived as being more risky to smaller firms trying to stay competitive.

Table 3. Statistically significant association between the size of the firm and innovativeness, as per Pearson's chi-squared test.

Innovativeness dimension	p-value	chi-squared
"Firm collaborates with other firms"	0.003	16.017
"Firm collaborates with research centers"	0.008	13.745
"Firm open to collaborate with manufacturers"	0.001	17.576
"Firm collaborates with universities"	0.002	17.361

3.6 Type of Buildings

Similarly to a previous study to U.S. architecture firms conducted by the authors (Laguarda Mallo & Espinoza 2015), participants of this study were also requested to state all the type of buildings their firm is most commonly involved with. Responses to this question are indicated in Table 4. As expected, per our sampling method, two-thirds (66.4%) of respondents indicated that they work with commercial construction. Other frequent responses included Industrial (46%), Educational (45.1%), and Multi-family (44.2%). Only 23.9% of sampled firms work with single-family residential buildings.

Table 4. Type of buildings that participant firms specialize on. N=113.

Type of building	Count of respondents	Percent*
Commercial	75	66.4%
Industrial	52	46.0%
Educational	51	45.1%
Multi-family residential	50	44.2%
Recreational	43	38.1%
Government	35	31.0%
Transportation	30	26.5%
Religious	29	25.7%
Single-family residential	27	23.9%
Non responses	19	16.8%

* Multiple responses were possible

3.7 Materials Used by Type of Construction

According to an exploratory study conducted by Laguarda-Mallo and Espinoza (2016), decisions regarding the structural material to be used in a commercial, industrial, institutional, or educational construction project are frequently made early in the design process. These decisions are influenced by many factors, including cost, code, and structural requirements. When asked about the materials used with each type of construction, respondents indicated light wood-frame as the primary type of material used for single-family residential construction and multi-family residential construction above foundation (53.1% and 32.5% respectively; see Figure 3). For single and multi-family buildings, light wood-frame construction is generally more cost-competitive than concrete or steel alternatives (Laguarda-Mallo & Espinoza 2016). For taller (more than 5 stories) and larger buildings with complex geometries and greater dead loads (i.e. stationary loads, such as self-weight of structural members), live loads (i.e. loads assumed by the intended use or occupancy of the building), rain, wind, snow, or even, in some cases, earthquake loads (ICC 2015) other materials become more cost-effective. This tends to be the case with commercial, institutional, transportation, and government buildings. Results shown in Figure 3 indicate that for these types of construction, steel, concrete or a mix of both is typically selected. Due to the low response rate for each category tested, chi-squared tests could not be performed to evaluate the relationship between the materials used by each type of construction and other items in the questionnaire.

3.8 Importance of Materials Characteristics

Decisions made during the material selection process are affected by personal materials preferences of construction professionals and priorities set during the design process (e.g. cost, aesthetics, durability etc.) (Laguarda-Mallo & Espinoza 2016) For this reason, firms participating in this study were asked to rate the importance of several materials attributes when selecting construction materials. A 6-point Likert scale was used, ranging from "very important" to "not at all important. Figure 4 summarizes responses to these questions.

Findings presented in Table 4 show that the highest rated attributes that engineers look for in a construction material include "compatibility with building code" (76.1% of respondents rated this attribute as "extremely important" or "very important"), "mechanical properties" (72.6%), "economic performance" (76.1%), "fire performance" (64.6%), "post-construction maintenance" (62.9%) and "availability in the market" (62.8%). LEED credits and acoustic performance did not appear to be a priority of engineers when selecting a material, as only 28.3% of respondents rated these characteristics as "extremely important" or "very important." Similarly to the what was found in the study to U.S. architecture firms conducted by the authors (Laguarda Mallo & Espinoza 2015), attributes that are directly associated to the performance of structural elements are usually related the highest. Authors hypothesize that this is due to the fact that structural performance is intrinsically related to the safety of buildings and its occupants for which construction professionals are legally responsible for (Laguarda Mallo & Espinoza 2015, Pealer 2007, Sido 2006). Other features, including "economic performance," "availability in the market," and "post-construction maintenance", which are commonly associated with the short and long-term cost of buildings (Laguarda Mallo & Espinoza 2015) were also rated high in importance among the engineering firms that participated in this study.

These results were compared to a previous study conducted by Laguarda-Mallo and Espinoza (2015) to

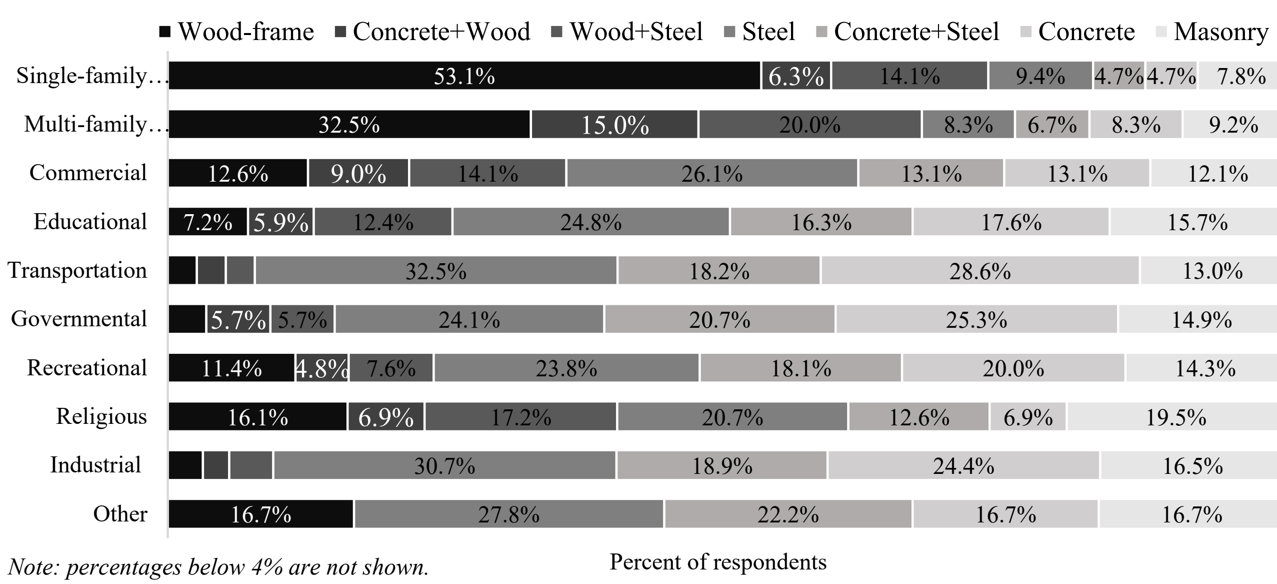
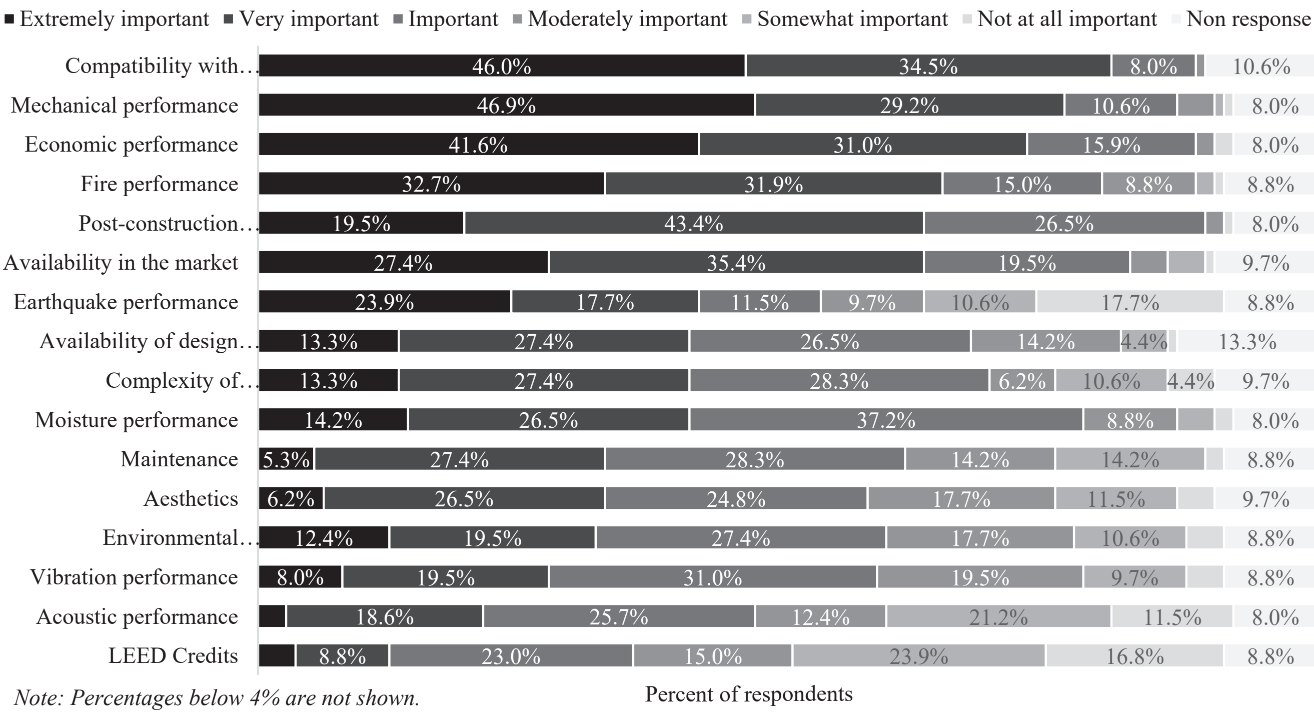


Figure 3. Structural materials (or combination of materials) typically used by respondents for building types listed on the left. N=113.



Note: Percentages below 4% are not shown.

Characteristics on the left are sorted using the two highest importance ratings ("Extremely important" and "Very important"), with the largest percentage at the top.

Figure 4. Importance of the characteristics listed on the left for specifying a structural material. N=113.

identify similarities and differences between architects and engineers. Both professions place considerable importance on the cost and structural capabilities of construction materials, but demonstrate very different opinions toward the aesthetic performance of construction materials. Aesthetics was rated as "Very Important" or "Important" by 94.0% of architects that participated in the previous study (Laguarda Mallo & Espinoza 2015) and by only 6.2% of engineers that participated in the study discussed in this paper.

The results from two previous studies conducted by the authors (Laguarda-Mallo & Espinoza 2014, Laguarda Mallo & Espinoza 2015) indicated that location and size of firm may be associated with the way professionals rate material's attributes. For this reason, chi-square tests at a 0.05 alpha were conducted to determine the validity of this statement. Results from the tests performed indicate that there are statistically significant differences between engineering firms in different locations and how "earthquake performance" was rated (p-value = 0.000, chi-squared = 21.027). This isn't surprising, given that some regions experience seismic events with more frequency and intensity than others (Dieterich & Okubo 1996, Koyanagi, Endo, & Ward 1976). In regard to firm size, responses were significantly different for "earthquake performance" (p-value = 0.006, chi-square = 14.601) and "vibration performance" (p-value = 0.027, chi-squared = 10.961). These results may suggest that smaller firms, which are more likely to be associated with commissioned projects, such as single and multi-family residential buildings, could be placing a higher importance on vibration - a greater concern for these types of buildings than others.

3.9 Level of Awareness

As seen in the introductory section of this manuscript, the first step to the adoption of a new product relates to how familiar of potential consumers are with said product. One of the purposes of this research was to establish the level of familiarity or awareness about CLT among U.S. structural engineering firms. Findings (Table 5) indicate that the familiarity with CLT among engineering firms in the U.S. is low to moderate. A combined 59.3% of respondents indicated that they were "not very familiar" or that they "have not heard about it." This indicates that there is a need for education and training on CLT among the engineering community if this product is going to be more widely adopted in the U.S.

Table 5. Familiarity with CLT reported by respondents? N=113.

Familiarity with CLT	Count of respondents	Percent
Very familiar	13	11.5%
Somewhat familiar	29	25.7%
Not very familiar	45	39.8%
Have not heard about it	22	19.5%
Unanswered	4	3.5%

Due to the low response rate for each category tested, chi-squared tests could not be performed to evaluate relationships between the level of awareness, location, and firm size. Because the rest of the survey questions required some knowledge of CLT, a "skip logic" was set up in the questionnaire to direct those respondents that "have not heard about CLT" to a short description about CLT, its characteristics, and claimed advantages, followed by two questions. The first question addressed the survey respondent's interest in learning more about CLT; the second question addressed the likelihood that the respondent would adopt the system for future projects. Of the 22 respondents that had not heard about CLT, 12 indicated that they were at least "somewhat interested" in learning more about it. With regard to the likelihood that the respondent would adopt CLT for a future project, 5 respondents indicated that it would be adequate while 7 indicated uncertainty. This uncertainty is consistent with the low familiarity of these respondents with CLT.

The following section will explore the responses of those participants of the study that reported having some familiarity with CLT. These participants were ask to indicate how through which source they first learned about CLT. The results in Table 6 show that most firms learned about CLT from the internet, design and construction-themed magazines and conferences (37.9%, 36.8% and 36.8% respectively). The least mentioned media included radio, television, newspaper and word-of-mouth, each of which were selected by less than 7% of the respondents. Respondents were also given the option to indicate whether they heard about CLT from another source. Two respondents indicated that they learned about CLT from a "design partner," one indicated "PE (The Principles and Practice of Engineering) Exam," another indicated "salesman," and one respondent wrote that they heard about CLT through this survey. Beyond the 22 respondents that did not know about CLT, 87 respondents that were familiar with CLT were left for analysis.

Table 6. Sources of information from which respondents learned about CLT for the first time. N=87.

Source of information	Count of respondents	Percent
Internet	33	37.9%
Magazine	32	36.8%
Conference	32	36.8%
Academic Journal	8	9.2%
Relative/ Friend	6	6.9%
Newspaper	5	5.7%
Television	1	1.1%
Radio	0	0.0%
Non-responses	3	3.4%

3.10 Perceptions About CLT

The way potential consumers perceive new products is central in the adoption process. According to Cooney (2014) and Armstrong et al. (2013), perceptions could be as or more important than the actual characteristics of the product. To address this question, participants of this study were requested to rate CLT attributes in comparison to traditional building materials (e.g., steel and concrete). Findings are presented in Figure 5.

The highest-rated features of CLT included "aesthetics," "environmental performance," and "mechanical performance;" which were perceived as "good" or "average" by 51.7%, 51.7%, and 36.8% of respondents, respectively. This is consistent with the results from a previous study of U.S. architecture firms (Laguarda-Mallo and Espinoza 2014), in which aesthetics, environmental and structural performance were also the highest ranked CLT attributes. The lowest ranked characteristics were "availability in the market," "acoustic performance," and "vibration performance," perceived as "good" or "average" by only 3.4%, 8.0% and 9.9% of respondents, respectively. Recent research indicates that due to its massive nature, CLT-based systems achieve good acoustic performance and provide adequate noise control for both airborne and impact sound transmissions, especially if sealant and other types of acoustic membranes are used to provide air tightness and improve sound insulation at the interfaces between floor and wall plates (Sylvain Gagnon 2011, S. Gagnon & Karacabeyli 2013). With regard to availability in the U.S. market, as of October 2016, CLT panels are not yet widely available. Only three U.S. manufacturers exist and only one of which is certified to produce CLT panels for construction under the ANSI/APA Standard for Performance rated CLT (PRG 320 (ANSI 2012)). Due

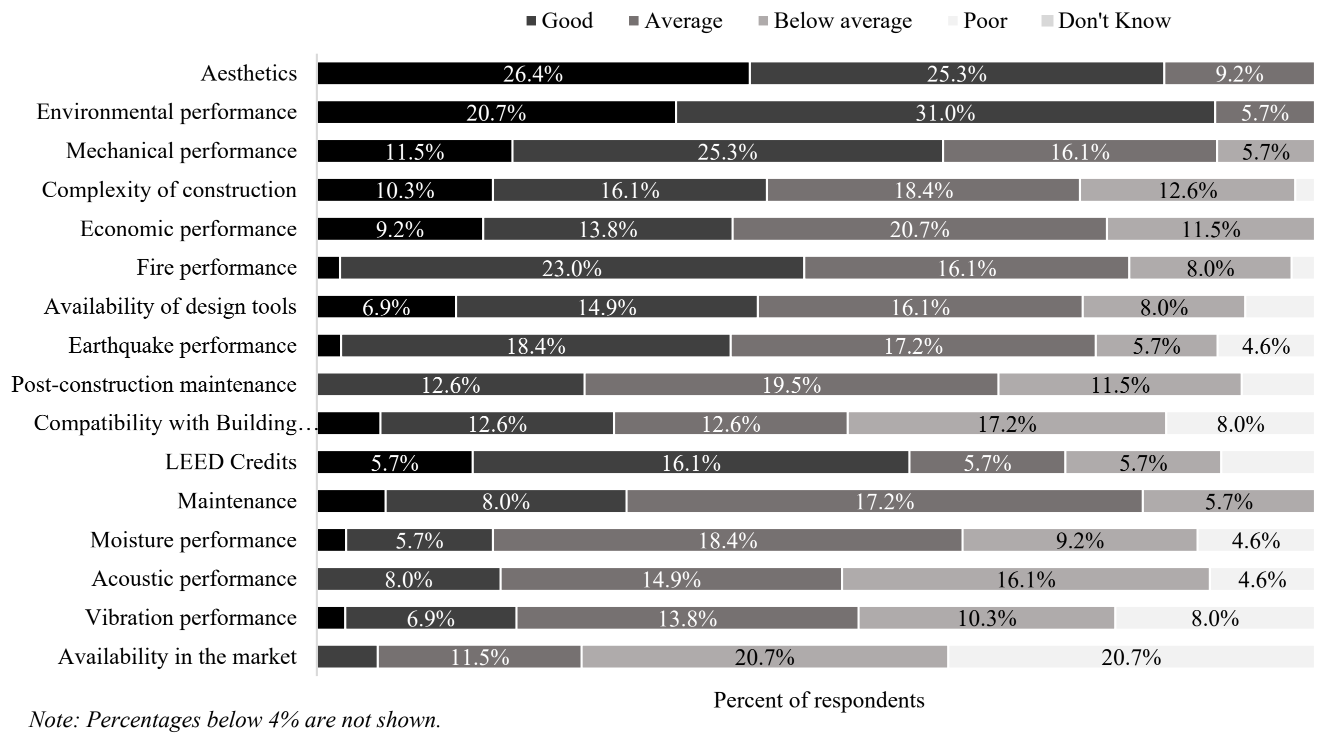


Figure 5. Respondents' perceptions about the performance of CLT compared to other materials (e.g. steel, concrete). N=87.

to the low data count for each category tested, chi-squared tests could not be performed to evaluate the relationship between how CLT attributes are perceived and other criteria within the survey.

3.11 Willingness to Adopt CLT

The third objective of this study was to determine whether the population of interest would be willing to adopt CLT if it were available in the market. This information is essential to evaluate the potential market success of CLT in the U.S. Table 7 presents participants' responses to this question. More than half of respondents (57.8%) indicated that they would be "very likely" or "likely" to adopt CLT in one of their future building projects if it were available in the U.S.; 35.6% were "uncertain" and 12.6% indicated "unlikely" or "very unlikely" to adopt the system in the future. These findings are consistent with the level of awareness reported previously, as more than a third of professionals would be hesitant to adopt a material with which they are not very familiar.

3.12 Barriers to the Adoption of CLT

To comprehend which product or market factors could hinder the widespread adoption of CLT in the U.S. (Laguarda Mallo & Espinoza 2015), participants of this study were asked to rate the importance of a series of barriers. Findings presented in Figure 6 show that "availability in the market" is considered the largest barrier among respondents (85.0% of respondents considered it a large or potential barrier). Second, 78.1% of respondents perceived cost as a large or potential barrier. Third, compatibility with building codes was also considered a barrier, with 75.9% of respondents indicating that the building code is a large or potential barrier. Fourth, the lack of technical information about CLT was perceived as a large barrier by 70.1% of respondents. Furthermore, 69.0% of respondents also indicated "promotion/education" as a large barrier. These results indicate that non-profit organizations looking into the advancement of wood construction could have an opportunity to further educate the U.S. engineering community.

Table 7. Willingness to adopt CLT by respondents, if it were "readily available" in the U.S. for the participants' building projects in the near future? N=87.

Likelihood to adopt	Count of respondents	Percent
Very likely	12	13.8%
Likely	32	36.8%
Uncertain	31	35.6%
Unlikely	8	9.2%
Very unlikely	3	3.4%
Non-responses	1	1.1%

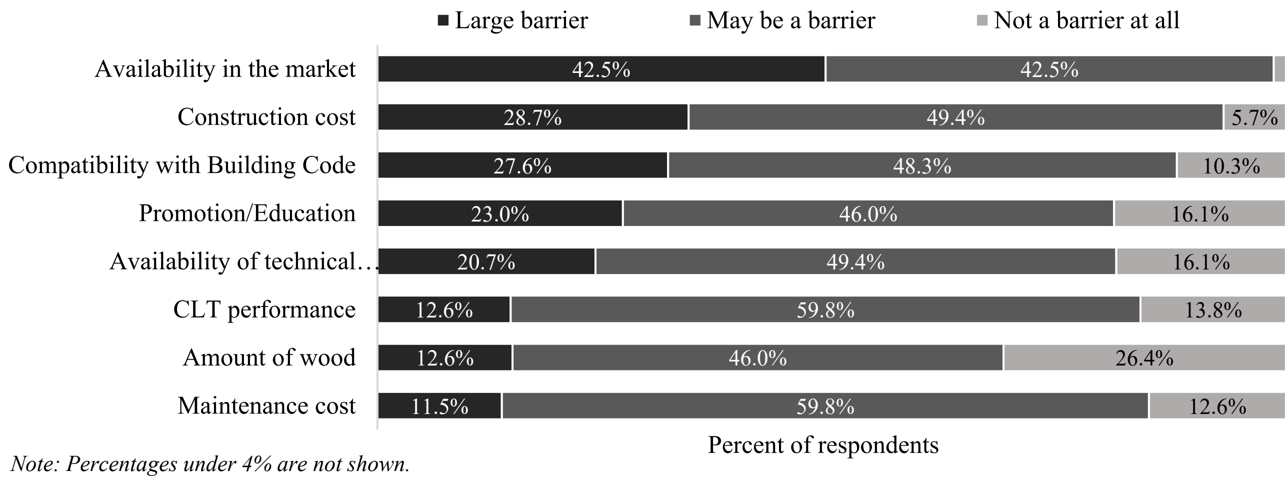


Figure 6. Perceived barriers to adoption of CLT in the U.S. N=87.

Findings also demonstrate that 58.6% of participants of this study believe that the amount of raw material used to manufacture CLT panels could represent a large barrier for the wide adoption of the system in the U.S. Based on the ten expert interviews from the study conducted by the authors in 2014, 6 respondents agreed that the main disadvantage of CLT is the large volume of wood required for its manufacture (Laguarda-Mallo and Espinoza 2014). In the same study, one interviewee with experience in design and calculation of CLT structures estimated that CLT panels use approximately three times the wood a wood-frame system requires. Unexpectedly, however, the amount of wood necessary to manufacture CLT panels was not seen as one of the possible barriers to architecture firms surveyed in a later study (Laguarda-Mallo and Espinoza 2015), which suggests either informed knowledge about the U.S. forest inventory, or a lack of knowledge about the amount of wood required in the production of CLT, which is likely the case given that the level of familiarity with CLT was still low (only 4.3% of respondents indicated they were "very familiar" with CLT). In the present study, respondents were also given the opportunity to indicate any other perceived barriers not listed in the questionnaire. "Other" barriers listed included "no experience" and "contractor education."

Chi-squared tests (alpha = 0.05) were performed to determine whether there was a significant relationship between the level of familiarity with CLT and barriers to adoption of the system in the U.S. Tests indicate that there is a statistically significant relationship between the level of awareness of the respondent and the way the respondent perceives CLT availability (p-value =0.022, chi-squared = 14.732) as well as with the amount of wood required to manufacture CLT panels (p-value = 0.008, chi-squared =17.370). Results indicate a significant relationship between the likelihood of adoption and the availability of technical information (p-value =0.032, chi-square = 13.767) as well as CLT performance (p-value =0.003, chi-square = 19.965), stressing the importance information has on the adoption process. Results also indicate that there is an opportunity to improve the likelihood of adoption by making information about CLT available to potential adopters.

4.0 Conclusion

The primary purpose of this research was to examine the level of awareness, perceptions, and willingness to adopt CLT by engineering firms in the U.S, known as key actors in the material selection process. Finding of this study indicate that the level of familiarity with CLT in the structural engineering community in the U.S. is moderate, as only 13 respondents indicated they were "very familiar" with the CLT system. From all respondents with some familiarity with CLT, 33 firms indicated that they obtained the information from internet, 32 from magazines, and 32 at conferences, seminars or workshops. These findings are consistent with the results obtained from a similar study conducted by the authors with U.S. architecture firms (Laguarda-Mallo and Espinoza 2015).

Results from this study show that the highest rated attributes of CLT are its aesthetic characteristics and its environmental and structural performance. On the other hand, lacking availability in the market was one of the perceived disadvantages of the product, which coincides with the current state and domestic availability of CLT in the U.S. Similarly to what was found in a previous study by the authors (Laguarda Mallo & Espinoza 2015), engineering firms familiar with CLT participating in this survey indicated lacking availability, initial costs, and building code compatibility issues as the largest perceived barriers to adoption of the system in the U.S. Further, a considerable percentage of study respondents perceived CLT performance and maintenance costs as additional barriers. This is consistent with the lack of experience surrounding CLT among U.S. construction professionals. Survey results suggest that engineers would be hesitant to adopt CLT, even if it were readily available in the U.S. market.

Findings of this study show that improving and expanding wood educational programs and making information about innovative wood-based construction systems readily available to potential adopters (e.g. architects, engineers, contractors, etc.) will be of great importance to the CLT market. Certainly, the wide adoption of CLT in the U.S. will take time. Demonstration projects recently developed in the U.S. and Canada may help. The experiences of professional that worked in the design and/or construction of these projects, as well as the perceptions and experiences of end users, could be used to educate professionals and consumers alike on the possibilities of CLT systems and promote its wide adoption across the U.S. Rewards for embracing CLT will also help with the acceptance of the construction system in the U.S., while showcasing CLT's capabilities in demonstration buildings. Information obtained from this study will inform organizations supporting the forest products industry, such as non-profit, government and industry associations, businesses willing to enter the CLT market, and professionals interested in embracing the possibilities this novel system has to offer.

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