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# Perceptions of the Environmental and Health Impacts of Wood Product Use in Buildings: A Survey Among Architects on the United States West Coast

Kendall Conroy[1], Mariapaola Riggio[2]*, Chris Knowles[3]

## Abstract

*Accepted paradigms concerning the built environment are shifting. Sustainability practices now consider the potential impact on human health and well-being in addition to the resultant impact on the natural environment. This changing paradigm is reflected in new sustainable building certification and sustainability assessment tools. In light of these evolving priorities, wood has become an increasingly advantageous construction material. It presents more positive attributes in comparison to other construction materials, such as steel and concrete, including: renewability, a smaller carbon footprint, and human health benefits. Within an increasingly health- and environmentally-conscious field, wood is positioned to meet sustainability demands on multiple levels. Because architects are one of the key decision-makers for building material selection, both their perceptions of the sustainability of wood products and their familiarity with sustainability certification and assessment tools were investigated, along with their knowledge of the relationship between the two. Architects certified by the American Institute of Architects (AIA) practicing on the United States West Coast, a prominent market for the forest product industry and green building, were contacted to complete a questionnaire. The responding architects indicated that they hold an overall positive perception of the environmental and health impacts of using wood products in the built environment, with some concerns about the impacts building with wood can have on forests. It appears that the environmental and health impacts building materials have is important to the responding architects. However, these attributes are currently not as important when compared to aesthetics, codes, and cost in making material decisions for a building.*

*Keywords:* architect perceptions, sustainability, wood construction industry

## 1. Introduction

Our built enviroment plays a fundamental role in our societal goals for sustainable development. Buildings—and the manner in which we design, construct, operate, and maintain them—can have a huge environmental impact. Unfortunately, building construction and operation are currently the largest overall contributors of $CO_2$ emissions in the United States (USGBC 2010). As a result, the construction sector has a larger greenhouse gas reduction potential than other sectors (Ürge-Vorsatz et al. 2007). The sustainability of construction practices is also associated with material sourcing, renewability, and recyclability in the perspective of circular economy (Korhonen et al. 2018).The language of sustainability within the built environment and its implications for designers and other Architecture, Engineering and Construction (AEC) stakeholders is evolving. We are experiencing a paradigm shift in how we conceptualize

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our built environment: sustainability is no longer only considered in terms of energy and resources, but now also includes human-centric factors driven by rapidly changing global conditions (Brown et al. 2018). Among these considerations is population growth; estimates suggest the world population will be at 9 billion people by the year 2050 (Roberts 2011), with approximately 80% of the global population residing in urban areas (Kellert 2004) and spending most of their time indoors (Ott 1988). These projections reinforce the significance of how our built environment impacts human health. This is already recognized in current research (e.g., Kellert 2004), and sustainable building certifications (e.g., Living Building Challenge). Beyond the various sustainability benefits of wood, such as renewability (Forest Products Lab 2010), relatively low embodied energy (Petersen & Solberg 2002), lower carbon emissions (Buchannan & Levine 1999, Gustavsson et al. 2006, Lippke et al. 2010), and overall lower global warming potential (Cole & Kernan 1996, Gerilla et al. 2007, Perez-Garcia et al. 2005), it is also shown to benefit human health in indoor environments (Burnard & Kutnar 2015, Fell 2010, Nyrud et al. 2010, Rice et al. 2006). This could become an especially valuable function of the built environment as people spend more time indoors. Currently, in North America, the utilization of wood products in low-rise residential construction is high; however, the utilization of wood products in non-residential buildings is much lower (Gaston 2014, Kozak & Cohen 1999, O'Connor et al. 2004) making up roughly 10% of market share, with steel accounting for 60%, and concrete accounting for 30% (Robichaud et al. 2009, Softwood Lumber Council 2018). Currently, wood construction in the U.S. is largely feasible in buildings five to six stories or less. However, with the adoption of the new building codes (American Wood Council 2018), mass timber buildings will be allowed up to 18 stories, if fully protected with non-combustible materials, and up to 12 stories with a limited amount of allowed exposed wood. Notably, studies conducted in the last 30 years show that there is potential for an increase in the use of wood products to create more sustainable buildings in the United States: according to Spelter & Anderson (1985) estimates have shown that roughly 90% of non-residential construction in the United States could utilize wood products. More recent findings indicate the potential for an increase in annual wood consumption of up 5.7 billion board feet (13.5 $m^3$) (Bowyer et al., 2016).

The implementation of wood within the built environment depends also on its cultural and industrial perception. Architects are one of the key decision makers for the selection of materials being used in the construction sector (Gaston et al. 2001, Laguarda Mallo & Espinoza 2015, O'Connor et al. 2003, O'Connor et al. 2004). The perception or understanding that architects hold about building materials can differ, resulting in different materials being specified in building design. An architect's perception of wood products and how they perceive the sustainability of wood as a building material are therefore of high importance for stakeholders in the wood products industry or for any persons desiring the replacement of non-renewable construction materials with wood. In past studies, it has been found that architects perceive wood as a more environmentally-friendly building material than other materials, largely as a result of lifecycle analysis (Knowles et al. 2011, O'Connor et al. 2004, Robichaud et al. 2009, Roos et al. 2010). However, in 2015, architects on the US West Coast were found to have lower-than-average knowledge in areas of interest that deal with the environmental impact of wood (Roth 2015).

In comparison with other contexts, such as in the United Kingdom, experts identified changes in the use of wood in "green building" from 2006 to 2012 (Wang et al. 2013). Of these changes, they noted that the development and public awareness of green building has increased. Stakeholders involved in the construction of green buildings have increased their preference for wood, and there has been a rise in acceptance towards new technologies involving wood in green building. This is evidenced by the emergence of mass timber construction applications in the United Kingdom. One area that did not improve from 2006 to 2012 was wood promotion and communication.

Healthy construction has also been a topic of interest in Canada, with experts predicting a movement towards occupant desire for healthier home and living spaces (Spetic et al. 2005, Shaw et al. 2002). While there are differences between the UK or Canada and the US, these findings, combined with recent building code changes discussed earlier, justify further exploration of stakeholder (i.e., architects) perceptions of wood products in the United States.

The research presented in this study provides a current overview of the perceptions of the environmental and health impacts of wood products, as well as the familiarity and use of sustainable building certifications and sustainability assessment tools, among the architects surveyed on the US West Coast. The West

Coast was chosen as it is home to many forest product companies and sustainable building programs, including the Living Building Challenge, created by the Cascadia Green Building Council, and the first statewide sustainable building code created by California, the California Green Building Standards Code. While the concept of sustainability is complex and continuously evolving—entailing multiple dimensions and definitions—this study focuses on categories that correspond to the seminal elements of sustainability. These elements are used to elicit views of sustainability in the built environment and in the context of forest products.

Using information obtained in this study, members of the forest products industry can identify and address the material needs of architects and develop effective communication/educational initiatives to be used with the aim of increasing architects' specification of wood products in the built environment over non-renewable alternatives.

### *1.1 Research objectives*

1. Investigate the current perceptions held by architects from the three target states about the sustainability of wood products.
2. Investigate the current perceptions held by architects from the three target states about the impact wood products have in creating a healthy living environment.
3. Investigate what sustainable building certifications and sustainability assessment tools architects are currently using, and if there is a possible relationship between familiarity with these tools, use of these tools, and their perception of sustainable attributes of wood.

## 2. Literature Review

### *2.1 Environmental impact*

Wood products have been shown to have small carbon footprints (Sinha et al. 2013). As a result, it has been suggested that multi-story wood buildings could be more environmentally friendly than their non-wood equivalents (Hammond & Jones 2008, John et al. 2009, Robertson et al. 2012). Hammond & Jones (2008) looked into cross-laminated timber (CLT) buildings and found that they have about half as much embodied $CO_2$ as equivalent steel or concrete buildings. Robertson et al. (2012) found that a wood-based CLT mid-rise office building consumed 15% less energy than an equivalent concrete building in a comparative cradle-to-gate life-cycle analysis. Another potential environmental advantage of wood is the carbon credit that can be assigned to wood products (Howe & Fernholz 2015), as they sequester the carbon absorbed during the tree's lifespan in the processed material. Some research suggests that wooden buildings have the potential to be carbon sinks (Lehmann 2012, Salazar & Meil 2009, Wang et al. 2013); however, other research suggests that carbon storage is miniscule and cannot be used to offset emissions long term (Buchanan & Levine 1999). Some environmental benefits can be outweighed by energy consumption during transportation of materials, depending on the distances from forest, to production, to site (Cuadrado et al. 2015). Considering the different variables at play, it is important to base communication on factual evidence, as there is a risk of "green washing," real or perceived, in many sustainability communication campaigns (Lähtinen et al. 2017).

### *2.2 Perceptions of wood as a sustainable material: related studies*

Existing literature on specifiers' perceptions of wood products include studies focusing on architects in Sweden (Hemström et al. 2010, Roos et al. 2010) and in North America (Kozak and Cohen 1999, Knowles et al. 2011, O'Connor et. al. 2004, Robichaud et al. 2009). More recent perceptions research focuses on end users (Hammon 2016, Larasatie et al. 2018). Many of the past studies have found that architects perceive wood products to be environmentally friendly (Hemström et al. 2010, Kozak & Cohen 1999, O'Connor et al. 2004, Robichaud et al. 2009, Roos et al. 2010). Work by Knowles et al. (2011), in particular, focuses on design professionals' perceptions of wood as a structural material in "green buildings." The researchers found that design professionals viewed wood—as long as it was Forest Stewardship Council (FSC) certified—as having the least amount of impact on the environment, compared to alternative structural materials (Knowles et al. 2011). Conversely, they found that indoor air quality was a concern associated with using wood products because of formaldehyde emissions from glues used in producing the final product (Knowles et al. 2011).

Recent results of a parallel study aimed to provide current familiarity, use, and perceptions of wood products among the same group of respondents (Conroy et al. 2018). These results showed that responding architects ranked "environmental impact" as the fourth-most important advantage of wood products from a list of eight attributes, following ease of use, aesthetics, and cost. However, when asked about weaknesses of wood products, 16% of respondents said "environmental concern" was a weakness of wood products (Conroy et al. 2018). When broken down by state, respondents from Washington (11%) and California (15%) were less likely to report "environmental concern" than were those from Oregon (22%). Additionally, 4% of responding architects listed "glues/VOCs" as a weakness of wood products and as a human health concern. While this percentage is small, health was also ranked as least important in a list of advantages to using wood products (Conroy et al. 2018). Interestingly, responses to other items in the questionnaire indicate that the responding architects believe the use of wood contributes somewhat positively to reducing human stress, improving indoor air quality, and occupant comfort, which are factors of human health. This could mean environmental impact and health are currently not topics of high concern to architects on the West Coast when making material decisions, although 88% of respondents did respond that material choice is "important" for sustainable design.

## 2.3 Healthy living environment creation

Some sustainable building certifications incorporate human health aspects into their point categories, such as indoor air, lighting, and acoustics. Additional factors that influence human health in indoor environments can include material choice, the shape of the space, and perceptions of the space (Bysheim et al. 2016). The way humans perceive their environments can affect their physical and psychological health (Wade and Tavris 2000). The public has a perception that wood used in building interiors creates a natural, healthy, warm, and relaxing environment (Nyrud & Bringslimark 2010, Rice et al. 2006). Although the use of too much wood has shown to be associated with a "claustrophobic" feeling (Nyrud & Bringslimark 2010), the presence of exposed wood in indoor environments has been shown to have positive impacts on an occupant's health and stress responses (Burnard & Kutnar 2015, Fell 2010, Nyrud et al. 2010, Rice 2006). Additionally, wood may be beneficial for use in health care facilities because bacteria's ability to survive on the material decreases over time (Kotradoyová et al. 2015). Few studies measure factors that impact indoor environmental quality (IEQ) of occupied timber buildings. Stenson et al. (2019) present a monitoring study analyzing indoor air quality, bacterial community composition, and floor vibration of a mass timber building. While the building as whole was found to perform well, the study highlights limitation of using currently available IEQ evaluating criteria, as for instance, the lack of univocal formaldehyde exposure limits (Stenton et al. 2019).

## 2.4 Sustainable building certifications

Sustainable building certifications, sometimes referred to as "green building certifications," are one tool designers can use to create, in theory, a more environmentally-responsible building. These certifications have benchmarks achieved through a credit system, where different credits address specific sustainability concerns. Achieving the benchmark of credits earns a building a certification or rating. The credits typically revolve around minimizing energy and resource use, maximizing occupant comfort and health, reducing waste, and using more environmentally-friendly materials. Some examples of credits pertinent to wood are using FSC-certified wood, sourcing materials locally, and using materials with recycled content. The overarching goal of these green-building rating systems is to reduce the impact a building has throughout its lifecycle. Three prominent sustainable building certification programs in the United States are Leadership in Energy and Environmental Design (LEED), Green Globes, and the Living Building Challenge. Of these three programs, LEED is the most widely used and recognized in the United States. The Living Building Challenge has a "red list" of materials not allowed in certified buildings. Some of the "red list" materials are common to find in wood products (added formaldehyde) or in wood treatments (creosote, arsenic, etc.). These programs apply to both residential and non-residential construction, but award credits differently in different types of construction. Both LEED and the Living Building Challenge assign credits to categories which are related to building occupant well-being and indoor environmental comfort. In particular, the second certification system includes some "intangible" qualities, such as beauty, health, and happiness, among the criteria for the assignment of credits. Comparisons of the role of wood in these green-building systems have been performed by other researchers (i.e., Smith et al. 2006, Bowyer et al. 2008).

## 2.5 Sustainability assessment tools

Material selection in sustainable construction projects is a task that can come with uncertainty. Architects often have incomplete information available to them regarding material choice implications for a building's environmental, economic, and societal impact (Attallah et al. 2017). Two tools for assessing the impact a material can have on the sustainability of a building are environmental product declarations (EPDs), and life cycle assessments (LCAs). An EPD is similar to a nutrition label, but for a material. An EPD is a document that discloses quantified information about a product's environmental impact, including contents of materials and chemical substances; how raw materials are acquired; energy use in production; emissions to air, soil, and water; and waste generated. EPDs are standardized by the International Organization for Standardization (ISO) (ISO 2006:14025). EPDs are created by using LCAs. LCAs are evaluations of all the inputs, outputs, and potential environmental impacts of a product or process during its lifetime (ISO, 2006: 14040). LCAs can consider the whole system from raw material aquisition (cradle), through production (gate), use (site), and disposal (grave), or some subsect of the whole system (e.g., "cradle to gate" vs. "cradle to grave").

Sustainable building certifications, including LEED and Green Globes, have credits achievable by performing an LCA showing the proposed building to have reduced environmental impacts. This is a credit category that has high incentives for wood use, as wood performs well in LCAs when compared to alternative construction materials (Gerilla et al. 2007, John et al. 2009, Lippke et al. 2010, Perez-Garcia et al. 2005, Robertson et al. 2012). Building certifications can also have credits achievable for providing EPDs, of which many are readily available for wood products through the American Wood Council.

# 3. Methods

## 3.1 Target population

The focus of this study was on architects on the US West coast (California, Oregon and Washington) who are certified by the American Institute of Architects (AIA). This target population was chosen because AIA-certified architects are required to meet minimum continuing education criteria in order to maintain their certification, and the AIA served as an accessible sample frame. A list of contacts was generated from membership lists available on the websites for AIA chapters in Washington, Oregon, and California. Only one architect per architecture firm was contacted, with priority on the principal or main contact for the firm. Some architects in this region may not have been included if they were not listed on their AIA chapter's website or did not have an available email. A total of 3,469 architects were identified: 297 from Washington, 172 from Oregon, and 3,000 from California. The three states examined in this study have different laws regulating both forest management and building codes. For example, California has the CalGreen building code resulting in differing legal requirements for California when compared to Oregon and Washington. The differences in these legal requirements provide a natural platform to investigate the impact of these differencs on the adoption and perception of sustainable building tools.

## 3.2 Data collection

Data was collected using an online questionnaire administered through the platform Qualtrics. Participation was solicited via email utilizing the MailChimp email distribution software. Prior to distribution, approval was obtained from the Institutional Review Board (IRB) at Oregon State University. Distribution of questionnaires through Mailchimp began in June and ended in November of 2017. Following an adaption of the Tailored Design Method (Dillman et al. 2014), three rounds of emails were sent to each architect, with each round two to three weeks apart. Emails were sent to one contact per firm requesting that they complete the questionnaire.

## 3.3 Questionnaire

The questionnaire utilized in the study was developed for use in a broader international study with regional focuses on the US West Coast, Central and Eastern Europe, and Sweden (Markström et al. 2018). Prior to use in this study, a focus group was held with regional experts in wood science, forest products marketing, civil engineering, and architecture, to further refine the questionnaire for the context of the US West Coast. The questionnaire included two major sections: (1) familiarity with and perceptions of wood products and (2) perceptions of the sustainability of wood products. Questionnaire items were generated by researchers across these regions, incorporating and building upon questions from previous wood product perception studies (Kozak & Cohen 1999, O'Connor 2004, Robichaud et al. 2009).

Different intertwining concepts related to wood's ability to meet the environmental aspects of being a sustainable material, as well as to contribute to creating a healthy living environment were included in the questionnaire (Figure 1 and Figure 2, respectively).

Questionnaire items were worded equally in positive and negative formats as a means of minimizing any bias.

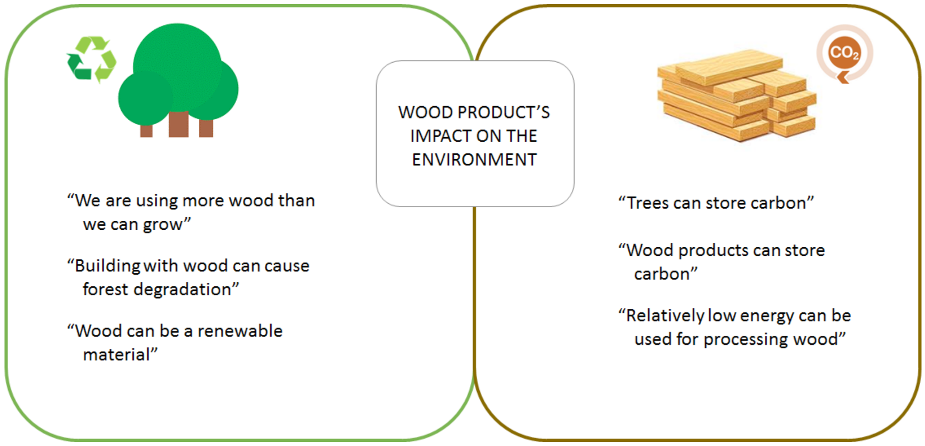



*Figure 1. Conceptual model illustrating questions to investigate architects' perceptions of the impact wood products have on the environment.*


*Figure 2. Conceptual model illustrating questionnaire items to investigate architects' perceptions wood products' ability to create a healthy living environment.*

Items in the questionnaire utilized 5-point Likert-type scales, multiple choice, and short answer options. All questions had an "unsure" answer option to prevent respondents from providing incorrect information on questions, as well as to be able to differentiate on Likert-type scale questions between respondents who were unsure about a question versus respondents who were sure but had a neutral response.

A pretest of the questionnaire was conducted with four architects within the target audience (Dillman et al. 2014). The respondents to the pretest provided feedback helping to improve clarity and validity (Vaske 2008) to better align with the terminology architects use. The responses from the pre-test were not included in the final results.

The present study analyzed 8 of the 22 total questionnaire items, focusing on four sections: environmental impact, healthy living environment creation, sustainable building tools, and respondent demographics (Table 1).

### 3.4 Data analysis

Descriptive data analysis of questionnaire items was conducted with Microsoft Excel (2013 edition). Statistical analysis was conducted by using the software SPSS (version 24.0, 2016). All statistical analysis used $\alpha = 0.05$ for significance levels. One-way ANOVA was used on items comparing groups of architects by state, as well as examining the contribution of materials to occupant comfort, human stress, and other variables. Equal variance was tested between groups; items with equal variance used Scheffe's post-hoc test, and items with unequal variance used Tamhane's T2 post-hoc test. Unsure responses for all items were not included in the statistical analysis because their values disrupt the means. However, items with high percentages of unsure responses were identified and reported where appropriate.

### 3.5 Response rate

The adjusted response rate was calculated as the number of completed responses divided by the remainder of architects emailed minus the bounced emails. Out of the 3,469 architects emailed, 263 emails bounced and 533 architects completed the questionnaire, resulting in an adjusted response rate of 16.6%. This is comparable to response rates in similar studies that reported response rates from architects ranging from 3.7% to 21.4% (Kozak

**Table 1. List of Questionnaire items.**

| Topic | Question | Type[1] |
|---|---|---|
| Demographic | Where is your practice located?[2] | (MC) |
| | What percent of your projects are located in [selected location]? | (MC) |
| | What is your position at your company? | (SA) |
| | How many years of professional experiences do you have? | (MC) |
| Environmental Impact | Please indicate the degree to which you agree with the statements: [3]<br>Wood can be a renewable material<br>Trees can store carbon<br>Wood products can store carbon<br>We are using more wood than we can grow<br>Building with wood can cause forest degradation<br>Relatively low energy can be used for processing wood | (LS) |
| | Do you think that material choice is important for sustainable design? | (LS) |
| Healthy Living Environment Creation | Please indicate the degree to which you feel that the use of wood in a building contributes to:<br>Aesthetics; Connection with nature; Indoor thermal comfort; Indoor air quality; Acoustic comfort | (LS) |
| | Please indicate the degree to which you agree with the statement: "Wood can emit dangerous volatile organic compounds (VOCs)"[3] | (LS) |
| | Please indicate the degree to which each of the following materials (Concrete, Steel, Wood) contributes to:<br>Human stress; Indoor air quality; Occupant productivity; Occupant comfort; Aesthetics | (LS) |
| | Please indicate how important the use of wood in construction is to creating a healthy living environment for the following types of buildings [list of 11 building types see Table 3.2] | (LS) |
| Sustainable Building Tools | Please indicate if you are familiar with and the approximate number of projects where you have utilized the following:<br>Life Cycle Assessment (LCA); Environmental Product Declarations (EPDs); Green Globes; Leadership in Energy and Environmental Design (LEED); Living Building Challenge; Other | (LS) |

1 Questionnaire item types: MC = multiple choice, LS = Likert-type scales, SA = short answer.
2 This item was used for screening at the beginning of the questionnaire, to make sure the sample only included the target population.
3 Same item in questionnaire, results separated for flow.

and Cohen 1999, O'Connor et al. 2004, Robichaud et al. 2009). Washington and Oregon had higher response rates (25% and 42%, respectively) than California (14%). The questionnaire did not require respondents to answer every question, resulting in sample sizes per question varying from 533 to 353. In general, the sample sizes per item trended higher to lower, from the beginning of the questionnaire to the end. There did not appear to be one particular item at which the architects stopped.

### 3.6 Non-response bias

A common concern with surveys is that non-respondents would have answered the questions differently than would those who did respond, resulting in non-response bias (Dillman et al. 2014). To check if there were differences in responses from architects who filled out the questionnaire compared with those who did not, a shortened questionnaire containing 4 of the original 22 items was sent to the architects who did not respond to the first questionnaire; 48 architects responded to the shortened questionnaire. Statistically significant differences were found for the respondents' locations: the proportion of architects from California was lower in the non-respondent group ($p = 0.037$) than in the initial respondent group. For another questionnaire item, there was a higher familiarity/use of three out of five sustainability tools by the non-respondent group (EPD, $p = 0.002$; LEED, $p = 0.015$; LCA, $p = 0.039$) than the initial respondent group. T-tests revealed no statistically significant differences between the groups of respondents for the rest of the non-response bias test, which included architect's years of experience, architect's opinions on whether material choice is important for sustainable design, and the familiarity/use of two other sustainability tools. The results of the non-response bias test should be interpreted with the understanding that California may be underrepresented (due to the lower response rate from Californian architects in the full questionnaire). Furthermore, it is possible that Californian architects may be more familiar with sustainable building certifications and sustainability assessment tools than were the respondents in this study.

# 4. Results and Discussion

## *4.1 Respondent demographics*

Of the 533 completed questionnaires, 13% were from Washington, 12% were from Oregon, and 75% were from California (Figure 3). Seventy-eight percent of respondents indicated that 76%-100% of their projects are located in the state in which their firm is based (n = 533). This means some of the responses could be based on projects in states outside our region of focus, but that a majority of the respondents mainly work within the US West Coast region. Sixty-two percent of respondents held a principal or other management role at their firm; other respondents included designers (17%), designer/managers (18%), technical roles (3%), and just under 1% happened to focus on sustainable design specifically (Figure 4). The number of years of experience respondents had was, overall, very high, which aligns with most of them being the principal of their firm. Of the 398 respondents 62% had more than 25 years of experience, 23% had 16-25 years of experience, 12% had 5-15 years of experience, and 3% had less than 5 years of experience.

## *4.2 Environmental impact*

When asked if respondents thought material choice is important for sustainable design, 88% indicated that it was important, 10% indicated that it was somewhat important, and 2% were neutral (n = 399). Knowles et al. (2011) had similar findings, but with the caveat that building codes and cost take precedence in material decisions.

Figure 5 illustrates levels of respondent agreement to a series of statements related to the environmental impact of wood products, and in particular the impact of raw material sourcing, as described in the conceptual model in Figure 1. Ninety-one percent of responding architects agreed that "wood can be a renewable material." The high level of agreement to this statement is probably due to the possibilistic formulation (can) of the question, which implies that wood renewability is recognized as a fact, if other preconditions are respected. With sustainably managed forests, wood is a renewable material (Forest Products Lab 2010). However, wood's attribute of renewability might not be appropriate if a steady-state balance between consumption and replenishment is not achieved world-wide (Hammond and Jones 2008).

It is interesting to compare the almost unanimity of this response with the varying opinions about the statements "We are using more wood than we can grow" and "Building with wood can cause forest degradation." Forest area in the United States has remained stable, with the volume of wood in the forests increasing (USDA 2011). Conversely, worldwide annual forest growth has a net decrease (Mayo 2015), which may indicate that other countries' forests are less sustainable. It is important to keep location in mind when discussing the sustainability of wood products or the potential contribution these products may have to deforestation. Inconsistencies in the results for these questions could be due to respondents having different geographical locations in mind when responding.

It is worth mentionining that in a one-way ANOVA analysis of respondent answers when grouped by state, the statement about forest degradation was the only statement from this section that showed a statistically significant difference in means ($p < 0.05$), using Scheffee's post-hoc test for equal variance. In particular, respondents from Oregon ($m = 3.76$) were statistically significantly ($f = 3.59$, $p = 0.028$) more likely to agree with the statement "building with wood can cause forest degradation" than were respondents from Washington ($m = 3.11$),where means were taken from a 5-point Likert-type scale with 1 = "disagree," and 5 = "agree." Effect size (ETA = 0.12) was between small and medium (Cohen 1988). This result may be due to the fact that laws governing forest management are more stringent in Washington than in Oregon (Bernstein et al. 2013).

Despite the location an architect had in mind, the questionnaire used the phrase "forest degradation" when the intent was to address deforestation. Forest degradation could have been interpreted differently by different respondents; thus, the associated results should be interpreted with caution.

Levels of respondant agreement to statements addressing carbon storage and energy use in processing are illustrated in Figure 6. These statements reflect criteria used for the assessments of embodied energy of products. It is worth mentioning, however, that in most cases LCA does not assign timber products a carbon credit, since only the emissions from fossil fuel combustion are accounted for in terms of embodied carbon (Hammond and Jones 2008). Eighty-five percent of responding architects agreed with the supposedly obvious statement "Trees can store carbon," and 67% agreed to the statement "Wood products can store carbon." This latter statement, which is not necessarily self-evident for a non-expert audience, is a message the wood product industry actively promotes. How this message has been

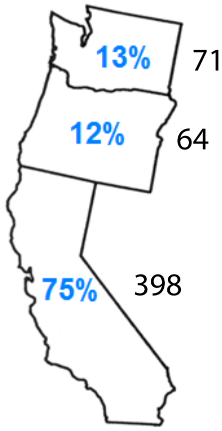



*Figure 3. Respondent's location by state. (Percent and frequency).*

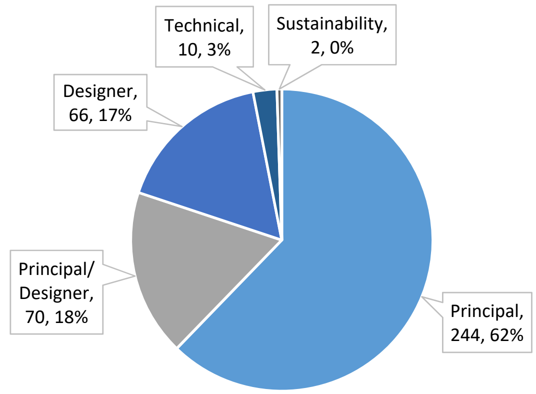



*Figure 4. Respondent's role at their firm (frequency, percent; n = 392).*

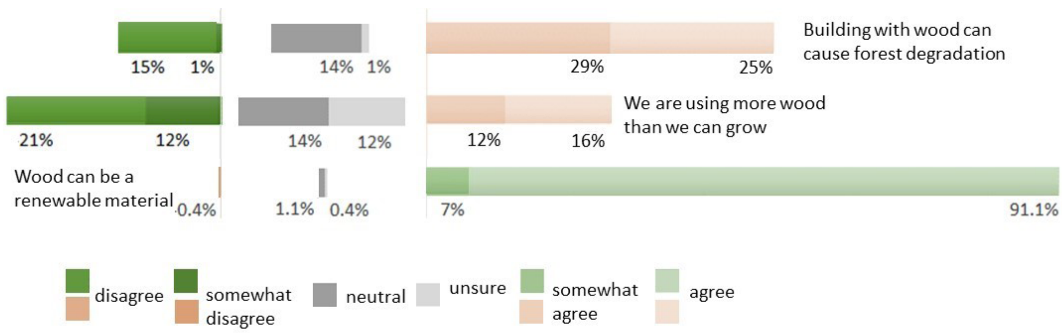



*Figure 5. Levels of respondent agreement to statements related to the environmental impact of wood sourcing (renewability of wood).*

communicated to the architecture community could be an example case to follow for messages not well communicated as of yet.

As for the statement "Relatively low energy can be used for processing wood," respondents had varying opinions (Figure 6), reflecting current ambiguities in the calculation of the embodied energy depending on the applied method (Crawford and Stephan 2013). Even though wood processing typically requires less energy than that required to manufacture other building materials, such as steel and concrete (Buchanan & Levine 1999, Attallah et al. 2017), some processing techniques such as kiln drying and hot pressing of wood composites are energy-intensive processes. Wood treatments and use of adhesives futher increase the embodied energy of wood (Bejo 2017). These controversial elements are reflected in the results, where 10% of respondents disagreed or somewhat disagreed, and 13% of respondents were unsure about energy use in processing wood products. If this statement is true, this is an area the forest product

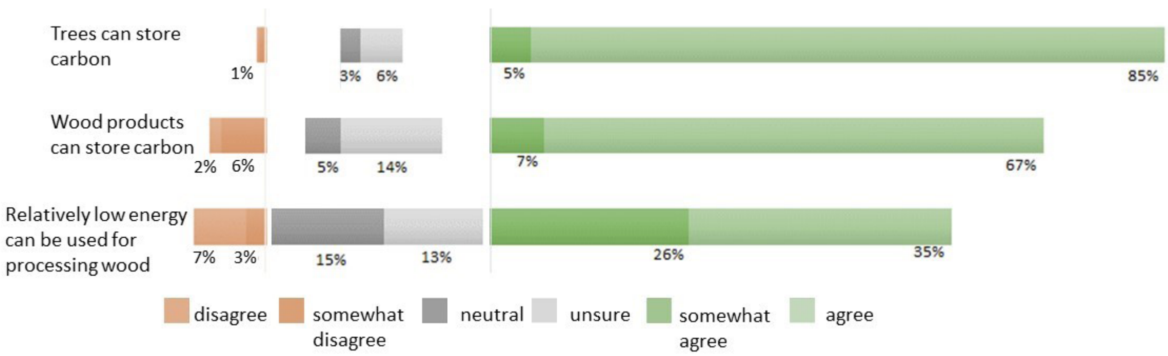



*Figure 6. Levels of respondent agreement to statements related to the carbon footprint of wood products (carbon storage and embedded energy).*

industry could potentially improve perceptions within the architect community by effectively communicating how they operate.

### *4.3 Role of materials in creating a healthy living environment*

Respondents indicated that the importance of wood use to creating a healthy living environment in different types of construction was "somewhat important" in six types of construction. Wood was considered "somewhat not important" in industrial buildings. Interestingly, respondents indicated wood as "neutral" in creating a healthy living environment for health facilities (e.g., hospitals, care facilities, etc.) (Figure 7).

The responding architects reported that wood "contributes positively" or "contributes somewhat positively" to all six of building attributes related to human health: aesthetics, connection with nature, indoor thermal comfort, indoor air quality, and acoustic comfort (Figure 8). Aesthetics and connection with nature had the highest means, and indoor air quality and acoustic comfort had the lowest. Some of these attributes have been reported in past studies. Aesthetics has been reported as a top attribute of wood products by architects (Kozak & Cohen 1999, O'Connor et al. 2004). Indoor air quality has been reported as a concern about using wood products (Knowles et al. 2011). However, responses in the present study indicate that responding architects' perceptions

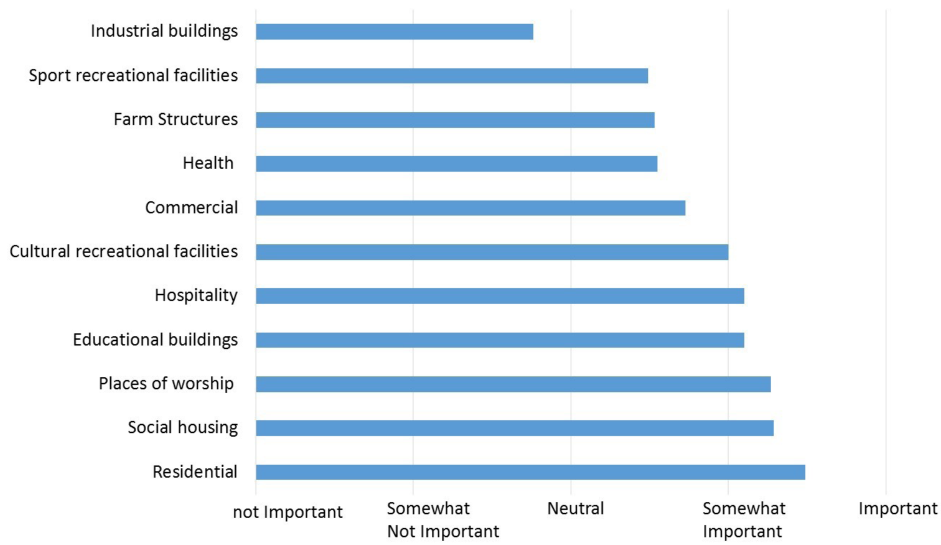



*Figure 7. How important the use of wood in different types of construction is to creating a healthy living environment.*

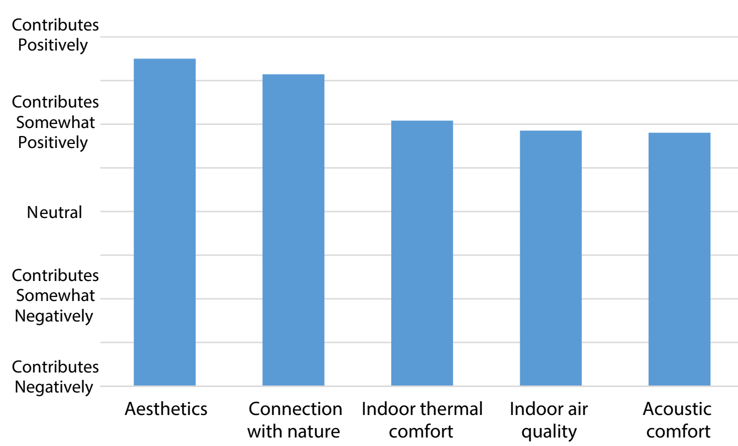



*Figure 8. Respondent opinions on how the use of wood products in a building contributes to various attributes. Chart shows respondents' mean opinions of how wood usage impacts various building attributes.*

might be changing towards the idea that wood contributes somewhat positively to indoor air quality.

When comparing materials, the responding architects indicated that wood had a significantly more positive contribution than did steel or concrete to human stress, indoor air quality, occupant productivity, occupant comfort, and aesthetics (Figure 9).

The results for "aesthetics" coincide with past studies (Kozak & Cohen 1999, O'Connor et al. 2004, Roos et al. 2010). The results for indoor air quality however, have changed since past studies. In 2011, a study reported architects expressing high levels of concern about the impact wood products have on indoor air quality, referencing the commonly used formaldehyde-based adhesives in composite wood products (Knowles et al. 2011). However, the present study, seven years later, shows that the responding architects perceive using wood products in a building as being between "contributing somewhat positively" and "neutral" in impacting indoor air quality. Wood was perceived as significantly better than both steel and concrete. This could be due to regulations for formaldehyde emissions from wood products being introduced or revised since the past study (e.g., California's airborne toxic control measure to reduce formaldehyde emissions from composite wood products).

A common consideration for indoor air quality is the emission of volatile organic compounds (VOCs). Respondents had mixed perceptions regarding whether wood products can emit dangerous VOCs: 42% disagreed, which was the majority response, followed by 19% somewhat disagreeing (Figure 10). Other responses were scattered, including 12% of respondents being

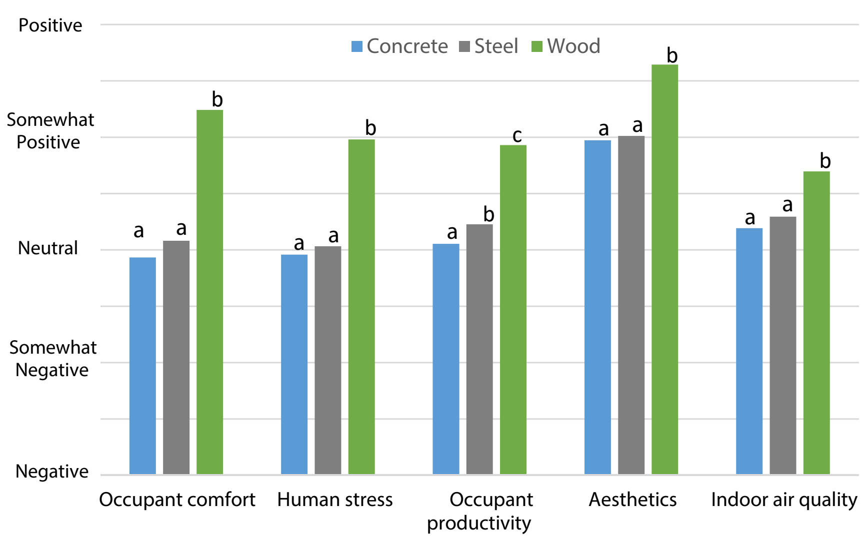



*Figure 9. Respondent opinions on how the use of different materials in a building contribute to various attributes. Chart shows respondents mean opinions of how concrete, steel, and wood usage contributes to various building attributes (n=358 to 378; SD=0.60 to 1.16). Bars with different letters indicate significant differences.*

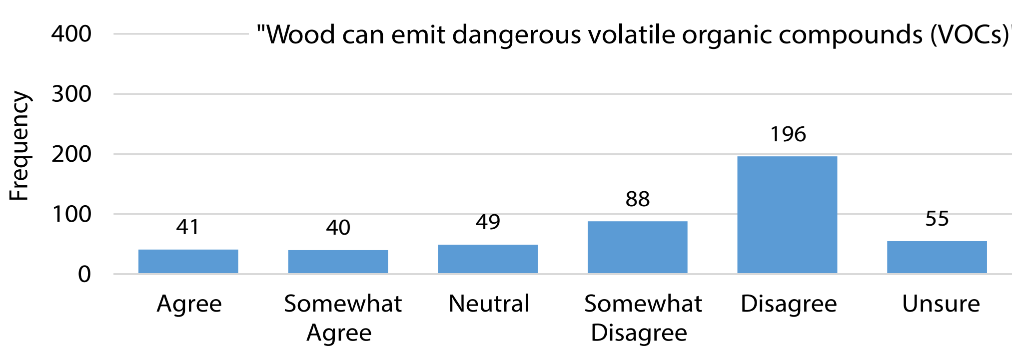



*Figure 10. Levels of respondent agreement to the statement "Wood can emit dangerous volatile organic compounds (VOCs)". (n=469).*

unsure. A study in 2015, surveying architects in the same locations as in the present study, found that responding architects had an "average" knowledge of VOCs (Roth 2015). Wood itself can emit VOCs. As the processing increases, and if glues or binders are added to the product, the VOC levels increase as well (Roffael 2006). Levels of formaldehyde released from composite wood products have been declining as new binders and technologies are developed; this is potentially why the results here show a more positive perception of this topic. For all variables, concrete and steel were viewed as similar by respondents, with the exception of occupant productivity, where respondents found steel to have a more positive contribution than concrete.

### *4.4 Sustainable building tools*

The responding architects were generally familiar with and had used LEED: 96% of respondents were at least familiar with it, and 69% of respondents had used the certification on at least one project (Figures 11 and 12). Respondents were much less familiar with the Living Building Challenge and Green Globes. Sixty-three percent of respondents were at least familiar with the Living Building Challenge, but only 13% had used the certification on at least one project. Green Globes was the least known and utilized, with 60% of respondents being at least familiar with Green Globes, and only 8% of respondents having used it on at least one project.

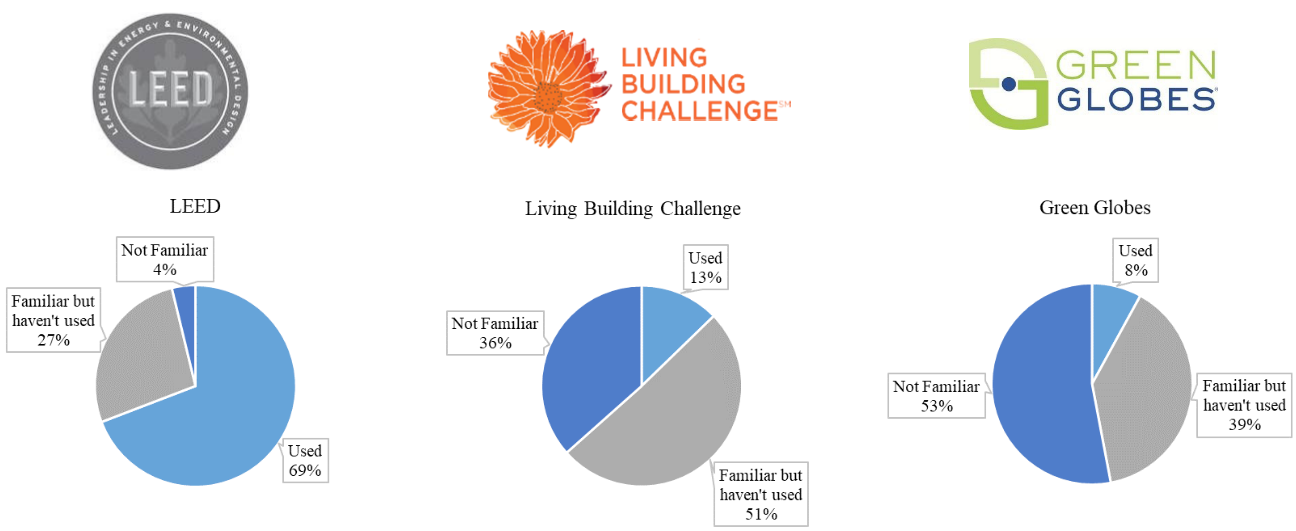



*Figure 11. Respondent familiarity of different sustainable building rating systems. Top left n=376, top right n=370, and bottom n=374. (Logos from: http://leed.usgbc.org/leed.html, https://living-future.org/lbc/, and http://www.greenglobes.com/home.asp)*

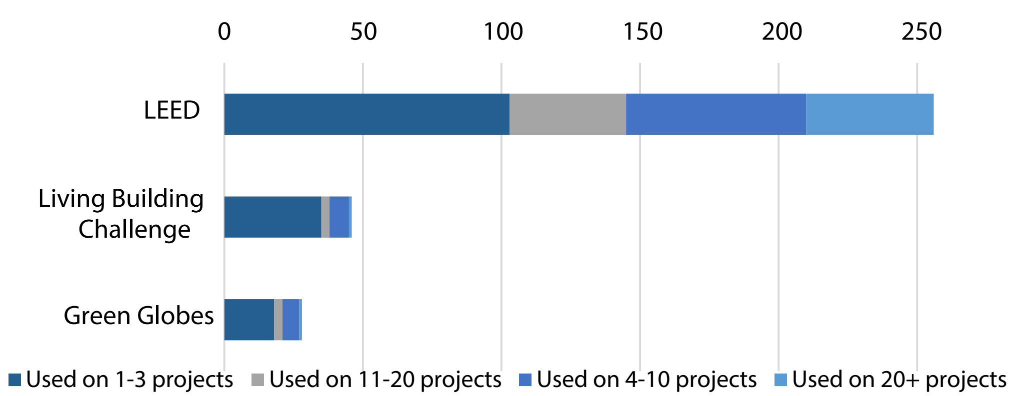
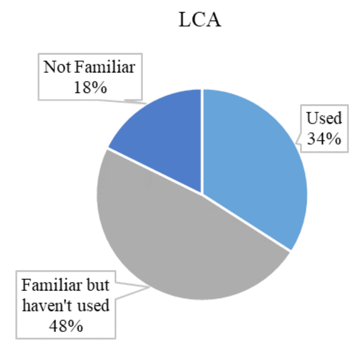



*Figure 12. Respondent utilization of different sustainable building rating systems. From left to right, higher number of projects where a tool has been utilized, to fewer, (n=256, 46, and 28).*

There was an option to specify other sustainable building rating systems the respondents had used. Responses for "other" that were specified more than twice included CALGreen (occurred 8 times), Passive House (7), WELL Building Standard (7), Green Point Rating (5), Build it Green (4) Collaborative for High Performance Schools (4), and Earth Advantage (4).

These results show increased awareness of sustainable building certifications compared with those of another study, which found that responding architects from the same region had an average knowledge of LEED (Roth 2015). However, regarding Green Globes, awareness has not changed since 2015, when it was found that responding architects had low knowledge of the certification (Roth 2015). The Roth (2015) study did not inquire about the Living Building Challenge. The Living Building Challenge was introduced after Green Globes, and has fewer certified projects. It is interesting that responding architects were more familiar with and have used the Living Building Challenge certification more than Green Globes. This could be an indicator that the Living Building Challenge is quickly gaining a strong presence in this region. The forest product industry could thus benefit from ensuring their products can be incorporated into Living Building Challenge buildings by ensuring they are free of "red list" substances. Additionally, the industry could benefit from improving communication regarding how their products can be used in LEED and Living Building Challenge buildings.

The responding architects were generally at least familiar with LCAs and EPDs, but did not use them extensively (Figures 13 and 14). Eighty-two percent of respondents were at least familiar with LCAs, and 34% of respondents had used LCAs on at least one project.



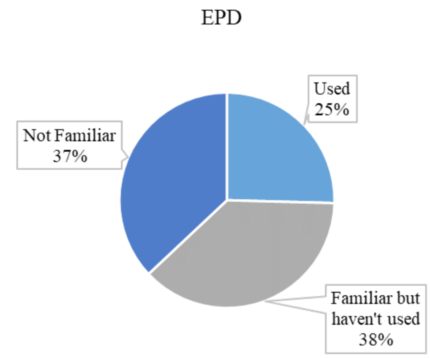




*Figure 13. Respondent familiarity of different sustainability assessment tools (n = 374 and 373).*

Sixty-three percent of respondents were at least familiar with EPDs, but only 25% of respondents had used EPDs on at least one project. These results were surprising because many respondents had used LEED on multiple projects which can utilize LCAs and EPDs for attaining credits. Utilizing LCAs and EPDs with wood products to achieve sustainable building rating system credits may be an area in which the wood product industry could communicate further to the architecture community.

No relationship was found between responding architects' familiarity and use of these tools and their percep-

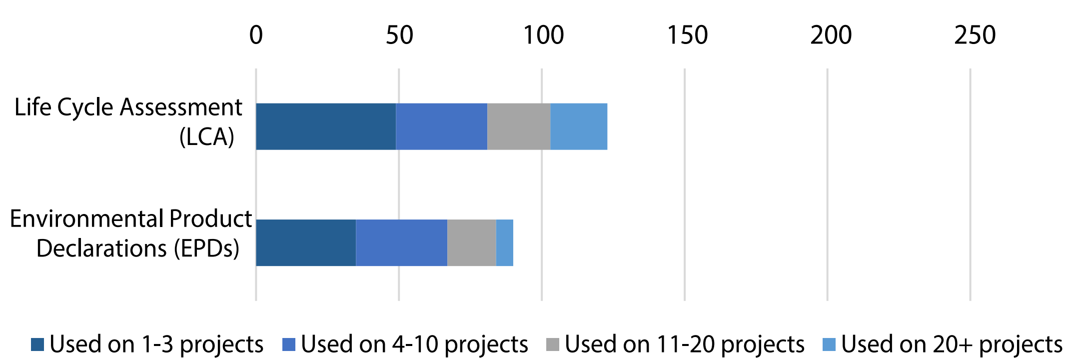



*Figure 14. Respondent utilization of different sustainability assessment tools. From left to right, higher number of projects where a tool has been utilized, to fewer, (n=123 and 90).*

tions of wood as an environmentally friendly material or wood's ability to create a heathy built environment.

# 5. Conclusion

Responding AIA-certified architects on the US West Coast have an overall positive perception of the environmental and health impacts of using wood products in the built environment. There were concerns about the impacts that building with wood can have on forests. It has also been found that forest depletion was one of the top three concerns that the general public from the Pacific Coast had about increasing the use of wood in construction (Hammon 2016). This concern is consistent across different stakeholders in the wood products industry.

Responding architects indicated that LCAs or EPDs are not widely utilized. A majority of respondents were familiar with and use the sustainability rating system LEED, but not many use the Living Building Challenge or Green Globes. Because LCAs and EPDs of wood products can be used to achieve credits in these rating systems, the wood products industry could further communicate this opportunity to architects.

However, while it appears that the environmental and health impacts building materials have is important to the responding architects, they are not as important attributes when making material decisions for a building as aesthetics, codes, and cost. This is confirmed by past studies in other regions, showing that sustainability is not the main quality attribute driving customers in their choice of building materials (Toivonen and Hansen 2003).

It is recommended that the forest product industry focus its communication and education efforts on other attributes of wood products until environmental and health impacts of materials are a higher priority to architects on the US West Coast. Alternatively, effective communication or improved technologies regarding the areas responding architects are currently wary of could further improve the perceptions architects hold regarding the environmental and health impacts of using wood. Since one of the main environmental concerns of respondents is related to the sustainability of forestry practices, targeted and bidirectional campaigns communicating forest sector sustainability are recommended, as also suggested by Lähtinen et al. (2017).

## *5.1 Recommendations for future research*

As sustainability concerns of society increase, the information in this study should be reinvestigated while incorporating any new concerns to ensure that communication addresses relevant issues. Sustainability rating systems focusing on human health could be incorporated (e.g., WELL building standard). Future research could be conducted to address where architects get their information about the sustainability of different materials, how effective the communication is, and how it impacts their perceptions of the environmental and health impacts of wood use in the built environment.

## *5.2 Limitations*

Because of a smaller response rate in California, and statistically significant differences in questions about sustainable building tools in the non-response bias test, the results from California should be interpreted with caution. Additionally, a survey pretest was conducted to help reduce the probability of differing interpretations on items in this questionnaire, but it is possible this still occurred. It is also possible that architects with a more positive perception of wood, or with a connection to the university conducting the research, were more likely to complete the questionnaire. This could explain the higher response rate in the state of Oregon.

In the interpretation of the survey results, it should be noted that some results could have been different if questions were worded slightly differently (i.e., using a more peremptory tone, rather than the adopted possibilistic). Some questions may be considered self-evident statements (i.e., "Wood can be a renewable material," "Trees store carbon," and "Wood products store carbon"). However, they were a useful "litmus test" to evaluate the respondent awareness of some of the most exploited promotional messages of the wood industry.

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