

# Barriers to the implementation of sustainable structural materials in green buildings

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**ABSTRACT:** The purpose of this research was to discover what limits the ability of building design and construction professionals to use environmentally responsible materials in the structural systems of buildings. The researchers interviewed building design professionals in Oregon with experience incorporating structural materials that are more environmentally responsible than the materials used in conventional practice. This research identifies gaps in information as well as gaps in access to or availability of sustainable materials for structural use that will help material producers better understand the needs of designers who are responsible for green material selection as well as identify future research opportunities related to the development and evaluation of green structural materials.

The survey process was divided into two phases. Phase I was a series of eight exploratory interviews with individuals who assisted in refining questions and identifying potential participants in the focus group discussions of Phase II. In Phase II, expert opinion about barriers to implementing sustainable structural materials was collected through interviews conducted in four focus groups. Twenty-two professionals in architecture, engineering, construction and development participated in the interviews conducted in Phase II. Similar survey questions were used to conduct the semi-structured interviews in both phases.

This paper outlines the existing barriers, the role of rating systems such as LEED, and strategies for the increased use of sustainable structural materials and systems. The interviews highlight the need for more concise and credible environmental and economic information, integrated design teams, and analysis tools for comparing alternatives.

## 1 INTRODUCTION

### 1.1 *Rationale*

The impacts of buildings on the natural environment are well documented. The United States Department of Energy (2009) reported that the operation of buildings used 39% of the primary energy consumed and emitted 38% of the carbon dioxide released in the USA during 2006. These numbers exclude the significant environmental impact of manufacturing building materials. Depending on the climate, type of construction and energy efficiency, the embodied energy<sup>1</sup> of a commercial building can equal 2.6 to 4.9 years of operational energy (Cole & Kernan 1996) or 8 to 15% of the primary energy consumed in the USA. The carbon emissions emitted in the manufacture of building materials are also significant as the worldwide production of cement accounted for 4.2% of global carbon dioxide emissions in 2006 alone (Boden, et al. 2009). The

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<sup>1</sup> For the purposes of this paper, embodied energy is defined as the total primary energy consumed during resource extraction, transportation, manufacturing and fabrication of construction materials, known as “cradle-to-gate” or “cradle-to-site” as opposed to the “cradle-to-grave” method of calculating embodied energy that would also include primary energy expended on the maintenance and disposal of building materials (Hammond & Jones 2008).

resource use and emissions from the building sector are a significant part of human activities that have been shown to contribute to global climate change, and even slight changes in climate could have potentially disastrous consequences for physical and biological systems on which humans rely (Rosenzweig, et al. 2008).

To minimize the impact of the building sector on the natural environment, stakeholders, including building owners, developers, architects, engineers and contractors as well as governmental planning agencies and non-profit organizations, have promoted the design and construction of green buildings. A green building can be defined as one built to the standards of a green building certification program, such as the United States Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED) or Green Globes (GG), or one that incorporates multiple sustainability measures across a range of categories including energy efficiency, water efficiency, resource efficiency, responsible site management and improved indoor air quality (McGraw Hill 2008). "Sustainable" or "high-performance" are two other adjectives often used to describe green buildings within the literature reviewed for this paper. Typically, buildings defined as sustainable have economic and social goals outside of the design, construction and operation of the building itself, and those described as high-performance focused more on reducing the operational energy and resource consumption.

While the USGBC Research Committee (2007) has identified the need for more green building research and innovation, there are technologies, materials and design strategies that could be deployed now to reduce the environmental impact of the construction and operation of new buildings. Post-occupancy studies have documented the improved performance of existing green buildings over conventional or baseline buildings (Turner 2006, Diamond, et al. 2006) and over 2,400 buildings have been LEED certified since the inception of the program in 2000 (USGBC 2009). Despite the availability of more sustainable alternatives to normative building design and construction practices, green buildings made up only an estimated 10-12% of non-residential construction starts in 2008 (McGraw Hill 2008). If the knowledge and ability exist to create green buildings, then there must be non-technical barriers that must be overcome to reduce the environmental burden of the building sector.

## 1.2 *Non-technical barriers to green building*

Throughout the existing literature on non-technical barriers to green buildings, the interactions between stakeholders are highlighted as a primary concern. Boden (1996) predicted that a paradigm shift beyond the inclusion of specialty services and manufactures of sustainable technologies would be necessary in the construction industry to realize green buildings. The structure of the industry itself would have to modify as communication and relationships between stakeholders change to meet green building goals. These transformations would face significant barriers from existing policies and regulations, market forces, and the existing structure of the construction industry.

Taking this argument further, green buildings can be viewed as part of a social-technical system that accounts for "functional dependencies and requirements, but also interests, perspectives and the interaction of actors" (Rohracher 2001). The largest barrier to green building is not developing the technology necessary but disseminating it broadly due to the "lack of available services, lack of collaboration between different groups of professional and construction companies, lack of articulate demand, or inappropriate regulations" (Rohracher 2001). In an analysis of the institutional barriers to green building in the Netherlands, the asymmetric distribution of costs and benefits between different stakeholders and the lack of interaction and cooperation between them were noted as major obstacles (van Bueren & Priemus 2002). In terms of disparate goals as well as communication, the gap between those involved with the design and construction of buildings and the end users proved to be the greatest barrier to green building.

The complexity and availability of information about the environmental performance and interaction of building materials and systems is also a significant barrier to green buildings during the design process. Access to consistent, comparable information about building materials is essential to advance the production of green buildings (Jonsson 2000). Yet data about building materials is often incomplete or difficult to interpret, particularly in cases when building project teams are comparing materials produced by different building industries (Seo 2002).

All of the aforementioned research did not include interviews. Therefore, the authors describe barriers that *might* exist in the design and construction of a green building rather than the barriers actually experienced by stakeholders. Williams and Dair (2007) examined five case studies of residential and mixed-use buildings in the UK to determine the barriers to green building. Four of the case studies were randomly selected and the remaining case study was chosen for its “sustainability credentials” in order to compare the processes of a successful green building with those of conventional buildings. Using semi-structured interviews with stakeholders and planning documents, the authors used an analytical framework of sustainability objectives including environmental, economic and social goals as a checklist to compare the case studies. Twelve barriers were identified to meeting the sustainability objectives. The most commonly recorded barrier was that the stakeholders did not consider the sustainability measure. As four of the projects were selected at random and green buildings make up a small portion of existing building stocks, this result is not surprise. Without regulatory or policy requirements, sustainability objectives would only be considered if your goal was to create a green building. The other commonly recorded barriers included a lack of client demand, regulations, cost (or assumed cost), availability or trading one sustainability measure for another.

## 2 METHODOLOGY

### 2.1 Overview

This study focuses on the selection of structural materials and systems in green buildings due to its relative importance and limited alternatives. The design and construction of any building is a complex process involving numerous decisions made by a wide range of stakeholders over the course of months or years. Focusing on one of the decisions made could more clearly elucidate the barriers to green building as a whole. While a wide range of different enclosure and mechanical systems as well as interior finishes exist, every building must have a structural system which typically fall into four categories: steel, wood, concrete and masonry. Nearly one-quarter of the embodied energy of a typical office building can be attributed to the structural materials (Cole & Kernan 1996). The manufacture of structural materials also accounts for significant portion of US and global carbon emissions (Stubbles 2000, Boden, et al. 2009). Consequently, discovering the non-technical barriers to minimizing the environmental impact of structural materials and systems is a critical component of the green building movement.

Through two-phases of semi-structured interviews with stakeholders based in the state of Oregon, expert opinion about the barriers to the evaluation and selection of green materials was collected. Portland, the largest city in Oregon with the metro area containing of over 60% of the state’s population, has a strong green building industry complete with local demand, a critical mass of firms specializing in green building, qualified employees, and a robust supply chain (Allen & Potiowsky 2008). Consequently, this study had a deep pool of experienced and knowledgeable green building professionals from which to draw. By focusing on expert opinion over a representative sample of all building professionals, this study hopes to identify those barriers encountered when stakeholders strive to create a green building over the barriers encountered when green building is not a priority.

### 2.2 Interview Participants and Data Collection

All of the interviewees for this study represent a wide range of the construction industry (i.e. commercial, institutional and residential), have experience with projects of different scales, and are responsible for different aspects of specifying structural materials (Table 1). Half of the participants were LEED Accredited Professionals, and most had worked on a project that had been LEED certified.

The eight participants for Phase I of data collection were selected based on their significant previous experience as part of the design and construction of green buildings. Individual exploratory interviews were held in the Portland area in person or on the phone during December 2008. A questionnaire consisting of eight questions focusing on structural systems in green buildings was used in each of the interviews. Questions included topics such as establishing performance criteria, the influence of green building rating systems, barriers to the use of green

structural materials, information gaps, and the reliability of information sources. The questionnaire did not specifically mention any green structural materials or systems in order to allow the participants to define performance criteria. The primary goal of Phase I was to collect feedback on the questionnaire itself and identify participants for Phase II.

Table 1. Interview participants for Phase I and Phase II of data collection.

	Architect	Engineer	Contractor	Developer	Other*	Total
Phase I	3	2	2	0	2	8
Phase II	9	6	4	2	1	22
Total	12	8	5	2	3	30
Percent (%)	40	27	16	7	10	100

\*Includes green building material and systems consultant, home builders association representative, green building council representative

Phase II of the data collection consisted of interviewing four focus groups of building design and construction professionals. Each focus group included those responsible for the different aspects of structural design and material selection (Table 2). All of the members in a given group had collaborated together previously on at least one green building, so that responses to the questionnaire could reference specific experiences and barriers faced during the design and construction of a realized green building. Using a revised version of the questionnaire employed in Phase I, the Phase II interviews were semi-structured to allow for follow-up questions and discussion to occur amongst group members. Two of the focus groups were interviewed in Portland and two were interviewed in Eugene between March and June 2009. All of the Phase I and II interviews were audio recorded.

Table 2. Interview participant breakdown in Phase II focus groups.

	Architect	Engineer	Contractor	Developer	Other*	Total
Group 1	3	2	1	0	0	6
Group 2	2	2	1	0	0	5
Group 3	2	1	2	0	0	5
Group 4	1	2	1	1	1	6

\*Includes green building material and systems consultant

### 2.3 Data Analysis

Audio recordings of all interviews were transcribed. From the interview transcripts of Phase II, the frequencies of responses and anecdotal quotes were recorded. The semi-structured nature of the interviews makes a quantitative analysis of the results difficult. Consequently, a qualitative analysis was deployed ranking responses as “frequently recorded” (appearing at least once in each of the four interviews), “commonly recorded” (appearing at least once in two to three of the interviews) or “infrequently recorded” (appearing in only one of the interviews). Quotes from participants that provided a succinct description of the aspects of or barriers to green structural material and systems were also recorded.

## 3 FINDINGS

### 3.1 Structural Selection Process

Before discussing the barriers, the focus groups were asked to describe the process of selecting and implementing green structural materials and systems. The responses in Table 3 highlight that there is little difference between how the structure for green building is selected in comparison to a conventional building. There was a clear consensus from all of the groups that the initial selection process typically occurs with little discussion about sustainability. The choice between steel, concrete, wood and masonry is dictated primarily by building codes or the lowest cost.

The type and scale of the building is a priority in the initial selection of material as an office building might need long spans that can only be provided by steel or the acoustic and fire separation of concrete might be required for residential buildings.

Table 3. Performance criteria for structural materials used in green buildings.

Performance criteria	Incidence of criteria
Building code	frequently recorded
Lowest cost	frequently recorded
Height, size, form of the building	commonly recorded
Structural bay size required by the program	commonly recorded

Once the structural material is selected, the stakeholders then determine how to improve the green aspects of the chosen material system. Increasing the material efficiency within the structural system and thereby using less material was by far the most common response from all of the focus groups. This is not surprising as material efficiency within the bounds of safety and serviceability requirements is typically a part of the structural design process of any building. Structural systems such as advanced wood framing and post-tensioned concrete slabs were both discussed as alternatives to conventional systems that can use significantly less material. Reducing the carbon footprint of the selected material, in particular the use of fly ash to replace cement in reinforced concrete and using recycled steel, was the only other commonly recorded response.

### 3.2 Barriers to Green Structural Materials and Systems

From a list of possible barriers, focus groups were asked to comment on the degree to which a given topic, such as cost, had been encountered on previous green building projects. Given the structural design process outlined above, it is not a surprise that the two most frequent design constraints likely to pose challenges when stakeholders attempt to use green structural materials involve cost and code compliance (Table 4). While some alternatives to conventional structural materials can cost more, the larger issue is the assumption made by many stakeholders that green always costs more. As the specifying of a green material can often take place a year or more before the actual purchase and procurement of the materials, there is uncertainty about future costs and availability. Contractors often address uncertainty by increasing the cost of these materials in cost estimates and bids. This potential increase in cost often deters other stakeholders from pursuing the green structural material.

Code compliance is another major barrier to green structural materials and systems as there is currently no incentive for regulatory agencies to include alternative materials and systems. Advanced framing is one such system that can significantly reduce the amount of wood used in platform framed buildings, unfortunately there are no fire-ratings for advanced framed walls. Consequently, the use of advanced framing in multistory residential buildings is limited. Performance-based building codes could address this issue, but stakeholders seldom have the funds in a project budget for testing materials and systems.

Table 4. Barriers to using green structural materials and systems.

Barrier	Incidence of barrier
Increase in cost or perceived cost	frequently recorded
Code and regulation compliance	frequently recorded
Availability of green structural materials	frequently recorded
Client expectations	commonly recorded
Construction time, methods, or quality	commonly recorded
Stakeholders understanding of green options	commonly recorded
Time available to identify and evaluate alternatives	commonly recorded

The last of the most frequently recorded barriers was the limited or variable availability of green structural materials. Interviewees voiced frustration finding adequate quantities of Forest Stewardship Council (FSC) or other certified sustainably harvested wood for projects larger than the scale of a small house. While stakeholders had successfully used fly ash to replace cement in previous projects, the availability of the fly ash in the Portland area was unpredictable and procuring the required quantities of a specific type of fly ash to control the concrete finish and color was difficult.

As the client (owner or developer) has the greatest financial interest in the building and will often have the longest relationship with the building of all the stakeholders, they are also the most risk adverse of all the involved parties. Consequently, the client is often risk adverse to use newer structural materials and systems over those with a proven track record in other buildings. Due to the increased real or perceived cost of green buildings, clients must be one of the stakeholders advocating for the green aspects of the building (see Section 3.4).

One of the commonly recorded barriers included the additional construction time or reduction in quality attributed to contractors and subcontractors unfamiliar with a green structural material or system. Additional construction time can increase cost. With experience, this barrier is diminished significantly. Some interviewees noted that contractors, who first resisted using a new material, often find the green material, such as high-volume fly ash concrete, easier to use than the conventional alternatives.

### *3.3 Information Gaps*

Two of the commonly recorded barriers, stakeholder understanding of green options and the time available to identify and evaluate alternatives, are the result of information gaps about green structural materials and systems. All of the focus groups strongly agreed that the information currently available about green alternatives is not adequate. Consequently, stakeholders are not aware of possible options and do not have the time required to do in-depth research. It was commonly recorded that stakeholders do not trust the information provided by product representatives or literature provided by a manufacture. This is a major issue as most building product research in the US is done by the manufactures of products, and there is little research into how products perform once in place. Consequently, the use of an internet search or asking other building professionals were commonly recorded information sources. Mentioned by three of the focus groups, the Environmental Building News was the only specific information source cited.

### *3.4 Green Building Advocates*

When asked who the primary advocates for greener-than-standard performance objectives for structural materials, both the client and the design team were noted by at least three of the focus groups. As discussed in Section 3.2, the client is the most financially invested and consequently exercises a commensurate amount of authority to cut aspects of the project that cost more or are perceived to cost more than conventional construction. Therefore, the client must be convinced of the value added by incorporating green structural materials and systems.

As the term “design team” suggests, stakeholders involved in the design, including architects and engineers, must work more collaboratively to achieve green building objectives. As outlined in Section 2.1, if one member of the design team, such as the mechanical engineer, is not an integrated advocate for green building it will have a major impact on the efficiency of that system and other interconnected systems as well (see Section 3.6). Consequently, barriers to green structural materials and systems can be better addressed by a design team that has already developed a green building together. Beyond having established a collaborative working relationship, such a team has the experience to understand where the benefits are, where the barriers are, and how to maximize performance with the least effort.

### *3.5 Role of Green Building Rating Systems in Selecting Structural Materials*

One of the most surprising findings is that green building ratings systems, and LEED in particular, had little impact on selecting structural materials. The only commonly recorded benefits were an increased focus on recycled content in structural materials and increasing demand for

FCS timber as FSC is the only certification recognized by LEED for wood. Overall, LEED was considered a “side note” due to the lack of benchmarks for structural materials and systems. LEED contains no incentives for structural systems that use less material. Due to the high recycled of most steel produced in the US and use of fly ash in concrete, the LEED credit for buildings with a certain percentage of recycle materials may actually encourage the use of more structural materials. One structural engineer summarized the situation: “Right now LEED doesn’t care if I specify a design really lazily, and I have 50% more steel in the building.”

### 3.6 Systems Integration

While the primary focus of this study was the barriers to the selection and implementation of green structural materials, the interrelation of technical systems in green buildings allows for the structural system to contribute to other aspects of improved performance and reduced material use. Every focus group noted the ability to use exposed structural concrete and even steel as thermal mass to dampen interior temperature swings, help optimize the size of mechanical systems, and reduce the amount of energy required for heating and cooling (Table 5). Exposed structure, such as concrete walls and floors, can be used in the place of interior finishes or exterior cladding. Similarly a structural system could be selected in part due to its acoustic properties to avoid additional specialized materials or systems. As structural systems are the most permanent and least changed element in a building, the durability and design of the structure affects the longevity of the building. Structural systems might be designed beyond code to provide immediate occupancy after a seismic event, so that buildings don’t need to be torn down and rebuilt. Structural systems could also be designed to accommodate new systems and uses over time to ensure their reuse and avoid obsolescence.

Table 5. Other potential green aspects of the structural system beyond material selection.

Potential green aspect	Incidence of aspect
Thermal mass to reduce heating and cooling needs	frequently recorded
Exposed structure to reduce materials used for finishes	commonly recorded
Acoustic properties	commonly recorded
Integration with other systems or system synergies	commonly recorded
Durability and longevity of the structural system and building	commonly recorded

## 4 CONCLUSIONS AND RECOMENDATIONS

The primary barriers to implementing sustainable structural materials are the perceived increase in cost, regulations that do not recognize new green materials and systems, and the availability of the materials themselves. The lack of readily accessible and reliable information comparing alternative structural materials and systems also poses a significant barrier during the design and selection process. This study also reaffirmed the need for strong collaboration between stakeholders that are experienced and knowledgeable about green building strategies.

To overcome these barriers, new analysis tools that can be used during the design process to compare both the environmental and economic implications of alternative materials and systems. Due to their perceived higher cost, many green initiatives are currently eliminated from projects before the real costs are understood. Increased costs in the structural system could be off set by using less material elsewhere or reducing the size of other systems. Consequently, these new analysis tools cannot look at the structural system in isolation but must include its impact on other aspects of the project. Barriers in the supply chain must be addressed by product manufactures to ensure availability as this study highlights there is clearly demand in Oregon that is not currently being met. Focus groups frequently responded that stakeholders need to know how work in an integrated design process where the different technical systems are more dependent on one another to increase the performance of the building and reduce the resources required to construct it. This would include a better understanding of how different stakeholders approach the design and construction process where current educational and professional models isolate stakeholders from one another.

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