The Green Structural Paradox
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Figure 1: Tepeyac Haven Residence, Pasco, WA. LEED for Homes Gold Rating, 2007.
(USGBC, 2007, “Project Profile”)

CEE600 - Independent Study Research
University of Washington
Department of Civil and Environmental Engineering
April 19, 2008
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“It’s sort of funny from a structural perspective, there’s actually a basic paradox with structural engineering and green design. To be “sustainable” in some way you want more material not less, to allow flexibility to systems for future use and to ensure that they are reused in the next building cycle. The basic question is, should it be more efficient or more robust?”

Craig Schwitter, Buro Happold Consulting Engineers
Former President of SEAONY
(SEAONY, 2006, para. 2)

Introduction

What is the role of the structural engineer in green building? Even though the green building industry is exponentially expanding (see Figure 2), involvement of structural engineers in the sustainable design process is simply not strongly emphasized. However, other engineering disciplines and, notably, the architecture field are very prominent. Market research in the United States is currently focused on the real-time operating costs of building structures, where energy consumption, water use, occupant comfort, and ongoing site (and landscape) management are at the forefront of both the sustainable mindset and traditional capitalistic economics.

Materials research has been more or less relegated to development of green technologies for architectural finishes, such as interior products, flooring and insulation. Not much attention is given to purely structural elements, typically understood as commonplace or necessary building materials (timber, concrete, masonry, metals and some plastics). For example, merely 10 out of the approximately 1200 booths at the United States Green Building Council (USGBC) marketing exposition for their 2007 GreenBuild Expo in Chicago, Illinois were related to structural applications. These related structural products represent only a few possibilities of structurally-oriented “green” thinking: insulated concrete forms (three companies), precast concrete with carbon-fiber reinforcing (one), steel...
framing (one), engineered and sustainably harvested lumber (one) and a handful of pervious pavement and concrete manufacturers (not a directly structural building element, but a related material). Perhaps more surprising was the absence of two of the largest structural manufacturers of residential and commercial products for wood framing, as well as some of the major manufacturers of concrete products. The demand for green structural products is remarkably small. This highlights part of the problem between the structural profession and the green building movement: there is a severe lack of awareness of sustainable design among educated professional and practicing structural engineers.

The amount of information available on the topic of green building is considerable. In fact, it is daunting. Numerous books, articles, and online resources are publicly available on the built environment, sustainable construction and market research. Accessibility of information is a non-issue. It is, however, no simple endeavor to summarize all of this work. Defining the role of the structural engineer actually includes “overarching philosophical and scientific concepts that apply to a paradigm shift toward sustainability” (Kibert, 2005, p. 3) which are perhaps best addressed generally herein, with all the smaller tributary questions to be considered later, in detail, for future studies.

**Purpose**

It is undeniable that the structural engineer plays a significantly influential role in the building process. Trends in the building industry have put architects, contractors and engineers at the brink of cutting edge technology, yet contributions from the structural engineering profession are scarcely documented or nearly all behind the scenes. How much of an effect does the structural engineer have on the green building process when they are typically a secondary consultant to the architect? In essence, the structural engineer is responsible for the building’s composition at conception, which ultimately determines its performance over its life cycle.

**Scope**

This document:

- Defines terms and acronyms used herein.
- Identifies the economic influences of the green building movement and the role of the structural engineer.
- Identifies the environmental responsibility of the structural engineer.
- Briefly addresses social impacts of structural engineering for sustainable construction.
- Identifies the role of the structural engineer as a member of an integrated design team.
- Discusses materials selection and specification process as it relates to role of the structural engineer.
- Identifies weaknesses in the progression of the green building movement related to structural engineering.
- Identifies professional organizations and resources involved with the green building movement related to structural engineering.
- Briefly describes the potential sustainability market and interests for structural engineers in the residential construction industry.
- Presents solutions to be implemented in simple to complex projects that affect the overall level of sustainability achieved during the design and construction process.
- Presents recommendations based on the author’s professional and academic experience to increase the level of awareness in the structural engineering profession about available green building resources.

References are listed at the end of this document, along with additional resources recommended for further study.
**Glossary of Terms**

This section identifies key terms commonly used for discussing the topics of green building and sustainable design.

*Closed-loop system*

The term “closed-loop” identifies a process which strives to minimize waste by keep materials of useable quality and value in the materials cycle by means of recycling, reusing, or refurbishing or salvage. An ideal closed-loop has zero end waste; though building systems are typically far from ideally closed.

*Deconstruction*

Deconstruction is the whole or partial disassembly of buildings to facilitate component reuse and materials recycling (Kibert, 2005). Deconstruction is *not* analogous to conventional demolition.

*Design for Disassembly*

Design for Disassembly (DfD) is a design-stage process which plans for the disassembly and deconstruction of a building structure, “to allow the recovery of components for reuse and materials for recycling, and to reduce long-term waste generation” (Kibert, 2005, p. 299).

*Design for Environment*

Design for Environment, (DfE), also generally referred to as *green design*, is a “practice that integrates environmental considerations into…engineering” over the design life of a building and its components (Kibert, 2005, p. 37).

*Embodied energy*

“Embodied energy refers to the total energy consumed in the acquisition and processing of raw materials, including manufacturing, transportation, and final installation. Products with greater embodied energy usually have higher environmental impact due to the emissions and greenhouse gases associated with energy consumption. However, another calculation, which divides the embodied energy by the number of times the product is utilized, yields a truer indicator of environmental impact. More durable products will have a lower embodied energy per time in use” (Kibert, 2005, p. 44). (See Figure 5 for examples of the embodied energy in building materials.)

*Green building materials*

Green building materials are the “basic materials that may be the components of products or used in a stand-alone manner in a building. Green building materials would have low environmental impacts compared to the alternatives” (Kibert, 2005, p. 274). It is worth noting here that a green or sustainable building material or product is not necessarily environmentally conscious. The concept of “green” is highly subjective and often subject of debate.

*Green engineering*

Green engineering, according to the Environmental Protection Agency, is “the design, commercialization, and use of processes and products, which are feasible and economical while minimizing 1) generation of pollution at the source and 2) risk to human health and the environment. Green engineering embraces the concept that decisions to protect human health and the environment can have the greatest impact and cost effectiveness when applied early to the design and development phase of a process or product” (USEPA, 2007, para. 1).
Integrated design

Integrated design, as applied to the members of the design team, indicates a collaborative and communicative group effort toward achieving an economically, socially, and environmentally sustainable built environment for a building project.

Life Cycle Assessment (LCA)

Life-cycle assessment in the building industry, sometimes termed “cradle-to-cradle” or “cradle-to-grave” theory, compares the environmental performance, resource input, waste output and level of impact of a specific product or process. When using LCA in selection of project alternatives, ideally the product or process with the lowest environmental burden is chosen. The assessment is conducted over the design life of the product or structure, from extraction of materials, through production and end use, and finally disposal or recovery (how it is made, how it is fueled, and how it is disposed). Kibert (2005, p. 285) notes, “LCA is an important, comprehensive approach that examines all impacts of material selection decisions, rather than simply an item’s performance in the building.” LCA is becoming much more mainstream in the building industry as more analyses, data, and case studies of existing and new construction are becoming publicly available.

Life-cycle costing (LCC)

Life-cycle costing (LCC) is a method of cost/benefit analysis for each year of a building’s design life applied to determine if the building systems and components meet the owner’s economic goals (Kibert, 2005). LCC is comparable to conventional first-cost economic analyses.

Structural engineering

Structural engineering is the creative manipulation of materials and forms and their inherent mathematical and physical properties and principles, to achieve an end which meets form and function requirements, is structurally safe under reasonably estimated design loads, and economical and practical to construct.

Sustainability

The broadly accepted definition of sustainability has been stated in the 1987 Brundtland Report issued by the former World Commission on Environment and Development, “Our Common Future” (p. 24):

“Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs.”

Figure 3 is a symbolic representation of sustainability as an intersection of broader economic, environmental and social issues. Sustainability requires equal application and attention to each of these concepts.

Figure 3: Sustainability diagram.
Image by Johann Dréo
(http://commons.wikimedia.org/wiki/Image:Sustainable_development.svg)
Sustainable construction

In 1994, the Conseil International du Batiment (CIB), an international construction research networking organization, defined the goal of sustainable construction as “…creating and operating a healthy built environment based on resource efficiency and ecological design.”

- Reduce resource consumption (reduce).
- Reuse resources (reuse).
- Use recyclable resources (recycle).
- Protect nature (nature).
- Eliminate toxics (toxics).
- Apply life-cycle costing (economics).
- Focus on quality (quality). (Kibert, 2005)

Systems thinking

Systems thinking, also “whole-systems thinking,” is a term referring to the macroscopic consideration of the buildings structure and components in terms of the total energy use, optimizing the parts and internal processes to reduce overall impact on the surrounding ecology. Interconnections between the smaller subsystems are considered wholistically and approached with the mindset of “killing two birds with one stone” in order to create a more environmentally efficient building.

The Three R’s

Implementing the “three R’s” into the traditional design process imply a mindset geared toward Reducing, Reusing, and Recycling building materials. Materials use is an area of the design development process that is significantly influenced by the structural engineer. In sustainable construction (green building, hereafter used interchangeably), designs more often call for recycled or refurbished materials for use in the end structure over new materials. An additional “R” is sometimes considered “Refurbishing” or salvaging of previously used materials to lower inputs of virgin resources into a design.

Whole-building design

Whole-building design is a process which strives to “achieve energy, economic, and environmental performance that is substantially better than standard practice” (Kibert, 2005, p. 13). Success is often the result of integrated design.
Economic Implications

Perhaps it may be best stated that money is the driving force behind the green building movement, at least in the construction industry. Developers constantly strive to lower costs and increase profit margins, making the building industry one of the largest contributors to the United States gross domestic product every year. Approximately 20 billion dollars a year is spent maintaining buildings that are unnecessarily energy inefficient; money which could be saved if improvements or renovations were made (qtd. in Johnston, 2004, p. 82). It is no surprise, then, that the potential savings touted by sustainable construction methods have been embraced by owner/developers, architects, contractors and engineers.

Notably, the annual rate of spending for the construction industry in the United States is roughly 12 trillion dollars per year, as shown in Table 1. Within the past 10 years, green engineering and technology has been a specialty field, with a limited market and interest. Now the green building industry is estimated to be worth around $12 billion dollars per year (USGBC), with an exponential growth rate. Consequently, there is an incredible demand for efficiency and newer technologies.

The USGBC’s LEED™ Rating System’s overwhelming industry acceptance has likely resulted from its authors’ focus on fashioning LEED™ as a consensus-based standard, creating buildings that have higher market value than those that are conventionally constructed (Kibert, 2005). Buildings that are designed to be sustainable typically have much lower maintenance and energy costs. Tangible benefits realized from green real estate range from lower energy cost and water savings, to reduced waste, improved indoor environmental quality, greater employee or occupant comfort and productivity, and lower operations and maintenance expenses. For real estate investors, the reduced costs of green properties can increase rents and building values. McGraw-Hill’s 2006 SmartMarket Report states that buildings renovated to meet green standards can bring three percent higher occupancy rates and a 7.5 percent increase in a building's value. This makes green building an increasingly attractive option, despite its potential for higher initial costs.

On average, green buildings tend to increase first costs by between two and three percent, but they are estimated to use between 25 and 30 percent less energy over their life-cycle than conventional buildings (Van Schyndel, 2007, para. 6). Buildings striving to meet standards set by current green building rating systems typically can reduce energy and water usage by up to 50 percent or greater (USGBC, 2005, “LEED”). In fact, the LEED rating system requires a minimum reduction in power use and water use in order to qualify for green building accreditation.

Value Engineering

Though ultimately greener components will save more money in the long run, often these components are “value engineered” out of the initial project plan. New conservational technologies lack recorded use history, and often are deemed luxuries instead of necessities even with the backing of substantial scientific evidence of their benefits. During the Engineering Green 2007 Conference in Portland, Oregon, owner-developer Gary Christensen suggests that engineers consider the economic influence of their engineering discipline during the value-engineering
process. “If an alternate approach is cost neutral, make the more efficient choice. If the first cost is higher, there may be a tradeoff in another discipline. Energy efficiency increases the value of the building and can trump everything else.” These ideals are significant considerations for the integrated design process in sustainable buildings because many systems are interconnected in building construction.

Johnson et al. (1993, p. 53), however, notes the implications of the structural system specifically and the responsibility of the design engineers: “Systems of structure and the full range of building services including ventilation, electrical installations, water supply and drainage can usually be found in even the smallest building and the degree of complexity often increases with the size of the project. In a large modern building the building services can account for 40 per cent of the total cost of a project and consequently it is important to ensure that the design integrates all of these diverse systems in an economical and elegant manner….The structural system will tend to remain more static. However, as it often defines workspaces it is important for designers to test structural systems against different layouts.”

The structural system has greater impact on the capital project costs than do ongoing maintenance costs due to the massive inputs of bulk materials and labor at conception. “Architects and their projects are at the mercy of first cost. Because buildings are expensive and large, the initial construction cost often dominates all other lifetime costs of the building” (Fernandez, 2005, p. 104). In conventional construction industry practice, a project is sent out for bid and the owner-developer requests prices from contractors for the construction cost. Sometimes this cost also includes design fees from subconsultants, including the structural engineer. Generally, this type of process incorporates “very little science and very much messy accounting that results in a number that can be applied to the construction cost of a building” (Fernandez, 2005, p. 105).

A blossoming branch of value engineering is the concept of performance-based design fees. This type of fee schedule hinges on the overall expectations of the client, measured against actual savings accrued after the building is in use. Performance-based design fees are sensible for engineering disciplines like mechanical and electrical engineers, whose integrated systems consume most of the energy on a continuous basis. Since the structural engineer is generally involved at the front and tail ends of the design project (demolition), these types of fees may not seem feasible or realistic to apply because of time. Often overlooked, however, is that the structure continually protects the other engineering systems and must be carefully designed for performance as well.

**Life Cycle Costs**

During the integrated design process in a green building project, it is often lucrative to perform life cycle cost (LCC) analyses which demonstrate the projected benefits of these components across the entire design life of the building. As Johnson et al. (1993, p. 62) states, LCC “allows comparisons to be made at the design stage in order to examine the merits of investing in the most appropriate option. The technique cannot be used by the design team in isolation and it is necessary to work in close conjunction with the client and his financial and legal advisers. Considering life cycle implications in terms of design as a separate area from low energy cost and low maintenance cost is a way of seeking to achieve a long building life with the minimisation [sic] of maintenance operations.” The diagram, Figure 4, on the following page demonstrates the timeline for design lives depending on the type of structure and proposed use. This is a reference frame for design teams to make informed design decisions for the anticipated life-cycle. Typically, these design-life considerations are made as part of an overall building life cycle assessment, or LCA, which are becoming more common to the industry.
Figure 4: Probability distributions, cumulative probabilities and building types for short-, mid- and long-lived buildings.
(Fernandez, 2005, p. 56)
“Nature, after all, does not use energy efficiently, but it does employ it effectively; that is, it matches the energy needed to the available energy sources” (Kibert, 2005, p. 272).

**Environmental Synergy**

Environmental burden, in a geographic context, can be defined as a function of at least three parameters: population, consumption, and technology (Institution of Structural Engineers, 1999). Where populations are large, consumption is high, but so is access to green technology. On a rural scale, sustainability takes on a different meaning—one of conservation and maintenance of existing environments. In general, sustainable construction always requires an environmentally ethical stance, within the means and bounds of the location. Sometimes the confidence to deviate from the norm is necessary for the benefit, maintenance, or preservation of the surrounding environment.

**Embodied Energy**

Minimizing energy consumption at all stages of construction is key—not just operating energy. The energy of a structural system, as a static component of the building, can be measured in terms of its embodied energy represented by a sum of all input materials (see Figure 5). Kibert (2005, p. 39) states, “The material input is defined as the life-cycle-wide, total quantity (in pounds or kilograms) of natural material physically displaced in order to generate a particular product….The environmental stress caused by an activity is proportional to the quantity of materials removed.” In the meantime, a useful rule of thumb to consider is that the greater the degree of processing or manufacture, the greater the energy consumed (Johnson et al., 1993).

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>EMBODIED ENERGY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregate</td>
<td>0.10</td>
</tr>
<tr>
<td>Straw bale</td>
<td>0.24</td>
</tr>
<tr>
<td>Soil-cement</td>
<td>0.42</td>
</tr>
<tr>
<td>Stone (local)</td>
<td>0.79</td>
</tr>
<tr>
<td>Concrete block</td>
<td>0.94</td>
</tr>
<tr>
<td>Concrete (30 Mpa)</td>
<td>1.3</td>
</tr>
<tr>
<td>Concrete precast</td>
<td>2.0</td>
</tr>
<tr>
<td>Lumber</td>
<td>2.5</td>
</tr>
<tr>
<td>Brick</td>
<td>2.5</td>
</tr>
<tr>
<td>Cellulose insulation</td>
<td>3.3</td>
</tr>
<tr>
<td>Gypsum wallboard</td>
<td>6.1</td>
</tr>
<tr>
<td>Particle board</td>
<td>8.0</td>
</tr>
<tr>
<td>Aluminum (recycled)</td>
<td>8.1</td>
</tr>
<tr>
<td>Steel (recycled)</td>
<td>8.9</td>
</tr>
<tr>
<td>Shingles (asphalt)</td>
<td>9.0</td>
</tr>
<tr>
<td>Plywood</td>
<td>10.4</td>
</tr>
<tr>
<td>Mineral wool insulation</td>
<td>14.6</td>
</tr>
<tr>
<td>Glass</td>
<td>15.9</td>
</tr>
<tr>
<td>Fiberglass insulation</td>
<td>30.3</td>
</tr>
<tr>
<td>Steel</td>
<td>32.0</td>
</tr>
<tr>
<td>Zinc</td>
<td>51.0</td>
</tr>
<tr>
<td>Brass</td>
<td>62.0</td>
</tr>
<tr>
<td>PVC</td>
<td>70.0</td>
</tr>
<tr>
<td>Copper</td>
<td>70.6</td>
</tr>
<tr>
<td>Paint</td>
<td>93.3</td>
</tr>
<tr>
<td>Linoleum</td>
<td>116</td>
</tr>
<tr>
<td>Polystyrene Insulation</td>
<td>117</td>
</tr>
<tr>
<td>Carpet (synthetic)</td>
<td>148</td>
</tr>
<tr>
<td>Aluminum</td>
<td>227</td>
</tr>
</tbody>
</table>

**NOTE:** Embodied energy values based on several international sources - local values may vary.

Figure 5: Embodied energy in building materials. (2030 Inc., “Building Strategies.”)
Buildings are integrated into their surrounding ecosystems. This integration process should minimally disturb the natural habitat, and if possible, restore or improve this original state. The design life of a building has two components, durability and flexibility, which combine to avoid premature failure and obsolescence (Johnson et al., 1993). It may seem that durability and flexibility are paradoxical terms. The structural engineer must understand that “the manufacture of building materials entails energy consumption and this varies widely depending on the product” (Johnson et al., 1993, p. 74). Typically, the most durable materials have high embodied energies (like concrete), where materials that provide structural flexibility for easy replacement (such as wood) are often much lower. It is not necessarily a black and white tradeoff, nor must it be a paradox; durability and flexibility can coexist in a complementary structural system. Creative engineering can achieve the ultimate goal of optimizing both characteristics by carefully selecting materials for the structural system based on the total environmental burden. In a sustainable structure, the best materials selections will meet design criteria for both durability and flexibility, while minimizing the total embodied energy of the building. “To minimise [sic] environmental impact, durable and soundly detailed individual elements should combine with ease of maintenance to create a building of maximum life expectancy” (Johnson et al., 1993, p. 74). Structural engineers, then, are ultimately tasked with creating the basis for the entire building’s environmental synergy.

Climate Change

Little consideration has been given to how human activity and building construction should adapt to potentially significant climate alterations. Global temperature increases must now be considered when forming assumptions about passive design, the building envelope, materials selection, and the types of equipment required to cope with higher atmospheric energy levels (Kibert, 2005). “This is not to say that a greater proportion of our electricity will not be generated without the use of fossil fuels in the medium to long term. However, this is outside our direct control, so, in the meantime, we should take individual responsibility for energy conservation” (Johnson et al., 1993, p. 68). Sustainability has to be central to any design process at all times in order for a project to be a successfully environmentally responsible. The global economy, social structure and environment all play equal roles in creating a balanced product.

On the forefront of market curve are two concepts that are leading the direction of sustainability in the design industry. Both life-cycle assessments (LCA) and building information modeling (BIM) involve highly technical analytical software and drafting packages which can produce wholistic data representing the proposed energy consumption, along with potential climate change impacts, of the building prior to construction. These types of analyses both help to eliminate conflicts in the actual construction phase, and also optimize energy use and materials resources. In the future, these two ideas will likely become embedded in the rating systems and also required technical skills for educated professionals.
The Role of Engineering Disciplines in a Design Project
(Christensen, 2007)

Duty to the Owner/Developer and Architect
Make sure:

The structure stands.
The air blows.
The pipes drain.

Engineer’s Traditional Motivation
Avoid Liability
Meet the Deadline
Avoid Liability
Collect the Fee
Avoid Liability
Repeat

Social Awareness
The social value of structural engineering is not as easy to quantify as economic value, nor as easy to qualify as environmental values. Structural engineers, however, do have a very real social responsibility regarding the preservation and maintenance of public health and safety. When considering green building, the structural engineer is now additionally charged with making sustainable design choices to protect the health and safety of the environment, too; all, of course, while remaining within budget and on schedule. Structural engineers can best provide this social validation to a design project by furthering their education, participating on an integrated design team, specifying green products, working with professional organizations and staying up to date on the latest materials.

Learning Curves
Like trying to teach an old dog a new trick, changing the mindset of the construction industry is a remarkable struggle. The industry’s inability to accept and adopt changes to traditional practice is well-founded in the mantra: “if it ain’t broke, don’t fix it!” Historically, buildings have been designed and erected successfully with increasing safety and growing profits. However, as the green building movement progresses internationally, awareness by clients, the commercial market and the general public is rising. Green buildings are penetrating the U.S. construction market primarily because it offers a sensible and responsible alternative to conventional construction. Sustainable construction provides a morally comforting and practical solution to address issues of environmental impact and resource consumption. Additionally, green buildings virtually always make economic sense on a life-cycle cost (LCC) basis and most systems will recoup their original investment within a relatively short time (Kibert, 2005).

Government institutions and design professionals as well as contractors are lagging behind on the learning curve, mostly out of concern for liability and also for lack of scientific evidence to support most of the newer technologies. “Industry professionals, in both design and construction disciplines, are generally slow to change and tend to be risk-averse. Likewise, building codes are inherently difficult to change, and fears of liability and litigation over the performance of new products and systems pose appreciable challenges” (Kibert, 2005, p. 21)

Breaking Traditions
Fernandez (2005, p. 16-17) writes of the chasm between the disciplines of architecture and the engineering professions as a “cultural distinction” where clearly defined roles based on intense specialization of design have essentially created “gated communities.” Information is distributed
among the separate communities, but not shared across professional boundaries through an equal medium, fueling an “enduring tendency for a growing segregation of technologies from [architectural] design.” The primary mode of communication and distribution of information in the engineering communities are professional documents and scholarly and peer-reviewed research and development journals. In the architectural community, work is primarily announced through periodicals, non-reviewed journals, built work essays, and marketing journals.

The solution seems obvious: education and coordination of the professional technical disciplines in project planning. The integrated design team is essential. Involvement of professional organizations and government agencies is crucial. Innovation and implementation of unconventional designs breaks old traditions. A great wealth of information is available, but the facilities to distribute them are not. In fact, information is divided among the professions and generally not shared. It is important for ecological design to be included in the structural engineer’s educational curriculum such that they can participate knowledgeably in the integrated design process (Kibert, 2005).

### Educating Ecologically

The principles of an ecological education should include an understanding of the application of ecology to the built environment, modeling the building after nature, how to use conventional construction processes to achieve unconventional and sustainable goals, and trying to reversing at least two centuries [since the Industrial Revolution] of design that used the machine as its model and metaphor (Kibert, 2005).

An educational background in ecological growth and development will help the design professional make informed decisions in the green building process. Since government policies are not on the near horizon, it is important that ecological curriculum is implemented oft more of a grass-roots level, starting potentially at the higher education facilities where young engineers are trained, and also on the level of professional societies and organizations as part of their continuing education pledge. “Buildings can, for example, teach how to conserve energy, recycle materials, integrate with nature, and contribute rather than detract from their surroundings….we need a national effort [to] engage students of every discipline in ecological design because our current system of production and consumption is poorly designed”(Kibert, 2005, p. 126).
“We seek spaces that satisfy not only the basic requirements of size and function, but also our beliefs and philosophy. You, your architect, and your builders will define those beliefs in tangible terms that can be made real with wood, steel, glass, and stone. In other words, you have dreams for your home, your architect informs those dreams, and your builders materialize the informed dreams. However, the process is rarely this linear and straight-forward…”

George Watt, Architect
(qtd. in Johnston, 2004, p. 58)

Integrating the Design Process

A large portion of the success (or failure) of a green building project is centered on the selection of the project design team. The design team is typically led by the architect, who is hired by the client. The architect hires out subconsultants in varying disciplines including engineering, in order to meet the project requirements for competent design of the building systems. The building process is a collaborative effort of the architect with structural, mechanical, electrical, city and county officials, land surveyors, contractors, landscape architects, general civil engineers, and interior designers; inevitably, the design process is never quite seamless.

Conventionally, the subdisciplines do not communicate with each other during the design phase. Unless there is a conflict of systems, which generally surface, albeit unfortunately, when project is already in construction, these minds never meet. The integrated design process, as part of the green building mindset, is achieved by a massive collaborative effort and project management to promote communication across these unique disciplines to achieve a better end product, with fewer conflicts in construction. “It is important that this collaboration commences as early as possible, particularly in the design of large and complex buildings, and that it is maintained from the development of initial ideas through detailed design to the eventual construction of a building, for each of these disciplines has a major contribution to make. Thoughtful planning and an integrated approach to design can create buildings that are not only elegant but are also sensitive to their physical setting, economical to build, energy efficient, and which will have a long useful life” (Johnson et al., 1993, p. 45).

Two concepts important in the integrated design process are striving for a purely closed-loop whole-building system and building commissioning.

Closed-Loop Theory

The integrated design team must consider the full extent of their product and materials decisions, from cradle-to-cradle. Ideally, as Kibert (2005) shows in his Table 9.2:

- Buildings must be deconstructable
- Products must be disassemblable.
- Materials must be recyclable.
- Products/materials must be harmless in production and in use.
- Materials dissipated from recycling must be harmless.
Life-cycle assessment (LCA) is a major concept in the application of closed-loop theory; however, it is not often implemented due to its additional cost. It is not always necessary, especially for smaller projects, but does often provide significant cost and environmental benefits for larger projects. Generally, detailed planning on the part of the design team can eliminate the need for these assessments unless a specific element requires an LCA; however, it is becoming a more mainstream technique as the green building industry continues to grow.

Building Commissioning

The building commissioning concept is a recent institution for many green rating systems. The commissioning process essentially invites a third-party mediator to the table of the integrated design team. The commissioning agent’s job is general quality control, as well as noting areas for combining systems and maximizing the potential of materials and their intended use. As a result of this assistance in the project planning phase, generally final construction documents have fewer errors, less construction waste and fewer change orders during construction (Kibert, 2005), and the building systems have a unique synergy which is more ecologically sound than conventional construction.
“There are so many resources that go into new houses and so much of it is built without thinking about it carefully. The house is going to be there for a long time; don’t let it be a missed opportunity.”

Cate Leger, Architect
(qtd. in Johnston, 2004, p. 57)

Materials Selection

The construction industry, which accounts for roughly eight percent of the gross domestic product, uses 40 percent of the annually extracted materials and six billion tons of basic materials per year (Kibert, 2005). Figure 6 shows the total materials used in the lifetime of the average American. Note nearly all of the materials are construction-related. The most influential role that the structural engineer plays during the conception and design/development phases of the project revolves around selection of the building materials for the structural system.

Regarding sustainability, the current approach uses a perspective based on the embodied energy of the building materials. “The basic materials of construction and construction products have changed over time from relatively simple, locally available, natural, minimally processed resources to a combination of synthetic and largely engineered products, especially for commercial and institutional buildings….Today’s buildings are made of a far wider variety of materials, including polymers, composite materials, and metal alloys. A side effect of these evolving building practices and materials technology is that neither buildings nor the products that comprise them can be readily disassembled and recycled” (Kibert, 2005, p. 275).

Selection of building materials and design processes has several implications from an engineering perspective. Traditionally, structural engineers are primarily concerned with basic concepts for their selected structural components such as:

- Design life
- Working loads
- Durability
- Strength
- Stiffness
- Ductility
- Feasibility
- Maintenance
- Economics
- Failure criteria
- Serviceability
- Performance

Additional non-traditional considerations for structural engineers to consider during the design phases of green building projects include ecological concepts not normally addressed in conventional practice. Ideally, all members of the design team, including the structural engineer, would have educational training in industrial ecology or another field related to the built...
environment’s interaction with natural systems. Structural engineers should also incorporate these concepts into their designs to minimize the environmental burden:

- Ecosystem maintenance (or improvement)
- Recyclable materials
- System component reuse
- Materials reuse
- Material minimization
- Material reduction
- Energy conservation
- Health and safety considerations
- Waste minimization
- Footprint minimization
- Innovation in design
- Life-cycle impact
- Transportation costs
- Socioeconomic impact

Still, sustainability, as a complex global issue, is difficult to isolate for application to the very specialized systems of a built environment. If the material resources are creatively engineered for simplicity and efficiency of application, the complexity fades and the building tends to complement its surroundings, rather than distract from them.
“Engineers ... are not mere technicians and should not approve or lend their name to any project that does not promise to be beneficent to man and the advancement of civilization.”

John Fowler
(http://www.ukcivilengineering.co.uk/quotes.html)

Green Specifications

Since the Industrial Revolution, the term “conventional construction materials” has included concrete, steel, timber, masonry and some plastics. Newer technologies have been developed more recently, which may be considered during green design to minimize environmental impacts and satisfy building requirements. For example, wood products have been developed as engineered lumber that has superior engineering properties, with increased load carrying capacity for longer spans. Similarly, concrete has evolved specialty techniques to improve the stiffness and limit cracking in slabs and other concrete elements through the use of prestressing reinforcement or fiber-reinforced polymers. However, Fernandez (2005, p. 46) notes:

“[The] ‘traditional’ materials continue to provide the majority of primary materials for buildings today, while the addition of aluminum and polymers in all forms will continue to affect the overall diversity of materials used in buildings.

Therefore, despite anecdotes to the contrary, buildings do contain many of the same materials that were used before 1900. However, important improvements to those materials, changes in their placement within architectural assemblies, overall mass of the material used for particular purposes, and the nature of the craft used during the process of construction have all changed dramatically. In addition, while many traditional materials are used, their proportional contribution to the mass of contemporary building has radically changed. The change in the proportion of various materials used in buildings has resulted in some important trends, including the increased use of nonrenewables and the emerging priority to account for the embodied energy of architectural assemblies.”

Green Materials

What makes a material green? “The selection of building materials and products for a high-performance green building project is by far the most difficult and challenging task facing the project team” (Kibert, 2005, p. 271).

Table 2: What Makes A Product Green?
(qtd. in Kibert, 2005, p. 280)

<table>
<thead>
<tr>
<th>Traits of Green Building Products</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Products are made from environmentally attractive materials</td>
<td>Salvaged or recycled materials and new materials from renewable sources.</td>
</tr>
<tr>
<td>Products that are green because of what is not there</td>
<td>Materials designed without containing ozone-depleting substances or substances harmful to human health.</td>
</tr>
<tr>
<td>Products that reduce environmental impacts during construction, renovation, or demolition</td>
<td>Easily disassembled connections to minimize waste.</td>
</tr>
<tr>
<td>Products that reduce the environmental impacts of building operation</td>
<td>Products that reduce waste or materials that reduce heating or cooling loads.</td>
</tr>
<tr>
<td>Products that contribute to a safe, healthy indoor environment</td>
<td>Materials that contain do not off-gas or those which help prevent the growth of indoor molds.</td>
</tr>
</tbody>
</table>
Standard construction materials, such as wood, concrete, metals, and plastics have varying and subjective degrees of “sustainability” or “greenness.” During the materials selection process, again, it is useful to consider the total embodied energy of the material and also, where appropriate, perform life-cycle assessments to determine the projected environmental costs and benefits of the material. Products that are labeled sustainable or green should be priority, and where possible the highest recycled content should be incorporated. For example, sustainable wood products in the United States are governed by the Forestry Stewardship Council FSC-Smartwood Program and Scientific Certification Systems. These wood products are a “greener” choice because they come from sustainably managed certified forests. Also, approximately 60 percent of steel is recycled (over the past 20 years) and approximately 95 percent of aluminum is recycled (Fernandez, 2005). Plastics require careful consideration as a material option because they are fossil-fuel derivatives. Some plastics are also not recyclable, so waste management plans should be implemented to retain this material for reuse instead of disposal at the end of the design life.

Concrete and concrete derivatives require a cradle-to-cradle perspective; though it has a very low embodied energy, most of the environmental impact of concrete is actually contributed by the manufacturing process itself (due to the high input of fossil fuel energy), including emissions from the extraction of materials, like aggregates, and production plants that make cement. However, it is arguably the most durable (some would say “sustainable” as far as providing an extended design life) and robust material, which can also be recycled at deconstruction. The industry is currently striving to make the concrete manufacturing process greener; “Ecologically improved and sustainable materials for concrete are an important part of the research effort now and will surely be ever more important as stresses on material resources and energy increase. The topic is a multifaceted one because it involves the impact of processing, construction, demolition and waste produced from the use of concrete in buildings. The use of materials and the emissions associated with these processes should be examined individually and opportunities for improvements should be sought” (Fernandez, 2005, p. 218-219).

**Waste Management and Minimization**

In the United States, the 145 million tons of construction and demolition waste comprise about one-third of the total annual solid waste stream, which equates to 5-10 pounds per square foot of new construction and 70-100 pounds per square foot from renovation. “The demolition process results in staggering quantities of waste, with little or no reuse or recycling occurring,” which alone is the culprit for 92 percent of that waste (Kibert, 2005, p. 298).

Waste management planning is generally not the responsibility of the structural engineer. However, Kibert (2005, p. 357) states “source reduction [in the construction and demolition waste management plan] is the most relevant to new construction and large renovation projects, as it involves reduced ‘waste factors’ on materials ordering, tighter contract language assigning waste management responsibilities among trade contractors, and value-engineering of building design and components.” Since the structural engineer is responsible for the main structural components of a building, i.e. the largest portion of the buildings mass, there is an indirect responsibility to handle the selection process for these materials very sustainably, while keeping the end of the design life in mind.

The structural engineer should involve him/herself in the design process such that text regarding recycling or salvaging structural materials is included in the original contract documents for the project. “On many construction projects, recyclable materials such as wood, concrete and masonry, metals, and drywall make up as much as 75 percent of the total waste stream…” (Kibert, 2005, p.
The structural engineer should provide a detailed list which indicates the degree of recyclability and salvagability, keeping project costs in mind and also including any special handling rules to maintain integrity of material through the demolition process. Additionally, the structural engineer should assist in general education of the contractor and subcontractors to familiarize them with the components of the structure and discuss waste prevention and management opportunities. “For a green building project to meet its objectives, the subcontractors must be made aware of how the building project differs from a conventional construction project” (Kibert, 2005, p. 361).

Table 3: Problems with Designing for Deconstruction
(Kibert, 2005, Table 9.8)

<table>
<thead>
<tr>
<th>Problem</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buildings are custom-designed and custom-built by a lengthy roster of participants.</td>
</tr>
<tr>
<td>No single “manufacturer” is associated with the end product.</td>
</tr>
<tr>
<td>Building systems are updated and replaced at intervals during the building’s lifetime</td>
</tr>
<tr>
<td>The connections of building components are defined by building codes to meet specific objectives (e.g. wind load, seismic requirements), not for ease of disassembly.</td>
</tr>
<tr>
<td>Historically, building products have not been designed for disassembly and recycling.</td>
</tr>
<tr>
<td>Buildings can have a very long lifetime exceeding that of other industrial products; consequently, materials have a long “residence” period.</td>
</tr>
<tr>
<td>Aggregate, for use in subbase or concrete, brick, clay block, fill, and other products derived from rock and earth are commonly used only in building projects.</td>
</tr>
</tbody>
</table>

Closed-Loop Design and DfD

Kibert (2005) states, “the vision of a closed-loop system for the construction industry is, by necessity, one that is integrated with other industries to the maximum extent possible. Many materials – again, [like] metals – can flow back and forth for various uses, whereas others, such as aggregates and gypsum drywall, are unique to construction, so their reuse or recycling would stay within [the] construction [industry]. Closing materials loops for the built environment will be much more difficult due to the factors that make its materials cycles differ significantly from those of other industries.” (299) For a structure to be environmentally neutral or low-impact, a savvy structural engineer will plan for a simple deconstruction process following the cardinal rules of reduction of waste, reusing existing materials, and recycling old materials; this becomes imperative for consideration during the initial design process. Tables 3 and 4 show typical problems that should be considered by the structural engineer, as well as concepts that may be incorporated into the final construction plan and design documents, respectively.
### Table 4: Project Planning for Deconstruction
(Kibert, 2005, Table 9.9)

<table>
<thead>
<tr>
<th>• Use recycled and recyclable materials.</th>
<th>• Use modular design.</th>
<th>• Design joints and connectors to withstand repeated assembly and disassembly.</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Minimize the number of types of materials.</td>
<td>• Use assembly technologies compatible with standard building practice.</td>
<td>• Allow for parallel disassembly.</td>
</tr>
<tr>
<td>• Avoid toxic and hazardous materials.</td>
<td>• Separate the structure from the cladding.</td>
<td>• Provide permanent identification for each component.</td>
</tr>
<tr>
<td>• Avoid composite materials, and make inseparable products from the same material.</td>
<td>• Provide access to all building components.</td>
<td>• Use a standard structural grid.</td>
</tr>
<tr>
<td>• Avoid secondary finishes to materials.</td>
<td>• Design components sized to suit handling at all stages.</td>
<td>• Use prefabricated subassemblies.</td>
</tr>
<tr>
<td>• Provide standard and permanent identification of material types.</td>
<td>• Provide for handling components during assembly and disassembly.</td>
<td>• Use lightweight materials and components.</td>
</tr>
<tr>
<td>• Minimize the number of different types of components.</td>
<td>• Provide adequate tolerance to allow for disassembly.</td>
<td>• Identify point of disassembly permanently.</td>
</tr>
<tr>
<td>• Use mechanical rather than chemical connections.</td>
<td>• Minimize numbers of fasteners and connectors.</td>
<td>• Provide spare parts and storage for them.</td>
</tr>
<tr>
<td>• Use an open building system with interchangeable parts.</td>
<td>• Minimize the types of connectors.</td>
<td>• Retain information on the building and its assembly process.</td>
</tr>
</tbody>
</table>
Professional Resources

Construction documents are probably the most important product of the structural engineer. Heightened awareness of the availability of resources, natural, human or otherwise, always leads to a more comprehensive set of structural drawings and calculations. The role of higher education and professional organizations in the development of these pathways is enormous. For green engineering processes to be a success from cradle to grave, human resources become the driving force behind that success.

Professional organizations, one of the most influential types of human resources, should promote the existence and welfare of the blossoming market and strive to educate their associates and members. Professional affiliations are also one of the most lucrative environments for knowledge exchange between registered engineers. Without awareness and a solid background, or a technological ambition for invention and creativity, no green structure will be a success.

This section provides a brief, and by no means all-inclusive, synopsis of the resources (both non-human and human) available to the public regarding green and sustainable design or engineering.

Databases

Two major public resources are available through the internet, which provide information on green building, green products and other sustainability topics.

GreenSpec

Also known as “BuildingGreen.com,” this is a commercial resource available for public use. It is invaluable for the aspiring green engineer because it contains contact information for distributors and retailers of every imaginable kind of eco-conscious product. The website is http://www.buildinggreen.com and the information contained on this site is published regularly in the GreenSpec Directory.

Pharos

The Pharos Project is an open-source materials selection tool, currently in the beta version, that is available to all materials specifiers via the world wide web at http://www.pharosproject.net.

National and International Organizations

National and international organizations play a major role in changing and shaping the direction of the building industry. Corporate sponsors, investors, project managers and design professionals create a massive resource network by holding membership in these groups.

USGBC

The United States Green Building Council (http://www.usgbc.org) is the formative resource in the nation for sustainability practices and resources. They are a non-profit made of up numerous building industry corporations and individuals working to advance “structures that are environmentally responsible, profitable, and healthy places to live and work. Members includes building owners and end-users, real estate developers, facility managers, architects, designers, engineers, general contractors, subcontractors, product and building system manufacturers, government agencies, and nonprofits.” The USGBC currently manages the LEED™ green building rating systems and distributes LEED™-certified building awards.
NAHB

A conglomeration of state and national trade-organizations, the National Association of Home Builders (http://www.nahb.org/) is based in Washington, D.C. “striving to enhance the climate for housing and the building industry. Chief among NAHB’s goals is providing and expanding opportunities for all consumers to have safe, decent and affordable housing.” NAHB publishes a free document for voluntary use in residential construction called Model Green Home Building Guidelines.

SBIC

Formerly the Passive Solar Industries Council, Sustainable Buildings Industry Council (SBIC) was founded by the major building trade associations in 1980. More information is available at http://www.sbicouncil.org/.

Other

Canada, Mexico, Japan, Australia and the United Kingdom all have individual government installations which deal with green building. Additionally, several “think-tanks” exist for the research of the construction industry, such as the Conseil International du Batiment (CIB), an international construction research networking organization; the International Union of Laboratories and Experts in Construction Materials, Structures and Systems (RILEM), which promotes scientific developments in the construction industry and professions; and International Initiative for a Sustainable Built Environment (iSBE), a California-based, USGBC-related organization which promotes the forwarding of sustainability in the built environment.

Professional Organizations

Professional groups similarly influence the direction of the structural engineering field. However, in the United States the most cohesive associations of professional structural engineers seem to have the very little grasp on the implementation of green building practices.

SEAI

The Structural Engineers Association, International (http://www.seaint.org/) currently does not have a special committee focused development of sustainability criteria for structural engineering. Additionally, there are no published resources or documents on this subject in their available online resources or recent volumes of their Structure magazine.

ASCE (SEI)

The Structural Engineers Institute (a division of the American Society of Civil Engineers) began looking for engineers in 2006 to assist in the development of green guidelines for structural engineers for their Sustainability Committee. Their purpose is acknowledged as advancing “the understanding of sustainability in the structural community, and to incorporate concepts of sustainability into structural engineering standards and practices. The Committee is currently developing guidelines to assist the structural engineer in incorporating the fundamentals of sustainability into practice. The guidelines will include strategies for design and integration of sustainable practices as well as information on materials, sample specifications, and case studies” (http://content.seinstitute.org/).
I\textit{StructE (UK)}

Currently the world’s largest structural engineering body, the members of the Institute of Structural Engineering is based in the United Kingdom and is on the cutting edge of green building and sustainable design. In 1999, IStructE published a journal document called “Building for a Sustainable Future: Construction Without Depletion,” which was intended as a sort of handbook for implementation of sustainable design practices into standard practice for structural engineering.
Green Rating Systems

“Green” rating systems, developed by national and international organizations, set the standards for sustainability and performance targets. Generally, these systems rely heavily on the electrical and mechanical systems to improve the overall building performance and reduce operating costs. It should be noted that these standards vary significantly between the governing bodies for minimum acceptable performance criteria, and they also grade on different scales. Structural contributions are related mostly to criteria revolving around waste reduction, materials selection and site development.

LEED™

The USGBC created the Leadership in Energy and Environmental Design (LEED™), the nation’s foremost green building rating system, in 1993. It is currently the standard system in the United States. The LEED™ system by definition “encourages and accelerates global adoption of sustainable green building and development practices through the creation and implementation of universally understood and accepted tools and performance criteria.” The first version was published in 1998 and has been regularly revised to include new information about the industry and expand the rating systems to adjust to the growing market. The current systems in place are shown in Table 5.

Sustainable Project Rating Tool (SPiRiT)

Based on LEED™ version 2.0, the Department of Defense created its own military-specific rating system, called SPiRiT, which is now a required rating tool. The system offers military-specific installations similarly formatted and guided by the same principles of the LEED™ system, without being under the direct supervision of the USGBC. In the spirit of sustainable design, SPiRiT rates the military institution on their demonstrated abilities to “create and maintain sustainable facilities, and to plan improvements to the process of planning, programming, designing, building, and maintaining sustainable facilities...SPiRiT takes a "whole building" perspective to help preserve the environment and improve facility life-cycle management, and to integrate environmentally responsible practices into the facility delivery process from its design stages” (U.S. Army, 2007).

Other Rating Systems

While LEED™ is currently at the forefront of rating system development to homogenize the American building industry, other countries have also acknowledged the need for ecological considerations in the design of the built environment. In the United Kingdom, a well-established program called the Building Rating Environmental Assessment System (BREEAM), was created by Building Research Establishment Limited, a non-profit organization staffed by professionals of all ranges of green building trades. The BREEAM system rates buildings for their sustainability on a much different, more globally oriented scale, implemented throughout the UK to promote and maintain the establishment of the sustainable built environment.

Additionally, LEED™ success in the U.S. has prompted offshoots such as CASBEE, the Comprehensive Assessment System for Building Environmental Efficiency in Japan, and the Green Star program in Australia.
Considerations for Residential Construction

Residential construction is a major draw on natural resources. As noted in Table 1, residential construction accounts for roughly 43 percent of construction industry spending every year. The U.S. consumes 15 percent of the world’s wood resources even though it comprises only 4.5 percent of the world’s population (qtd. in Johnston, 2004, p. 98). Though the available literature on sustainable construction and green building typically focuses on new large construction and major renovation projects, the concepts can be scaled down for application on a smaller level as well.

The scaling-down process of sustainability has some interesting implications. For example, Kibert (2005 p. 29) notes, “The greening of single-family home residential construction and land development is far more decentralized and varies from state to state.” Uniform application of green concepts is inherently difficult to implement on the national spectrum. Across the U.S., building codes and regulations differ between states, so rules in one state may not be applicable in another. Still, the USGBC has taken on the task of attempting to homogenize the industry with a subcategory of LEED™ for homes. Currently, the LEED™ rating system for homes (LEED-H) has been selectively released and is scheduled for industry use in mid-2008.

Customization

Perhaps more so than in large construction, customization is often the key in residential construction. This makes the green building process much easier to implement on a professional scale, regardless of the implications of a wholistic rating system. At times, non-standard construction, like straw-bale, adobe, or rammed earth may be a feasible design alternative. It is the engineer’s responsibility to keep up with new technologies and materials. Listed below in Table 6, adapted from Wilson and Piepkorn (2006), are a number of examples of materials, processes and applications that are influenced by sustainable design and green building practices. These are all immediately applicable in structural design and should be considered for inclusion in construction documents and design by the project engineer.

Table 6: Customizable Residential Structural Components and Materials

<table>
<thead>
<tr>
<th>Foundations, Footers and Slabs</th>
<th>Structural Systems and Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Coal Fly Ash</td>
<td>• Adobe Masonry Units</td>
</tr>
<tr>
<td>• Concrete Accessories</td>
<td>• Autoclaved Aerated Concrete Masonry Units</td>
</tr>
<tr>
<td>• Concrete Curing</td>
<td>• Certified Lumber and Timbers</td>
</tr>
<tr>
<td>• Concrete Rehabilitation</td>
<td>• Cold-Formed Metal Framing</td>
</tr>
<tr>
<td>• Driven Piles</td>
<td>• Concrete Masonry Units</td>
</tr>
<tr>
<td>• Fluid-Applied Waterproofing</td>
<td>• Engineered Lumber Products</td>
</tr>
<tr>
<td>• Form Release Agents</td>
<td>• Exterior Wall Assemblies</td>
</tr>
<tr>
<td>• Forms for Cast-In-Place Concrete</td>
<td>• Masonry Mortar</td>
</tr>
<tr>
<td>• Foundation and Load-Bearing Elements</td>
<td>• Metal-Web Wood Joists</td>
</tr>
<tr>
<td>• Low Density Concrete</td>
<td>• Permanent Forms (ICF)</td>
</tr>
<tr>
<td>• Rebar Supports</td>
<td>• Precast Concrete</td>
</tr>
<tr>
<td><strong>Exterior Components</strong></td>
<td>• Reclaimed Lumber and Timbers</td>
</tr>
<tr>
<td>• Certified Wood Decking</td>
<td>• Rough Carpentry Accessories</td>
</tr>
<tr>
<td>• Plastic Lumber</td>
<td>• Sheathing (including Plywood &amp; OSB)</td>
</tr>
<tr>
<td>• Preservative-Treated Wood and Treatment Products</td>
<td>• Structural Insulated Panels</td>
</tr>
<tr>
<td>• Wood-Plastic Composite Lumber</td>
<td>• Wood Framing Fasteners</td>
</tr>
<tr>
<td></td>
<td>• Wood Trusses</td>
</tr>
</tbody>
</table>
Building Codes and Policy

“Evermore regulation and legislation is affecting energy performance of buildings, and it will surely not be too long before greater energy conservation is no longer discretionary….Eco-conscious structural designers will likely encounter resistance at the local government level for residential designs that use alternative building methods. Unfortunately, this often leads to increased lag time in the planning departments due to lack of familiarity with certain structural products” (Johnson et al., 1993, p. 69). For as slow as the construction industry is to change, changes to public policy, including building codes, are even slower. “Building codes are intended to protect the health, safety, and welfare of the public. They are inherently flawed in that they must respond to changing conditions and empirical evidence after the fact. New technologies present new hazards as well as new benefits previously unimagined. We try to codify new systems based on old understandings” (Spiegel, Meadows, 1999, p. 60). Currently for residential applications, structural design is heavily code-based. Until changes are made to the existing code texts to incorporate the language of sustainability, the governing rules of structural engineering will likely not change drastically in the coming years. Green building, then, ultimately relies on the successful implementation of innovative and sound structural engineering judgment to validate new technologies and non-traditional building strategies.
Recommendations

The Institution of Structural Engineers (1999) in the United Kingdom notes these following recommendations for the structural engineer and tasks during design and construction of the built environment:

- Minimize offsite disposal.
- Standardize formwork and where possible, reuse it.
- Focus design loads to be adequate for the proposed use that meet current building code requirements.
- Do not overdesign for liability reasons. The structure should have an appropriate amount of built-in redundancy, but not too much so that disassembly is hindered.
- Assess potential implications of the design life on the actual service life.
- Choose a structural system that is capable of being recycled or reused elsewhere.
- Carefully consider connection and joint design. Where possible, simplify for both assembly and disassembly.
- Use recycled and reused materials in new construction where feasible.
- Choose a structural system that is economical to build and minimizes embodied energy.
- Consider future use and adaptability of the system for alternative uses.
- Consider prefabricated materials where possible to minimize waste on site and recycling at the source.
- Provide and maintain digital documentation for the client, including drawings and calculations and supplemental building system and materials information.

Other important recommendations for the practicing structural engineer are noted below.

- Participate fully in the design-development phase of the project as a part of the integrated design team.
- Designs should be creative, innovative and ecologically responsible.
- Discuss potential materials alternatives with the project architect. Depending on local geographic and cultural norms, non-standard building materials such as adobe, straw-bale or others might be feasible options.
- Contract documents generated by the structural engineer should include specific information regarding recyclability, deconstructable connections, salvagability, and where possible, information directing the contractor to local companies offering these types of services.
- The materials selection process should incorporate life-cycle analyses into consideration prior to final specification.
- Avoid use of tropical hardwoods; instead use an alternative or verify that the hardwood is labeled as sustainably harvested.
• Use careful detailing to curb the need for treated wood products where possible, which may contain chemicals that are hazardous or toxic to humans during production, service (in the form of gas emissions) or demolition. Examples of chemical treatments to avoid are formaldehyde and pre-treating chemicals. Check the manufacturer’s labels prior to specifying a product in the construction documents.

• Consider recycled, salvaged or refurbished building components and note the pre- or post-consumer recycled content.

• Specify and design materials and systems to be both durable and flexible, to maximize the product and building life, within the means of the project budget, intended design life, and applicable codes.

• Participate in continuing education classes, professional groups, and keep updated on current building technologies in the structural engineering profession.

• Share knowledge of sustainable concepts with others in the profession and students of the profession.

• Additionally, structural engineers may consider becoming Commissioning agents. Due to the general engineering background, regular communication with architects, as well as the professional license (indicating a degree of professional merit), often the structural engineer is an ideal candidate to be a building commissioning agent.
Closure

Though Schwitter makes a worthy argument between robustness and efficiency, he does not quite capture the entire view of green design in the structural engineering profession. Sustainability is not only a wholistic concept, it is an inherently dynamic process. It is relatively young in development, and even younger in implementation on social, economic and environmental levels. It involves all elements and professions of the building process and construction industry. It is uniquely human-dependent, yet tied directly to both the living and inert environments. It has cultural and moral implications. It is impossible to quantify, and even less possible to summarize. Macroscopic consideration is the only appropriate way to address the issue of sustainability in the building industry. However, structural engineering is very specialized contributor to this macroscopic picture. Conceptually, the structural paradox really boils down to two rules of thumb when considering sustainability and green building: the sum of all the structural parts is greater than the value of the individual structural elements, and all of these parts have to work together such that the overall result does more for the greater good, with less.
References


Additional Resources

www.aisc.org/sustainability
American Institute of Steel Construction. Includes detailed information on how steel fits the LEED™ rating system, recycled steel content documentation, and technical articles.

www.concretethinker.org
Portland Cement Association affiliate website. Information on green building and sustainable development with concrete.

www.fsc.org/en/
The Forest Stewardship Council. Includes resources dedicated to improving forest management internationally, and wood certification process.

http://www ncma.org
National Concrete Masonry Association. Sustainable concrete products for structures and hardscapes.

www.recycle-steel.org
Steel Recycling Institute. Includes detailed information on recycling rates, recycling databases, and the environmental benefits of steel for homes building, steel roofing, and bridges.