Sustainability and Structural Engineering

By Lisa Aukeman

"Green Building" and "Sustainable Design" are more than just buzz words in the built environment today. It is important for an engineer to understand what sustainability is and why it is important for the wellbeing of our future environment and follow the initiative that the industry has taken in improving the environmental impact of structural development on society. Finally, as students it is our call to become educated and creative in order to bring innovation to the developing industry.

What is Sustainability and Why Is It Important?

Sustainability is essentially a personal investment towards a level of performance throughout an indefinite period of time. Not only can buildings affect the environment, social and economic impacts are also made. Buildings have an effect over the course of development as well as life of the structure. **Figure 1** shows a relationship between a positive environmental, economic, and social impact. When all three occur, it can be considered fully sustainable. Upon examining the carbon footprint of a structure, one might be surprised at the amount of fuel and energy used during the production and assembly process. It is important to consider production strategy; transportation demands as well as the life span of materials in order to fairly assess the interaction between a building project and the environment. An ideal material is manufactured minimizing pollution and locally produced to minimize transportation costs. The performance of the material is also evaluated by considering the lifespan of a material including the thermal efficiency for the building structure.

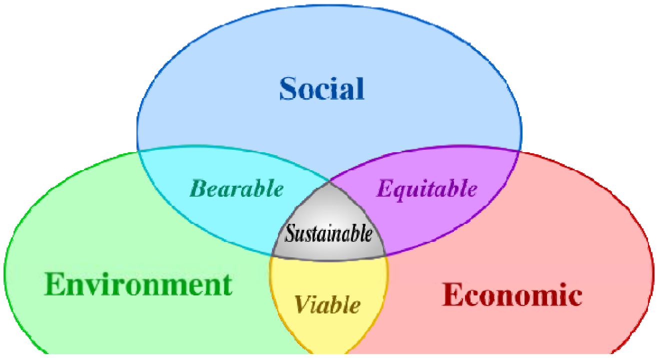

Figure 1 : The above diagram defines sustainability by relating all factors considered in sustainable analysis.

For years, most designers and engineers have overlooked sustainability as a factor in the design process. "Building operation accounts for 40% of U.S. energy use; this number increases to an estimated 48% when the energy required to make building materials and construct buildings are included. Building operations alone contribute over 38% of the U.S.'s carbon dioxide emissions and over 12% of its water consumption. Waste from demolition, construction and remodeling makes up over 35% of all non-industrial waste (Statistics from 1996)." (Baum, 2006) We must become increasingly more vigilant in design practices to plan and design for growth. Cement production alone accounts for approximately 8% of the Carbon Dioxide emissions mentioned above. It is said that approximately 37% of CO_2 released today will still be present in the atmosphere 100 years later. (Kang, Grace S., SE, LEED AP; Kren, Alan, SE, LEED AP, 2007)

The Design Industry in Sustainability

The American Society of Civil Engineers (ASCE) recognizes that structures have an undeniable affect on the environment and has implemented the following policy:

"The American Society of Civil Engineers (ASCE) believes that sustainable development is the challenge of meeting human needs for natural resources, industrial products, energy, food, transportation, shelter and effective waste management, while conserving and protecting environmental quality and the natural resource base essential for future development."

Sustainable development requires strengthening and broadening the education of engineers and finding innovative ways to achieve needed development while conserving and preserving natural resources. To achieve these objectives; ASCE supports the following implementation strategies:

- Promote broad understanding of political, economic, social and technical issues and processes as related to sustainable development.
- Advance the skills, knowledge and information to facilitate a sustainable future; including habitats, natural systems, system flows, and the effects of all phases of the life cycle of projects on the ecosystem.
- Advocate economic approaches that recognize natural resources and our environment as capital assets.
- Promote multidisciplinary, whole system, integrated and multi-objective goals in all phases of project planning, design, construction, operations, and decommissioning.
- Promote reduction of vulnerability to natural, accidental, and willful hazards to be part of sustainable development.
- Promote performance based standards and guidelines as bases for voluntary actions and for regulations in sustainable development for new and existing infrastructure (American Society of Civil Engineers, 2007). "

At this point, education is a key ingredient to sustainability. Currently ASCE has put together a sustainability committee and is working on sustainability guidelines for structural engineers to reference and follow in future projects. Also, ASCE is teaming up with other organizations such as Engineers without Borders and US Green Building Council to educate engineers on sustainable solutions by holding conferences and seminars for those interested in sustainability.

US Green Building Council has established its own certification process through Leadership in Energy and Environmental Design (LEED). Through LEED, designers can learn how to achieve certified sustainability in both new and existing structures.

LEED was created to accomplish the following:

- Define "green building" by establishing a common standard of measurement.
- Promote integrated, whole-building design practices
- Recognize environmental leadership in the building industry
- Stimulate green competition
- Raise consumer awareness of green building benefits
- Transform the building market

The rating system for LEED addresses six major areas:

- Sustainable sites
- Water Efficiency
- Energy and atmosphere
- Materials and resources
- Indoor environmental quality
- Innovation and design process

(LEED for New Construction and Major Renovation, 2005)

Structures can be certified through LEED and categorized as Basic Certified, Silver, Gold, or Platinum based on a point system calculated according to the above criterion.

The Structural Engineering Association of California (SEAOC) is also placing a higher emphasis on sustainability as the Northern California Chapter has implemented a sustainable design committee and offers a Sustainable Award of Merritt. Recently, this award was given to the UC Merced Central Information Technology Center (**Figure 2**); a LEED- gold certified building (39 pts.). The use and placement of glass in deep set windows brings natural lighting into the structure while maintaining a cool interior environment. This is especially important in the warm San Joaquin Valley to allow for thermal efficiency. The orientation of the structure also helps take advantage of the refreshing prevailing winds from Yosemite Lake. Due to intense summer heat, shaded outdoor areas also give more pleasant circulation space for student gatherings. Sustainable building materials include a concrete mix that uses fly ash (later discussed). This structure has also received awards for Architecture and innovation.

Figure 2: Information Technology Center; UC Merced, Photo by Tim Griffith (Green Source, 2008)

UC Merced hopes to achieve LEED Silver status for a total of 11 of its buildings which include classrooms/offices, central plant, library/information technology center, student housing, common area, and dining facilities.

UC Merced participates in the Green Campus Program which includes involvement of twelve UC/CSU schools. Sustainability on university campuses is important because of the around the clock use of the facilities and utility services. Not only is there a demand for energy efficiency within the university system, implementing sustainability on campuses also creates an awareness and responsibility to the future generations of designers.

The Alliance to Save Energy (ASE) Green Campus Program published the following goals:

- Design and implement student-led campaigns that result in measurable energy savings;
- Create effective and lasting student-staff partnerships that lead to systemic and sustainable energy efficiency;
- Foster environmental stewardship by raising campus awareness about the relationship between energy and the environment;
- Develop replicable energy education curriculum and integrate it into academic offerings.

(ASE, 2005)

It shows that the numerous organization that are pushing towards sustainable construction standards agree that education is the beginning of creating a sustainable future in the building environment.

Engineers in Sustainability

The public has become increasingly interested in adopting the green building strategy for new buildings. In fact, in the state of California, some agencies are requiring new projects to be LEED certified. Specifically, San Diego, Los Angeles and San Jose require municipal buildings of a particular size be LEED Certified. San Francisco, Pleasanton, and San Mateo County also have similar ordinances as well as many corporations like Ford, Toyota and Sprint. Considering the future standards of the industry, designers must rise to the demand as well by training and refining their practices to be in compliance with sustainable designs at the lowest expense to the owner.

The role of a Structural Engineer in sustainable design is difficult to define. Many of the aspects of accreditation are determined by other contributors of the design such as architectural, civil, mechanical and electrical. However, it is important for the Structural Engineer to choose the most appropriate material and load resisting system, including considering the possibility of reuse or recycling of materials throughout the design and planning phase. Also, often times the engineers must be able to come up with creative solutions to support sustainable design practices while at the same time maintaining public safety. Special considerations might also be made based on the "Green" attributes of a project. For example, Photovoltaic panels or "green" rooftops (see **Error! Reference source not found.**) greatly increase the structural loads to be considered. Light shelves to minimize direct sun require increased engineering and detailing. Strength properties of fly ash concrete (see **Figure 4**) might be limiting or taken advantage of by the engineer.

Figure 3: California Academy of Sciences: "The 2.5 acres of Living Roof will absorb nearly two million gallons of rainwater per year" (California Academy of Sciences)

Often times, the Structural Engineer may choose the material for a new project. Ease of production, availability, ease of transportation, and ease of construction, efficiency, and lifespan of a material are all considered when choosing a project material such as concrete, masonry, steel and wood or combinations of these materials.

Concrete is an essential material to most all structures. Unfortunately, for every amount of cement produced, an equal amount of CO_2 is emitted into the atmosphere (Headwaters Incorporated).

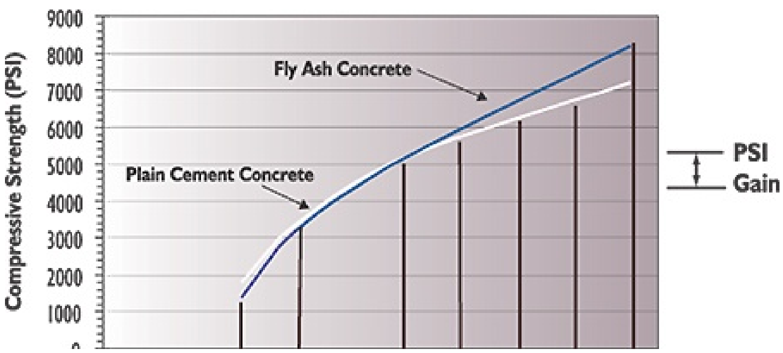

Figure 4: Strength comparison of fly Ash and plain cement concrete. (Headwaters Incorporated)

The demand for cement can be reduced by replacing it with 15-25% fly ash, a product of coal combustion. By using fly ash, the properties of concrete can be improved in the following ways: easier workability, increased strength, decreased bleeding and less shrinkage. An advantage of using fly ash also includes a reduced need for landfill space by making use of the coal combustion waste product. The use of fly ash over cement in the long run increases strength capacity yet requires a curing time of 56 days for design strength rather than 28 days (see **Figure 4**) (Kang, Grace S., SE, LEED AP; Kren, Alan, SE, LEED AP, 2007). If more than 25% fly ash is added curing time should be increased and corrosion to reinforcing might become a problem (Headwaters Incorporated). Concrete also offers environmentally friendly examples. Concrete has a long lifespan and it can easily be crushed and recycled as aggregate. Concrete also has excellent thermal properties. The light color of concrete reduces extreme temperatures and can be used for portions of highways as well as areas for parking. A Concrete parking area will reduce temperatures outside of a building therefore conserving energy inside the building.

Concrete can also be a great thermal mass in the interior of a building absorbing solar heat on a cold day and releasing that heat into the interior space. The Structural Engineer is responsible to specify the design of the concrete mix and has to freedom to explore, test, and use sustainable variations of concrete. (Headwaters Incorporated)

Masonry is a naturally sustainable material (**Figure 5**). Masonry units can be made from concrete, clay, or adobe. It has a long life span, it is thermally efficient, eliminates the concern for mold, and provides a good natural interior environment. Masonry projects can be more easily constructed than concrete projects because there is no formwork. Fly ash can also be specified as a binder for CMU blocks as well as in grout taking caution that the bonding strength is not compromised by the supplement. Thermal properties of masonry also include the prevention of large temperature swings by absorption and releasing energy and heat. (Kang, Grace S., SE, LEED AP; Kren, Alan, SE, LEED AP, 2007)

Figure 5: Brick masonry (Diamondmountain)

Steel is easily reused and often recycled. In fact, structural steel is made from a variety of recycled products (Zoruba & Grubb, 2003). For this reason, the use of steel is in and of itself a sustainable effort. However, since recycling is a process which requires melting and reforming which requires energy, reuse of structural members is the best way to incorporate sustainable design into a structure. When specifying reused structural members, the loading conditions (and overstresses) as well as exposure to weather during previous use should be considered to accurately predict the future load capacity of the member. Not only can an engineer specify reused products, he or she is encouraged to incorporate concepts of reuse into future designs. For example, designing simple connections based on mechanical fasteners and fewer welds allow for the ease of deconstruction and more intact members to be reused upon the demolition of the structure in the future.

Timber is a unique material in the sense that it is highly renewable. In addition to this, wood is also "biodegradable, non-toxic, energy efficient, recyclable, and reusable (Kang, Grace S., SE, LEED AP; Kren, Alan, SE, LEED AP, 2007)." However, there is a level of energy required for the harvesting of timber, as well as a concern for global deforestation. An engineer should be sure that the specified use of the wood products is efficient.

Figure 6: A timber framed residence in Katy, Texas. (Jaksmata)

Framing techniques can be analyzed by planning a grid to evenly match plywood sheets to eliminate waste and trimming (**Figure 6**). Also, increasing joist and stud spacing to up to 24 inches on center and minimizing lumber sizes where possible is good practice for an engineer. Similar to steel, wood members can also be reused taking similar precautions as mentioned above.

Furthermore, the availability of large trees is very limited. Smaller and younger trees can be used for the manufacturing of engineered wood products. While the products are a great use of natural resources, these products should be carefully specified considering that recyclability is limited. Also many of the common binders used to manufacture members are potentially toxic to inhabitants of the structure. Urea formaldehyde resin is a common binder in glulams which can potentially emit carcinogen gasses for years.

Figure 7: (Jaksmata)

Finally, much of the energy consumed as a result of timber construction comes from the forestry process, for this reason a sustainable practice is to specify certified lumber by the Forest Stewardship Council (FSC). Harvesting of timber can be extremely invasive and harmful to the natural environment (see **Figure 7**). FSC ensures sustainability and eco-friendly practices in harvesting as other harvesting practices might cause erosion, pollution, excess CO_2 emission (global warming) and damage to the natural environment of the surrounding ecosystem.

Straw bale construction, while far less common than other building materials mentioned above, is one of the most sustainable building materials. Straw consists of the plant portion (oats, wheat, barley) that is non-living and left over after harvesting. Since it is otherwise a waste material used for livestock bedding, it is an excellent, inexpensive building material. Straw bales also provide insulation of approximately R30-R45 (or 30-45˚Fahrenheit square feet hours per Btu) for the structure. A concrete/stucco covering on the bales provides a high resistance to fire.

Figure 8a: Hopi Elder Housing Prototypes: Structural straw bale
(Enterprise Community Partners, 2006)

Figure 8b: Hopi Elder Housing Prototypes: finished exterior
(Enterprise Community Partners, 2006)

There are two types of methods in straw bale construction. One, the bales are stacked and tied- used as bearing walls (**Figure 8a**). This method requires a delay after stacking to allow for settlement of the bales before the stucco finish can be applied (**Figure b**). The second method is a post and beam method where bales are used as a fill between basic timber frames. This method is slightly more expensive and labor intensive but more readily accepted by building officials. Wood stakes, steel reinforcing or bamboo can be used to tie one bale to the next for stability during construction and performance of the building during loading is enhanced as a result of reinforcing in this way. Building with straw bales raises a concern for moisture protection. Bales must be stored at moisture content of below 14% and kept dry throughout the construction process. While straw bale construction is not common, it is an old technique and many projects remain in use as a statement of success to the use of straw bale construction. (AEA: Architectural and Environmental Associates, 2006)

While sustainable design of structures aims to reduce energy costs as well as increase the lifespan of a building structure, there are some increased costs that might be considered in the process. On average, LEED projects might add an addition 1%-2% in construction costs. Often the costs of engineering might be increased as well. However, 10%-20% of the total cost of a new building structure is due to the structural system itself (Kang, Grace S., SE, LEED AP; Kren, Alan, SE, LEED AP, 2007). The addition 1-2% investment on a sustainable building structure and structural system will be compensated for in the lifetime savings of sustainable and energy efficient materials.

Performance based design is another consideration to take when thinking of the life cycle cost of a building project. Performance based design is a design strategy where the level of acceptable damage is assessed in the design stage as well as the necessary degree of functionality or occupancy of the building in the event of a major earthquake. As a result, the necessary structural system is designed to perform in this way. Ultimately, an owner or financer hopes to save money in the future by eliminating a certain amount of damage by providing an adequate structural system regardless of the provisions in the building code. While a larger initial investment might be made in the beginning, it is saved in the future.

Additional information and descriptions of various LEED projects and sustainable properties is shown below. The following list is available through US Green Building Council.

LEED Gold:

Byron G. Rogers U.S. Courthouse (Denver, CO)
Wayne L. Morse Courthouse (Eugene, OR)
NOAA Satellite Operations Center (Suitland, MD)
U.S. Environmental Protection Agency Science and Technology Center (Kansas City, KS
U.S. Environmental Protection Agency New England Regional Laboratory (Chelmsford, MA)
Carl T. Curtis Midwest Regional Headquarters of the National Park Service (Omaha, NE)
Department of Homeland Security/INS (Omaha, NE)
Potomac Yards 1 and 2/EPA (Arlington, VA)
U.S. Environmental Protection Agency Regional Headquarters (Denver, CO)

LEED Silver :

Social Security Administration Teleservice Center (Auburn, WA)
Department of Transportation Office Building (Lakewood, CO)
CIS Nebraska Service Center (Lincoln, NE)
Scowcroft Building Renovation (Ogden, UT)
OSHA Salt Lake Technical Center (Sandy, UT)
Veterans Affairs Regional Office (Reno, NV)
U.S. Department of Agriculture Service Center (Manhattan, KS)

LEED Certified:

Howard M. Metzenbaum U.S. Courthouse (Cleveland, OH)
Frank J. Battisti and Nathaniel R. Jones Federal Building and U.S. Courthouse (Youngstown, OH)
Annex Building for Social Security Administration (Woodlawn, MD)
Child Care Building for Social Security Administration (Woodlawn, MD)
Shared Port-of-Entry, (Sweet Grass, MT; Coutts, AB)

John Duncan Federal Office Building (Knoxville, TN)
(GSA, 2008)

In addition there are several case studies available through U.S. General Services Administration discussing the following projects:

Arizona State University Biodesign Institute: a new standard for research facilities.
Tim and Karen Hixon Visitor Center : A visitors center used to collect and save water for a drought prone area.
University of California: A research center for students encouraging sustainable perspective.
Zhong Xiao Pavilion: a garden and sustainable office space in the city of Taipei .
(Green Source, 2008)

Students in Sustainability

Finally, as students we are encouraged to get involved with activities that peak our interests. Students are encouraged to be innovative and curious. Thinking outside the box is what sustainable design requires and new methods and ideas are being tested and welcomed into sustainability.

Specifically, our own campus is hosting the UC/CSU/CCC Sustainability Conference 2008 from July 31- August 3. During the conference an emphasis will be made on a sustainable lifestyle. The administrators of the sustainability conference recognize that sustainability is a lifestyle that must start somewhere. The use of non recycled or non recyclables will be limited throughout the weekend, while biodegradable or reusable products are highly encouraged. In addition to this, workshops will be held concerning the implementation of sustainability within the educational system, curriculum as well as professional practice. For more information, see http://www.sustainability.calpoly.edu.

The Renewable Energy Institute (REI) has also been put into place at Cal Poly as an organization within the department of Architecture co-directed by Professor Margot McDonald, AIA and Dr. Doug Williams. The REI includes both research and teaching opportunities on campus as well as in local communities on the subject of sustainability. It is an interdisciplinary opportunity that includes involvement from the fields of Agriculture, Engineering and Architecture. Ultimately, the goal of REI is to create a more sustainable atmosphere here on campus at California Polytechnic State University, San Luis Obispo. For more information, see http://www.calpoly.edu/~rgp/Research/rei.html.

In closing, it is clear that the way we live our lives, and more importantly, the way we build our future will have an effect on our health and well being. It is our responsibility to do what we can to preserve our surrounding environment. The first step to this action is to understand the need and importance and knowing how we can make our contribution to the built environment as inhabitants, students and engineers. Only a few of many ideas have been mentioned above as ways we can consciously consider the effects of our buildings on the environment. This is a developing study that depends on the support and inquisition of a new generation.

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