Project-based Education on Sustainability Principles for Engineers

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Abstract:

Sustainable Development is defined as any *development that meets the needs of the present without compromising the ability of future generations to meet their own needs*. With noticeable global climate change, unprecedented amount of waste generation, increased demand on water, energy, and other natural resources -- conservation and use of alternatives in infrastructure design and construction will become standard practice for future projects. All branches of Civil engineers play a vital role in designing sustainable projects and in shaping and achieving the sustainability credentials for a project. Traditionally, classroom courses tend to place more emphasis on theory, with limited integration of real-world engineering problems and applications. The paper describes components of an undergraduate course on sustainability principles for engineers and provide example of how the rating tools LEED, Envision, and Sustainable Sites were incorporated in evaluating real-world civil engineering projects in Louisiana.

Introduction:

Immediate threat to the human civilization refer to (i) the use of natural resources at a rate that will limit the ability of future generations to obtain/utilize resources such as materials, fuels, water, and air, and (ii) the degradation of natural systems to the point that may jeopardize their beneficial balancing functions (Fragaszy et el., 2011). The negative impact of the world's use of fossil fuel will add to this problem. In 2007, the world consumed approximately 504 EJ of energy (exojoules; 1 EJ = 10^{18} J), equivalent to 12 Gton (gigatons of oil equivalent), 81% of which was derived from fossil fuels (IEA, 2009). Despite large deposits of coal, oil shales, and possible methane hydrates, fossil fuels are ultimately exhaustible.

Energy and quality of life (infant mortality, education, life expectancy) are intimately related, as shown by the high correlation between the Human Development Index (HDI) and energy consumption per capita (www.undp.org). The main sources of energy worldwide are petroleum (34%), coal (26.5%), natural gas (20.9%), combustible renewables and waste (9.8%), nuclear power (5.9%), and hydroelectric (2.2%) and other, mainly wind and solar (0.7%) (2007 data in International Energy Agency, 2009). Therefore, 81% of all the energy consumed worldwide is obtained from fossil fuels, primarily because of their low cost under present pricing conditions. Fossil fuel burning is accompanied by the emission of carbon dioxide, which gradually accumulates in the atmosphere, leading to anthropogenic-driven climate change. Based on reported national values, the current global energy consumption rate is ~15 TW (1TW=1012W). There will be a pronounced increase in energy demand in the next 25 years associated with economic development and population growth worldwide: (1) 17% increase if consumption and population growth continue at current rates -the business-as-usual option-, (2) 66% increase if consumption in the underdeveloped world increases to levels required to attain proper quality of life (i.e., 1.5 kW/person-Santamarina, 2006). This situation will exacerbate current issues caused by the dependency on fossil fuels, its environmental consequences, and the international implications due to the mismatch between the geographic distributions of supply and demand of fossil fuels.

Engineering and Sustainable Development:

Sustainable Development is defined as any *development that meets the needs of the present without compromising the ability of future generations to meet their own needs* (Brutland Commission's Report, 1987). It is a process of change, in which investments, technology, resource allocation, and institutions transition toward longer-term sustainable activities (Weston, 1994). The development of a sustainable world will require an in depth understanding of global coupled complex adaptive physical, biological, and human systems (Holling, 2001). Therefore, with global climate change, increased demand on water, energy, and other natural resources -- conservation and use of alternatives in infrastructure design and construction will become standard practice for future projects.

Sustainability has slowly gained worldwide acceptance as an essential guiding principle for governance, science, business, and society (Lafferty et. al., 2001). A sustainable development starts at the planning and design phase of the project, where engineers play a vital role. Design and construction of engineering infrastructures consume vast amount of resources (concrete, steel, land, water etc.) and energy, and change the landscape that has been in existence for centuries. Engineers have a major impact on the natural environment and water resources by reforming the earth's surface, changing soil properties, and addressing contamination and often are involved in site selection for major infrastructure works, transportation services, and buildings which can have a significant impact on the social and economic aspects of the project (Abreu et al., 2008). Since engineering projects interfere with many social, environmental, and economic issues, improving the sustainability of the processes is extremely important in achieving overall sustainable development.

A limitation in introducing sustainability concepts in engineering projects is inadequate knowledge of the effect of the different processes on the ecological balance of the surrounding area. Moreover, planning and design of an engineering project is often driven by economic considerations, whereas environmental and societal sustainability are generally neglected during project planning and design. There is also an absence of reference framework which can help in determining the best engineering solution balancing both economy and ecology. These drawbacks are compounded by the scarcity of sustainability literature and of a proper sustainability assessment framework for engineering practice. Therefore, addressing sustainability in engineering is fundamental to addressing sustainability in construction of infrastructure projects that impacts the natural and built environment.

Sustainability Principles in Engineering curriculum:

Practicing engineers currently face the challenge of changing the status quo of their work and adapting their design methods to embed sustainable thought process throughout all their decision making processes. The challenges facing the engineering community in the future will require a much broader knowledge base than is currently included in educational programs. The engineering curriculum, from undergraduate education through continuing professional education, must address the changing needs of a profession that will increasingly be engaged in sustainable design, renewable energy source, enhanced/more efficient use of natural resources, underground utilization, and proper waste management, (Fragaszy et al., 2011).

To build a more environmentally, economically, and socially sustainable natural and built environment, Engineers' role should evolve as policy leaders, environmental stewards, and life-cycle planners. Engineering analysis and design will change profoundly when sustainability driven scientific principles and concepts are integrated in the planning phase of a project. These changes will require renewed engineering curriculum, adapted continuing education programs for practitioners, experimental and project-based learning, and increased public awareness and expectations for civil engineering infrastructure. Engineers and researchers can extend their research, education and professional practices in the fields of highways, environment, transportation, renewable energy, coastal infrastructure including flooding and erosion, as well as earthquake prediction using innovative and sustainable design practices. Therefore, discussion about sustainability principles should be incorporated in undergraduate and graduate level engineering curriculum.

Project-Based Engineering Education on Sustainability:

Traditionally, classroom-engineering courses tend to place more emphasis on theory, with limited integration of real-world engineering problems and applications. Additionally, students work mostly on their own, thereby failing to learn the importance of working in a group and developing effective interpersonal communication skills. Employers want entry-level engineers to be technically sound and possess a variety of professional and interpersonal skills, so they can work effectively as part of teams to execute and manage real-world projects, communicate well, and understand the economic, social, and political aspects of their professional activities. Engineers need these skills to maximize their importance and value in society and to fulfill society's expectations of engineers. These professional expectations complicate engineering education in universities worldwide. Lack of appropriate practical skill acquisition in engineering education is a topic of debate and concern in academia and industry.

The following sections describe components of an undergraduate course on sustainability principles for engineers at the University of New Orleans. Examples of how sustainability rating tools like LEED, Envision, and SITES were incorporated in the course to evaluate real-world civil infrastructure projects in Louisiana, will also be discussed.

Real-World-Project-Based Engineering Education:

A new undergraduate course titled Sustainability Principles for Engineers was taught at the University of New Orleans during the summer semester of 2013. The course covered several important aspects of sustainability principles pertaining to engineering, such as (i) sustainability concepts and definitions, (ii) climate science and environmental policies, (iii) physical and natural resource management, (iv) alternate energy resources, (v) Sustainable infrastructure design, (vi) engineering ethics and sustainability, (vii) Life Cycle Assessment (LCA), and (viii) sustainability rating tools (LEED, Envision, and SITES).

In addition to homeworks, examinations, and class quizzes, the students were required to participate in, and complete a class-project using the above mentioned sustainability rating tools. The students in the course were divided into three teams. Each team used a different sustainability rating tool to evaluate three different, but real-world project located in southeast Louisiana. The students also worked with, and under the supervision, of professional engineers, who assisted them in data collection, and guided them with the project evaluation.

Class Project Selection Criteria:

The components of the class project were selected by the course instructor based on the following criteria:

- The teams should be able to complete the project from start to finish within 4 months
- Components of the project should match the theory covered in the classroom
- The project should have multiple non-technical components (verbal and written communication with client, report writing, oral presentation, working in a team)
- The project scope should include pre-defined deliverables (proposal, report, powerpoint presentation)
- The project will require the students to study additional material beyond what is covered in the classroom lecture

Examples of Class Projects

1. LEED by Example – Historical House renovation and redevelopment

This project consisted of evaluating the renovation and redevelopment plan of a century old residence using the sustainability rating tool LEED. The residence is located within the historic area of New Orleans warehouse district. A photograph of the house is shown in Picture 1.

Picture 1: Photograph of the historic residence evaluated using LEED

The Leadership in Energy and Environmental Design (LEED) Green Building Rating System™ is the national benchmark for high performance green buildings. LEED promotes a whole-building approach to sustainability by recognizing performance in five key areas of human and environmental health:

- sustainable site development
- water savings
- energy efficiency
- materials selection
- indoor environmental quality

Projects are evaluated by answering questions within each of the above mentioned key areas. Based on the performance benchmarks and proposed plan, points are assigned to each answer, depending upon the level of sustainability achieved. Based on the total points received, the following LEED certification credentials are bestowed upon the project:

- Certified – 26 + points
- Silver – 33 + points
- Gold – 39 + points
- Platinum – 52 + points

With assistance from the professional mentor, the students performed a site visit to the residence and gathered all necessary information pertaining to the renovation plan. The student team then evaluated the different aspects of LEED certification using the project checklist spreadsheet downloaded from United States Breen Building Council (USBGC) website. Based on the team's assessment, the historic residence will receive a total of 41 points, if all renovation activities were performed as planned. This will give them a LEED Gold credential.

2. Sustainable SITES – New Orleans City Park Festival Grounds Bioswale

The students evaluated a bioswale that was recently constructed within the New Orleans City Park. Figure 2 shows portion of the bioswale at the city park. A variety of trees, namely pond cypress, swamp tupelo, red maple, and hydroseed were planted to help protect and restore the wetland area. A walking deck is also provided as an amenity to enjoy the Bioswale. Ponding water feature not only conserves and manages stormwater but also provides water to wildlife and small fish.

Figure 2: Bioswale at New Orleans City park

The city park bioswale area was evaluated by the students using Sustainable Sites Initiative™ rating tool. The Sustainable Sites Initiative™ (SITES™) program is an interdisciplinary effort by the American Society of Landscape Architects, the Lady Bird Johnson Wildflower Center at The University of Texas at Austin and the United States Botanic Garden to create voluntary national guidelines and performance benchmarks for sustainable land design, construction and maintenance practices.

The Sustainable Sites Initiative: Guidelines and Performance Benchmarks 2009 is the product of more than four years of work by a diverse group of experts in soils, hydrology, vegetation, materials and human health and well-being (released November 2009). It includes criteria for sustainable land practices that will enable built landscapes to support natural ecological functions by protecting existing ecosystems and regenerating ecological capacity where it has been lost. This report focuses on measuring and rewarding a project that protects, restores and regenerates ecosystem services – benefits provided by natural ecosystems such as cleaning air and water, climate regulation and human health benefits. The 2009 rating system contains 15 prerequisites and 51 credits that cover all stages of the site development process from site selection to landscape maintenance.

Based on their evaluation, the students agreed that the New Orleans city park bioswale project should accumulate enough points to get the SITES credential.

3. Visionary ENVISION™ – Huey P Long bridge widening project

The third student group evaluate the expansion of Huey P Long bridge widening project using the Envision™ sustainability rating tool. When it was opened in 1935, the original Huey P. Long Bridge was the longest railroad bridge in the world crossing the mighty Mississippi river near New Orleans, Louisiana. Prior to the construction of the Huey P. Long Bridge, automobiles and rail cars had to be ferried across the Mississippi River on a daily basis. In 1989, the expansion of the Huey P Long bridge was included as a Louisiana TIMED project. The TIMED Program was created by Act 16 of the 1989 Louisiana Legislature, was voted for by the people and is the single largest transportation program in state history. It is designed to enhance economic development in Louisiana through an investment in transportation projects. The expansion of the HPL quickly became a top priority. Construction on the Huey P began in April 2006, and the first changes to the structure took place since it opened in 1935. The $1.2 billion widening project, completed in 2013, expanded the structure from two 9-foot lanes to three 11-foot lanes with a 2-foot inside shoulder and an 8-foot outside shoulder. It also included new signalized intersections to replace the traffic circle at Jefferson Highway and Bridge City Avenue in Jefferson Parish, LA. Figure 3 shows the widended Huey P Long bridge

Figure 3: Huey P Long bridge widening project

The Envision™ sustainable infrastructure rating system is a comprehensive tool that provides a holistic, cost effective framework for evaluating and rating the community, environmental and economic benefits of all types and sizes of infrastructure projects. Envision™ evaluates, grades, and gives public recognition to infrastructure projects that use transformational, collaborative approaches to assess sustainability indicators over the course of the project's respective life cycle. Envision™ has assessment tools that can be used for infrastructure projects of all types, sizes, complexities, and locations: from roads and bridges to airports and water treatment facilities; to ports and refineries; from pipelines to electricity grids. The Envision rating system evaluates five major components:

- *Quality of Life*: The health and wellbeing of individuals and society as a whole.
- *Leadership*: Effective and collaborative leadership produces a truly sustainable project.
- *Resource Allocation*: Resources are the assets that are needed to build infrastructure and keep it running.
- *Natural World*: Infrastructure projects have an impact on the natural world around them.
- *Climate and Risk*: Minimize emissions and ensure resiliency

Envision™ can be used by infrastructure owners, design teams, community groups, environmental organizations, constructors, regulators, and policy makers to:

- Meet sustainability goals
- Be publicly recognized for high levels of achievement in sustainability
- Help communities and project teams to collaborate and discuss, "are we doing the right project?" and, "are we doing the project right?"
- Make decisions about the investment of scarce resources, and
- Include community priorities in civil infrastructure projects

The Envision tools help the project design team:

- Assess costs and benefits over the project lifecycle
- Evaluate environmental benefits
- Use outcome-based objectives, and
- Reach higher levels of sustainability achievement

Together, all five consist of 60 sustainability criteria, called credits. The amount of points earned in each credit depends on the evaluated level of achievement: improved, enhanced, superior, conserving, and restorative. Projects that attain high levels of achievement in using the Envision™ Rating System will qualify for one of four award levels: Bronze, Silver, Gold and Platinum. Based on the student team's evaluation, the Huey P Long bridge widening project scored 51 total points which earned them a bronze rating.

Benefits of Project-based Learning in Engineering Education:

The project-based course on Sustainability Principles offered at the University of New Orleans created the following benefits for the students, professional mentors, and course instructor:

- *Benefits to the Students:*
    1. Students were able to apply classroom theory to analyze a real-world project
    2. Students learned to work in a team under the supervision of a professional engineer. They also learned to interact with each other and with the mentor, professionally and with respect
    3. Students learned about (a) the importance of interpersonal communication skills, (b) benefits of working in a team, (c) how work environment will be after they graduate and join a company, (d) and proper time management.
    4. Students learned about valuable professional and life experiences from the experiences of their mentors
    5. Students learned about effective presentation skills (written and verbal)
    6. Students learned about professional liability and how to avoid costly mistakes
    7. Students got the opportunity to network with industry peers for future job opportunities

- *Benefits to the Professional Mentors:*
    1. The professional mentors made important connection with potential interns/part-time employees
    2. The mentors strengthened their resume by adding this involvement to their outreach activities
    3. The professional mentors enjoyed interacting with future-generation engineers and giving back to their profession. The mentors enjoyed sharing their life experience with the future engineers

- *Benefits to Faculty and University:*
    1. Faculty is able to make contact with key players of the local industry
    2. The interaction can lead to collaboration opportunities with professional mentors on research activities and journal publications
    3. The partnership can lead to the faculty receiving in-kind contribution from professional mentors on research activities
    4. Feedback from professional mentors can help the faculty improve the course content
    5. Due to their involvement in this course, the professional mentors will be more willing to participate and support other activities at the university

Summary and Conclusion:

The undergraduate course gave the students an opportunity to learn about sustainability and how they can incorporate sustainability principles in a real world project after graduation. The course also highlighted three sustainability rating tools commonly used in the industry. The students learned about LEED, Envision, and SITES and, with the help from practicing engineers, used these tools to evaluate three different engineering projects in southeast Louisiana.

This interactive, hands-on experience helped the students better understand the application of theory in real-world projects. The students realized the importance of working in a group and developing effective interpersonal communication skills. Experiences like this will nurture them to be competent engineers, who will be technically sound, but will also possess a variety of professional and interpersonal skills, so they can work effectively as part of teams to execute and manage real-world projects, communicate well, and understand the economic, social, and political aspects of their professional activities. The students were also able to make valuable professional contacts. The professional mentors, on the other hand, enjoyed giving back to their profession and, as a side benefit, met potential employees.

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