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Jason Kirby, University of Alabama at Birmingham

Hilal Ozcan, Prairie View A&M University

Fouad Fouad, University of Alabama at Birmingham

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Abstract

Engineering and architecture are inseparable disciplines when contemplating the design and construction of the built environment. Together these professions have helped shape our world to include everything from thriving metropolitan cities to quaint residential suburbs. Regrettably, these developments often come at a high cost to the natural environment; routinely polluting air, water, and land resources. In response, the study of "Green Engineering and Architecture" has emerged in an attempt to rectify damages and forge new environmentally-sound construction techniques and technologies. This manuscript provides an overview of sustainable design as it relates to architecture and engineering within the United States and identifies education opportunities both domestically and abroad.

Keywords: Green Engineering, Sustainable Architectural Design, International Education

Introduction

Energy consumption, rising cost of petroleum, poor ambient/indoor air quality, severe weather, and global warming are important issues that have been consistently in the news and are likely to have a continued and profound effect on the natural environment and society. While automobiles have been traditionally blamed for energy consumption and polluting of the environment, buildings are the single largest contributor to the nation's environmental and energy-supply challenges. The U.S. Energy Information Administration reports that buildings are responsible for approximately half of all greenhouse gas emissions and annually consume over seventy percent of the domestically generated power[1]. Energy consumption has increased 30% in the past 25 years, and current projections indicate another 35% increase over the next 25 years primarily due to population growth and increased industrialization.

"Sustainable development" is a direct response to these concerns. The term has been defined by the World Commission on Environment and Development[2] as "Meeting the needs of the present without compromising the ability of future generations to meet their own needs." Sustainable buildings, also referred to as "green construction", require special techniques and materials to achieve the desired characteristics of functionality, indoor air quality, economy, safety, and aesthetics. Sustainability must be achieved over the entire life cycle of the building which includes: planning, design, construction, commissioning, operation, maintenance, renovation, and removal. Environmental life cycle assessments must consider the various stages of a product's existence and it's ecological impact to aid in selection of building materials that are both environmentally and economically responsible. Hence, sustainable design requires special engineering and architectural expertise coupled with a good understanding of new materials and building products. Therefore, design professionals play a crucial role in improving living standards and can have a significant impact on progress toward sustainable development.

Sustainability focuses on making the best possible use of available resources, minimizing impacts on the environment, and developing durable / healthy buildings. Several organizations have produced building guidelines and rating systems to help assess sustainability or green design features including: Leadership in Energy and Environmental Design[3], the National Green Building Standards[4], and the Green Building Initiative[5]. Although these rating systems vary in complexity they share a common focus on encouraging responsible land use, recycled material content, energy conservation features, community planning and overall quality of life.

The future of sustainable design will highly depend on institutions of higher education incorporating green concepts into the curriculum. Academic institutions can contribute to the acceptance of sustainability in architectural and engineering design by offering courses and programs on the subject and by presenting sustainability in conjunction with well-established considerations such as ethics, economics, aesthetics, and structural integrity. Architecture and civil engineering departments should take the lead and responsibility for promoting sustainable development, and the topic should be treated as a major consideration similar to protection of the public health and safety in design. Ultimately, the objective should be to graduate a new breed of design professionals (engineers and architects) who are knowledgeable of sustainable design and can integrate its concepts in real-world design projects.

Diversity in Architectural Design and its Relation to Sustainability

In recent years, the discipline of architecture has been impacted and reshaped most dramatically by two critical understandings: 1) the awareness of diversity and multicultural relationships within a holistic world, and 2) the awareness of sustainability and green transformation. This raises the question: How do you understand and even measure diversity and sustainability as a value affecting architectural form?

While numerous studies and national / international standards have been developed addressing the sustainability efforts in design, very few studies have been published that aim to analyze and measure the potential of diversity as an expression of design. Diversity in architecture supports a conscious act that formalizes place differentiating qualities presupposing that there is a relationship between diversity awareness and a subsequence architectural form consequence. Architecture congruently reflects culture and includes the diversity characteristics inextricably linked to culture. Architecture inherently possesses a certain formal nature, which can be evaluated. The approach to identifying diversity-defining characteristics is intended to reveal key indicators inherent to primary form responses. These indicators, in part, grow out of basic architectural determinants of form and may be simplified into the following taxonomy of three groupings of factors: external (PLACE), internal (PEOPLE) and the in-between (ARCHITECTURE) indicators. External indicators present opportunities for integration of cultural and contextual diversity. Internal indicators provide opportunities for the domain and specific detailed user or people related diversity. The in-between indicator grouping is given meaning though the concept of “twin-phenomenon”[6], developed by Aldo Van Eyck, where design responses can affect both differently and simultaneously the inside and outside environments. The threshold between these two realms is the focus of great architectural attention.

The nine form-responsive characteristics that provide a dynamic system for evaluating diversity in architecture are 1) context, 2) climate, 3) site, 4) form language, 5) scale/detail, 6) interiority, 7) internal order, 8) degree of transparency, and 9) materiality (see Table1).

Table 1. Nine form-responsive characteristics for evaluating diversity in architecture[7]

Diversity Indicator	Descriptors
Contextual Responses	temporal, historic, cultural, ethnic, external infrastructural, legal, jurisdictional, sacred, adjacent built formal conditions, and simply the ground.
Climatic Responses	response to solar energy, precipitation, humidity, wind, annual and diurnal atmospheric changes particular to a region and specific site.
Site Conditions	topological, micro-climatic, vegetative, bio-diversity, geological, geomantic, existing built works, internal infrastructural, views, vistas, local historic sacred and archeological conditions.
Form Language	semiotic geometry, gestures, messages, signs, symbols and meanings expressed by architectural form and building skin.
Scale	human and anthropomorphic characteristics, scaling and proportional relationships to buildings and building elements, and ennobling relational effects.
Interiority	furnishings, interior arrangements of partitions, furniture and other space dividing elements, lighting levels, ADA compliance, and use of color.
Order	spatial topological arrangements, massing schemes, domain, and geometric systems of order, way finding, including ceremonial order.
Transparency	opaque, solid, translucent, and transparent surfaces, thresholds, dematerialization and materials contributing to visual interactions between inside and outside of buildings.
Materiality	selection and expression of specific building material, systems, surfaces, and finishes.

While these characteristics and categories are chosen purposefully to define the meaning and function of diversity in architecture, they simultaneously relate to and reveal opportunities to incorporate sustainability features into architecture design. For instance, the diversity indicator "materiality" would allow the selection of engineered green construction products that minimize adverse impacts upon the environment and can provide a number of improvements to facility characteristics such as energy efficiency, fire resistance and sound / thermal insulation.

Evolution of Green Concepts

Human evolution is often driven by the invention and utilization of new technologies. For our ancient ancestors, the development of simple stone tools allowed them to hunt larger game, move out of the caves and support their families with less physical effort. Over millennia, man further evolved from nomadic hunters/gathers to agrarian societies which harnessed the power of irrigation to provide more reliable food crops. These early civilization embraced the environment, while citizens of modern era have often sought to conquer it.

The "Industrial Revolution" brought on significant change to the practices of agriculture, manufacturing, transportation and construction. The production of inorganic fertilizers, electrical power generation (via coal and hydroelectric dams), petroleum mining (oil and gas) and numerous construction materials (concrete and steel) were in their infancy; but as US populations grew so did their demand for "modern conveniences". In the absence of environmental regulations, pollution of the air, water and terrestrial resources went unchecked. Enforceable US federal laws expressly for the protection of the natural environment were nonexistent until 1970; nearly two hundred years after the signing of the Declaration of Independence. The Environmental Protection Agency (EPA) was founded with the express purpose of protecting human health and to safeguard the natural environment[8]. However, as the EPA was soon to realize, the environmental damage of nearly two centuries would be hard to manage.

The American environmentalism movement has been plagued by ebbs and flows, with momentum for change predominately in the 60-70's and 90-00's[9,10]. Like all social reform, these efforts have been subject to popular support and political action. Modern environmentalism has begun to embrace the concepts of green and sustainable development. However, in order to be successful engineers, architects, and building contractors must modify traditional materials/techniques to include those which are not adverse to ecologic health. For example, greenroofs (or vegetated roofs) can be substituted for traditional asphalt shingles. These systems offer enhancements to energy consumption, roof longevity, aesthetics, and urban runoff.

Engineering and architecture are inseparable disciplines when contemplating the design and construction of the built environment. These professionals are therefore in a unique position to conceive and fabricate the next generation of residential, commercial, and institutional buildings that can dramatically reduce their adverse footprint upon the environment.

Green Design

Evaluation Methodologies: The Leadership in Energy and Environmental Design (LEED) Green Building Rating System encourages domestic and international firms to implement sustainable green construction practices that conform to a defined set of performance criteria[3]. Established in 1999 by the US Green Building Council (USGBC), the LEED program has developed into the benchmark for design, construction and operation of residential, commercial, and institutional buildings. The evaluation program promotes a holistic approach to sustainability by recognizing building performance in five areas: site development, water conservation, energy efficiency, materials selection and indoor environmental quality. To obtain LEED certification, a building must show evidence to secure a specified number of credits. For instance, limiting water requirements for landscaping is awarded 1 point while reusing 10% of discarded construction materials (to minimize the waste stream) is awarded 2 points. Designations from Platinum to Certified may then be bestowed based the building's ability to adopt green and sustainable features[11].

LEED, because of its systematic certification process, has become a recognized authority in the construction industry; widely endorsed by architects, engineers, contractors and owner/operators. However, LEED is just one of several national initiatives which encourage green and sustainable

construction practices. Architecture 2030, was established to combat the emerging climate change crisis by architect Edward Mazria in 2002[12]. 2030's vision is to minimize the ecological impact of domestic and international building infrastructure; or more specifically to reduce the carbon footprint and power utilization of these structures. As stated earlier, the U.S. Energy Information Administration reports that buildings are responsible for approximately half of all greenhouse gas emissions and annually consume over seventy percent of the domestically generated power[1]. Now while not a certification program per se, Architecture 2030 does set up a system of obtainable targets for the global architecture and building community to adopt.

The National Association of Home Builders (NAHB), whose membership is responsible for the construction of more than 80% of US residential homes, is presently drafting the "National Green Building Standards"[13]. Anticipated adoption in 2008 by the American National Standards Institute (ANSI) will allow this voluntary system of practice to be incorporated not only into those homes potentially seeking LEED certification, but rather and perhaps more importantly into the development, design and construction of a majority of new residential homes.

Regardless of evaluation methodology, all buildings which incorporate sustainable and green technologies provide an edifice whose function and operation minimizes the traditionally adverse impacts on the natural environment.

Green Education in the US: The United States is a recognized world leader in higher education; a destination for countless domestic and international students pursuing numerous fields of study including engineering and architecture. However, as a nation we lag behind other countries (England, Germany, etc.) in terms of environmental stewardship. Only within the past few decades have Americans begun to realize that we must protect environmental assets to sustain socioeconomic development.

Recent advances in environmental education have focused on conferences, workshops, seminars and short courses to introduce professional practitioners to the concepts of sustainable and green design. National programs, including LEED and Architecture 2030, have been at the

To achieve an acceptable level of education on sustainable design, the architectural and civil engineering curricula must be expanded to include in depth information on sustainable materials, construction systems and the method of their integration into actual projects. Although formal curricula on sustainable design and development are not prevalent, outstanding efforts have emerged to introduce this growing field into academia. These pioneering innovative efforts in learning should be applauded and encouraged as they lay the foundation for future curricula that will be devoted to sustainability.

A few examples of leading university programs that have integrated sustainability and green design concepts as a major focus in their educational programs are cited herein. Duke University Civil and Environmental Engineering Department recently introducing a new course entitled "Engineering Sustainable Design and Construction." The course pairs students from interdisciplinary teams with community partners to address real-world sustainability design problems geared toward public service in the US as well as in other nations across the world.

The student design teams were vertically integrated to include architectural and mechanical engineering students to provide realistic solutions to provided design problems[14].

Boston Architectural College has a program in sustainable design and presently offers a certificate in the subject area. The certificate program is an option for individuals that are ultimately seeking LEED accreditation. All courses in the sustainable design program are approved for Health, Safety, and Welfare continuing education learning units for architectural registration requirements. Course titles include: Green Practice, Building Envelope, Sustainable Design, High Performance Buildings, Marketing Sustainability, and Indoor Air Quality[15].

Massachusetts Institute of Technology (MIT) has adopted the motto "Engineering and Science for the Provision of Human Services in a Sustainable Way," and is planning to launch specific educational and research components around this theme. They are also encouraging that all new academic buildings be at least LEED "Silver" certified with energy-saving features including encouragement of alternative transportation (bikes and "Zip Cars"), water conservation fixtures, energy efficient lighting, and natural ventilation[16].

In addition to formal curricula, university student chapters can serve as ambassadors for global environmental change. For example, "Engineers Without Borders" are very effective in promoting the concepts of sustainability for improving the quality of life across the world. The University of Alabama at Birmingham student chapter has recently traveled to Peru to assess community health and water supply needs. In addition the students began construction of an observation tower that can be used to promote environmental tourism, as this region is a popular habitat for exotic bird species. This structure promotes sustainability because if not for the subsequent influx of tourism dollars the population would likely allow timber companies to harvest the surrounding forests; thereby heavily impacting the environment.

Examples of Green Construction Applications: The U.S. Green Building Council projects that the value of green construction will exceed twelve billion dollars in 2007 [3]. Owners are beginning to demanding green construction and contractors are responding positively.

A house in Athens, Vermont, was recently featured on "ABC's Extreme Makeover: Home Edition", a nation wide television program that rewards deserving families with a new house. What was unique for this episode is that the builders utilized sustainable and green material construction systems, thereby allowing the structure to uses only a fraction of the energy typically needed for a home of its size. These materials included insulating concrete forms (ICF) for the exterior walls and foundations, fiberglass windows, sprayed-in urethane foam insulation, photovoltaic solar panels, and Energy Star-rated appliances[17].

ICF roof and floor systems have also been incorporated into a school's construction in El Cerrito, California, resulting in significant energy savings (approximately 96% more energy efficient than conventional construction). The structure, which is anticipated to receive LEED Sliver certification, has other sustainable features integrated into the building design, including a visually-appealing roof that combines photovoltaic panels, green planters, and skylights for the classrooms below. Naturally ventilated classrooms have replaced dependence on mechanical HVAC systems; bioretention planters are utilized to reduce stormwater runoff; and sustainable

interior finishes with low volatile organic chemical emitting paints are incorporated into design[18].

Permeable interlocking concrete pavement pavers are becoming increasingly popular as more communities are faced with meeting stormwater runoff regulations, increased impervious cover restrictions and the adoption of LEED practices.

Another green construction material, Autoclaved Aerated Concrete is fairly new in the U.S. for use in commercial and residential buildings that provides significant energy savings, fire resistance and sound insulation. The material's green characteristics are invaluable especially since it utilizes very little raw material in its manufacture[19].

Sustainable green design has come to the forefront for its use of products and materials that conserve natural resources, provide greater energy efficiency, reduce pollution, and create a healthier and safer environment. A multitude of products, materials and systems similar to the ones described above are now available and being aggressively marketed for sustainable and green building construction.

International Educational Programs to Introduce Sustainability Concepts

After the 9/11 terrorist attacks, it became evident that broader understanding and global engagement is needed among America's future leaders to promote peace and national security. International educational experiences help students to develop international and cross-cultural competency and create globally-minded individuals who can successfully work alongside people with diverse cultural backgrounds. Study abroad programs, especially in developing countries, is one way to facilitate global understanding / engagement and should be an essential component of the student's educational experience. Endorsing sustainability as the platform for global engagement can have a great impact on world resources and economic development.

Two international educational activities that address sustainable design were organized by the authors. The first program is a partnership between the University of Alabama at Birmingham (UAB), Tuskegee University (TU), and Misr University for Science and Technology (MUST) in Cairo, Egypt to offer undergraduate students in Egypt a certificate in construction management with a focus on sustainable design. The certificate courses will cover topics on improved construction and equipment technologies, sustainable design, and environmental concepts. Among the various course offerings being presented, CE 694: Sustainable Construction will provide a fundamental understanding of the interdependencies between design, construction, occupancy, maintenance and ultimate destruction of the built environment (residential, commercial, and industrial) and the potential impacts these operations can have on the natural ecosystem. For many of the prospective students, who hail from the Persian Gulf region, this will be their first exposure to "Green Engineering and Architecture" concepts. It is hoped that this course can help shape the perceptions of these future engineering practitioners and encourage responsible environmental stewardship.

The second activity is a study abroad program with the theme of sustainable architectural design. Study abroad students from North American architecture and engineering colleges will be

visiting ancient Aegean sites in the summer of 2008. One of these sites, Asklepion in Bergama, Turkey, will be used for a week-long design charette with participating Turkish architecture faculty and students. Bergama is a perfect case study for sustainability both for historical and practical reasons. Historically this location, a Hellenistic city, included the first health resort in the world and due to available mineral resources the surrounding countryside was subject to excessive gold mining operations. Associated ecological damage has created a modern grassroots environmental movement within Turkey. To prepare for the study abroad program, US students will analyze provided site information as part of the spring 2008 architecture design studio. Students will tasked with designing a sustainable urban conservation project addressing both the local and international community, revealing the historical conceptions of a healing center and exploring the current environmental problems faced by the population. The students will be encouraged to use a high degree of creativity and will work in teams to provide an atmosphere similar to that of the international design charette.

Conclusions

Sustainability in architectural and engineering design is rapidly gaining acceptance and the construction industry is going "green". A multitude of products, materials, services and systems are currently available in the marketplace for green building construction. However, as a nation we lag behind European countries such as Germany and England in terms of environmental stewardship. Only within the past few decades have Americans begun to realize that we must protect environmental assets to sustain socioeconomic development.

Formal education on sustainability is needed to ensure that future architects and engineers are knowledgeable of sustainable design and can integrate its concepts in real-world design projects. Architectural and engineering colleges should take the lead and responsibility for promoting education on sustainable development. The topic should be treated as a major consideration within the curricula, similar to the protection of public health and safety in design. International education also serves as an excellent venue in promoting sustainability across the world and should be included as part of undergraduate and graduate educational programs.

Bibliography

1. < www.eia.doe.gov/>, accessed January 2008.
2. *Common Future*, World Commission on Environment and Development, Oxford, England: Oxford University Press, 1987.
3. < www.usgbc.org > accessed January 2008.
4. *Model Green Home Building Guidelines, Version 1*, National Association of Home Builders (NAHB), Washington, D.C., 2007.
5. < www.thegbi.com >, accessed January 2008.
6. Smithson, A., *The Team Ten Primer*, Cambridge, MA: MIT Press, 1968.
7. Tabb, P. and H. Ozcan. *Diversity in Design: A working paper on the Relationship between Diversity and Architectural Design,* College Station, TX: Department of Architecture, Texas A&M University, 2004.
8. Lewis, J., "The Birth of EPA," *Environmental Protection Agency Journal*, Nov. 1985.
9. Dowie, M., *Losing Ground: American Environmentalism at the Close of the Twentieth Century*, Cambridge, MA: MIT Press, 1996.

10. Taylor, D., *Race, Class, Gender, and American Environmentalism: USDA Technical Report PNW-GTR-534*, Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 2002.
11. *LEED-NC Green Building Rating System for New Construction and Major Renovations, Version 2.2*, Washington, D.C., USGBC (US Green Building Council), 2005.
12. <www.architecture2030.org>, accessed January 2008
13. <www.nahb.org>, accessed January 2008
14. <www.duke.edu/>, accessed January 2008
15. <www.the-bac.edu/>, accessed January 2008
16. <web.mit.edu/environment/> accessed January 2008
17. <www.abc.go.com/primetime/xtremehome/>, accessed January 2008
18. "ICF roof, floor system helps school achieve energy efficiency," *Concrete Monthly*, Vol. 5, No.11., 2007.
19. Fouad, F., "Standards for Autoclaved Aerated Concrete Promote Sustainability," *ASTM International Standardization News*, Vol. 35, No. 3, 2007.