# Integrating Sustainable Building Design and Construction Principles into Engineering Technology and Construction Management Curricula

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**ABSTRACT**

A sustainable system can be defined as a system exhibiting the characteristics of continued successful operation indefinitely without degrading or reducing the supplies that feed the system, and without degrading the system's surrounding environment. This definition can easily be applied to the construction industry, and thus is born the concept of sustainable design and construction. As the world's population continues to grow at an ever-increasing rate, implementation of resource-efficient measures in all areas of human activity is imperative. The construction industry and the built environment in general represent one of the clearest and most significant avenues where improvement is obtainable and necessary. Buildings have a very significant impact on the environment, accounting for one-sixth of the world's fresh water withdrawals, one-quarter of its wood harvest, and at least two-fifths of its material and energy flows. In the United States, the construction industry represents 10%-12% of annual Gross Domestic Product. The building construction and design industries have recently begun to recognize that a more sustainable path must be implemented if the industry is to continue to survive and remain a vibrant and significant portion of the economy, providing jobs as well as necessary services. Historically the construction industry has selected the least expensive initial

cost alternative to get a project built. Designs have traditionally been undertaken to minimize the initial investment required of developers or owners. With a growing awareness of the negative environmental impacts of the design and construction industries, these industries have begun to re-orient themselves onto paths where fewer raw materials are being used and the selection and specification of materials to be used has begun to take into account the impacts of manufacturing and transportation. Also being considered by innovative and forward-thinking building designers and builders are the health and comfort of users of the built environment. High quality design and construction can reduce energy consumption while providing a healthier indoor environment than conventionally designed buildings provide. Currently the move toward lowering the environmental impacts of building has been largely voluntary, but with the advent of new and tougher indoor air quality requirements, water use restrictions, and land use guidelines, developers, building designers, and construction companies have had to adapt to a changing paradigm. Construction Management programs need to reflect these rapidly changing circumstances and our curricula must be adjusted to a new and evolving situation. This paper will share specific improvements and additions to both Construction Management and Civil Engineering Technology curricula that will introduce students to a new and still evolving landscape for building in the future, one that will allow students to adapt to the new field of sustainable building design and construction successfully.

## INTRODUCTION

The sustainable building design and construction movement had its origins in the American energy crisis of the early 1970's. The realization that unlimited energy supplies at low cost was no longer realistic forced Americans to re-think many aspects of life. One area drastically altered was the way we design and construct buildings. Building designers suddenly had to consider energy consumption as a primary issue dictating design. The Department of Energy (DOE) was created in 1977 to combine and coordinate the activities of the Federal Energy Administration, the Energy Research and Development Administration, the Federal Power Commission, and parts of several other agencies. The newly formed Department of Energy found itself charged with developing strategic plans and programs for long-term energy development and policy, including energy conservation programs.

During this time in American history, the environmental movement focused much national attention on the degradation of our environment due to man's activities and ignorance of the results of some of our actions. The Environmental Protection Agency (EPA) was formed in 1970 to address the nation's environmental conditions and policies, and worked with the Department of Energy in developing programs, rules, and laws to deal with the environment and with the nation's energy production.

An EPA position paper from 1974 stated accurately that "…ultimately, the goals of protecting our environment and having adequate energy supplies to meet our needs are compatible. Both involve a transition from current ways of thinking about how we live and how we use our resources. Environmental protection means finding cleaner ways of doing things. Energy self-sufficiency means reducing wasted energy and switching from traditional to newer sources of energy. In the short run, while these changes are taking place, there will be dislocations; but in general. Energy conservation, higher efficiencies, and use of new clean fuels are all in line with environmental objectives." (www.epa.gov)

The energy crisis and the concurrent environmental movement were what set in motion what has become the sustainable design and construction movement. The American Institute of Architects defines sustainability as "…the ability of society to continue functioning into the future without being forced into decline through exhaustion or overloading of the key resources on which that system depends." Sustainability can be thought of as representing a balance that accommodates current human needs without diminishing the health and productivity of natural systems, and without diminishing the ability of future generations to accommodate there own needs.

Building construction in the United States has historically represented between 10 and 12 percent of the nation's annual Gross Domestic Product (GDP). Construction spending in the United States amounted to $861 Billion in 2002.
(www.census.gov/const/www/Sitemap.html, 2002) Within the United States, buildings represent up to 50% of the nation's wealth. (Public Technology, Inc., 1996) The United States construction industry has historically been cost-driven and profit-motivated, causing wasteful and sometimes dangerous practices to become accepted as the norm. Recently, certain building resources have begun becoming more limited in availability,

while concurrently the science of indoor environmental quality has advanced. The building industry has recognized the consequences of past wasteful, inefficient and sometimes dangerous practices. The continuing growth of the sustainable design and construction movement is a reaction to this recognition.

With the population of the world continuing to increase, and with the corresponding over-taxation of the world's natural resources, the building design and construction industries are uniquely situated to continue to improve efficiency and make a positive difference in the world. It is imperative that we continue to improve the efficiency of the building design and construction process if the building construction industry is to remain vibrant and successful in the United States and the world. The shift away from traditional design and construction toward sustainable design and green building is a strong start.

**THE GREEN BUILDING MOVEMENT**

The United States Green Building Council (USGBC) is leading the way in sustainable building design with the implementation of the LEED Standards building rating system. The LEED Standards (Leadership in Energy and Environmental Design) are a voluntary set of building design and construction guidelines which when followed in whole or in part result in buildings that require less energy to construct and operate, have less environmental impact due to selection and specification of efficient materials and methods, and which result in healthier indoor environments than those built along more traditional lines. To date, approximately 70 buildings have been successfully completed using LEED as design and construction guidelines, and approximately 700 more buildings are in the works. Of these buildings, approximately 39 percent are state and local government projects, 39 percent are from the private sector, 13 percent are from the non-profit business sector, and 10 percent are federal government projects. Currently, nearly three percent of new commercial building construction is being conducted under the LEED rating system. At present, eight states are preparing to require LEED Standards be used in the design of all schools, firehouses, police stations, and government buildings. The USGBC has more than 3000 companies and individuals registered as members committed to building using the LEED standards.

One of the American Architecture firms at the forefront of sustainable design of buildings is Hellmuth, Obata and Kassabaum (HOK). HOK has broken sustainable design and construction down into ten items to consider when developing a building project. They closely mirror the LEED Standard guidelines, and are as follows:

1) Select and Develop Sites to Promote Livable Communities.
2) Develop Flexible Designs to Enhance Building Longevity.
3) Use Natural Strategies to Protect and Restore Water Resources.
4) Improve Energy Efficiency While Ensuring Thermal Comfort
5) Reduce Environmental Impacts Related to Energy Use.
6) Promote Occupant Health and Well-Being in the Indoor Environment.
7) Conserve Water and Consider Water Reuse Systems.
8) Use Environmentally Preferable Building Materials.
9) Use Appropriate Plant Materials.

10) Plan for Recycling During Construction, Demolition, and Occupancy.

These ten items included in sustainable design and construction closely mirror the features required in the LEED criteria, but are broader and more general in nature. The LEED standards are much more specific, but cover the same basic issues. How to implement the design guidelines into a green or sustainable design and construction project is what makes up the technical features of green buildings. These technical features are required in whole or in part to create buildings using sustainable design and construction methods.

## TECHNICAL FEATURES OF GREEN BUILDINGS

To remain competitive, and to continue to enjoy the success and profitability the construction industry has experienced in the past, the industry is being forced to address the environmental and economic consequences of its actions. Green building design and construction are direct results of the effort by the construction industry to improve efficiency and raise the quality of the finished product. Specific examples of building features included in many green buildings follow.

### Passive Solar Design

Passive solar design encompasses a broad range of building design strategies aimed at harnessing the power of the sun to accomplish what would otherwise require electrical, gas or some other form of energy to accomplish. Successful examples of passive solar building design allow sunlight, heat and air flow into buildings only when needed, and only in amounts necessary to increase the building occupants' comfort level without using outside energy sources. Passive solar design attempts to balance the use of available sunlight to accomplish adequate levels of natural light, heating, cooling, and ventilation while minimizing the use of non-renewable resources used to generate power or heating. A successful approach to passive solar design integrates and balances the use of daylighting, building citing, an efficient building envelope, appropriate fenestration, and the use of energy efficient mechanical and electrical equipment. A well designed building will use all of the above features in unison to create a comfortable, healthy and energy efficient indoor environment.

The United States Department of Energy has shown that passive solar buildings consume up to 47% less energy than conventional new buildings, and up to 60% less than comparable older buildings. (U.S. Dept. of Energy, 1995) Passive design strategies can be used most effectively on new construction projects, but can also be used on major renovations. Minor renovations are not good candidates for passive design, since most components of a passive solar design strategy involve integral parts of the building, and even building footprint location. Renovation components such as glazing, landscaping, and highly efficient heating and air conditioning equipment can be specified for a successful project.

**Daylighting**

Daylighting is the architectural or building design feature that allows natural light to be brought into interior spaces, and distributed adequately within the interior space. Successful daylighting of interior spaces reduces the need for electrical light sources, reducing energy demands and costs, while also reducing the heat generated by electrical light sources. This reduction in heat generation can allow for smaller air conditioning systems, saving further energy consumption costs. Studies completed by the Rocky Mountain Institute have shown that daylighting of interior spaces creates "…healthier and more stimulating work environments than artificial lighting systems, and can increase productivity up to 15%." (Rocky Mountain Institute, 1994) Surveys conducted by the Anderson Window Company revealed that up to 90% of employees prefer work spaces with windows that provide at least some natural light in their work areas. The same series of studies showed that 75% of employees felt that natural light provided better quality illumination in work areas than artificial light. (Advanced Design Research Group, 1993)

Energy used for lighting within buildings in America accounts for between 40 and 50% of total building energy consumption. (Rocky Mountain Institute, 1988) Properly designed and implemented daylighting strategies can and have saved between 50 and 80% of the electrical energy required to light interior spaces in the built environment in the United States. (Rocky Mountain Institute, 1988) (McCluney, R., 1984)

The potential energy savings to be realized from significant and widespread daylighting of buildings is astonishing. Lighting and additional cooling loads generated by the heat released by light fixtures accounts for between 20 and 30% of the total energy production in the United States. (Rocky Mountain Institute, 1994) It is estimated that approximately 75% of this amount of energy is consumed by the light commercial and industrial sectors of American business. The United States Energy Information Service has estimated that if daylighting measures were implemented successfully enough to realize a 40% lighting energy savings, the total of national electrical energy consumption would be reduced by six to nine percent. (U.S. Energy Information Service, 1994) It is also noted that daylighting would provide a savings in electrical demand during the peak energy demand time periods, namely during the daylight business hours. The savings would reduce the need for peak demand capacity of electrical generation, creating a further savings in infrastructure investment. All in all, a successful implementation of daylighting, even on a limited scale, has the potential for significant savings in energy consumption and an improvement in quality of the indoor built environment.

Numerous design features can be included in the interior of the building to allow for natural daylight illumination. The most common feature is fenestration, or window apertures, properly spaced and located within the exterior walls to avoid direct sunlight, while allowing indirect illumination. A common feature used to distribute indirect sunlight is the light shelf. This passive architectural device is actually a shelf structure, placed well above eye level, but below a glazed opening in a wall, and is used to reflect light above the height of the eye up onto the ceiling of the room, allowing natural light to penetrate deeper into the interior space. A simple light shelf system is shown below in Figure 1.

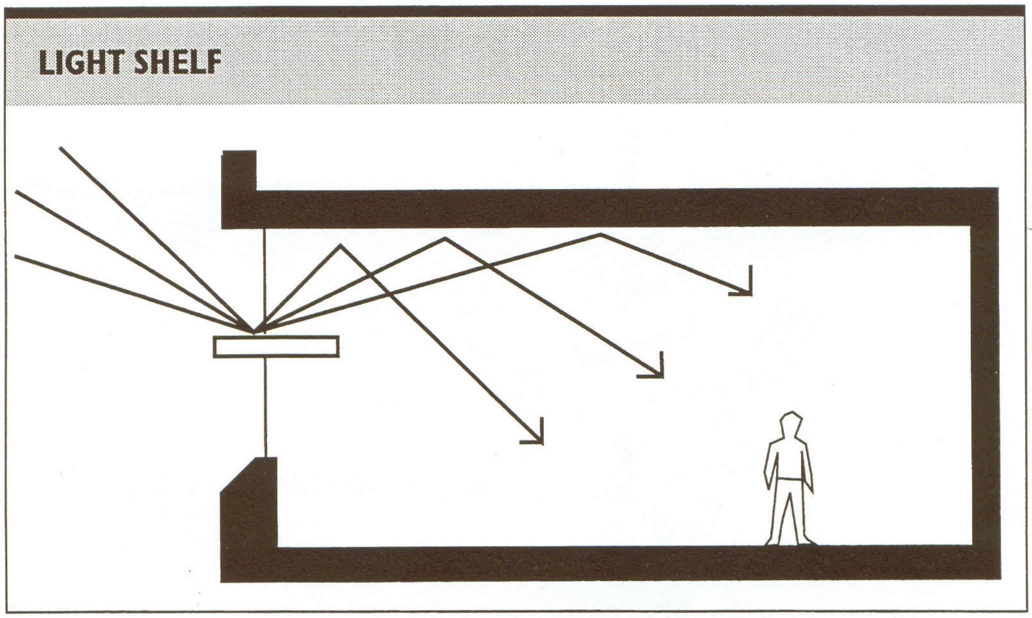


**Figure 1, Simple Light Shelf System**

A second, less common design feature that allows natural daylight into interior building spaces is the clerestory. The clerestory must be included in the initial building design to be most effective. See Figure 2 below for an example of a simple clerestory.

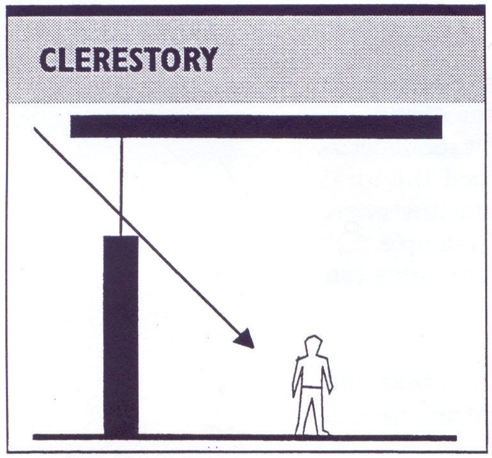


**Figure 2, Simple Clerestory**

**Photovoltaics**

Photovoltaic cells create electrical current from sunlight. The technology has advanced to the point where certain building components contain photovoltaic cells integrally. Photovoltaic cell integrated standing seam roofing panels can be purchased and installed in a manner similar to those fabricated out of sheet metal, while taking advantage of the ambient sunlight to generate electricity. Stand-alone photovoltaic cell panels are also available, and can be placed away from sight lines, or can be mounted on the building. Cost has come down as the technology has advanced in recent years, and the recent difficulties faced by California regarding power generation capacity have spurred renewed interest in photovoltaics. New developments such as reversing power consumption meters and legislation requiring local utility companies to purchase excess power generated on site by photovoltaics have opened up new avenues for further development of photovoltaic electric generation development. See Figure 3 below for a typical photovoltaic cell panel installation.

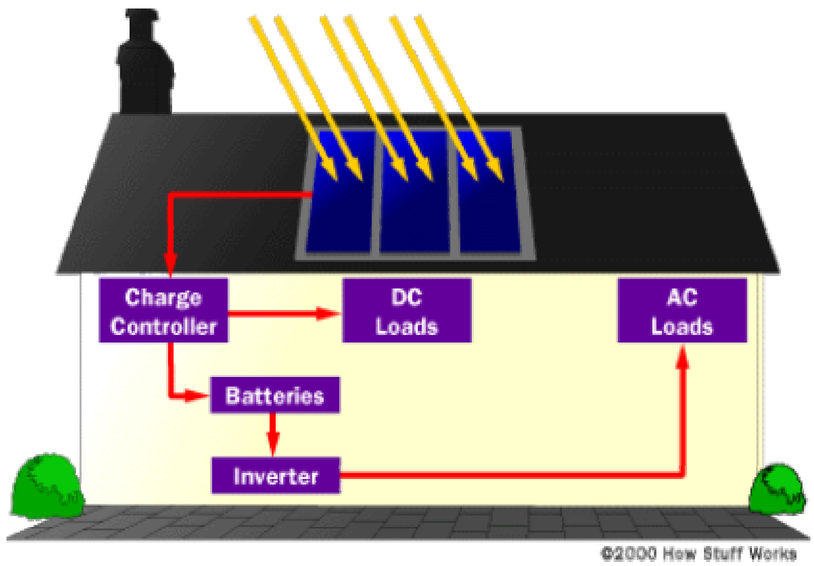


**Figure 3, Typical Residential Solar Electric System**

**Solar Water Heating**

Solar water heating is another passive solar design that uses available sunlight to increase a building's energy efficiency. Solar water heaters use the sun's energy to heat water for building occupants' use. Solar water heaters are most often installed on roofs of buildings. They are used in line with electric or gas water heaters. The basic design intent is to pre-heat water, before it enters the electric or gas hot water heater. When hot water is demanded by building occupants, it is drawn from the electric or gas hot water heater. Water is drawn from the solar hot water heater into the gas or electric hot water heater to replenish the water drawn by building occupants. The system reduces energy consumption by making the utility powered hot water heater in essence a storage facility for hot water heated by the solar system. Below, in Figure 4, is a typical solar water heating system.

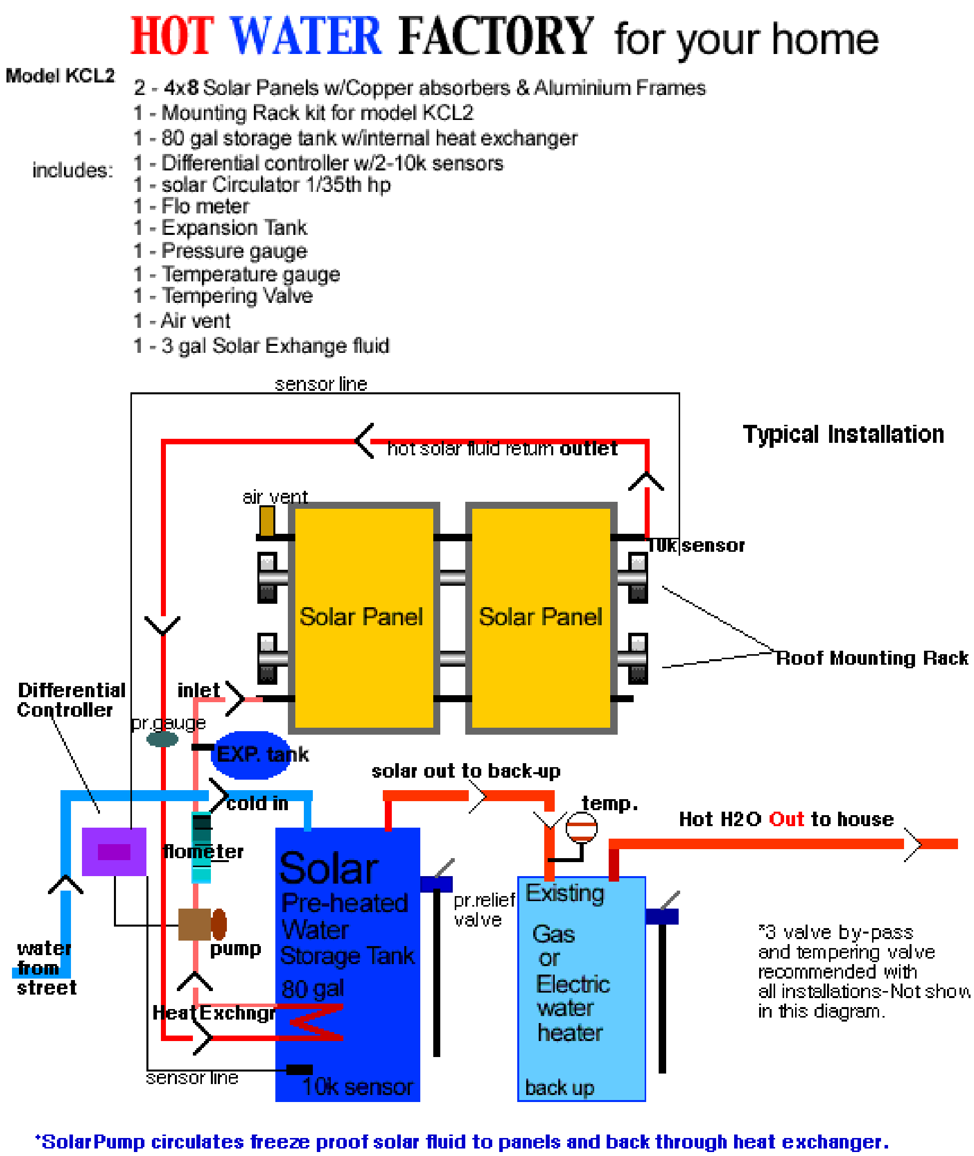


**Figure 4, Typical Solar Water Heating System**

**Grey Water Recycling**

Grey water recycling systems involve additional plumbing work during construction in order to separate water that can be used on site for irrigation from sanitary waste to be disposed of at a municipal wastewater treatment facility or through an onsite sewage disposal system. Grey water recycling systems have been used extensively in areas where rainfall quantities are low. The systems require separate grey water piping from sinks, showers, and lavatories. The grey water is collected in a tank, to be used for on site irrigation.

**Water Saving Plumbing Fixtures**

Advances in plumbing fixtures have allowed for the continued reduction in building water demands. The latest advance is the waterless urinal. Installed in men's bathrooms, these fixtures require no water to operate, and require minimal maintenance. A waterless urinal is shown in Figure 5 below.

**Figure 5, Waterless Urinal**

Low flow plumbing fixtures are required in most building jurisdictions in the United States today, but where not required, they are a good idea and should be specified.

**Energy Star Appliances**

The basic intent of requiring energy star appliances in new buildings is to force owners and/or occupants to spend the extra money on energy efficient appliances at the beginning of a building's useful life. The energy savings yielded by energy star appliances make recovery of initial costs occur within a couple of years at the most. From this point onward, energy savings result in a net reduction in building occupancy costs. While energy star appliances do result in higher initial costs to building owners or developers, the payback period is short, so these types of appliances are becoming the standard in most new construction today. Energy Star appliances show the symbol below to indicate that the EPA has rated the equipment.

**Figure 6, Energy Star Logo**

**Energy Efficient Windows**

Advances in window and glass technology have resulted in greater energy efficiency in buildings, while yielding improvements in quality of indoor environment through better natural lighting. Such advances as ultraviolet light-filtering glazing have led to reduced energy demands from buildings outfitted with these new types of glazing, while giving the occupants of the building better quality natural indoor illumination.

**Roofing Products**

The biggest recent advance in roofing products technology came with the advent of the radiant barrier. This physical layer in the roofing system acts to reflect sunlight back out of the roofing system before the light can be trapped and converted into heat inside the building envelope. The systems are simple to install, and only add slightly to initial building costs. Research has shown that radiant barriers can reduce air conditioning energy demands by up to 20 percent. Below is a typical radiant barrier application.

**Figure 7, Radiant Barrier Application**

Another innovation in roofing systems had its origins in the LEED standard requirement to reduce heat islands or man-made areas within building projects that generate large amounts of heat. Identified first and foremost was building roofs. Innovative designers began to include rooftop gardens to alleviate the heat island problem, and the practice has grown tremendously. Below are rooftop garden applications.

**Figure 8, Rooftop Garden Applications**

While the previous discussion is in no way all-inclusive, it does give a good indication of the innovative design and construction methods which continue to grow in prevalence.

The student of any of the building sciences needs to be aware of the new and growing field of environmentally sensitive design and construction.

**INTEGRATING GREEN BUILDING/SUSTAINABE CONSTRUCTION INTO EDUCATIONAL PROGRAMS**

In order for students to be able to implement sustainable design and construction principles into the working world when they graduate and become involved with industry, we must integrate this knowledge into our educational programs. Although all educational programs would benefit from exposure to the concepts of sustainability, the specific majors suited to immediate improvement are Construction Management, Construction Engineering, and Civil Engineering Technology programs. Many large construction contracts are of the Design-Build variety today. This type of contract requires the construction company to be involved in creating a design that includes construction expertise, often of the green building nature. In this relationship and contract structure, the construction company is uniquely situated to suggest and argue for the inclusion of specific building features that either reduce the environmental impact of the construction project, or improve the quality of the built environment at conclusion of the project. Often green building features accomplish both, and lead to more work for the construction company from the same client.

LEED Certified buildings are becoming more and more common today, and will continue to do so in the future. Our graduates should be at least familiar with the LEED rating system or similar design and construction rating systems, and be familiar with the major portions of work that are effected by these rating systems. Well prepared graduates will need this information to succeed in the industry. Following are several courses that should include information on sustainability and green building.

First and foremost, Construction Materials courses can be improved by including discussion of new and improved materials available, and by discussing the environmental ramifications of using the same materials used in conventional or traditional construction. Some examples are selecting carpeting manufactured from recycled plastics, specifying ceramic tile manufactured from recycled glass, or choosing low VOC emitting paints in order to improve the indoor air quality of the finished building. For almost all construction materials applications, the green building movement has created an awareness that many materials alternatives exist that are more environmentally sensible than are traditionally selected and specified. It is our responsibility to our students to seek out information on these newly available materials and expose our students to this knowledge. To neglect to do so is doing a disservice to our students and our profession.

Construction Methods classes can be improved by including new and improved processes involved with low-impact construction. These improvements have assumed many catchy names, such as Lean Construction, Green Building, Low-Impact Construction, and Sustainable Construction. Concepts which can and should be covered in a thorough methods course include elimination of entire building systems. An example of this concept is floor coverings. With a systems elimination approach, floor coverings can be eliminated by specifying polished or stained concrete floors instead of the traditional vinyl composition tile floors. Another systems elimination or reduction example is selection of low heat emitting light fixtures along with daylighting. The cooling load that a building's HVAC system is required to satisfy can be significantly reduced by selecting a design that includes daylighting along with the newly available low heat emitting light fixtures. While the cost of the light fixtures is higher than conventional light fixtures, the cost can often be more than offset by the reduced size requirements of the HVAC systems and by the reduced energy use and power bills expected in the future.

Construction Estimating courses must include at least a section on how to recognize and deal with an unconventional design which includes non-traditional materials. Since many graduates go into the estimating department of construction companies as there first assignment, we as the teaching profession would be neglecting our duties unless we prepare our students for what they are more and more likely to see, namely green construction designs and materials specifications. Most new green design and construction projects include a contractual requirement that the contractor run the building site in a certain manner. The contractual requirements often include a minimum indoor air quality during construction work, several different dumpsters and the requirement that construction demolition and waste materials be separated and re-cycled. Documentation is often required that shows the ultimate destination of the waste materials. All of this can have a significant effect on the project budget, and our students must learn to take this into account.

Construction Financial Management courses can and should include a section on the life cycle cost ramifications of choosing certain construction materials and equipment. A piece of HVAC equipment may have a higher initial cost, but lower operation and maintenance costs over the life cycle of the building. Many owners are recognizing that they have a more marketable product if they market not only the initial costs of construction, but also the life cycle costs of the building. Tax ramifications of selecting certain materials and equipment can also affect the financial bottom line for both owners and construction companies. This topic should also be covered in a thorough Construction Financial Management course.

## CONCLUSIONS

Green building attempts to mimic sustainable natural systems, where raw materials are used at a rate equal to or less than nature's ability to regenerate these same raw materials. Recycling of construction waste is analogous to nature's reuse of waste streams of one system as fuel or raw materials for another system. As developers and owners, and indeed our federal government continue to recognize the importance of sustainable systems in building design and construction, graduating students who become involved in these fields must be familiar with the green building movement. Students will be expected to know what the movement is all about, and will be expected to be able to implement features into building design and construction, as well as run construction sites in a more efficient manner. This will benefit both the end user and occupant of the finished building, as well as society and nature as a whole through reduced environmental impacts of the building design and construction process. It is our responsibility as educators to seek out this new information and include it in the material covered in our coursework. To do any less would be a disservice to our students, our teaching profession, and to society and the environment that we all share.

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