
AC 2012-3110: INTEGRATING SUSTAINABILITY IN THE CURRICULUM THROUGH CAPSTONE PROJECTS: A CASE STUDY

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Integrating Sustainability in the Curriculum through Capstone Projects: A Case Study

Abstract

The construction research, education, and practice are increasingly adopting the concepts of sustainability that apply to both design and construction phases of projects. The challenges faced in such adoption are a function of the maturity of the local industry and the support that it can lend to the sustainable initiatives. The Leadership in Energy and Environmental Design (LEED) certification system developed by the U.S. Green Building Council provides a set of guidelines and principles related to the design aspects of projects. The design choices motivated by these guidelines are made early in the project and are difficult to change during the execution stages of the project. The existing construction management curriculum does not adequately address the project management impact of green design. The students can best appreciate this impact through a comparative analysis of the traditional and the sustainable practices.

This paper reports on the integration of sustainability in the curriculum through a capstone project centered course. The student project studied the impact of sustainable design choices on the construction management aspects (time, cost, quality, risk, procurement, safety etc.) of projects in Saudi Arabia. The project centered on a detailed comparative analysis of an existing building design and its variant; a variant that was incrementally modified by the students to gain points on the LEED certification criteria. The emphasis was on identifying the low hanging fruit i.e. design modifications that can have the highest sustainability impact per dollar spent. A comparative lifecycle cost analysis was conducted to highlight the cost impact of sustainability. Project management challenges from the perspectives of various stakeholders were investigated. A student centered learning methodology was adopted for the course to ensure that students can benefit the most from this integration of sustainability and the core curriculum. The outcomes of the course indicate that the course was a huge success from the students' perspective as it exposed them to a relevant body of knowledge that was missing from their original curriculum. The students took ownership of their own learning and appreciated that they were able to learn at their own pace.

Although there is an eventual need to revise the curriculum to address sustainable principles, the reported study indicates that, as a first step, such integration can be achieved through project based learning approaches as they are less disruptive and do not require a drastic overhaul of the entire curriculum.

Introduction

The applied nature of the Construction Engineering and Management (CEM) discipline renders the traditional teaching and learning approaches ineffective where the instructors rely mostly on lectures and homework assignments. Bernold¹ raises two key questions for a future learning paradigm for CEM: 1. What changes are required to create a student centered holistic learning environment?, 2. How to empower students in such a learning paradigm? These fundamental questions are increasingly relevant in today's changing landscape where future engineers will be working on projects that are becoming increasingly complex, timelines are drastically

compressed, the resources are ever scarce and the need for better quality is never ending. In this challenging context, construction engineering can be defined as “..the series of technical activities throughout the project delivery process that influence design, support construction means and methods decisions, create a safe and productive construction environment, and seek to avoid and solve the engineering issues associated with project delivery.”². Another definition of what constitutes as construction engineering describes the discipline as “...the application of technical fundamentals and knowledge from experience to integrate design and construction, foster innovation in both, provide technical information and physical resources for field operations, avoid and solve field problems, and transfer experience between projects.”³. Project based learning is one of the widely accepted methodologies for CEM education where students work on real life or arbitrary projects and learn through the application of the fundamentals to an entire project as a team. However, such project based learning has traditionally not included the emerging trends in the discipline such as sustainability.

Through its Engineer for 2020 studies ⁴, the National Academy of Engineering (NAE) has highlighted, among other things, sustainability as one of the core knowledge areas through which the profession of engineering can be improved. Integration of sustainability into the CEM curriculum is an active area of research where a number of studies have explored how best to achieve such integration. Wang conducted a comprehensive survey of sustainability in construction education and has identified a number of challenges ⁵. A key challenge is that, unlike other CEM disciplines, the definition of what constitutes as sustainability is quite variable. The approaches adopted by various institutions that explicitly address sustainability as a part of the curriculum are also very diverse in nature. The emphasis of the incorporation has largely been in the building construction area whereas engineering construction projects have received minimal attention. At the end of the study, Wang ⁵ reported his experiences in offering a special course in sustainability in construction.

Although such specialized courses can be offered as an introduction to sustainability, this paper reports on a case study of the integration of sustainability into the CEM curriculum through a different approach – capstone projects. The course under study was conducted following a student centered learning approach and a holistic learning environment was sought where the students themselves set their learning goals. To enhance the learning experience, the course was tailored such that different components were given adequate time and effort. The course included activities that covered the entire range of learning objectives as per the Blooms Taxonomy⁶. The paper uses a case study methodology and presents a single case project for one offering of the course as an example of successful integration of sustainability into the CEM curriculum. The paper proceeds with a detailed description of the project undertaken by the students. The paper highlights the need for sustainable development in the local context of Saudi Arabia. Student evaluation results and feedback are presented at the end.

Case Study – Green Building Project

The case study focuses on a project that was conducted by students as a part of the graduate course “Construction Project Management” at the King Fahd University of Petroleum and Minerals. The course is routinely offered as a capstone course for students pursuing a Masters degree in Construction Engineering and Management. This particular offering of the course

reported here was in the Fall semester of 2010. As a part of the capstone course objectives, the students link the integrative perspective of Construction Project Management to the knowledge areas of Project Management that have been individually covered under various courses such as Planning and Scheduling, Cost Estimating, Quality Management, Human Resources Management and Risk Management. The expected output is typically a project proposal that emphasizes the project management challenges for a project.

Project Selection

The students were asked to propose a project for the course for which they would prepare a detailed project management plan. The student team came up with seven proposals, including; construction of a Solar Power Plant, a Football Stadium, a Green Building, a Shopping mall, a Hospital, a Water amusement park, and a Sky train project. The students rated the projects based on a number of factors (Need, Uniqueness, Data Availability, Cost, Income, and Execution) as shown in Table 1. The green building project was ranked the highest based on the rating criteria. The three shortlisted projects were presented to the course instructor and as per the Student Centered Learning (SCL) approach, the Green Building project was selected as it was also ranked the highest by the students.

Table 1: Student Rating of the 7 Proposed Projects of the Capstone Project

No.	Project Title	Criterion Score (on a scale of 1-10)						Rank	
		Need	Uniq.	Data Ava.	Cost	Income	Exec.		Total
1.	Solar Power Plant	5	9	1	2	7	3	27	
2.	Football Stadium	6	9	7	6	9	7	44	2
3.	Green Building	7	7	9	10	5	10	48	1
4.	Hospital	8	2	7	8	6	9	40	
5.	Water Amusement	5	9	4	7	8	5	38	
6.	Shopping Mall	6	2	9	8	9	9	43	3
7.	Sky Train	8	8	5	2	3	4	30	

Project Description

The students were advised by the instructor to focus on the LEED certification guidelines published by the US Green Building Council⁷. The concepts and principles had not been previously covered in the curriculum for the program. The students were therefore asked to familiarize themselves with the concept of the green buildings and the associated opportunities, challenges for sustainable construction in the local and regional context. Once the challenges were identified, the students selected the design for an existing building for a detailed analysis. The scope of the project was modified by the instructor (reduction in number of stories from 9 to 6 for the existing office building) to create a hypothetical project for the course. The students

prepared detailed cost and time estimates for the course project. Incremental design changes were introduced to the project to gain points on the LEED criteria. The cost impact of these changes was studied in terms of initial costs as well as through a lifecycle cost analysis for the two projects (modified initial design and the green building). This approach allowed the students to explore the initial project management impact (time, cost, quality, risk) of sustainability and more importantly the lifecycle benefits of sustainable construction. The next sections describe the outcome of the student work.

Sustainability and Saudi Arabia

Green building is “the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle”⁸. The processes and practices for green buildings include all stages of execution from inception, design, construction, maintenance and operation, to demolition. To better understand the risks and challenges of building a green building in Saudi Arabia, the students were asked to individually explore the literature and establish contacts with the local industry to explore the perspectives of the various stakeholders. The results of the individual reports by the students are summarized below to highlight the overall regional context for the reported case project.

Green building processes are essential for projects in Saudi Arabia. Although the country is blessed with hydrocarbon resources, water resources are limited with low rain fall, high evaporation, and rapid increasing demand. Further, the peak electrical loads reached nearly 24 Gigawatts (GW) in 2001—25 times that of the 1975 level. The demand for electricity is rising at an alarming rate and in the last decade alone the peak loads have nearly double to 42 GW in 2009. The country relies heavily on desalination for its water needs and was ranked 10th by the Carbon Dioxide Information Analysis Center⁹ among the worst carbon emissions countries based on fossil fuel combustion and cement production for the year 2010. Saudi Arabia accounted for nearly 5.1 hectares of ecological footprint per person in 2010¹⁰; a number that is approximately twice the world average (2.7). The ecological deficit or the difference between the footprint and the total biocapacity was estimated at -4.2 placing Saudi Arabia among the top 10 countries in the world with the worst ecological deficit. Green buildings have the potential to help in the reduction of energy consumption, water consumption rate per person, and can help sustain the ecological footprint of the country.

A number of recent Green Buildings have been constructed in the larger Middle East region. The King Abdullah University of Science and Technology (KAUST) campus is one such example which is LEED platinum, one of a kind in Saudi Arabia at the time¹¹. However, to build a green building, a number of project management challenges are presented that are shared by the various project stakeholders including the owners, architects, contractors, subcontractors, facility managers and material suppliers. Interactions with the local companies in Saudi Arabia helped identify the prevailing challenges in the regional context. The challenges identified include (but are no limited to): reluctance to pursue green due to high initial costs, insufficient experience with sustainable construction, challenges faced in finding regional suppliers of certified green materials, unknown lead times and costs for the green materials, LEED requirements during and at the end of project, and hidden costs associated with building green.

In addition to the project management challenges, awareness about sustainability is lacking among the general public as well as the practitioners. In a survey¹² conducted to explore awareness about sustainability, out of a sample of 693 Saudi Arabian Engineers, 52.2% of the participants were not aware of the issue of sustainability and had not heard of the term before. However, more than 70% of the participants agreed that sustainable housing will save energy and will reduce the bills¹². This further reflects the limited availability of local expertise for starting a green building project. Lack of engineering and project management resources would thus affect the project management processes associated with sustainable construction. Other factors affecting the management aspects for a green building project include: uncertain project durations and costs, lack of skilled manpower, quality of work, material procurement, and safety.

The Project Process for the Case Study

Given the risks associated with the building of Green projects in Saudi Arabia, as a starting point, the team contacted several local and USA experts in Green Building area and various expert suppliers and vendors to further their understanding of procurement related issues for sustainable construction. The students conducted a site visit to the Saudi Aramco Al-Midra building project that is registered to be platinum certified. The students held detailed discussions with the engineering management team for that project and the visit provided an enhanced learning opportunity for the students.

As described earlier in the project description, detailed data for the existing building was available to the students. The students prepared a modified cost estimate and schedule for the course project by incorporating the instructor initiated project scope changes. These estimates were used as the initial baseline for the project cost and schedule.

The modified building was branded by the students as the “Green Knowledge Center” building project. The objective for the proposed facility was for it to be used as knowledge sharing center between Saudi Aramco (Saudi Arabian Oil Company) and KFUPM. The facility could also be used to showcase high value green projects such as the collaborative ongoing research projects for clean energy and water between KFUPM and MIT. The students further envisioned that this high profile nature of use for the building would promote green building initiative in Saudi Arabia. Design-Bid-Build with a CM firm to overlook the contractor’s work and handle the coordination with the design team (A/E) was proposed as a possible delivery system.

Table 2: Summary of targeted points under each subsection

LEED Category	Achievable Points
Sustainable Sites	20
Water Efficiency	8
Energy and Atmosphere	19
Material and Resources	5
Indoor Environmental Quality	10
Innovation and Design Processes	3
Total	65 (Gold Certification)

The students were part of a single team with members representing 6 role players: owner, architect, contractor, subcontractor, facility manager and material supplier. The project team lengthily discussed the best possible LEED certification and decided to incrementally modify the design and to aim for the LEED Gold certification. The prerequisites and credits in the LEED Green Building Rating System for New Construction (NC) address seven (7) topics. The targeted points for each topic are summarized in Table 2. Modification actions by the team for four of these categories are briefly discussed below.

Sustainable Sites (SS)

The project covered seven applicable SS credits excluding the brown field redevelopment since the site was within the university borders. The advantages of the proposed site for the project were that the site is free of any environmental hazards, 80% of the proposed learning center population would be living within half a mile radius, and the university has a bus transport system to connect with this population. The modified design of the building has 5% preferred parking spaces for fuel efficient vehicles. A landscaping plan was developed with palm trees and greenery. Light pollution reduction control was applied. More than half of the car parking was moved under ground and the roof was designed to be covered with high reflective paint (white). The modifications, if adopted, would earn 20 points toward LEED certification.

Water Efficiency (WE)

For the Water Efficiency (WE) topic, the team targeted 8 points as the project covered two of the three applicable new construction water efficiency credits. The points can be obtained through the installation of a temporary irrigation system for the first year and by using treated grey water for irrigation for subsequent years. For the water use reduction, the team proposed the use of water conserving fixtures, installation of automatic faucet sensors, and low consumption flushing fixtures.

Energy & Atmosphere (EA)

For the Energy & Atmosphere (EA), 19 credit points were targeted for the project. The project covers three of the six applicable energy efficiency credits. The design modifications proposed include optimizing energy performance by the use of VAV (variable air volume) flow controls instead of the existing CAV (constant air volume) controls for the HVAC system. This design modification was the costliest of all the changes for the project. In addition, the team anticipates that the building use can be maximized by scheduling the use time for the equipment so that the peak loads can be minimized. Credit is claimed through enhanced commissioning by beginning the commissioning process during the design process itself by forming a commissioning authority with prior experience in similar green building projects. The design was modified to use R134 refrigerant as a substitute for chlorofluorocarbons (CFC).

Materials & Resources (MR)

For the Materials & Resources (MR) section, the student design modification focused on achieving 5 credits. The LEED credits targeted include: credits for construction waste

management by using classified containers for different waste materials, utilization of locally produced construction materials (Cement/Steel), and by the use of rapidly renewable materials as a substitute (e.g. for concrete, use of slag which is a byproduct for the steel industry).

Similar efforts were targeted for the Indoor Environment Quality and Innovation in Design. Table 2 reflects the summary of the targeted points through design modifications. It is important to note that although some of the proposed points require additional re-engineering, most of the modifications can be done during the actual execution stages of the project without major schedule impacts.

Cost Estimation

A detailed cost analysis was conducted based on the bill of quantities for the modified ordinary building and for the modified building (green). Figure 1 and 2 shows the two estimates.

Figure 1: Base cost of the modified existing building (in Saudi Riyals, 1US\$ = 3.75 SAR)

FACTOR: 7,228,066.12/61,953,842 = 1.245642	Building COSTS (Bill of Quantities)	61,953,842
	Overheads (10%)	6,195,384.2
		68,149,226.2
	Markup (10%)	6,814,922.62
		74,964,148.82
	Bond (1%)	749,641.4882
		75,713,790.31
CM FEE (2%)	1,514,275.806	
	TOTAL COSTS	77,228,066.12

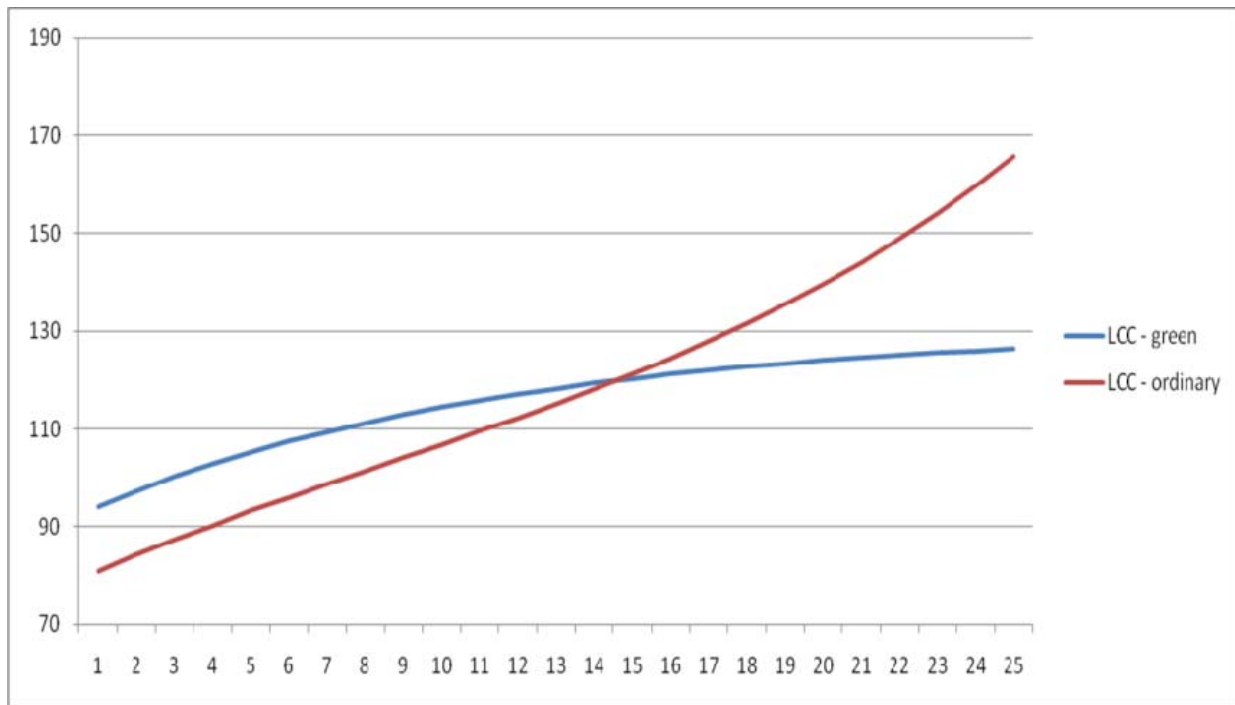
Figure 2: Cost for the Green Building based on the suggested design/construction modifications (in Saudi Riyals, 1US\$ = 3.75 SAR)

FACTOR: 78,742,341.92/61,953,842 = 1.270984 Total Cost Increase over Ordinary Building:17.8 million 23% cost increase over initial capital investment	Building COSTS (Bill of Quantities)	74,811,982.00
	Overheads (10%)	7,481,198.20
		82,293,180.20
	Markup (10%)	8,229,318.02
		90,522,498.22
	Bond (1%)	905,223
		91,427,723.2
CM FEE (4%)	3,657,109.00	
	TOTAL COSTS	95,084,832.2

The Construction Management (CM) fees are estimated to be higher for the green building as it is apparent from the local context that the green project would require substantial additional coordination effort from the agent. The above indicates a significant initial cost premium (23%) for the Green Building modifications suggested for the project. This additional investment is one of the biggest challenges for the owners in the region. In a build-to-sell market, the change in attitude can materialize only if it is mandated by the local building codes and government regulations. In the build-to-own market on the other hand, the change can be brought about by enhancing awareness about the benefits of the green buildings when considering lifecycle costs.

A detailed life cycle cost analysis was conducted to identify the added benefits of the Green Building over its useful life. Figure 3 reflects the results of the life cycle cost analysis for the student project for a useful life of 25 years. Although the initial costs are much higher, the energy savings over the useful life of the project far exceed the premium paid upfront. The curves project that the cost performance of the ordinary building and the green building would be relatively comparable during the early years however the difference would be magnified during the later years of the useful life of the project.

Figure 3: Lifecycle Cost comparison¹³ between the Ordinary and the Green Building over a period of 25 years (Costs in SAR, 1 US\$ = 3.75 SAR)



Student Evaluations of the Course

The course embodied a Student Centered Learning approach and the students responded very well to their empowerment. Table 3 below shows the part of the standardized student evaluations

for the course that focuses on the course and the textbook evaluation. There was no textbook adopted for the capstone course and hence that section is not relevant for this particular course.

Some of the student comments are motioned below for reference:

“This course has served the purpose of the real understanding of subject as well as integrating all the courses we have studied in this department.”

“The idea of promoting student based learning was excellent and helped a lot in developing the confidence and tackling the problems in practical life and work.”

Table 3: Section out of the course evaluation for the textbook and the course (A=4, B=3, C=2, D=1, E=Not Applicable)

Question Code	Question Description	A	B	C	D	E	Mean	Standard Deviation	Variance
04	The textbook is suitable for the course	0	1	0	0	6	3.00		
05	The textbook is easy to understand	0	1	0	0	6	3.00		
06	The textbook has sufficient examples and problems at end	0	0	0	0	7	0.00		
07	The textbook has many mistakes (e.g. typing errors, calculation errors, etc.)	0	0	0	0	7	0.00		
08	The course has good balance between theory and application	4	1	0	0	2	3.80	0.45	0.20
09	The course has made me interested in the subject area	4	2	0	0	1	3.67	0.52	0.27
10	The course increased my knowledge in subject area	5	1	0	0	1	3.83	0.41	0.17

“I would like to thank our instructor for his creativity and for the innovative way in teaching this course. I hope this way of teaching can be applied to other courses at the university.”

“More such student oriented teaching processes are required”

“I have benefited a lot from the course. The course has covered the knowledge gained from the CEM program and added a unique way for teaching and learning about a unique project (green building)”

Conclusions

The student team put in a lot of effort to contact the limited available local experts in sustainable, green construction. The students found that the difference the in the initial cost between the green building and the conventional building was substantial. Although the difference in initial investment would be sizeable even if the project was being built in a country with considerable sustainability awareness and infrastructure for building green (e.g. the US), the gap is magnified further due to the regional and local industry context for Saudi Arabia. The course project presented a learning opportunity for the students where a new topic was introduced into the curriculum by mutual discussion between the students and the instructor. The students, at the end

of the course, conducted a seminar for the wider university community and that seminar served as an added recognition for the students. Further, the students are listed as co-authors for this paper as well further highlighting their work. The paper reports on a single case study conducted during one offering of the course. Future work in this research will focus on successive application of a similar integration approach for future offerings of the capstone course. Data collected from these different courses can then be analyzed and will add strength to the argument.

The approach to integrate sustainability through a capstone project provides a different learning opportunity for students. Although there is an eventual need to overhaul the existing Construction Engineering and Management curriculum, the case presented indicates that sustainability can be successfully integrated into the CEM curricula, as a start, through existing courses and by using capstone projects. Such integration is not disruptive and does not require the instructors to wait for an overhaul of the curriculum to include key topics. In contrast to the approach of offering a separate course in sustainability, the capstone projects enable a deeper learning opportunity and the students can compare the benefits of the sustainable approaches by active comparison with the traditional existing curriculum, approaches.

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