“INTREGATING SUSTAINABILITY IN AN ENGINEERING CAPSTONE COURSE”

Joseph J. Cecere, Ph.D., CPC
Pennsylvania State University - Harrisburg
777 W. Harrisburg Pike, Middletown, Pa.17057

Abstract - Capstone courses in civil engineering programs are designed to reinforce and expand core topics in the fundamental program areas. However, most programs do not just have a capstone course which incorporates just two major areas - Structural Design and Construction Management that integrate sustainable principles. The knowledge and experience in these areas, as well as its sustainability, is crucial to work in today’s society and profession. The capstone course is an ideal platform for students to engage in a real world construction project procedures and structural design processes while focusing on the increasing demand of sustainability to the client.

Penn State Harrisburg’s Structural Design & Construction Engineering Technology (SDCET) program offers two different capstone courses. One course focuses on Structural Design, while the other capstone course relates to Construction Management. Student teams from both courses work together on the design and construction of a building structure. Typically, the building structure is a project provided by a local structural engineering or construction management firm. By working on a real world building project these two areas are naturally incorporated into the capstone course. Students in the construction capstone course focus on meeting the demands of the client, code requirements, constructability, and value engineering. Structural design students focus on determining the structural loads for a building and its design, while applying sustainable principles. Again, by incorporating both courses, there is an emphasis on sustainability throughout the entire process, thus reinforcing its importance.

INTRODUCTION

A major driver for sustainable construction is the need for people, countries, and continents to be able to build, renovate, and operate buildings within the available supply of natural resources. Therefore, during their education our future designers and builders should inegrate sustainability into their projects in order to meet the societal demands in the future. [1]

To a large extent, there is a great deal of latitude given to the design of a capstone course. The content of the course may be influenced by several factors including the geographic area the university services, the main focus area of the program (industrial, commercial, or residential), the program’s philosophy, the faculty's experience and expertise, and the perception of industry's needs. The course content may change with time, and courses may differ from program to program, but the basic goal is the same; to prepare students for a career in the civil engineering field. However, today the course focuses not only the basic civil engineering topics, but also on the increasing demand of sustainability.

This paper discusses the (SDCET) capstone courses, which incorporate the major areas of Structural Design and Construction Management. In addition to these areas, both courses place
an emphasis on sustainability throughout the entire process, thus reinforcing its importance. The goal of this effort is to foster cooperation with structural design and construction programs by exchanging ideas to improve their capstone educational processes, and while applying sustainability principles.

COURSE OVERVIEW

Senior Project - Construction (C E 488C) and Senior Project - Structural Design (C E 488D) are two capstone courses in the SDCET program at Penn State Harrisburg. SDCET major’s must enroll in one of these capstone courses, depending on their focus in the program. These courses are taken in a student’s senior year and are a year-long course. The course begins in the fall semester for one credit, and then continues in the spring semester for three credits.

The course is presented in a dual format with a one-period (50 minute) lecture discussion class and one laboratory class in the fall. The spring semester has two one-period lecture classes and one double-period project laboratory class. The project is a real commercial building project that is either under construction or that has just been completed. The project’s owner, architect, structural engineer and/or contractors donate project drawings and documents, as well as provide information about various aspects of the project, to the teams that assist the students with their assignments.

The structural design capstone course integrates the students’ previous course work into the design and structural construction of a building project. Throughout this capstone course, students gain a perspective of the structural design process within the entire scope of the project. The students focus on determining structural loads for a building, structural analysis and modeling, and designing and optimizing of structural systems (beam, columns, connections, foundation, etc.).

As the teams develop their design, they are also review sustainability factors. This may include the design’s construction ability, material availability and standard structural sizes, material usage of products as in recycling content in the concrete design or innovated design that affects its sustainability minimizing waste, and possibly others elements. In addition, the students work with a professional mentor from a structural engineering firm to possibly meet the client’s needs while trying to enhance its sustainability.

The construction management course syllabus also integrates the students’ previous courses with a focus on the construction process. The course outline starts with an overview of an established successful construction firm that provides a “Design-Build” component as one of their services and is expanded into a geographic location that they are working in and feels there is potential growth for more work. Therefore, the company decides that it should have a physical presence there. The courses then follow the branch location from its formation, seeking and securing clients, responding to a RFP for design-build services, constructability, performing a
sustainability review, conducting value engineering, creating bid packages and administering the project. These teams may verify the amount of material resources being consumed.

In addition to the individual topics covered by the courses, the importance of teamwork as well as sustainability, are repeatedly conveyed to the students through the project and reinforced by their final presentation to the client. This final presentation is presented to the actual engineers, architects, and contractors who incorporated sustainability into the existing project, as well as to their fellow students and instructors.

The lecture subjects’ content that the students have previously been exposed to in other courses, as well as current subjects, will benefit them in these projects. Industry presentations are regularly scheduled during the capstone course, and these presentations discuss real world experiences, which provide students with invaluable insight.

**CAPSTONE COURSE DISCUSSION**

The capstone course begins with an overview of the various components of the project that the student teams (Design – Build firms) are involved with. This provides a perspective for the student to revisit the elements in the Design – Build process. A re-introduction to sustainability is also addressed. Since the capstone courses focus on structural design and construction management, these are the only two sustainability areas students will focus in the courses.

The first capstone courses (fall semester) put this concept into perspective for the students. In the next capstone course (spring semester) students apply and expand upon their previous course to complete the construction/design of the project.

<table>
<thead>
<tr>
<th>1</th>
<th>Design – Build Process</th>
<th>9</th>
<th>Cost Estimating</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Project Management</td>
<td>10</td>
<td>Site Layout</td>
</tr>
<tr>
<td>3</td>
<td>Organization of a Construction Project</td>
<td>11</td>
<td>Quality Control</td>
</tr>
<tr>
<td>4</td>
<td>The Project Manager</td>
<td>12</td>
<td>Safety</td>
</tr>
<tr>
<td>5</td>
<td>Structural Engineer</td>
<td>13</td>
<td>Management of Change</td>
</tr>
<tr>
<td>6</td>
<td>Build- Award Process</td>
<td>14</td>
<td>Value Engineering</td>
</tr>
<tr>
<td>7</td>
<td>Pre- Construction Activates</td>
<td>15</td>
<td>Project Close - Out</td>
</tr>
<tr>
<td>8</td>
<td>Planning &amp; Scheduling</td>
<td>16</td>
<td>Educating the Occupancy</td>
</tr>
</tbody>
</table>

Table 1 lists topics that are covered in the capstone courses. Sustainability are integrated in the various topics to reinforce its importance. None of the topics are covered in great detail, since this is left to previous courses where they were studied at length. However, a new slant on sustainability is given which hopefully gives the student a better understanding of the "the big picture".

The following paragraphs briefly discuss those topics.
Design-Build (DB) Process
This process has the design professional and the construction firm combining their expertise as a single unit in the project delivery. The design firm marries its development of the building design with the thoughts and knowledge of the construction firm’s expertise. Consequently, the design-build team combines these tools to provide a unit that can deliver both the design and construction of the project while keeping the client’s budget, as well as timeline, obtainable.

Traditionally the main focus of most designers is to obtain the client’s needs while designing a structure that will define their style. Designers also typically employ the best value for the client when selecting materials or processes. “Client” satisfaction is increasingly seen by all concerned with the development and construction process to be largely dependent upon the selection of the most appropriate procurement. [2]. In the design-build process, the designers merge their skills with a construction firm that typically results in providing a project that meets the client’s goals of time and money.

The focus on best value and client satisfaction is relatively narrow in scope and mainly views the act of obtaining any building as a form of capital expenditure taking place at one point in time. This approach could be seen as less concerned with the longer-term continuous expenditure associated with the use of the building post-handover, and more focus on the building’s ability to function “here and now”. [2] Thus, the sustainability was less of a concern the client. However, this is becoming an increasing factor in the client’s goals.

The structural students are exposed to various factors that promote sustainability concepts and thus incorporate these as they create their designs. The procurement in the construction students’ review process may include the value of money ideas compared to the basis of “whole life costs,” as well as less waste during the construction. These students perform value engineering during the design phase that articulates a sustainability strategy.

Project Management
Knowing that project managers’ key goals are time and cost reinforces that students need to understand the basic functions of management: planning, organizing, staffing, directing and controlling. The students enjoy discussing management roles and they gain an appreciation for the differences in values and agendas of various people in the organization. However, project management must increasingly start understanding their involvement with substantiality.

Organization of a Construction Project
Two types of organizations are discussed. First is the organization of project phases, definition, planning, sustainability review, construction (or implementation) and close out. Time frames and levels of effort and costs are discussed, as well as the types of tasks that occur in each of the phases.
The second type of organization studied is the staffing organization as it relates to the various functions required for a project. Positions reviewed include the project and construction managers, legal, procurement, labor relations, engineering, safety, materials management, equipment management, communications, security, waste disposal, project control and more. An understanding of each of these functions and how they interrelate is necessary to appreciate the "big picture" of a construction project.

In addition to the project and staff organizations, relationships between the owner, designer, construction manager and the execution contractor (and its subcontractors) are reviewed. Project issues such as scope, project goals, "discovered" site conditions, submittals, documentation, delays, impact of rework, and the meaning of the word "design" are discussed. [3]

**The Project Manager**

The function of the project manager is presented. This person’s role as an observer, interpreter, judge, arbitrator, evaluator, and certifier are discussed. The students are reminded of the importance of sustainability and their involvement in the preconstruction, construction and post collection process. Several other important responsibilities that are covered include motivator, liaison, project leader, communicator, contract administrator and main point of contact for the owner, the subcontractors, the designer, and his/her home office.

The various management functions are presented so that the student appreciates the nature of his/her duties. It is emphasized that normally, as manager, he/she cannot become overly involved in details lest he/she lose site of the bigger picture. This tendency to become involved with details is usually strongest when the issue involves a specific area familiar to the manager. However, an emphasis on the project’s sustainability and their involvement is stressed.

**The Structural Engineer**

The steps involved in designing a building to be stable and practical are discussed and practiced. Relevant structural design codes (AISC, ACI 318, ASCE 7-10, etc.) are utilized to determine: a) the forces acting on a building, b) the strength of building members and connections, and c) design practices for serviceability (prevention of deflections, unsightly cracks, etc.). The completion of these tasks involves the production of calculations, structural models, and the drafting of building drawings. Most of the design work utilizes and expands upon the student’s previous coursework. However, portions of the building project often require a design methodology that the students are initially unfamiliar with (elevator pit design, handrail design, etc.). In turn, students must research how to utilize their basic principles to complete that part of the design. The students typically find this both challenging and rewarding. Again the sustainably process is incorporated in the team’s design in stressing its importance to this process.
Design students work with the construction students to ensure their design is practical in terms of constructability, construction time, and material availability and sustainability. The design students must also meet the architectural demands of the project, which often imposes constraints on unsustainable design and building member locations. In addition, the design students work with a professional mentor from a structural engineering firm to improve the quality of their design. Often times, the students will work with the structural model that was used in designing the building project. In the second semester of the course (spring semester), the students will present their design at a structural engineering firm. Students find that this is enlightening and a good preparation for the final capstone presentation.

The Bid Award Process
The steps leading up to bid submission are presented. Bid documents are discussed as they relate to the difficulty and accuracy of bid preparation. The perspective of the difficulty and accuracy of issue for bid documents usually results in poor bids (usually high bids due to ambiguities). Also discussed are pre-qualification lists and how one gets on them. The bid process steps are discussed including contract strategies, bidders list, pre bid conferences, items of importance when the owner/DB contractor reviews bids, subcontractors list, post bid meetings, kick off meetings and notices to proceed.

Depending on the construction approach for the project, there may not be a bidding process. The builder made be selected by Prequalification Statement, Price Based, Best Value, to mention a few critical factors. Unfortunately, project is typically priced based, as the economic bottom line tend to be the primer driver. LEED projects, the best value approach is not typically pursued for selecting a contractor. [4]

Pre Construction Activities
Students are introduced to the types of tasks required many times prior to site mobilization. These activities include the submittal of paperwork such as insurance certificates, MSDS sheets, invoicing formats, drug testing programs, safety plans, QC plans, and copies of business licenses. The necessary LEED procedures and documentation for certification verification are discussed. Also, depending on the type of project, other documents or LEED procedures for certification verification are discussed, as well as shop drawings, samples of special materials, detailed procedures for waste handling, and especially hazardous waste.

In addition to documentation, other pre construction activities include assignment and orientation of the full project team, training personnel (especially where safety is a special concern), procurement, equipment rental, arrangement for temporary utilities, and setting up a project accounting and reporting system.

Planning and Scheduling
This is principally a rehash of subject matter covered elsewhere in the student’s college career. Not much time is spent here except as it relates to the course project. Students must develop a Primavera CPM schedule for their projects. However, the general principals of planning and
Scheduling are reviewed again here. Although there is some over learning here, it is nonetheless done because of the importance of these functions in managing construction projects.

It is again stressed to the students the importance of time within the schedule, as well as the evaluation of the project’s sustainability. The importance to the investment of the elements may extend the project timeline, but it may be a critical factor in its sustainably.

Sustainable resources are covered to some extent in other courses such as planning and scheduling, and estimating. Here, however, the students are made aware that in addition to people and time, other important resources are available too, and needed by the construction manager including equipment, materials, money, space and technology. All of these areas play a role to the project’s sustainable review.

**Cost Estimating**

Like planning and scheduling, the student has previously had a course dedicated solely to cost estimating. Therefore, a detailed study of this subject is not made in the capstone course. However, there are a few things emphasized as they relate to the course project and projects in the real world. These include how indirect, overhead and fee are handled. Also, material take offs are discussed with regard to how they are organized based on how they will be used; resources, long term usage and cost saving, and integrating the project delivery systems. Also, the students are required to organize their cost estimates for the course project in an upper management format.

**Site Layout**

Usually the student has not yet been exposed to the need for site layout planning for a construction project. Considering "space" as a resource may not have ever occurred to him/her before. The concept of laydown areas, fabrication areas, personnel facilities like break shacks and porta potties, stockpile areas and the space requirements for excavations are likely new concepts for students. These requirements can be substantial and the construction manager must plan this carefully. The concepts of staggered arrival of materials on site, and backfilling excavations to create more space are practices presented to the student.

**Quality Control**

Students are presented with the difference between quality control (QC) and quality assurance (QA). There is a "codes" course students have already taken prior to their arrival in the capstone course, and so specific codes and specifications are not addressed. However, the efficiency of developing a "quality action plan" (or preprogrammed inspection plan) is presented to the students. The relationship between the QC inspector in the field and craft people is also discussed. Pitfalls related to sustainability are discussed through personal experiences of the engineers, architects and teacher.
Safety
Safety is discussed not so much in terms of codes and requirements (which is covered in a previous course), but in terms of root causes of accidents and steps some organizations have taken to minimize them. Two root causes specifically discussed are 1) doing things too fast, trying to make up time, taking short cuts, and 2) ignorance of the dangers around you. The advantages and disadvantages of incentive programs (safety awards, bonuses) used by contractors and owners alike for reducing job related accidents are discussed. It should be noted that safety is one of three issues (the others being attitude and communications) brought up throughout the course to instill awareness of its importance on any job.

Management of Change
Students are made aware that most projects require changes before the project is completed, and that these changes must be handled in an orderly, verifiable and trackable manner. The owner made select changes that may impact the sustainability of the project. Origins of changes are discussed, and they may from the owner, designer, contractor or from other sources such as code revisions, new ordinances, resource reviews, value engineering, etc. The paperwork required, such as the Change Order itself and all backup documentation is covered.

Value Engineering
Construction Management students are informed that the owner wants additional “Value Engineering” performed on a component of building. (Example: floor systems, shell structure, and roofing systems). Students are re-introduced to the components of value engineering that includes identifying the function that is being evaluated, the proposed item in the current design drawings, analyzing its features, studying and recommending alternate solutions. Students present supporting documentation of each option’s positive and negative elements, as well as the team’s recommendation to the client. The students’ V E evaluation reinforces the project’s sustainably to the client and the resources.

Holding Productive Meetings
Because meetings are an integral part of the engineer or project manager's job, and because many people feel meetings are a waste of time (and many of them are), techniques for holding effective meetings are presented and practiced. Three key elements of effective meetings, a prepared agenda, control, and decisive follow up, are the main points presented. Other issues are also discussed such as appropriate attendees, good meeting room environment, visual aids, and how personal agendas can be controlled.

Conflict Resolution
Construction management, like any other type of management, deals with people and invariably deals with differing attitudes, agendas, and goals. Conflicts are going to arise. How these conflicts are handled can greatly impact job productivity, profit and loss, and claims. The student is alerted to the fact that conflicts will arise, how emotions (anger) exacerbate the situation, and how listening and feedback play a big role in resolution of conflict. Methods to deal with anger are presented as well as listening and feedback techniques.
Project Close-Out
For many students, it's easy to see how a project starts, with mobilization, ordering and arrival of materials and equipment, site clearing and excavation. However, many do not realize how much work is involved when the job nears completion. One critical area for any certification is documentation. Students are presented with various components leading to verification and certification. Discussions include final inspections, functional issues, punch list generation, submittal of warranties and guarantees for workmanship and equipment, documentation, and turnover of “as-builts,” as well as certification material. The significance of turning over the care, custody and control of facilities to the owner is also discussed.

Educating the Occupancy
Educating the building occupants is one major part of an operational success. Focusing on the employees, it is critical the inhabitants will understand all of the sustainable features of the facility. The key of a sustainable building is not only building this type of structure but operating it.
Most of educational programing will address key features to the building, such as water efficiency, energy renewability, recyclables, indoor environmental, and the design itself. The construction achievements may be interesting to the users. These may include diverting a percentage of construction waste or purchasing salvaged material with recycled content, or recertified wood products.

CONCLUSIONS
The capstone course at Penn State Harrisburg presents a well-rounded picture of the Design-Build process in a civil engineering building project. Structural Design and Project Management activities are presented that include technical requirements for structural designing, organizing and controlling a project are practiced and discussed; and people skills are emphasized. And throughout the entire course, a special emphasis is placed on effective communication. The purpose for the course is to tie together much of what the student has learned in his/her four-year college career and add a few things to which the student has not yet been exposed. The subject matter puts construction management/structural design into a perspective so students see how the various subjects they have studied come into play. Students understood that sustainability is a key part of a project for many clients. The final presentation audience also found the sustainability concepts were well thought out and very interesting.

Overall, students in their respective areas had a better understanding of the other components related to sustainability.
BIOGRAPHICAL INFORMATION

JOSEPH J. CECERE, Ph.D., CPC, is an Associate Professor of Engineering in the Structural Design & Construction Engineering Technology as well as the Civil Engineering program at Penn State Harrisburg.

REFERENCES