AC 2012-3622: BUILDING CONSTRUCTION: INTERDISCIPLINARY CAPSTONE PROJECTS

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Abstract

The past four fall semesters, the COSC 440 Interdisciplinary Capstone classes of graduating construction science seniors have been teamed up with COSC 663, Sustainable Construction and charged with forming several design companies that will team up with construction companies to form Design-Build Companies. The companies will respond to a real life RFP for a building that meets and exceeds LEED 3.0 Platinum requirements, a Net Zero. Both classes are expected to coordinate the work among the respective companies. There is a final presentation of the companies’ responses to the RFP, held at the Texas A&M University Systems building where real companies compete for real projects. The proposals and presentations are reviewed and ranked by a jury of construction industry professionals. The written proposals are ranked and a separate ranking is done for the oral presentations. Grades are influenced by team rankings as determined by outside jurors. Students peer evaluate each other for performance according to posted rubrics; student project grades are affected by the peer evaluation. This approach has been very successful in the past four years and the current class of 23 attracted 1 landscape urban planning, 6 civil, 7 architecture, and 9 building construction students, resulting in a truly interdisciplinary class and team composition.

The goal of this paper is to showcase the framework, structure, and logic for integrating the two courses and compares the results in terms of grades and quality of the responses from the faculty and the jurors. All classes were asked to keep track of weekly percent plan complete (PPC) and interestingly, the virtual companies with the best PPC were the ones that won the RFP project.

The descriptive method of qualitative research is used. This method is used when an author is developing a coherent and comprehensive view of the subject at hand from the perspective of the faculty, students and jurors that are subjects of the study as well as observers (Oakley 1994). The motivation is to share an integrative teaching method that is finding traction among students and is highly successful, according to the participants.

Rationale and Objectives

The need to train the next generation of construction industry professionals is recognized as a significant challenge (Ottman, J. A. 1998). Climate change and
sustainability issues are at the forefront of issues facing the industry. However, recent research suggests that relatively little has occurred across the nation to proactively develop strategies and implement actions to strengthen the built environment, keeping in mind the predicted impacts of climate change and sustainability challenges.

The National Academies of Sciences and the United Nations, among others, have called for efforts to empower present and future decision makers with the climate change and sustainability knowledge required to become informed about the issues. However, research has noted the lack of systematic efforts to develop the necessary cross-disciplinary curricula to train current and future leaders and university students (Frause, B. and Colehour, J. 1994). As society and the building profession continue to embrace green building processes and practices, the need for and development of university-level sustainability related construction courses is expected and required.

Buildings, infrastructure, the environment, and societal wellbeing are inextricably linked. Energy, materials, water and land are all consumed in the construction and operation of buildings and infrastructure. Built structures in turn become part of the human environment, affecting living conditions, social well-being, and health. It is therefore important to explore environmentally and economically sound design and development techniques in order to create buildings and infrastructure that are sustainable, healthy and affordable, and encourage innovation in buildings and infrastructure systems and designs (Emiel, W. F. M. 2000).

Because construction engineering and project management education are critical to addressing these challenges, the construction-related curriculum at Texas A&M University has started to teach students how to address the environmental issues at hand with sustainability strategies. This course development strategy proposes the integration of sustainability into the construction and built environment-related curricula that cut across numerous schools and departments at Texas A&M University. Critical aspects of the proposed curricula include exposing cross-disciplinary students to sustainability related research, science and policy principals, and real-world construction problems presented by industry professionals.

From a pedagogical perspective, the development of the proposed structured sustainable construction course would lay the foundation for additional department-specific or university-wide marketing sustainability-related courses (Sheth, J. and Parvatiyar A. 1995). Results could also be used to create an additional sustainability focus area within the departments and develop faculty-led seminars and workshops. Continuing education courses could potentially be offered by TAMU System units. For example, the Texas Chapters of the U.S. Green Building Council have recently partnered with Texas Community Colleges to teach hands-on sustainable construction techniques, and the chapters are interested in a similar relationship with in-state research universities. Without question, the proposed structured sustainable construction course would facilitate
climate change and sustainability related research collaboration between faculty and research staff. This effort will also be used to seed long-term initiatives to further develop TAMU as a national leader in climate change and sustainability teaching and research.

**Previous similar course settings, lessons learned and recommendations**

The first time that the author combined two courses in a similar setting was with COSC 689 Lean Construction (LC) and COSC 440 Interdisciplinary Capstone (IC). LC formed four consultant firms, and the IC class formed four virtual companies. For the consultant firms, however, the lines of responsibility were blurred and the deliverables to the RFP mixed. From this arrangement, the author learned to make LC or, in this paper’s case, Sustainable Construction (SC) teams an integral part of the IC companies. This required a higher degree of coordination in using the templates created by IC and in the written and oral presentations. Also, the role of LC is very similar to that of the IC participants and does not merit adding four members to a presentation team just for Lean. However, the role of SC that deals with both the design and the logistics of making an otherwise LEED certified (Silver, Gold or Platinum) building a Net Zero building requires more focused intervention and justifies adding four members to the presentation team. Typically the SC team roles are: Project Executive, Senior Designer, Specialty Superintendent, Specialist Cost Estimator / Economist.

**Sustainability**

Sustainability is defined as: How sustainable construction materials and methods contribute to meeting the needs of the present without compromising the ability of future generations to meet their own needs (the Brundtland Report in the World Commission on Environment and Development 1987); identifies and analyzes those international, national and local net zero programs promoting sustainable construction; and characterizes the components of successful sustainable construction projects. COSC 663, Sustainable Construction, is charged with forming several design companies that will team up with construction companies from COSC 440 – Integrated Capstone Class to form Design-Build Companies. The companies will respond to a real life RFP for a building that meets and exceeds LEED 3.0 Platinum requirements, a Net Zero. Both classes are expected to coordinate the work among the respective companies. A final presentation of the companies’ response to the RFP is held at the Texas A&M University Systems building where real companies compete for real projects. The proposals and presentations are reviewed and ranked by a jury of construction industry professionals. The written proposals are ranked and a separate ranking is done for the oral presentations. Grades are influenced by team rankings as determined by outside jurors. Students peer evaluate each other in a company for performance according to posted rubrics. The Student Project grade is also affected by peer evaluations. This approach has been very successful in the past four years and the current class of 23 attracted 1 landscape urban planning, 6 civil, 7 architecture,
and 9 building construction student, resulting in a truly interdisciplinary team composition.

**Engagement**

The plan aims to grow from 35 students (23 graduate and 12 undergraduate) per year to a minimum of 120 students per year or 60 students per semester: 50 graduate students in COSC 663 (with the target of 10 CVEN (Civil Engineering); 10 COMG (Construction Management); 10 ARCH (Architecture); 10 LDEV (Land Development – Urban Planning); 10 MAYS (Mays Business School) to team up with 20 undergraduate students from COSC 440.

**Involvement**

The following faculty members have been identified as resources and are currently working towards the integration of practices:

College of Architecture:

COMG: Jose L. Fernandez-Solis, PhD  
ARCH: Prof. Rodney Hill  
LDEV: Prof. Geoffrey Booth

College of Engineering:

CVEN: John Walewski, PhD

Mays Business School:

MAYS: Prof. Cydney Donnell

**Integrate**

Both classes are writing intensive and have a research paper requirement. The classes form four virtual Construction Companies (VCC) and four virtual Environmental Consultant companies (VECC) that team up to respond to a real life RFP which is modified through Addenda to become a Net Zero project. For example, in fall 2011, Turner Construction provided the project: Deloitte University Campus in Dallas TX -- a $160m project COSC 663, as experts in sustainability, direct the design effort, while COSC 440 spearhead the project management effort in the RFP response.

In COSC 440, a list of research topics is given to undergraduate students to select and submit a professional paper that uses a journal guideline for presentation. In COSC 663, master’s students select a case study project from a list of global LEED Platinum certified projects. PhD students may propose a research topic
Experience

The VECC are charged with designing, drawing and specifying the performance requirements of the Addenda and the VCC are charged with modifying the original proposal, including among other items, site logistics and utilization plan, schedule, cost estimate, quality assurance / quality control plans. The companies then write a professional response to the RFP and make an oral presentation (typically at TAMUS) in front of a panel of 20 jurors from TAMUS, Sponsors, CIAC, Architects and Faculty.

Outcomes, Objectives and Assessments

1. Effective and professional oral and written communication: demonstrate mastery of communication requirements in the construction profession (assessed by weekly writing assignments, the written and oral research paper and RFP written response).
   a. Complete an individual research paper on a contemporary construction topic;
   b. Deliver an individual oral presentation on a contemporary construction topic;
   c. Complete a team written proposal in response to a real project RFP;
   d. Complete a team oral presentation of a proposal in response to a real RFP;
   e. Demonstrate communication proficiency in writing letters, memoranda, email and other media common to the construction profession

2. Principles of leadership in business and management: understand and appreciate the necessity of working with the full project delivery team, including: designers, subcontractors, vendors and facility managers (assessed by the written and oral research paper and RFP response).

3. Problem solving and decision making: respond to a real RFP and present the written and oral solution to a panel of jurors that includes among other topics (also assessed in quizzes and assignments):
   a. Construction company and owner: Strategic planning, logistics and tactical execution
   b. Company organization, financial statements, ratios, organization chart
   c. Bonding and insurance capacity and documentation
   d. Scheduling and estimating (conceptual or final)
   e. Building Information Modeling (use a project specific example)
   f. Pre-construction service practices and project specific plan
   g. SWPPP and site utilization practices and site specific plans
   h. Sustainable construction practices and site specific plan to achieve LEED platinum or Net Zero certificates and performance
   i. Lean construction practices and site specific plans
   j. Project management technology practices and site specific plans
k. Value engineering practices and site specific plans
l. Company safety and risk management plan and virtual company historical data
m. QA/QC, commissioning and close out documentation practices and site specific plans
n. Marketing of professional services practices and site specific plans
o. Subcontracting, HUB practices and site specific plans

4. Current issues in construction: understand the different project delivery systems available in the construction industry. Objective is assessed by quizzes, assignments, the RFP written and oral responses.

5. Critical thinking and creativity: understand the requirements and procedures to win new work in the commercial, design-build (interdisciplinary) construction sector. Objective is assessed by quizzes, assignments, the RFP written and oral responses.

6. Professional ethics including application to situations and choices: understand and appreciate the imperative of ethical practice in the construction profession (assessed by quizzes, assignments, the written paper, oral presentation and RFP response).

7. Use of information and communication technology: demonstrate understanding of evolving industry issues/practices; such as Lean construction, BIM and sustainable construction (assessed by quizzes, assignments, the written paper, oral presentation and RFP response).

8. Complex project decision making and associated risk management: negotiate with the internal virtual company team and the external team from sustainable construction or from lean construction virtual consultant companies concerning the decision making process that affects the design and construction of a net zero or lean construction project; manage the risks of time and cost involved. Objective is assessed by quizzes, assignments, the RFP written and oral responses.

**Replicable across disciplines**

This proposal integrates graduate and undergraduate students not only across colleges but also across departments in a real life project that involves research, is writing intensive, requires final publication of journal paper quality work, is assessed with weekly quizzes or assignments, requires weekly project meeting minutes with agenda and action items and involves a panel of jurors from industry and academia that awards the final project. Other disciplines may use this template to replicate the setting and verify student satisfaction and performance outcomes.

**Institutionalized - Permanence**

The proposal also envisions that the core faculty will be able to rotate in presenting and creating a similar course to COSC 663, along with a similar COSC 440 interdisciplinary capstone in CVEN, ARCH, MSLD/LDEV, therefore institutionalizing the learning method if not the content.
Typically, vertical construction involves all these disciplines and therefore we assume that the interdisciplinary program would be attractive to students regardless of which department or college is the main sponsor. In addition, CVEN has an emphasis in horizontal construction and industrial engineering and construction, with a focus on project management, which could be attractive, especially to graduate students in other disciplines with a Civil Engineering background. COSC has provided Dr. Walewski the current list of graduate applicants showcasing how many students come with a Civil Engineering background. Projects from large contractors such as Bechtel and Kiewit, who perform both vertical and horizontal construction, are ideal candidates to provide project RFPs, problem statement and research areas, as well as being presenters on selected topics that feed into the RFP response. All construction, vertical and horizontal, has business components which accreditation boards deem essential to the curriculum. The proposal will add to each course mix a strong business component of interested graduate students who would like to become more fluent with aspects of construction while enriching the group with their knowledge and expertise, as well as providing mentors and speakers to the whole class.

The first year, faculty from other departments and colleges are involved as student mentors. The second year, the faculty is further engaged and involved in (a) setting the integrated research agenda, (b) defining the experiential component of project RFP and selecting guest speakers from industry, (c) defining learning outcomes and methods that evaluate effectiveness and (c) further developing the plan for replicating the model in their departments and colleges. The third year, the model is replicated in departments and colleges and the Mays Business school component is added to the COSC 440/663 model as a testing bed for future adoption by other department and colleges. Table 1 represents the progression of this proposal.

**Table 1** Student Participation in the Interdisciplinary Capstone that Integrates Sustainability into the Curriculum

<table>
<thead>
<tr>
<th>College or School</th>
<th>Spring Semester</th>
<th>Fall Semester</th>
<th>Total Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>COA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ARCH</td>
<td>COSC 663 – 10</td>
<td>COSC 663 – 10</td>
<td>20 Graduate</td>
</tr>
<tr>
<td>COSC</td>
<td>COSC 663 – 10</td>
<td>COSC 663 – 10</td>
<td>20 Graduate</td>
</tr>
<tr>
<td></td>
<td>COSC 440 – 20</td>
<td>COSC 440 – 20</td>
<td>40 Undergraduate</td>
</tr>
<tr>
<td>MSLD/LDEV</td>
<td>COSC 663 – 10</td>
<td>COSC 663 – 10</td>
<td>20 Graduate</td>
</tr>
<tr>
<td>COE</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The teaching effort for a cross disciplinary project requires the integration of cross disciplinary faculty and a number of possible roles can be incorporated, from mentoring the team, involvement with the project definition, teaching and inviting guest speakers on the area of expertise that also covers the project type. Table 2 showcases student disciplines and faculty involvement. Graduate students can approach this class as a special topics class or, if the faculty allows, as a regular class with both local departmental as well as other departmental teaching involvement but under the course number and syllabus of the original department. In this case, the syllabus of the original course could be modified to allow student involvement in team activities. We have found that as long as the faculty agrees that this is a pedagogically valid exercise and the departments concur, the faculty of the disciplines involved can create their respective syllabi and include the common activities that create the teamwork required. A common RFP and project approach where the content is coordinated in both the deliverables and the assessment has been the key to success. The first session should be held by a special meeting of all enrolled students, held in one common location with the respective faculty members gathered and the approach to the class structure clearly explained and reinforced by each faculty.

**Table 2** Projected Interdisciplinary Capstone Curriculum Growth: Faculty roles and student enrollment target
Sample of Student Team Submittal

This work showcases the research synergy of a multi-disciplinary team (see Figures 1 to 3).

Figure 1 Scale of Power vs. Storage

- **Light Bulb:** 100 Watt Bulb x 10 Hours
- **100,000,000 kWh per year**
- **10,000 kWh per Year**

**Average U.S. Household:**

- **1,000,000 kWh per Year**
- **30 Megawatt Hours (MWh)**

**100 U.S. Households:**

- **100,000,000 kWh per Year**
- **300 Megawatt Hours (MWh)**

- **Power** is measured in kilowatts (kW) or megawatts (MW) and refers to the amount of electricity a storage system can absorb or supply at any given instant.

- **Energy** is measured in kilowatt-hours (kWh) or megawatt-hours (MWh) and refers to the total storage capacity of a system, or the length of time a battery can provide a set amount of power.

- **The rate at which water flows through the pipe** is analogous to a storage system’s electrical **POWER (MW)** capacity.

- **The length of time the pipe will dispense water** is limited by the amount of water the tank can hold and is analogous to a storage system’s electrical **ENERGY (MWh)**.

**Figure 2 Air to Air Heat Exchangers**

**Air-to-Air Heat Exchangers** are mechanical devices designed to effectively transfer heat from one airflow stream to another. The prototypical application is an air-to-air heat exchanger that transfers heat (or coldness) from exhaust air to incoming outdoor air, reducing the significant waste of energy normally inherent in the process of providing ventilation air to a building (for control of indoor air quality). The resulting increase in process efficiency translates to energy savings and often to reduced heating and cooling equipment sizes since loads are reduced.
The question always comes up of non-performing students in both attendance and participation. The team members peer review each other regarding participation and the individual student final grade is modified by a rate consisting of the sum of the reviews (self-review does not count) divided by the number of reviews. This is explained early in the course and repeated four times during the semester as a reminder. Participation in discussion is dependent on attendance as a minimum requirement. Therefore, all assessments are modified by the participation rate, which is comprised of the sum of all attendances as recorded by daily attendance sheets and the total number of attendances (credit is given for university sanctioned excuses that are clearly delineated in the syllabus) plus the syllabus published allowance of one unexcused absence.

This modifier was a cause of much consternation at the end of the semester and possible source of contention the first few times the course was offered. Afterwards, word got out that, not only were the classes excellent, it was essential that students attend all classes if they did not want a grade reduction. Thus far, I have experienced no problems with both the peer review rating and the attendance/participation rating that modifies the course final assessment. Please email me if you are interested in obtaining a copy of the class syllabus or would like to discuss the framework and logic of this interdisciplinary course setting: jsolis@tamu.edu or call me at (979) 458-1058.

Course Organization

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Company B Percent Plan Complete as reported weekly
The interdisciplinary course in the form described above has been offered four times. In each case, the students calculated their individual Percent Plan Complete and reported it weekly for a total of twelve weeks. The virtual company (team) cumulative PPC was also calculated weekly. Of interest is the finding that historically, the company with the highest PPC average has won the project, having been judged independently by the above mentioned set of jurors who have no access (blind) to the company PPC reports (see Figures 4 and 5).

Figure 4 Sample of Company B Percent Plan Complete as reported weekly
Figure 4 is the PPC of Company B, which is an average of the weekly PPC performance of each company participant (Fig. 5). A performance comparison establishes that company A has the best PPC and, as in past courses where this same technique was used, is the winner of the competition. PPC relates how well the students fulfill the promises they make to do a certain work correctly, completely and on time. This apparently indicates that, based on a limited and not statistically significant sample, good student and company PPC performance translates into winning a job at the academic level.

**Juror Rubrics for Scoring Oral Presentation Performance**

Company A had a higher PPC performance and on average, their written and oral RFP responses corresponded to their self-reporting efficiencies, as well as the individual student grades. However, we must note that all PPC reporting is susceptible to subjective interpretation and should be verified against actual performance (see Table 3).
### Table 3 Juror grading rubrics, grades by company, ranking, posted earned grades, and company PPC averages.

<table>
<thead>
<tr>
<th></th>
<th>Company A</th>
<th>Company B</th>
<th>Company C</th>
<th>Company D</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Team, Past Performance Data, Personnel Responsibility</td>
<td>8.75</td>
<td>7.00</td>
<td>7.75</td>
</tr>
<tr>
<td>2</td>
<td>Company, Bid Bond, Financial Strength</td>
<td>9.00</td>
<td>8.50</td>
<td>7.63</td>
</tr>
<tr>
<td>3</td>
<td>Information Technologies, CAD / BIM / Software Packages</td>
<td>8.50</td>
<td>6.75</td>
<td>7.25</td>
</tr>
<tr>
<td>4</td>
<td>Schedule of the Work</td>
<td>8.25</td>
<td>7.75</td>
<td>6.63</td>
</tr>
<tr>
<td>5</td>
<td>Site logistics, Jobsite Security provisions</td>
<td>8.75</td>
<td>8.25</td>
<td>7.13</td>
</tr>
<tr>
<td>6</td>
<td>Conceptual Estimate (assumptions and exceptions)</td>
<td>8.50</td>
<td>8.00</td>
<td>6.13</td>
</tr>
<tr>
<td>7</td>
<td>Safety, Security and Health Plan, HUB (culture of minority inclusion and participation)</td>
<td>7.75</td>
<td>8.25</td>
<td>5.75</td>
</tr>
<tr>
<td>8</td>
<td>Lean construction</td>
<td>6.25</td>
<td>8.50</td>
<td>7.75</td>
</tr>
<tr>
<td>9</td>
<td>Lean Zero</td>
<td>9.00</td>
<td>8.50</td>
<td>8.38</td>
</tr>
<tr>
<td>10</td>
<td>LEED Platinum</td>
<td>9.50</td>
<td>9.50</td>
<td>8.00</td>
</tr>
<tr>
<td>11</td>
<td>QA/QC (mock ups and inspections)</td>
<td>7.75</td>
<td>7.25</td>
<td>4.00</td>
</tr>
<tr>
<td>12</td>
<td>Cash Calls (loaded schedule)</td>
<td>5.50</td>
<td>2.75</td>
<td>3.13</td>
</tr>
<tr>
<td>13</td>
<td>Presentation (Professional quality)</td>
<td>10.00</td>
<td>7.75</td>
<td>7.25</td>
</tr>
<tr>
<td>14</td>
<td>Commissioning and close out process</td>
<td>5.25</td>
<td>8.50</td>
<td>2.13</td>
</tr>
<tr>
<td>15</td>
<td>Acceptance of terms and conditions</td>
<td>7.75</td>
<td>6.50</td>
<td>5.00</td>
</tr>
<tr>
<td><strong>ASKING FOR THE JOB (-10 points if not done)</strong></td>
<td>0.00</td>
<td>-1.25</td>
<td>-4.38</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>Total Points:</strong></td>
<td>120.50</td>
<td>112.50</td>
<td>89.50</td>
<td>107.38</td>
</tr>
<tr>
<td><strong>Grade score /150:</strong></td>
<td>140</td>
<td>135</td>
<td>110</td>
<td>127</td>
</tr>
<tr>
<td><strong>RANKING:</strong></td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td><strong>PPC Company Average</strong></td>
<td>92.55%</td>
<td>87.50%</td>
<td>82.24%</td>
<td>81.71%</td>
</tr>
</tbody>
</table>

### Comments

In the past the author experimented with coupling COSC 689 Lean Construction with COSC 440 Interdisciplinary Construction following the format previously mentioned, but the results were not as effective as coupling with COSC 663 Sustainable Construction.

Space precludes adding all the material that the team has created in the process of researching high performance projects. In this case, the list was of all LEED Platinum buildings, globally, published up to 2010, but in the near future, case studies will be drawn from a list of Net Zero energy consumption (EC) projects published up to that date; in the far future, the list may be of Net Zero embodied energy (EE) projects that are published up to that date. The RFQ/RFP should be of an interesting project that may or may not contain LEED platinum or Net Zero EC or EE with the challenge of responding to the RFP with an Addenda that changes the present design and documents to incorporate best practices design and construction features, while providing justification through Life Cycle Cost Analysis, Break Even analysis and other fundamental real life requirements that touch on the different disciplines aggregated for the project’s duration. The
synergy created by the knowledge brought to the team from different disciplines who approach a real life problem or project from different paradigms is an extremely rewarding experience for all involved and is worth the time and effort of the faculty, who must trust that everyone has the best interests of the student experience at heart.

The final project written and oral presentations are judged by a panel of approximately 20 experts from the profession and academia. The projects are ranked, critiqued by each team as a whole and awarded to the best team. The jurors then give a cardinal spread between the ranked teams and that determines the grade differential between teams.

References


