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ScienceDirect
Procedia Engineering 118 (2015) 819 – 826
Procedia Engineering
www.elsevier.com/locate/procedia

International Conference on Sustainable Design, Engineering and Construction

Sustainable Design with BIM Facilitation in Project-based Learning

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Abstract

Emerging trends of green building and building information modelling (BIM) are driving profound transformation within the architecture, engineering, and construction (AEC) industry nowadays. This paradigm shift has also set up new expectations on college students for their competencies in sustainability and BIM. While most higher education institutions have already incorporated such topics in their curricula, green building and BIM are typically taught separately. In this study, instructors from two classes adopted an integrated approach and designed a joint course project focusing on both sustainable design and BIM implementation. With BIM facilitation, students collaborated in teams working on artefacts and other tasks to accomplish predefined sustainable goals for a real building project. The project based learning provides an ideal framework to evaluate critical factors that influence the execution of BIM in green building project delivery. Formative and summative assessments of student learning outcomes in model communication, teamwork, critical thinking, problem-solving, and sustainability were conducted. The results of this study provide insight into innovative pedagogic design for sustainability and BIM education in the AEC curricula. The study also confirmed the effectiveness of project based learning in cultivating student competencies in critical thinking and problem-solving within a multidisciplinary project environment.

Peer-review under responsibility of organizing committee of the International Conference on Sustainable Design, Engineering and Construction 2015

Keywords: BIM, sustainability, project-based learning, student learning outcome, assessment

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Peer-review under responsibility of organizing committee of the International Conference on Sustainable Design, Engineering and Construction 2015
doi:10.1016/j.proeng.2015.08.519

1. Introduction

Construction engineering education is facing unprecedented challenges from transformative industry trends such as green building and building information modeling (BIM). Enormous efforts have been made in college curricula to adapt to the rapidly changing industry needs. While most pedagogical innovations have addressed sustainability and BIM, they are typically taught as separate subjects. Based upon the well-acknowledged synergies between the two, e.g. [1, 2], this study investigated an integrative teaching strategy through a joint course project focusing on sustainable design and BIM implementation.

This study was also motivated by the dual pressure from program assessment requirements and regional industry needs. The Construction Management program at California State University, Fresno recently went through the American Council for Construction Education (ACCE) re-accreditation. The internal review of annual assessment reports noted students' top weaknesses in graphical communication, construction modeling and visualization. Meanwhile, the Central Valley has seen a slow but steady rising trend in green building and BIM adoption. Recent recruiting events have also clearly confirmed the increasing needs of these competencies in the AEC industry. Prompt response and adaptation to industry needs is always a high priority for the program when it comes to curriculum design. Hence, in this study the course redesign was purposely aligned with the program student learning outcomes (SLOs) and emerging industry needs. The goal was to cultivate student competencies with effective means and better prepare them for their future careers in a multidisciplinary project-based industry.

2. Background

Building sustainability is an applied concept of the global sustainable development endeavor. It bears considerations not only related to building performance, but also the triple bottom line (i.e. the environmental, economic, and social impacts) of the building industry. Because of the abundance of needed information, efficient information-technological solutions are desirable. BIM arose as a solution to support the supply, integration, and management of information throughout the building life cycle [3].

The synergistic convergence of sustainability and BIM has been embraced by both professional and educational communities. For instance, in the United States, the general service administration (GSA) is leading the efforts to leverage BIM for high performance buildings by establishing the national 3D-4D BIM program and publishing the BIM guide series [4]. The U.S. Department of Energy (DOE) and the office of energy efficiency and renewable energy (EERE) have also instituted efforts to utilize advanced modeling and simulation technology via broad stakeholder involvement for significant energy savings in capital projects. The building technologies program, the commercial building initiative (CBI), and the commercial reference building models for national building stock are highlights among these efforts [5].

There is also a good diversity of scholarly research on BIM and green building design and construction. With Leadership in Energy and Environmental Design (LEED) being a globally recognized green building rating system, BIM implementation in LEED design, credit analysis, and documentation have caught great attention in the research community. Many researchers have addressed BIM/LEED synergies. For instance, [6] and [7] proposed system level integration of BIM and LEED; [8] and [9] demonstrated the possibilities of using BIM as a sustainable design decision-making tool, and performing certain LEED calculation with BIM based information. In addition, [10, 11, 12] looked at how BIM could facilitate the LEED certification process with design analysis optimization, information management, documentation generation, and certification review. The abundance of literature revealed great interests among industry players and research scholars in how BIM can facilitate sustainable project outcomes.

3. Pedagogical Approach, Project Objectives and Assessment Plan

3.1. Project-based Learning

The interest in project-based learning has grown over the past two decades and been increasingly implemented in engineering and construction management educational settings, especially with improved information technology and the Internet [13]. Unlike the traditional lecture-based, instructor-centered pedagogical models where students are passive recipients, project-based learning is a proven effective student-centered pedagogical approach [14]. Students are placed in realistic project scenarios facing, analyzing, and resolving real problems. This allows them to build knowledge [15], develop critical thinking, creativity [16] and a number of other soft skills (e.g. leadership and communication) [17]. All of these are desired skills for today's CM graduates to succeed in their careers.

3.2. Project Objectives

This study was a collaborative effort between two courses: CM-132: Advanced Architectural Design and CM-177: Green Building Design and Delivery. A recent campus laboratory project was selected as the joint course project. This 30,000 SF research facility broke ground in the early fall of 2014 and will be home for researchers from three colleges. The project was designed to meet the 2010 California Green Building Standards Code, Title 24/Part 11. The university decided not to pursue LEED certification due to budget concerns. Nevertheless, for the purpose of this study, the instructors added LEED targets ("Certified" and a higher level decided by the students) as the joint course project's "hypothetical" sustainability goals. The main objectives of this joint course project were (a) to guide students through a realistic and integrative green building design process with BIM facilitation, (b) to expose students to tasks and special challenges that they would not normally experience in a single course project, and (c) to assess selected program SLOs through project-based learning.

3.3. Assessment Plan

The assessment plan of this study emphasizes on the learning progressions and periodical reflections. The instructors would like to assess the following program SLOs through specified direct and indirect measures:

- **SLO 1: Communication**. Effective communication in graphical, oral, and written forms common in the construction industry.
  - *Direct Measures*: Building information models and design documentation, team presentations, team reports; and team Google sites.
  - *Indirect Measures*: Entry survey and exit survey.

- **SLO 3: Teamwork and Team Relations.** Work closely with other team members that are internal and external to the construction project team.
  - *Direct Measures*: Team presentations, team reports, and team Google sites.
  - *Indirect Measure*: Exit survey.

- **SLO 4: Problem Solving and Critical Thinking.** Solve diverse problems in the design and construction of the project.
  - *Direct Measures*: Building information models and design documentation, team presentation, team report, and BPAC modules/quizzes.
  - *Indirect Measure*: Exit survey.

- **SLO 11: Sustainability.** Become literate in sustainability and apply the principles to the design and construction process.
  - *Direct Measures*: Team reports and BPAC modules/quizzes.
  - *Indirect Measures*: Entry survey and exit survey.

To allow for quantitative analysis, specific grading rubrics for each direct measure were developed. The indirect measures (i.e. entry and exit surveys) aimed to obtain a quick grasp of students' background and their learning effectiveness. These however were not part of the quantitative analysis.

4. Implementation, Assessment Results, and Discussion

4.1. Implementation: The Delivery Process

The joint course project began in late September of 2014 and lasted for about 3.5 months. Students from the two classes formed teams of 4 or 5 with rotating roles including one (1) LEED consultant, one (1) BIM coordinator/project manager, one (1) design professional, one (1) owner's representative, and one (1) project engineer (optional). Their responsibilities are described as follows:

- *LEED Consultant*: Lead the LEED charrettes to develop alternative design strategies aiming at two LEED targets: LEED certified and one higher level LEED certification: silver, gold, or platinum (decided by the team). Prepare LEED documentation.
- *BIM Coordinator/Project Manager*: Establish the BIM execution plan with identified sustainability goals.
- *Design Professional*: Build the conceptual design model and conduct performance modeling based on the design strategies and performance criteria proposed by the LEED consultant.
- *Owner's Representative*: Provide inputs to other team members from the owner's perspective (focusing on budget and time control) to support their work.
- *Project Engineer*: Provide inputs to other team members from a project engineer's perspective (focusing on constructability) to support their work.

In general, the LEED consultants were students from CM-177, whereas the rest were from CM-132. Except for the LEED consultants, team members were encouraged to rotate roles during the process to enhance their learning experience.

A full set of original project plans was shared with the two classes electronically. During the semester students met with the project manager and the BIM manager to learn more about the design strategies and the actual BIM implementation on this campus project. A guided site tour was also provided. The joint course project was scheduled in phases that are typically followed in real green BIM project delivery practices, as illustrated in Fig. 1 below.

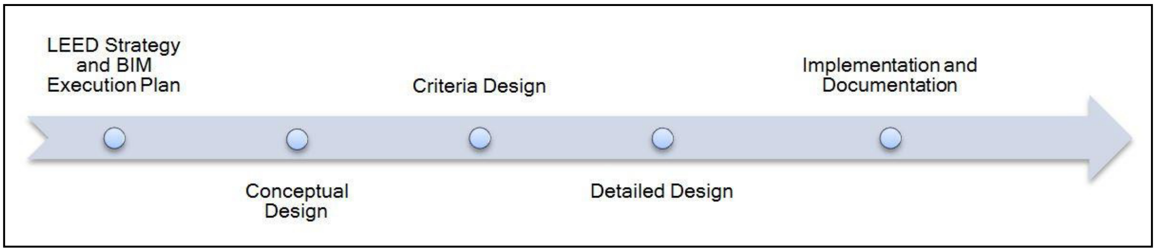

Fig. 1. The joint course project delivery process.

At each phase, there were specific tasks and deliverables to be completed by each team. Students were required to perform LEED strategy analysis via LEED design charrettes, determine the appropriate BIM execution plan, create the design and analysis models, conduct performance simulation, prepare reports on simulation results and LEED documentation, and eventually compile a final project manual summarizing all project activities and results.

Collaboration is key to optimal results. Teams were expected to meet weekly either face-to-face or online to collaborate on their assigned responsibilities. To better facilitate documentation management and communication among team members, each team was required to create and maintain a Google site introducing each individual's roles and presenting weekly updates on their project deliverables. Project files were stored on Google drive or Dropbox with links shared on the Google site. In addition, there was a joint course Google site co-managed by the two course instructors. The site served as a hub to share project documentation (i.e. links to original building plans and models), grading rubrics, as well as weekly assignments and/or announcements from both courses. All team sites were linked to this central site and were only accessible to the instructors.

4.2. Implementation: Technology Selection and Training

A great benefit for those who participated in this joint course project was the exposure to a wide selection of technological tools for various project tasks such as model authoring, performance simulation, documentation management, team communication, etc. Since the main goal was to simulate a real integrative project design process with BIM facilitation and sustainability goals, the tools were carefully selected based on specific project needs and the current industry trends. Fig. 2 summarizes the recommended and optional technology relevant to the joint course project.

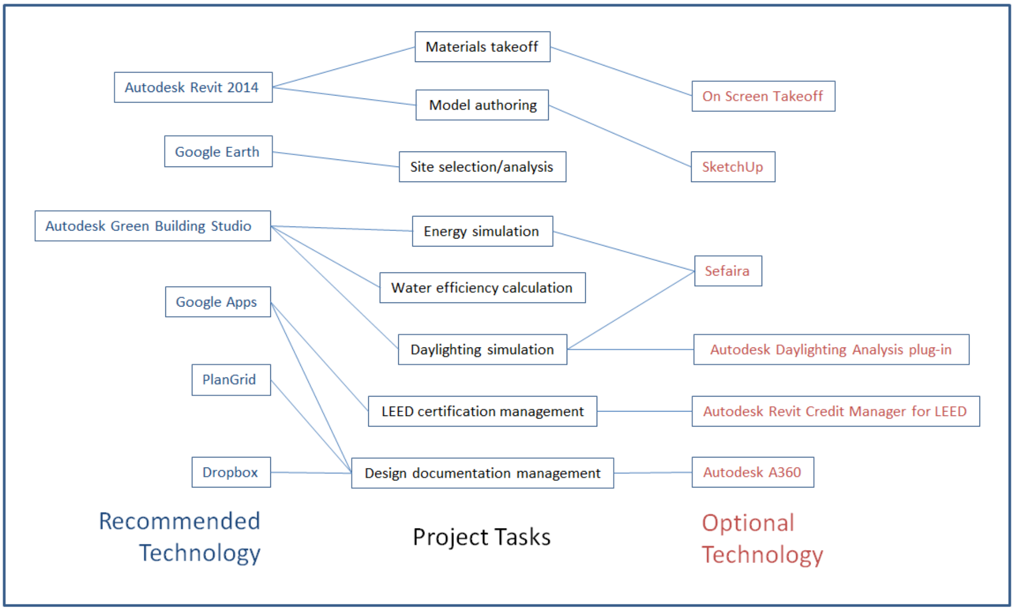

Fig. 2. Technology selection for the joint course project.

Considering students' lack of prior exposure to similar topics, the instructors incorporated external educational resources into the courses as part of the training requirements. For example, the Autodesk online Building Performance Analysis Certificate (BPAC) program offers a series of well-designed learning modules on fundamental knowledge and skills in building physics, building systems, and BIM applications. Meanwhile, students in CM-177 were asked to study the latest LEED requirements and documentation process through USGBC's interactive web-based LEED reference guide as well as actual LEED documents from two completed LEED projects.

4.3. Assessment Results and Discussion

The instructors collected the assessment data following the assessment plan. Fig.3. shows a summary of direct measure assessment results for the four pre-selected SLOs. Each SLO was assessed through multiple measures. Each measure has three performance levels: *Low*, *Medium*, and *High*, with their corresponding scoring thresholds. The student performance distribution is defined as the percentage of students whose scores met one of the three performance levels. As indicated in Fig.3 (a)-(d), the overall results are satisfactory. The only measure with a high percentage of *Low* performance level is the Team Google Site. This was mainly due to incomplete site content and late updates.

The Autodesk BPAC was used to assess students' fundamental knowledge in sustainability (SLO 11) as well as their problem-solving and critical thinking skills (SLO 4). Completing the training generally takes between 25 and 40 hours based on the experience of students. There were eight (8) learning modules in total. As indicated in Fig.4, only the relevant modules were included in the assessment calculations.

An entry survey and an exit survey were conducted online at the beginning and the end of the semester to assess students' knowledge on BIM implementation and green building design strategies. To facilitate future improvement, the exit survey also included open-ended questions regarding their overall joint course project experience. Out of 29 students from the two classes, all completed the entry survey and 24 completed the exit survey. According to the survey results, the joint course project had a significant positive impact on students' understanding of fundamental BIM and green building concepts. The majority of the respondents were able to provide correct answers in the exit survey.

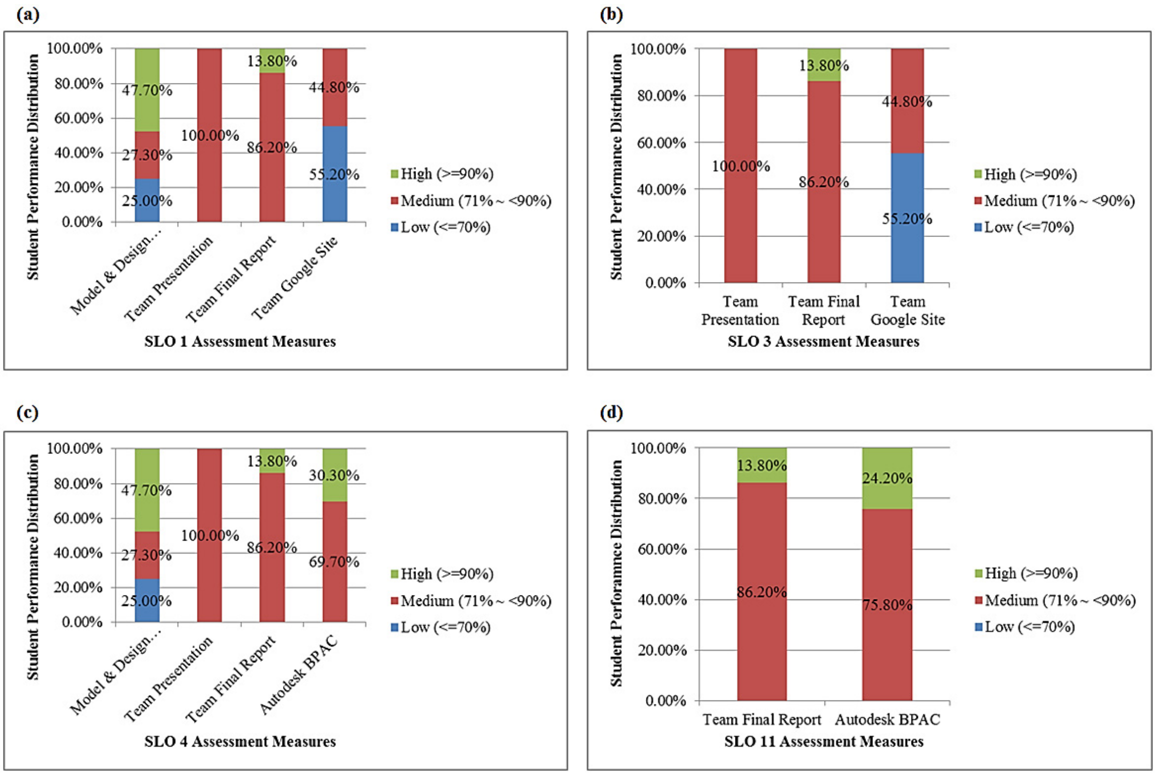

Fig.3. Assessment results of direct measures for (a) SLO 1, (b) SLO 3, (c) SLO 4, and (d) SLO 11.

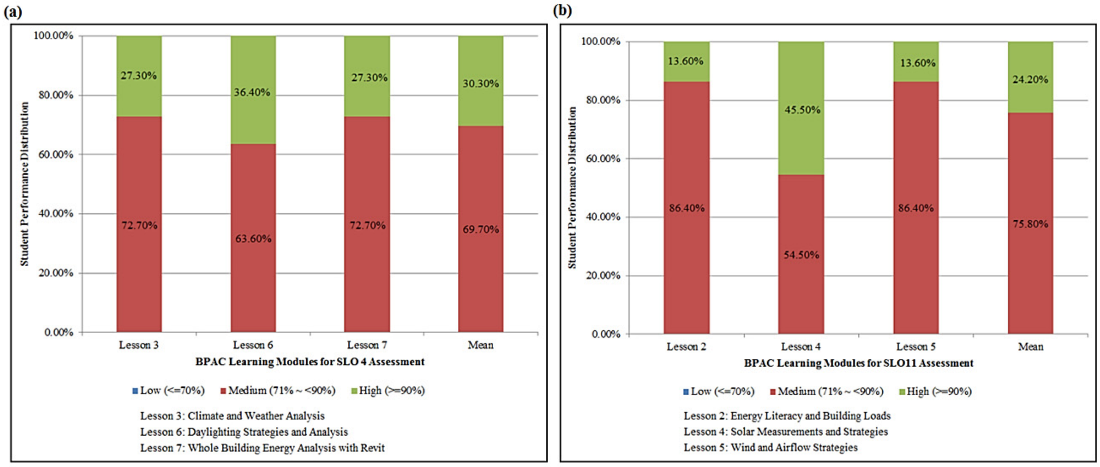

Fig.4. Assessment results for (a) SLO 4 and (b) SLO 11 from BPAC modules.

The main challenges experienced in this study were threefold: (a) *The LEED Challenges:* As it was an ongoing project which wasn't designed to be a LEED building, meeting LEED requirements were simply impossible in some cases unless significant design changes were made. This led to the lack of information when preparing supporting documents for certain LEED credits. Also, considering students' inexperience on LEED documentation, more time is needed to produce complete LEED files for such a complex project. In the future the instructor would like to explore new products such as the Revit Credit Manager for LEED (currently an Autodesk Labs product) which aims to automate calculations and LEED submittals on several LEED credits such as Daylighting and Recycled Content; (b) *The BIM Challenges*: Unexpected delays occurred frequently due to a combination of hardware and software failures (e.g. outdated computers and glitches of the Autodesk Energy Analysis plug-in); and (c) *The Communication Challenges*: All teams struggled with weekly meeting schedules. Some suggested the two courses be taught at the same time in the future to allow teams to meet during the second hour. This can also help minimize miscommunication between classes in case students are given different directions from the instructors.

As challenging as it was, many students stated that they enjoyed collaborating with another class and were glad they finished the project on time. Overall it was a rich and satisfying experience. They exchanged information through technology, learned various BIM tools, increased knowledge on LEED rating systems, and most importantly, practiced their learning on a real project.

5. Conclusion

This pilot study proposed an innovative way of applying the project-based learning approach through a joint course project to simulate a multidisciplinary project environment. Students were guided through a realistic green building design process with BIM facilitation. Formative and summative assessments of student learning outcomes in communication, teamwork, critical thinking, problem-solving, and sustainability were conducted. The results confirmed the effectiveness of the pedagogical approach and provided valuable insight on green building and BIM education.

Acknowledgements

The authors would like to acknowledge the great support on this pilot study from Harris Construction Co., Inc.

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