www.itcon.org - Journal of Information Technology in Construction - ISSN 1874-4753

PEDAGOGY AND ASSESSMENT OF STUDENT LEARNING IN BIM AND SUSTAINABLE DESIGN AND CONSTRUCTION

SUBMITTED: November 2015
REVISED: April 2016
PUBLISHED: July 2016 at http://www.itcon.org/2016/15
EDITOR: Issa R.

Wei Wu, Assistant Professor
Department of Construction Management, California State University, Fresno
Email: weiwu@csufresno.edu

Yupeng (Vivien) Luo, Associate Professor
Department of Construction Management, California State University, Fresno
Email: viluo@csufresno.edu

SUMMARY: *College construction management (CM) programs across the nation have been integrating building information modelling (BIM) in their curricula in various forms with specific priorities. Nevertheless, the common goal is to cultivate a competent workforce that possesses the desired knowledge, skills and abilities (KSAs) as the industry is largely embracing BIM. This study explores the project-based learning (PBL) pedagogy in a four-year undergraduate CM curriculum with a special focus on BIM implementation in sustainable design and construction. Through a joint course project, this study examines how PBL may improve critical student learning outcomes (SLOs) pertaining to institutional assessment and program accreditation requirements. Specifically, students in two upper division elective courses collaborated on an ongoing campus project through roleplay as they would in real project teams. Major project deliverables included developing the Leadership in Energy and Environmental Design (LEED) certification strategy and the BIM project execution plan, performing schematic design, conducting performance simulation for LEED credit compliance, and documenting project information for LEED submittals. Formative and summative assessments were conducted on the PBL pedagogy and the joint course experience in enhancing students' understanding and working knowledge of BIM implementation in the sustainability domain. The joint course project also provided the instructors with opportunities to align course redesign with program accreditation standards. This paper outlines the strategies of implementing and managing a joint course project, and shares various metrics and tools adopted in project evaluation. The results and the findings of this joint course project are expected to shed light on competency-based program assessment and future BIM curriculum innovation.*

KEYWORDS: *building information modelling, sustainability, project-based learning, student learning outcome, assessment.*

REFERENCE: *Wei Wu, Yupeng (Vivien) Luo (2016). Pedagogy and assessment of student learning in BIM and sustainable design and construction. Journal of Information Technology in Construction (ITcon), Special issue: 9th AiC BIM Academic Symposium & Job Task Analysis Review Conference, Vol. 21, pg. 218-232, http://www.itcon.org/2016/15*

1. INTRODUCTION

Building information modelling (BIM) has evidently gained wide acceptance and adoption in the North American construction industry (McGraw-Hill Construction, 2012). The challenge foreseen in sustaining this trend is the lack of competent workforce who will be performing day-to-day job tasks pertinent to BIM implementation (Smith & Tardif, 2009; Wu & Issa, 2014). College construction management (CM) programs across the nation have been integrating BIM with existing curricula in various forms with specific priorities (Wu & Issa, 2014). Nevertheless, a common goal is to develop desired knowledge, skills and abilities (KSAs) to better prepare students for their professional career. For years, scholars who have been continuously attending the BIM academic symposiums have investigated a broad spectrum of issues and best practices in college BIM education, such as pedagogical models, interdisciplinary approaches, industry involvement, accreditation issues, and to name a few. This study contributes to the body of knowledge by addressing an essential piece of such efforts, which is to assess the student learning outcomes (SLOs) with specific BIM education pedagogy.

This study chooses to assess student learning on BIM with a unique proposition to investigate synergies between BIM and sustainable design and construction. This is motivated by the dual pressure from program accreditation requirements and emerging needs of local industry. The CM program at Fresno State has just gone through the American Council for Construction Education (ACCE) reaccreditation. Internal review of assessment reports has revealed severe weaknesses of student learning outcomes in graphic communication, information modelling and visualization. Internally, the CM program is also subject to provisions in accordance with the Student Outcomes Assessment Plan (SOAP) and is expected to provide the necessary acquisition of professional knowledge, skills, and technical competencies for advanced participation within the construction field. At the same time, the Central Valley has seen a slow but steady growth of investment in green building and adoption of BIM. Regional and local construction companies have shown explicit interests in recruiting students with knowledge and skills in both sustainability and BIM. It is a high priority of the CM program to sustain a nimble and practical curriculum that is responsive to industry trends and able to cultivate the desired talent for regional and local employers. Hence, this study purposely aligns the course redesign with program SLOs and emerging industry needs. The goal is to explore effective pedagogy and assess student learning in the development of desired competencies in BIM and sustainability, and prepare them as future leaders in a highly technology-driven and interdisciplinary project-based industry.

2. BACKGROUND

2.1 Synergies of BIM and sustainable design and construction

The idea of utilizing a joint course project is premised upon the well-acknowledged synergies between BIM and sustainable design and construction. Building sustainability is an applied concept of the global sustainable development endeavour. 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 information needed, 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 (Häkkinen & Kiviniemi, 2008).

There is abundant literature suggesting strong interests among industry players and research scholars in exploring how BIM facilitates accomplishing more sustainable project outcomes (Bynum, Issa, & Olbina, 2013; McGraw-Hill Construction, 2010; Wu & Issa, 2015). Public agencies such as the General Service Administration (GSA) and the office of energy efficiency and renewable energy (EERE) in US Department of Energy (DOE) are also embracing advanced modelling and simulation technology via broad stakeholder involvement for significant energy savings in capital projects. Examples include the BIM implementation guidelines published by GSA (GSA, 2015) and the commercial reference building models for national building stock through the Commercial Building Initiative (CBI) through EERE (Deru et al., 2011).

A featured use case of synergies between BIM and sustainability is the practical implementation of BIM by project teams in pursuing green building certifications, such as the Leadership in Energy and Environmental Design (LEED) certification. LEED is a prevalent green building rating system in the global green building market, and recent market research and case studies (McGraw-Hill Construction, 2010) have shown various innovative usages of BIM in LEED certification efforts. The research community has also contributed to advancing knowledge in this field. For instance, several scholars have proposed system-level integration of BIM and LEED where BIM serves as a platform fostering the planning and execution of LEED project goals (Biswas, Wang, & Krishnamurti, 2008; Wu & Issa, 2010). BIM also captures essential physical, functional and relational information of the project that can be extracted to conduct performance modelling, design review, quantity take-off and documentation generation, which are critical for computing attainable LEED points for the certification purposes (Azhar, Carlton, Olsen, & Ahmad, 2011; Bank, McCarthy, Thompson, & Menassa, 2010; Barnes & Castro-Lacouture, 2009; O'keeffe, Shiratuddin, & Fletcher, 2009).

2.2 Project-based learning as a pedagogy for BIM education

The efforts to date in college BIM education have fallen into two major categories: (1) leveraging BIM as a disruptive technology to enhance course design and improve SLOs in traditional coursework, and (2) adopting BIM as a new paradigm that stimulates fundamental curriculum transformation (Wu & Issa, 2014). Various pedagogical models have been experimented to deliver a broad range of BIM topics at both undergraduate and graduate levels. There is a clear trend that educators are shifting from teaching BIM software packages to developing students' problem-solving skills (Wu and Issa, 2014). It has been revealed that transformative trends such as BIM and green building call for strong communication and teamwork skills, capacity to work efficiently within co-located teams and abilities to apply fundamental engineering, management and computer skills in real world scenarios (Becerik-Gerber, Ku, & Jazizadeh, 2012), yet traditional lecture-based pedagogical models are no longer efficient to delivery these goals. An intrinsic drawback of these models resides in the fact that students are treated as passive recipients with linear and fragmented teaching presentations, and deprived of the opportunities for learning the holistic nature and broad vision of the architecture, engineering and construction (AEC) disciplines (Chinowsky, Brown, Szajnman, & Realph, 2006).

Empirical evidence found in the adoption and implementation of BIM has suggested that integration, instead of specialization, is setting new skill set requirements for workforce in the construction industry featured with a brand new technological infrastructure. Project-based learning (PBL) holds the promise of cultivating the desired competency with breadth and depth (Goedert, Pawloski, Rokooeisadabad, & Subramaniam, 2013).

PBL is a proven effective student-centred pedagogical approach (Baş, 2011) that focuses on real-world issues (Chinowsky et al., 2006). PBL allows students to gain knowledge (Liu, Lou, Shih, Meng, & Lee, 2010) and develop critical thinking, creativity (Kubiatko & Vaculova, 2011) and a number of soft skills, e.g. leadership and communication (Walters & Sirotiak, 2011). These conducive outcomes reflect the objectives of the proposed study to assess selected program SLOs through the joint course project. Aside from student learning process, PBL also redefines and transforms the roles of instructors. Instead of being the point of authority and source of solution, instructors in PBL will work as mentors and/or expert consultants that help students formulate their own strategies towards the accomplishment of project goals with open-ended, heuristic suggestions while avoid providing the answer key. The underlying purpose is to develop students' metacognition and self-monitoring skills in facing, analysing and resolving problems and complexities in realistic project scenarios (Chinowsky et al., 2006). In the past two decades, interests in PBL have been increasing significantly in engineering and construction management curricula, especially with improved information technology and the Internet (Goedert et al., 2013).

3. PROJECT DESIGN AND ASSESSMENT PLAN

3.1 Joint course project activities and objectives

Two CM upper division electives (i.e. *CM132 Advanced Architectural Design* and *CM177 Sustainable Construction*) were participating in the joint course project with mostly graduating seniors and some junior students. The overall approach was to use an on-campus project to simulate the LEED project delivery and BIM project execution process in which students form learning groups (project teams) to perform essential tasks in pursuit of LEED certification with BIM as a facilitator. The joint course project was coordinated by the two instructors with assistance from the industry partner who was the general contractor for the on-campus project.

Roleplay was an important component of PBL, and in this joint course project it provided instructors with unique opportunities to observe the dynamics among technology, process and student learning behaviour. Learning groups, or project teams were made of four to five students from both elective courses with assigned roles and responsibilities (Table 1, *Project Engineer* is optional depending on the availability of students). Except for the LEED consultants, other team members were encouraged to rotate roles during the project to enhance their learning experience.

Table 1: Roles and responsibilities of project teams.

Role	Responsibilities	Elective	Number
LEED Consultant	Design charrettes, LEED strategy, credit interpretation, LEED documentation and certification management	CM177	1
Design Professional	Design authoring and analysis, performance modelling	CM132	1
Project Manager/BIM Coordinator	BIM execution planning, project management and coordination, budget and schedule, communication	CM132	1
Owner's Representative	Owner's project requirements, budget and schedule, design review and project documentation	CM132	1
Project Engineer	Constructability review, spatial coordination	CM132	1 or 0

The joint-course project was scheduled in phases, comparable to a typical project delivery process, and lasted three months, as shown in Fig. 1. At each phase, student teams would work on specific working orders and complete critical tasks to meet LEED certification requirements. 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, generate simulation reports and LEED documentation, and eventually compile a final report/project manual summarizing all project activities and results. The quality of student work in modelling and the final LEED scores achieved by student teams were important but not the major focus of the joint course project. Students were encouraged for independent thinking and defining their own expectations for this project.

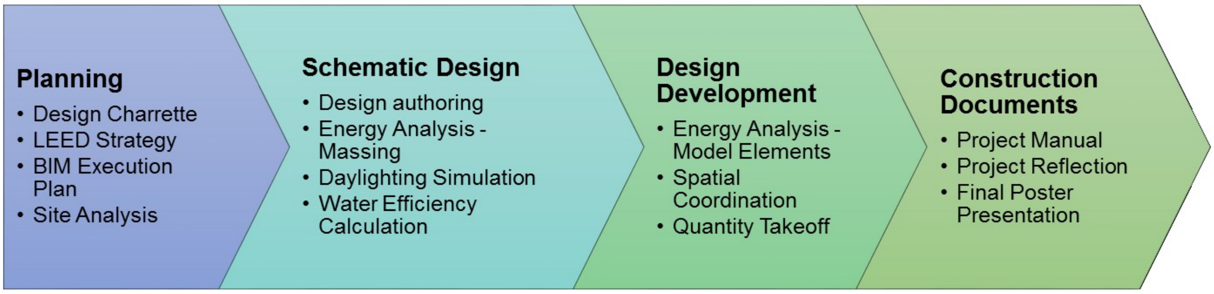


FIG. 1: Joint-course project delivery process.

Nevertheless, as is true in real project delivery, team communication and collaboration could considerably affect the overall project experience and the final project outcome. Student learning teams were required to meet weekly either face to face or online to stay on track of project progress. Each team was required to create and maintain a Google site for teamwork and weekly updates on their project deliverables. Completed project deliverables should be saved in Google Drive or Dropbox with links shared on the Google site. In addition, a joint course project Google site was co-managed by the two instructors. The site served as a hub to post announcements, place new working orders, share project documentation and clarify project performance requirements. All individual student team sites were linked to this central site.

The joint course project aimed to explore the PBL pedagogy in improving SLOs in BIM and sustainability, expose students to BIM project execution and green building certification process, and develop desired competencies (i.e. knowledge, skills and abilities) that better prepare them for a professional career in the rapidly changing industry environment.

3.2 Assessment plan

The joint course project assessed several program SLOs to shed light on possible pedagogical design and course innovation efforts catering to future accreditation needs:

- *SLO 1: Communication.* Effective communication in graphical, oral, and written forms common in the construction industry;
- *SLO 3: Teamwork and Team Relations.* Work closely with other team members that are internal and external to the construction project team;
- *SLO 4: Problem Solving and Critical Thinking.* Solve diverse problems in the design and construction of the project;
- *SLO 11: Sustainability.* Become literate in sustainability and apply the principles to the design and construction process.

Since BIM was a new element of the CM curriculum, *SLO 1* and *SLO 4* were used as the tentative placeholders to represent desired BIM learning outcomes for assessment purposes. As summarized in Table 2, the overall assessment plan of this study emphasized learning progressions and periodical reflections, and included both formative and summative approaches using direct and indirect measures. Considering the lack of established scales and metrics in the literature, the instructors opted to leverage external educational resources provided by Autodesk, and incorporated the online Building Performance Analysis Certificate (BPAC) program as part of the assessment. The certificate program provided students with a broad but fundamental exposure to knowledge and skills in building physics, building systems, and information modelling applications that considerably enhanced their understanding of the synergies between BIM and sustainable design and construction (Autodesk, 2015).

Table 2. Joint course project assessment plan.

Program SLOs	**Direct Measures**					**Indirect Measures**	
	Model & Design Documentation	Team Presentation	Team Project Manual	Team Google Site	Autodesk BPAC	Entry Survey	Exit survey
SLO 1	×	×	×	×		×	×
SLO 3		×	×	×			×
SLO 4	×	×	×		×		×
SLO 11			×	×	×	×	×

3.3 Role of technology

Technology was a key factor in this joint course project as recognized by instructors as well as students. It was both an opportunity and a challenge from a practicality standpoint. On one hand, to those who participated in this project, a great exposure to a wide selection of prevailing BIM and sustainability software solutions could enhance their chances in job interviews, and increase their proficiency and confidence in handling technology desired to fulfil job tasks in their professional career. On the other hand, given the tight schedule of the project, learning new technology might become a burden for students and the fear for time-consuming software training might compromise their overall learning experience. The instructors eventually chose to follow the “agnostic” principle: instead of stipulating the specific software vendors, recommendations were given while students were allowed to explore options to their preferences. Table 3 summarizes exemplary technology used in this joint course project.

Table 3. Technology selection for the joint course project.

Project activity/task	Recommended technology	Optional technology
Site selection/analysis	Google Earth	—
Model authoring	Autodesk Revit 2014	SketchUp
Energy simulation	Autodesk Green Building Studio	Sefaira
Water efficiency calculation	Autodesk Green Building Studio	—
Daylighting simulation	Autodesk Green Building Studio	Sefaira; Autodesk Daylighting Analysis plug-in
Materials take-off	Autodesk Revit 2014	On-Screen Takeoff
Design documentation communication & management	Google Apps; Dropbox; PlanGrid	Autodesk A360
LEED certification management	Google Apps	Autodesk Revit Credit Manager for LEED

4. PROJECT OUTCOMES AND ASSESSMENT RESULTS

4.1 Project outcomes

The joint course project kicked off on Sep. 26, 2014 and closed out on Dec. 11, 2014. Throughout the project, student teams worked on weekly job orders posted on the instructors' Google site, with allocated roles and responsibilities as planned in the kick-off meeting. Student teams also maintained individual team sites as documentation repository and communication portal internally (Fig. 2). Both *CM132* and *CM177* met twice a week but at different time slots, which was identified as a severe logistic hazard. Most classes were activity-based with some lecturing and demonstration. The intention was to adopt the flipped-classroom pedagogy, which was made possible with the institution's subscription to personal learning systems such as Lynda.com. However, the instructors found the flipped-classroom very challenging in this particular joint course project due to the lack of similar experience among the student population. There was also a lack of student engagement that made the pedagogy impractical in this project. Nonetheless, these observations suggested potential areas for improvement in future course redesign.

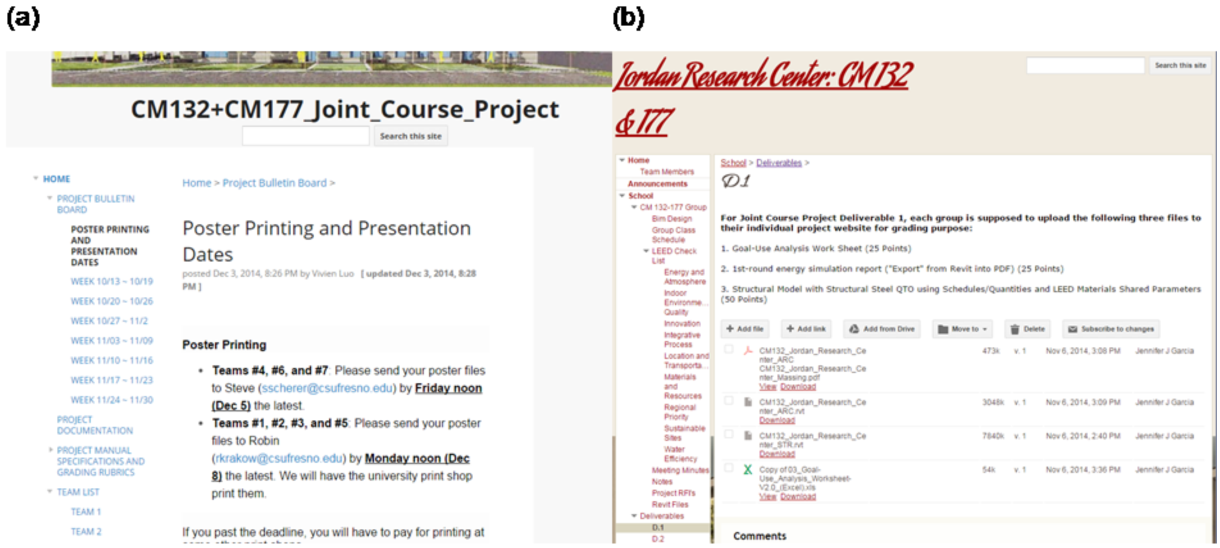


FIG. 2: Joint course project (a) instructors' website and (b) student team website.

During the project delivery, the instructors made substantial efforts to involve the industry partner. The project manager was brought on board from day one and the BIM manager taught a learning module on spatial coordination with BIM. A site visit was made and students met with the project superintendent for updates on the project progress, and field operations with BIM. Informal interviews were conducted with students on experience in interaction with the industry professionals, and the feedback was largely positive as expected.

Student teams made two milestone submissions: 1) a final report/project manual; and 2) a final presentation with poster exhibit on a project day of the CM department. The final report was a comprehensive project manual compiled with the following core project deliverables:

- LEED design charrette reports and meeting minutes
- LEED credit analysis and documentation
- BIM Execution Planning documentation
- Architectural and structural design models
- Performance simulation models and simulation result reports
- Model-based quantity take-off and estimating for LEED materials and products
- Spatial coordination and constructability review report
- Progress reports
- Team meeting minutes and communication notes

The joint course project was showcased in conjunction with other CM course projects on the project day that the department utilized as a social event to involve industry advisory board (IAB) members and other engaged community partners. Student teams were required to present the project posters (Fig. 3) and report on learning experience to attending industry professionals for feedback. A general comment from the audience was the timeliness of this project to respond to uprising demands for BIM talent in the Central Valley. Several local firms expressed interest in participating in future projects and requested referrals for BIM-savvy students.

FIG. 3: Sample final student posters of the joint course project.

4.2 Assessment results: direct measures

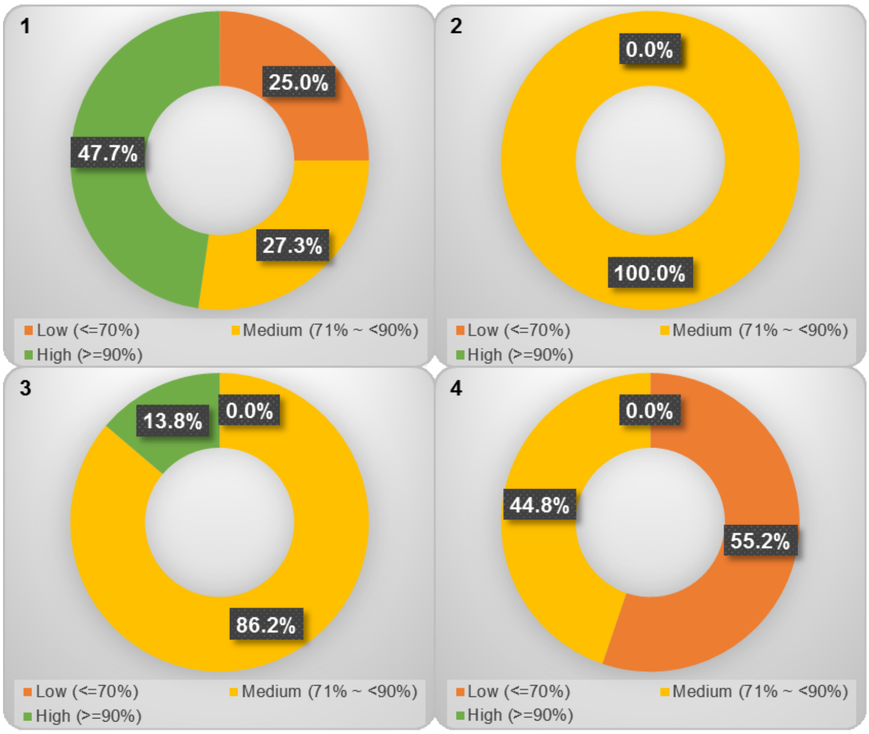
As specified in the assessment plan (Table 1), each SLO was assessed with multiple direct and indirect measures. Following common guidelines of project assessment (Frechtling, Frierson, Hood, & Hughes, 2002), both formative and summative assessment data were collected throughout the project. The formative assessment provided insights into the project process and implementation with focus on individual job orders and milestones. Examples include assessment of the conceptual models, simulation reports, meeting minutes, to name a few. The Autodesk BPAC program also provided learning module-based formative assessment data. The summative assessment on the other hand evaluated the project's success in reaching the stated goals. Examples include assessments of the final report and the exit survey. Both points-based grading and rubrics were used in assessment, and an exemplary rubric is illustrated in Fig. 4. Notice that a grading rubric represents a matrix of criteria and may be used for assessing several different SLOs at the same time. To simplify the interpretation of assessment results, three student performance levels, i.e. *Low (70% or below), Medium (71% ~ <90%),* and *High (90% or above)* were defined to align point grades with grading rubrics. Also it should be noted that individual scores were given to students even through the project deliverables were team-based. The following paragraphs will elaborate on the detailed results for each of the four critical SLOs assessed in this joint course project.

Grading Criteria	3	6	9	12	15
	Poor	Below Expectation	Meet Expectation	Confident	Advanced
Professional documentation	Binder is poorly prepared; no efforts in professional documentation	Some efforts in professional documentation; substandard physical binder appearance	Satisfactory professional documentation; acceptable binder physical appearance	Good professional documentation; good binder physical appearance	Excellent professional documentation; great binder physical appearance
Contents - Completion	Binder contains 50% or less of required project deliverables	Binder contains 51%~69% of required project deliverables	Binder contains 70%~79% of required project deliverables	Binder contains 80%~89% of required project deliverables	Binder contains 90%~100% of required project deliverables
Contents - Accuracy	Little information is provided in the deliverables with poor accuracy	Some information is provided in the deliverables with low accuracy	Solid information is provided in the deliverables with acceptable accuracy	Great amount of information is provided in the deliverables with good accuracy	Excellent coverage of information in the deliverables with impeccable accuracy
Formatting	No obvious efforts in compliance with formatting requirements	Some efforts in compliance with formatting requirements	Acceptable formatting, quite a few mistakes and inconsistencies	Good and consistent formatting, very few mistakes	Excellent formatting, almost impeccable consistency
Organization/ Collaboration	No obvious efforts in logical organization of manual; no group collaboration	Poor organization of manual and little sign of group collaboration	Acceptable manual organization and group collaboration	Good manual organization and apparent group collaboration	Excellent manual organization and highly consistent group collaboration

FIG. 4: Final report/project manual grading rubric of the joint course project.

4.2.1 SLO 1: communication

A total of four measures were utilized to assess *SLO 1: communication*, which includes written, oral and graphic communication. For formative measures, the assessment data and final performance level were based upon calculated averages for multiple submissions through the project delivery. As shown in Fig. 5, a quarter of students would still need polishing modelling and design documentation skills.



Measure No.	Description	Communication Type	Assessment Type
1	Model & Design Documentation	Graphic	Formative
2	Team Presentation	Oral	Summative
3	Team Final Report	Graphic & Written	Summative
4	Google Sites	Graphic & Written	Formative

FIG. 5: Measures and assessment results for SLO 1: communication.

Over half of the teams did not meet the requirements of actively maintaining a project site, according to periodical check by instructors. Students complained about difficulties in meeting up with teammates due to course schedule conflicts. On the other hand, the project manuals submitted were well received by instructors. Student teams also demonstrated solid presentation skills. Using multiple measures in assessment gives several advantages to instructors. It encourages different perspectives towards the learning outcome being assessed, and provides a more complete picture of the factors that may affect student learning. It also facilitates the identification of specific areas that need improvement, and makes it more effective for instructors to develop focused action plans.

4.2.2 SLO 3: team work and team relations

Team work and team relations have been the area that students in the CM program struggle with. Despite understanding of importance of collaboration in the professional world, students seemed to lack of the awareness or the desired attitudes towards team work and relationship building. Among the three measures used in this assessment, *Team Presentation* and *Team Final Report* both had fractional components relevant to team work. The most representative measure was the *Team Google Site,* which qualitatively reflected the commitments (e.g. group meeting minutes, documentation management, site maintenance and information exchange) of all team members to work with each other for a good overall project outcome. More than half of the students (55.2% due to different sizes of teams) were rated poor for this learning outcome, and some student teams even reported severe confrontations among students due to frustrations in team building. Several factors were identified through instructors' private communications with project team members. Except for the obvious logistic hazard of asynchronous course schedules, the unwillingness to contribute to group efforts was identified as the biggest barrier. The instructors also found that heavy workloads (a substantial percentage of the students were working more than twenty hours or fulltime to support family or pay tuition), personal issues and other non-academic factors were contributing to their low project engagement and interaction with teammates.

4.2.3 SLO 4: problem solving and critical thinking

Problem solving and critical thinking were also assessed with four measures, three of which (i.e. *Model & Design Documentation, Team Presentation* and *Team Final Report*) have already been discussed in **4.2.1.** The instructors recognized the limitation of using the same measures for multiple SLOs (although the grading rubrics could be configured with multiple criteria to reflect different SLOs as shown in Fig. 4), and introduced an external measure, the Autodesk BPAC program to help enhance the assessment. The BPAC program is basically a self-paced online training. Students have to go through several learning modules, conduct the formative assessment quizzes, and achieve an overall evaluation of 80% or better to claim the certificate. The contents and exercise of the BPAC program were carefully selected by established scholars and industry professionals, and represented the state of the art and best practices in the field of BIM and sustainable design and construction. As far as assessment was concerned, learning modules 3, 6 and 7 of the BPAC program had more focus on analysis and problem-solving, while learning modules 2, 4 and 5 emphasized understanding of concepts and knowledge of best practices.

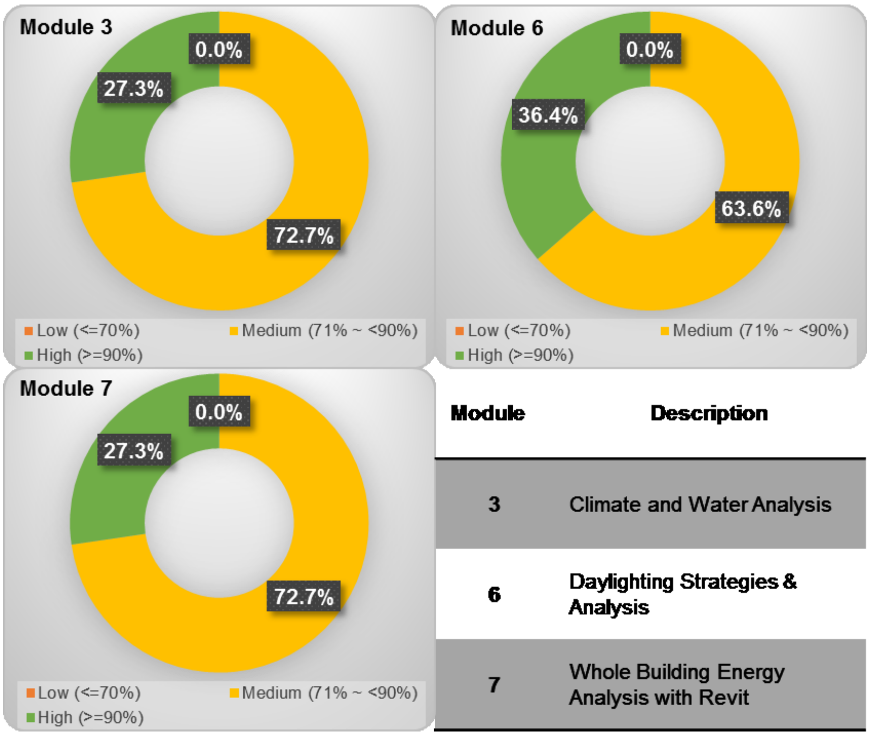
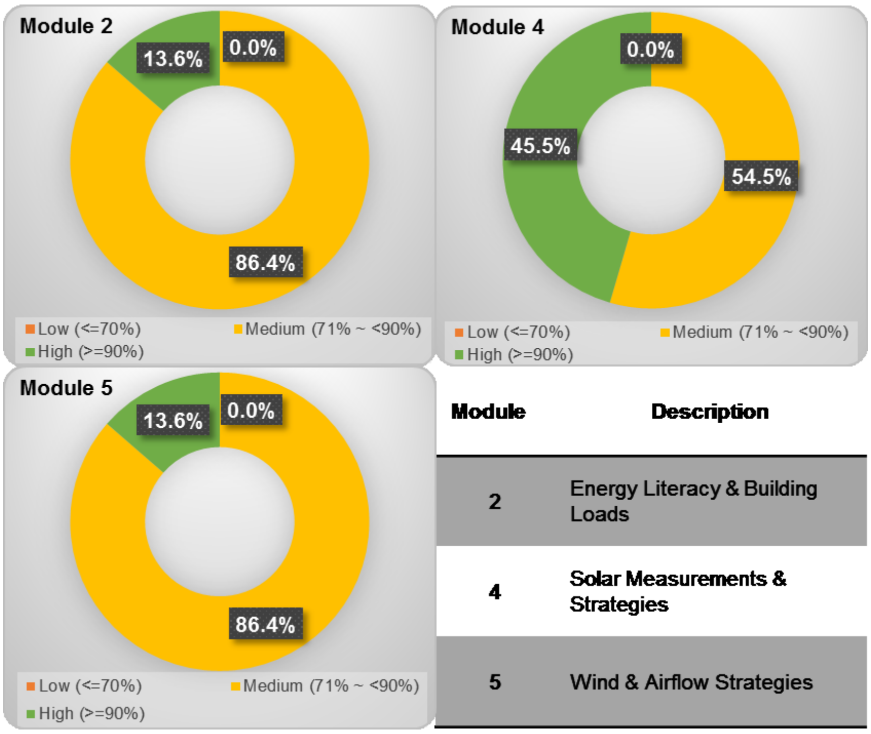


FIG. 6: BPAC modules 3, 6 & 7 assessment results for SLO 4

Therefore, the instructors decided to relate student performance in modules 3, 6 and 7 with SLO 4, while labelled modules 2, 4 and 5 more relevant with SLO 11. According to Fig. 6, students demonstrated solid problem solving and critical thinking capacities in all three modules. An immediate take-way from the Autodesk BPAC program was that by setting up a relatively higher performance standard and giving students the flexibility to make multiple attempts until reaching the target may be beneficial for both learning engagement and the eventual learning outcome.

4.2.4 SLO 11: sustainability

Sustainability was the last SLO that was assessed with two measures, the *Team Final Report* and the *Autodesk BPAC* (modules 2, 4 and 5) program. Student teams performed well in both measures. Other than the special use case of LEED certification, this assessment promoted understanding of the concepts, terminologies and principles, and attaining knowledge from best practices among the broad scope of sustainability (Fig. 7). Students started to truly comprehend that better building performance was the outcome of more sustainable design and construction, as well as what were the rationales behind it.



Module	Description
2	Energy Literacy & Building Loads
4	Solar Measurements & Strategies
5	Wind & Airflow Strategies

FIG. 7: BPAC modules 2, 4 & 5 assessment results for SLO 11.

4.3 Assessment results: indirect measures

Both *Entry* and *Exit Surveys* were conducted for the joint course project. Indirect measures such as student surveys could help understand student attitudes towards and reflections on the project-based learning experience, regardless of possible bias due to the small class size (twenty-nine students for two classes). There was no intention to draw any statistically significant conclusion here given the fact that no control or experiment groups were made in this study. Besides, the *Entry Survey* was simplistic and aimed only at the quick grasp of students' background. Therefore, the analysis was majorly directed on the *Exit Survey* that was conducted online using Qualtrics. A total of twenty-four completed responses were collected with a response rate at 82.8%.

4.3.1 Cognitive gains: concept, knowledge and reasoning

The *Exit Survey* asked a series of questions on fundamental concepts, knowledge, and reasoning process in sustainable design and construction with BIM facilitation. The goal was to qualitatively evaluate cognitive gains of students from the project-based learning experience. For instance, Fig. 8 suggested that students become much more confident in defining both BIM and green building in given contexts after the joint course project. Other cognitive gains students accomplished through the project include:

- Concept of integrative design and the process that facilitates it;
- Principal benefits of using BIM in sustainable design and construction and exemplary use cases;
- Knowledge of LEED credits, their performance provisions and compliance strategies;
- Knowledge of certain BIM uses and the business processes adopted to execute them;
- Understanding of success factors for certain BIM uses, and the decision-making process in weighing costs and benefits; and
- Working knowledge and fundamental skill in information gathering, processing and exchanging for performing certain modelling, simulating or analysing tasks.

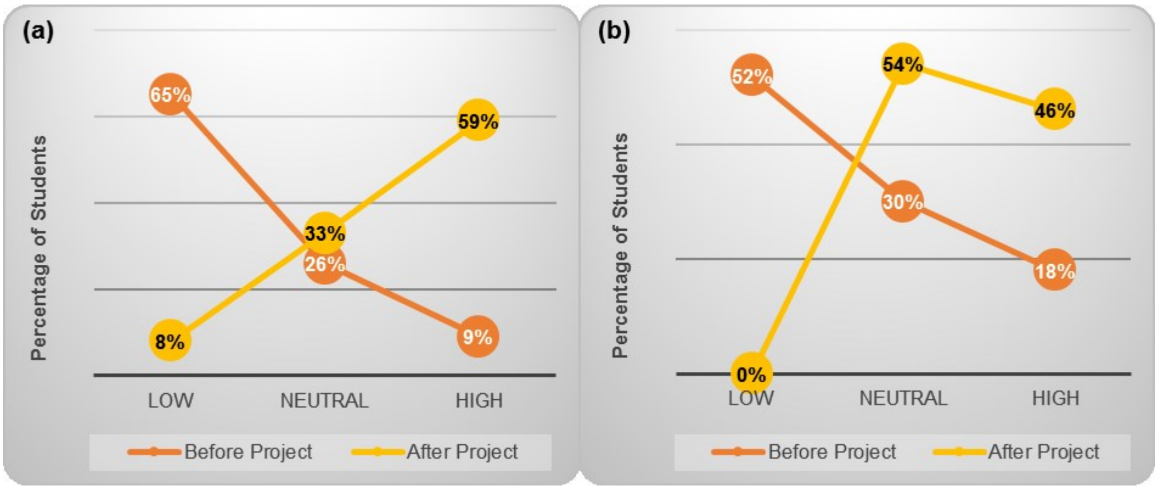


FIG. 8: Before- and after-project confidence levels in defining (a) BIM and (b) green building.

4.3.2 PBL and self-efficacy development

Roleplay in project-based learning encourages development of self-efficacy (Schaffer et al., 2012). Self-efficacy, simply defined as one's self-judgment concerning capability, has been shown to be an important mediating factor in cognitive motivation (Ponton et al., 2001). The *Exit Survey* assessed self-efficacy to investigate what motivation strategies should be developed in the future to engage students in behaviors conducive to becoming value-added practitioners in their professional career. A series of performance evaluation questions with *Likert* scales (1 to 5 where 5 denotes best performance) were used for student self-evaluation and comparison with project teammates. The results as shown in Fig. 9, indicate apparent biases on students' perceived self-efficacy in a series of key performance indicators (KPIs). The instructors also reflected on individual interviews with project teams through the joint course project, and found that when conflicts arising, students would usually blame their teammates instead of taking the responsibility and making endeavors to improve the team performance. It seemed that there was a lack of leadership among the students, which is concerning since leadership is essential to professional career in the construction management industry. Explicit self-efficacy and leadership development requirements may be needed in the future and the instructors would investigate theories of motivation for designing better instructional delivery strategies.

FIG. 9: Students' perceived self-efficacy in key performance indicators of the joint course project.

5. DISCUSSION AND CONCLUSION

A project report-out and debriefing session was conducted to identify both successes and failures of the joint course project, and to seek for constructive feedback from students on potential improvement for future implementation. The most commonly cited success by students was their successful completion of required project deliverables with satisfactory quality, considering the majority of them had little or no prior knowledge in BIM and sustainable design and construction. They also acknowledged that the PBL pedagogy and the roleplay experience helped bridge the gap between learning in typical classroom settings and working in the real world scenario. PBL was able to promote continued engagement and ongoing inquiries in knowledge, skills and abilities that were essential to implementing BIM in green building projects. On the other hand, the biggest failure, as unanimously criticized, was the logistic hazard due to poor course scheduling, which was referred to by student as "the biggest inconvenience" that severely undermined their learning experience. The students also expressed frustration with technological cumbersomeness due to outdated computers and persisting glitches of some of the essential software applications.

The instructors acknowledged the technological issues, and would consider better communication with vendors for technical support, or evaluate new products for future projects. However, a much more significant concern was the lack of self-motivation and leadership among the students. Rarely there were students who would be willing to step out of the comfort zone and push boundaries to learn more and do better, instead of getting by. Consistent efforts were made along the project by instructors to promote student engagement, but little success was accomplished. That being said, instructors did identify some best practices such as bringing industry speakers and conducting field trips. As for the future scope of work on LEED documentation, due to time constraints, the instructors plan to have students focus on only selected LEED credits rather than completing a full LEED documentation for the project during one semester. Funding is also being sought after for hardware upgrades to create a workplace that facilitates real collaboration in project-based learning.

There were some apparent limitations with the assessment of this project. The small class sizes and the lack of historical data on student learning in BIM and sustainable design and construction made it challenging to yield meaningful and statistically sound results for wide dissemination. Alternative grading and assessment methods that emphasize competency-based learning such as Specifications Grading (Nilson, 2015) might be considered in future experiments.

As a conclusion, construction and engineering education is facing dual challenges in meeting its academic goals as specified by accreditation and assessment requirements, as well as its professional mission of cultivating competent future workforce for the industry. This paper investigated the emerging trend of integrated BIM and sustainable design and construction practices, and aligned it with program assessment efforts in improving core SLOs. Using the PBL pedagogy, a joint course project was conducted to experiment innovative strategies to help students attain knowledge, skills and abilities (KSAs) that are essential to their future professional roles in the construction industry. Comprehensive assessments were conducted for the project, showing solid student performance in targeted learning outcomes but also suggesting engagement and leadership issues that deserved future investigation. Results of the study and lessons learned through the joint course project may become valuable reference to peer instructors and researchers who are also investigating BIM education integration strategies in undergraduate CM programs across the country.

ACKNOWLEDGEMENT

The authors would like to thank Harris Construction for providing the project documentation, giving guest lectures and accommodating student field trips.

REFERENCES

Autodesk. (2015). Building Performance Analysis Certificate. Retrieved Oct. 18, 2015, from http://sustainabilityworkshop.autodesk.com/bpac

Azhar, S., Carlton, W. A., Olsen, D., and Ahmad, I. (2011). Building information modeling for sustainable design and LEED (R) rating analysis. *Automation in Construction, 20*(2), 217-224. doi: 10.1016/j.autcon.2010.09.019

Bank, L. C., McCarthy, M., Thompson, B. P., and Menassa, C. C. (2010). *Integrating BIM with system dynamics as a decision-making framework for sustainable building design and operation*. Paper presented at the First International Conference on Sustainable Urbanization (ICSU 2010) Hong Kong, China.

Barnes, S., and Castro-Lacouture, D. (2009). *BIM-Enabled Integrated Optimization Tool for LEED Decisions.* Paper presented at the International Workshop on Computing in Civil Engineering 2009, Austin, Texas.

Baş, G. (2011). Investigating the effects of project-based learning on students' academic achievement and attitudes toward English lesson. *The Online Journal of New Horizons in Education, 1*(4), 1-15.

Becerik-Gerber, B., Ku, K. H., and Jazizadeh, F. (2012). BIM-Enabled Virtual and Collaborative Construction Engineering and Management. *Journal of Professional Issues in Engineering Education and Practice, 138*(3), 234-245. doi: Doi 10.1061/(Asce)Ei.1943-5541.0000098

Biswas, T., Wang, T. H., and Krishnamurti, R. (2008). *Integrating sustainable building rating systems with building information models*. Paper presented at the 13th Int. Conf. on Computer Aided Architectural Design Research in Asia, Hong Kong.

Bynum, P., Issa, R. R. A., and Olbina, S. (2013). Building Information Modeling in Support of Sustainable Design and Construction. *Journal of Construction Engineering and Management, 139*(1), 24-34. doi: 10.1061/(asce)co.1943-7862.0000560

Chinowsky, P. S., Brown, H., Szajnman, A., and Realph, A. (2006). Developing knowledge landscapes through project-based learning. *Journal of Professional Issues in Engineering Education and Practice, 132*(2), 118-124. doi: 10.1061/(Asce)1052-3928(2006)132:2(118)

Deru, M., Field, K., Studer, D., Benne, K., Griffith, B., Torcellini, P., . . . Crawley, D. (2011). U.S. Department of Energy Commercial Reference Building Models of the National Building Stock. Golden, Colorado: National Renewable Energy Laboratory.

Frechtling, J., Frierson, H., Hood, S., and Hughes, G. (2002). The 2002 User Friendly Handbook for Project Evaluation. Arlington, VA: National Science Foundation.

Goedert, J. D., Pawloski, R., Rokooeisadabad, S., and Subramaniam, M. (2013). Project-Oriented Pedagogical Model for Construction Engineering Education Using Cyberinfrastructure Tools. *Journal of Professional Issues in Engineering Education and Practice, 139*(4), 301-309. doi: 10.1061/(Asce)Ei.1943-5541.0000165

GSA. (2015). 3D-4D Building Information Modeling. Retrieved Oct. 18, 2015, from http://www.gsa.gov/portal/content/105075

Häkkinen, T., and Kiviniemi, A. (2008). *Sustainable building and BIM*. Paper presented at the 2008 World Sustainable Building Conference, Sydney, Australia.

Kubiatko, M., and Vaculova, I. (2011). Project-based learning: characteristic and the experiences with application in the science subjects. *Energy Education Science and Technology Part B-Social and Educational Studies, 3*(1-2), 65-74.

Liu, Y.-H., Lou, S.-J., Shih, R.-C., Meng, H.-J., and Lee, C.-P. (2010). A Case Study of Online Project-Based Learning: The Beer King Project. *International Journal of Technology in Teaching and Learning, 6*(1), 43-57.

McGraw-Hill Construction. (2010). Green BIM: How Building Information Modeling is Contributing to Green Design and Construction. Bedford, MA: McGraw-Hill Construction.

McGraw-Hill Construction. (2012). The Business Value of BIM in North America: Multi-Year Trend Analysis and User Ratings (2007–2012). Bedford, MA: McGraw-Hill Construction.

Nilson, L. B. (2015). *Specifications Grading: Restoring Rigor, Motivating Students, and Saving Faculty Time*. Sterling, Virginia: Stylus Publishing.

O'keeffe, S. E., Shiratuddin, M. F., and Fletcher, D. (2009). *LEED certification review in a virtual environment*. Paper presented at the 9th Int. Conf. on Construction Application of Virtual Reality, Sydney, NSW, Australia.

Ponton, M. K., Edmister, J. H., Ukeiley, L. S., and Seiner, J. M. (2001). Understanding the Role of Self-Efficacy in Engineering Education. *Journal of Engineering Education, 90*(2), 247-251. doi: 10.1002/j.2168-9830.2001.tb00599.x

Schaffer, S. P., Chen, X., Zhu, X., and Oakes, W. C. (2012). Self-Efficacy for Cross-Disciplinary Learning in Project-Based Teams. *Journal of Engineering Education, 101*(1), 82-94. doi: 10.1002/j.2168-9830.2012.tb00042.x

Smith, D. K., and Tardif, M. (2009). *Building Information Modeling: A Strategic Implementation Guide for Architects, Engineers, Constructors, and Real Estate Asset Managers*. Hoboken, NJ: John Wiley and Sons, Inc.

Walters, R. C., and Sirotiak, T. (2011, April 6-9, 2011). *Assessing the effect of project based learning on leadership abilities and communication skills.* Paper presented at the 47th ASC Annual International Conference, Omaha, NE.

Wu, W., and Issa, R. R. A. (2010). *Application of VDC in LEED projects: Framework and implementation strategy*. Paper presented at the CIB W-78 27th Int. Conf. on IT in Construction, Rotterdam, Netherlands.

Wu, W., and Issa, R. R. A. (2014). BIM Education and Recruiting: Survey-Based Comparative Analysis of Issues, Perceptions, and Collaboration Opportunities. *Journal of Professional Issues in Engineering Education and Practice, 140*(2), 04013014. doi: 10.1061/(asce)ei.1943-5541.0000186

Wu, W., and Issa, R. R. A. (2015). BIM Execution Planning in Green Building Projects: LEED as a Use Case. *Journal of Management in Engineering, 31*(1), A4014007. doi: 10.1061/(asce)me.1943-5479.0000314