Develop a TBL-facilitated BIM Education Framework for Civil Engineering and Management

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***Abstract*—In order to improve college students' competency in building information modeling (BIM) project execution process, this research adopted the module iterative structure of team-based learning (TBL) to create an educational framework that aims to develop core knowledge, skills, and abilities of students in the Civil Engineering and Management (CEM). Using a real-world project delivery perspective, this paper reviewed the TBL and outlined the TBL-facilitated BIM education framework along the various project life cycle phases including design, bidding/tendering, construction and post-construction. The paper then elaborated on the implementation of this framework in developing the four BIM education modules. Specific learning outcomes of each module and the pedagogical design are explained, highlighting the iterative structure of each module and the role play nature of students in the TBL learning environment. The proposed TBL-facilitated BIM education framework is anticipated to stimulate the enthusiasm of students in BIM, improve their BIM application skills, and effectively align CEM BIM learning outcomes with the industry expected BIM competency. The results of this research, including the educational framework and BIM education modules, may become a valuable reference as more CEM programs are embarking on the integration of collaborative interdisciplinary team experience in BIM education.**

***Keywords*—building information modeling; team-based learning; civil engineering and management; competency; project life cycle**

I. Introduction

There is an increased market demand for building information modeling (BIM) competent workforce in the construction industry as the Chinese government is deepening the transformation to an economy with the Internet+ based strategic development plan. Defined as the digital representation of the physical and functional characteristics of a facility through its lifecycle, BIM is gaining global momentum and becoming the new venue of global competition. According to the "2016-2020 Development Plan of Digitization of the Construction Industry" by the Ministry of Housing and Urban-Rural Development of People's Republic of China (MOHURD), the priority is to cultivate the BIM talent with the desired knowledge, skills and abilities (KSAs) to meet the industry needs of the BIM-based interoperable and collaborative research and development (R&D) among the architecture, structure, mechanical, electrical and plumbing (MEP) disciplines[1, 2]. Higher education plays an essential role in meeting this long-term strategic goal and holds to promise to bridge the gaps in skilled BIM workforce bottleneck through dedicated education and competency development to better prepare college architecture, engineering, construction management students for workplace performance [3, 4]. Among the multiple dimensions of the conceptualization of BIM, practitioners are increasingly acknowledging it as an integrated and collaborative process, rather than the software applications, to deliver business goals in project design, construction, operation, and maintenance. Correspondingly, higher education has the obligation to rethink the goals of BIM education and transform the current technology-intensive pedagogical approach to focus on information-driven, team-based learning and interdisciplinary collaboration. Real-world BIM project execution and job task leveling BIM implementation should be addressed and integrated into college curricula to cultivate career-specific BIM competencies among architecture, engineering and construction management students [5].

According to [5, 6], current BIM education research has a range of focused areas to address the varied needs and to understand the educational framework and objectives, curriculum and pedagogy design, as well as student learning outcomes and workforce development. Initially, software applications were at the center of BIM education, and subject matter experts from large vendors were brought to institution classrooms for BIM application training. Later, as BIM adoption and implementation made substantial strides in the industry, teaching software skills were no longer sufficient to fulfill the workforce requirements anticipated for college students. Enhanced collaboration and partnership between practitioners and educators contributed to the transformation of BIM education to focus more on project execution, especially in the context of real project delivery process[7, 8]. In addition to technical skills, soft skills such as collaboration, teamwork, communication, and leadership have created a lot of attention in BIM curriculum design [5, 9]. It is acknowledged that in a project based learning environment, students will not only attain a working knowledge of BIM but also gain insights into the collaborative teamwork and enhanced communication that form the foundation for effective BIM execution throughout the project life cycle [10].

Therefore, there is a research need to understand BIM education in the team context, and team-based learning (TBL) may provide educators with unique strengths in educating BIM concepts and processes, and developing students' career-specific BIM competency.

Therefore, this research proposes a TBL-facilitated education framework to develop effective BIM education modules and create an interactive and collaborative learning environment. The modules will expose students to roles and responsibilities of BIM project teams, facilitate their understanding of data sharing and interoperability within the project lifecycle, and develop skills through role play tasks that simulate interdisciplinary team interaction, coordination and collaboration in project execution [11, 12].

The paper is structured in the following 4 sections. Section II reviewed the related literature, including the TBL pedagogy, current BIM education practices, and industry-oriented education needs. Section III proposed and outlined the TBL-facilitated BIM education framework. Section IV discussed the proposed BIM education module with emphasis on delineating the TBL module iterative structure of each module. Section V discussed the planned pilot of the BIM education framework and modules, limitation of current research and future research agenda.

II. LITERATURE REVIEW

A. Team-based learning

Team-based learning (TBL) is a collaborative learning and teaching strategy that follows a structured process to enhance student engagement and the quality of student or trainee learning [8]. Popularized by Michaelsen, the TBL methodology can be used in any classroom or training sessions at school or in the workplace [9]. TBL follows an iterative learning process (Fig. 1) which repeats a sequence of activities consisting of: (1) individual preparation through out-of-class reading of the learning materials; (2) readiness assessments through both individual and team tests (iRAT and tRAT); (3) application of course concepts through multiple team activities; and (4) an (optional) end of module test [8, 9,10]. Originally implemented in medical education, the TBL pedagogy also finds its footprint in engineering education since engineering students have similar desired outcomes as medical students, such as teamwork skills, problem-solving skills, and creative thinking.

TBL as a student-centered, active learning pedagogical approach is often incorporated into a project-based learning environment that focuses on real-world issues [13]. Empirical evidence found in the performance of project-based industry such as engineering and construction suggested that it is necessary to develop work together among several members of the team resulting in positive outcomes that improve performance [14, 15]. Aside from student learning process, TBL in a project-based learning also redefines and transforms the roles of instructors. Instead of being the point of authority and source of solution, instructors in TBL 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 avoidance of providing the answer keys [16]. The purpose is to develop students' metacognition and self-monitoring skills in facing, analyzing and resolving problems and complexities in real project scenarios [13].

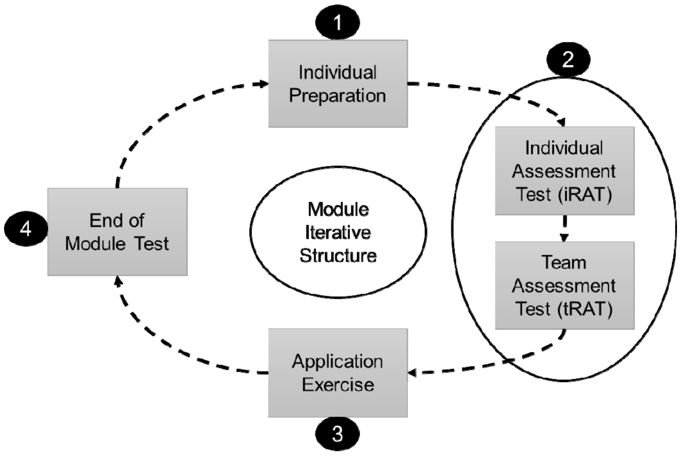

Fig. 1. Module iterative process for team-based learning [17].

B. Current BIM education practices

Various studies had discussed the strategy to integrate BIM into the college curriculum, the educational objectives and BIM course materials, and the pedagogical approaches to delivery BIM education [5, 6, 18]. Some programs chose to develop independent and dedicated BIM courses [19, 20], while others found it challenging to add extra courses to existing curricula due to constraints of a total number of program units. Instead, they would integrate BIM via redesigning existing courses to address BIM concepts, technical skills and implementation in traditional topics such as construction graphics [21], scheduling [22], cost estimating [23], capstone project [24] to name a few.

There are pros and cons in each scenario: 1) dedicated BIM courses seemed to be low hanging fruits and may generate fast and direct impacts among the student population. Nevertheless, independent BIM courses lacked the connection with existing curriculum and sometimes lost the context in which BIM was expected to be implemented; 2) Distributed, curriculum-level BIM integration seemed to significantly improve student learning outcomes and enhance BIM competency development. However, such integration typically necessitates a unified commitment to course redesign at department/program level, and requires collaboration among various faculty members; 3) Interdepartmental/intercollegiate BIM oriented capstone projects seemed to be the ideal test bed to cultivate desired BIM competency with intensive multidisciplinary collaboration and real world project simulation. Unfortunately, such collaboration and interaction often came at a high price and demands substantial investment in time commitment and human resources, information technology infrastructure, and highly dependent on faculty advisors' qualifications.

As an alternative method, the TBL pedagogy seems to hold the promise to facilitate BIM education within college curricula. BIM represents both physical and functional characteristics of a capital project along its lifecycle [25]. When transferring professional BIM best practices into higher education, both technical contents and the multi-party collaborative process should be mapped and incorporated to sufficiently replicate the context in which BIM is implemented. In this scenario, BIM is no longer only the learning objective but also function as a platform to foster team-based collaborative learning. These characteristics of BIM make it well suited with TBL. Synergies of TBL and BIM provide learners, educators and eventually employers with unique benefits by effectively transforming technical and non-technical knowledge and skills into career-specific competencies that are critical to the long-term prosperity of the construction industry [26].

C. *Industry-oriented BIM competency development needs*

Use of BIM in the global architecture, engineering and construction (AEC) industry has gained significant acceptance [27-29]. Over the years, a broad spectrum of potential BIM uses along the project life cycle have also been identified and experimented with documented best practices, including but not limited to: virtual design and visualization, spatial coordination and clash avoidance, digital fabrication, site logistics and safety management, field compliance and project controls, quantity takeoff and cost estimating [30].

From the project management and business value perspective, BIM is highly recognized for improving project productivity via promoted interoperability and collaboration among project team members [31, 32]. BIM provides project teams with a common digital data environment in which all critical decisions are made based upon a holistic understanding of most recent and accurate project information. To a certain degree, the business function of BIM is similar to an Enterprise Resource Planning (ERP) solution where all project resources are shared and optimized to achieve ultimate efficiency of the supply chain over the project's lifecycle.

Understanding how BIM is implemented in industry context and the perceived business value of BIM is essentially important for college AEC programs as they are making significant efforts to cultivate the next-generation workforce and future industry leaders. The industry-oriented BIM competency development needs should be mapped with foundational BIM educational objectives and student learning outcomes in the college curriculum. Based on the above literature, college BIM education and associated curriculum or course redesign should stress on the following key points: 1) BIM education should be project-based and encapsulate fundamental knowledge and technical skills; 2) BIM education should address the lifecycle BIM implementation and differentiate between disciplinary specificity and team-based collaboration and interoperability; 3) BIM education should address the balance between technical/hard skills in problem-solving and nontechnical/soft skills including teamwork, communication, business management and lifelong learning; and 4) BIM education should rely on real world context and industry involvement to provide students with realistic project experiences in both success and failure scenarios. In summary, college BIM education should be competency-oriented and serves the purpose to improve students' career preparedness.

III. TBL-FACILITATED BIM EDUCATION FRAMEWORK

Based on the study of [17] and[33], this research adopted the TBL pedagogy in an undergraduate Civil Engineering and Management (CEM) capstone project and proposed an iterative structure for BIM competency development as a new paradigm to facilitate fundamental curriculum transformation. This initiative fits with the overarching goal of the CEM program redesign, which was devoted to improving students' career-specific competency through a comprehensive mapping of knowledge, skills, and abilities (KSAs) defined according to the CEM program strategic plan, as illustrated in Fig. 2. It is anticipated that the TBL-facilitated BIM education would provide CEM students with desired educational experience to not only expose them to real-world BIM implementation and develop the desired KSAs for workplace job tasks but also help them understand the essence of the team-based, multidisciplinary collaboration in a project-based industry.

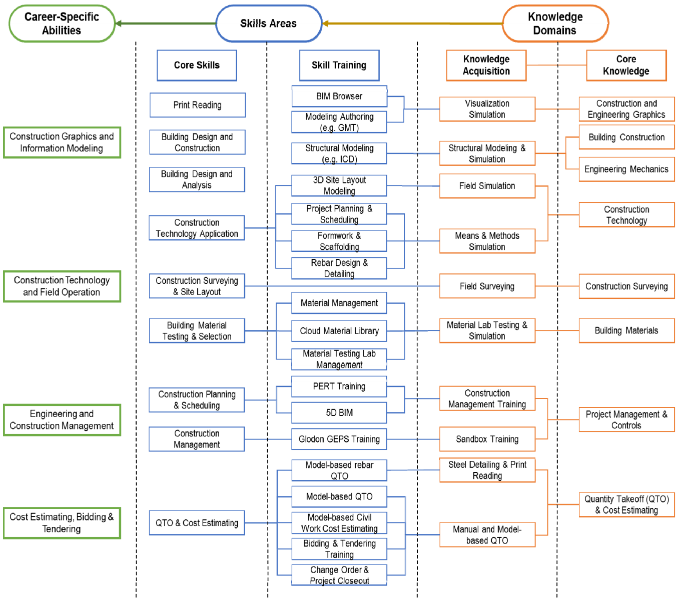

Fig. 2. The CEM program KSAs mapping.

A. *TBL-facilitated BIM Education Framework*

Specifically, this research intends to experiment with the TBL-facilitated BIM education model to systematically, yet qualitatively, evaluate how students may demonstrate core CEM learning outcomes and be able to apply curriculum-based knowledge and skills for problem-solving in a simulated BIM execution process using a real BIM project. Through role play in an interdisciplinary project team, students immerse themselves in TBL with individual and team responsibilities that demand extensive engagement with modeling, analysis, communication and management tasks designed to develop a broad spectrum of technical and non-technical BIM competencies (as illustrated in Fig. 2). A framework of TBL module iterative structure for BIM education is proposed and illustrated in Fig. 3. The framework consists of three major layers: TBL module iterative structure, BIM project execution phases, and the iterative BIM education module. The focus of this paper is to discuss the development of these education modules using the TBL iterative structure along a typical BIM project execution lifecycle.

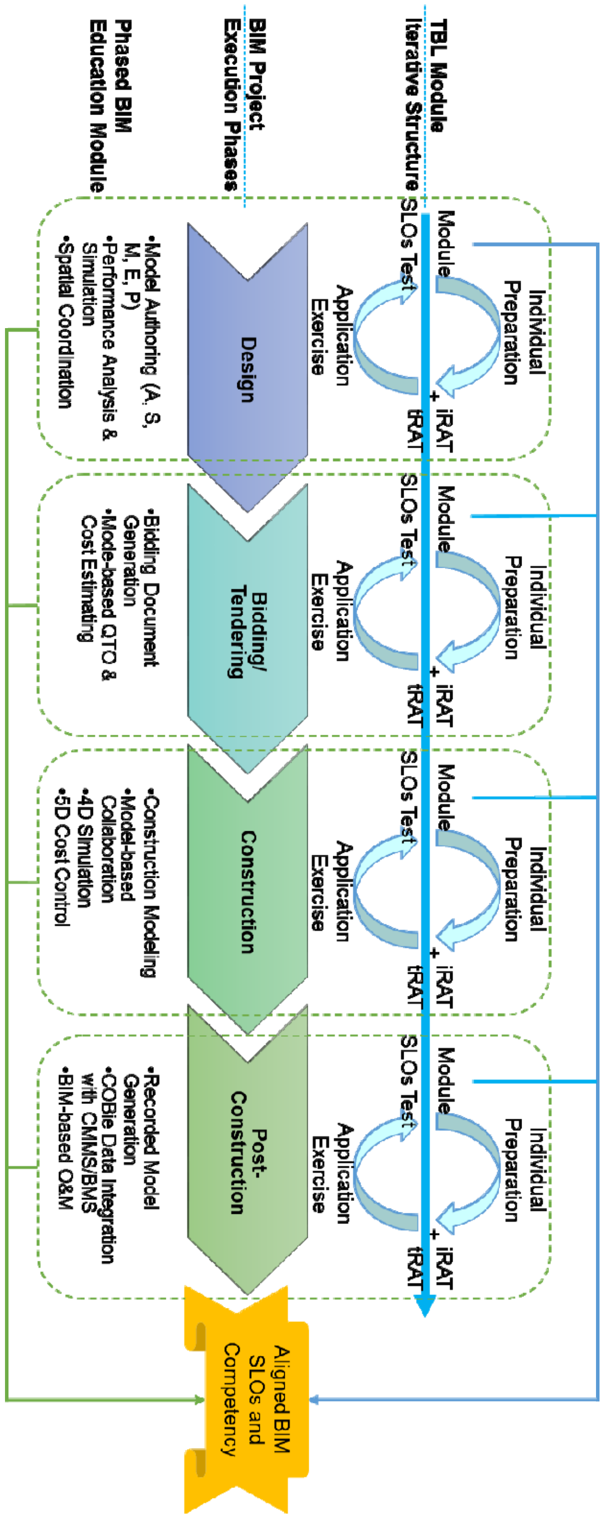

Fig. 3. The proposed TBL-facilitated BIM education framework.

B. Phased BIM Education Modules

As shown in Fig. 3, a series of BIM education modules were planned and scheduled in phases (i.e. Design, Bidding & Tendering, Construction, and Post-Construction), comparable to a typical project delivery process, and lasted for three months. At each phase, student teams would work on specific job orders and complete critical tasks to meet capstone project requirements. Each BIM education module covered various topics such as model authoring, design coordination, model-based quantity takeoff (QTO) and cost estimating, project planning or scheduling, and 4D simulation, and photogrammetry-based as-build model generation. To deliver these education modules, a spectrum of learning activities was planned and conducted, including individual learning (similar to a flipped classroom model when students got prepared before working as a team in the lab), lectures, BIM application hands-on training labs (by a student Teaching Assistant), project lab/design studios, team presentations, reflection and questions & answers (Q&A) sessions following deliverables submitted for each module.

C. TBL Team Role Building

Team building is essential to TBL. To form the TBL project teams, role play was an essentially important component. Appropriate role play by students in a simulated BIM project team provided instructors with unique opportunities to observe the dynamics among technology, process, and student learning behavior. Each capstone project team was made of five (5) students with assigned roles and responsibilities as indicated in Table 1, according to their background/area of studies in the CEM program. Typically, students' roles on a TBL team are fixed. Nevertheless, in the real-world practice, students were encouraged to start with one major role while they were also allowed to assist other team members when necessary to enhance both an individual learning experience and overall team performance.

TABLE 1. TBL STUDENT TEAM ROLE PLAY ASSIGNMENT IN THE REAL-WORLD PROJECT.

Roles	Student Background	Responsibilities	No. of Student
Design Professionals	Architecture, Structure, MEP	Design model authoring	1
Bidding/ Tendering Commissioner	Cost Engineering	Model-based quantity takeoff and cost estimating	1
Constructor	Contractor/ Specialty Contractor	Construction modeling	1
Project Manager	Construction Management	Project coordination and project controls	1
Project Engineer	Civil Engineering	Site layout, field operation, quality control,	1

IV. TBL Module Iterative Structure of BIM Education Modules

In each of the four (4) BIM education modules, the module iterative structure of TBL as illustrated in Fig. 1 was applied, as elaborated below. The module iterative structure aimed to: (1) emphasize the importance of understanding BIM as an iterative team-building effort and a continuous collaboration process; and (2) provide a formative assessment of student learning and allow faculty to provide students with timely feedback and intervene when necessary.

A. Step I – individual preparation

The TBL project was a highly synthesized experience for undergraduate CEM students, meant to conduct a comprehensive check on students' preparedness for their professional career. As the initial phase of each BIM education module, faculty advisors would quickly review the knowledge requirements reflected by the designated tasks assigned to each discipline/role of individual team members in this module. Students were debriefed with module objectives, tasks, deliverables and the timeline. Students would also spend time on reviewing project documentation (e.g. bidding documents, project plans, and specifications, etc.) to get familiar with the project assigned and develop strategies to fulfill individual tasks, conduct self-evaluation on resources needed, to name a few. When gaps were identified, faculty and student teaching assistant would offer lectures, lab tutorials, and other resources to facilitate students' acquisition of the desired knowledge.

B. Step II – readiness assurance process

The readiness assurance process is essential to ensure that students and project teams will have the desired knowledge and skills to fulfill the range of tasks prescribed in each BIM education module, and eventually complete the capstone project successfully. The readiness assurance test (both iRAT and tRAT) could follow the standard format with scratch cards or use multiple choice questions. In this research, due to the fact that a substantial part of knowledge and skills were related to specialized software applications (individuals) and model-based collaboration and communication (team), faculty advisers utilized live lab sessions and mock-up team presentations to observe and evaluate individual and team preparedness. Industry representatives were also invited to offer real life insights to encourage discussion on students' learning process and facilitate their further understanding of the tasks based on best practices, rather than focusing on the test result itself.

C. Step III – application activities

Application activities engage students in applying fundamental concepts and theories in real-world scenarios and truly develop the skills through experiential learning. After the initial two steps, students and their teams would be ready to start the actual tasks to simulate BIM implementation at the particular project phase. These could include modeling and authoring the architectural, structural, and MEP components, building performance simulation (e.g. structural, energy, daylighting, and indoor environment quality), spatial coordination, bid document generation, model-based QTO and cost estimating, construction modeling, 4D sequencing, and 5D cost control, to name a few. Due to the continuity between the BIM education modules, such application activities also involved data exchange and information handover between the project delivery phases, when students would also develop model management, interoperability, and model-based collaboration skills along the process.

D. Step IV – end of module assessment

At the end of each BIM education module, a list of deliverables was submitted by project teams and assessed by the cohort of faculty advisors with external industry reviewers. A significant portion of the deliverables were direct BIM outputs including modeling, simulation, and manipulation of model data, which accounted for 70% of the final assessment. Other deliverables include copies of reading assignments, quizzes, lab assignments, case studies and presentation exhibits, which were evaluated together with other communication records (e.g. minutes, reports and reflections). Instead of using the grades of these artifacts, the faculty advisors regarded this part of deliverables as indicators of professionalism and overall team performance. As in real project delivery, team communication and collaboration could considerably affect the overall project experience and the final project outcome [34, 35]. Thus, the bulk of materials were assessed from the standpoint of TBL organization, professional documentation, and formatting, which accounted for 30% of the final assessment. In defining the scales of assessment outcomes, the faculty advisors referred to the ABET standard and adopted the Bloom's taxonomy, i.e. *Remember, Understand, Apply, Analyze, Evaluate* and *Create* [36], to establish the level of performance in student competency assessment. Each team submission was assessed by a review panel that consisted of three members randomly selected from the faculty advisors (cannot be the team's faculty advisor) and industry subject matter experts.

To summarize the iterative structure in BIM education module development, it is meant to provide a generic process and instructional design approach rather stipulating the actual learning outcomes, learning activities or course contents. AEC programs may adopt the proposed TBL-facilitated BIM education framework with individually defined priorities and objectives.

V. PILOT TEST WITH A CAPSTONE PROJECT

A. Project Description

Considering this was the first-ever TBL-facilitated, BIM-integrated capstone project of the program, the faculty advisors agreed that it would be appropriate to use a small commercial project as the case study. A kindergarten project in Chongqing City was selected. The kindergarten was a three-story facility with a total of 4096.12 m^2 (approximately 44,090 ft^2). It was designed to accommodate 600 occupants including students, faculty, and staff, with a parking capacity of 20 spaces. The project cost was about $1.3 million (design and construction cost only, the land cost was subsidized by local government), and was delivered within 220 days.

B. Capstone Project Planning

To effectively pilot the TBL-facilitated BIM education model in the capstone project, the investigators and other faculty advisors conducted comprehensive planning on critical factors that may influence the project outcome (Anderson and Mourgues 2014; Apolloni et al. 2007; Elsaiah and Jansson 2016; Guerra and Holgaard 2016): (a) establish clear roles & responsibilities of team members, including discipline-specific modeling tasks and information exchange requirements between disciplines as required by team collaboration in project execution; (b) establish clear protocols and standards for information exchange between team members to facilitate productive communication and collaboration; (c) specify team project deliverables at the end of each BIM education module; (d) set goals of performance for each team and its members and how such performance will be assessed; (e) create a point of reference and protocols for team conflict resolution; (f) use cloud-based a platform to facilitate documentation sharing and management, and encourage knowledge sharing and management within the team. The participating students from the Civil Engineering and Construction Management program were interviewed by faculty advisors and allocated into teams based upon their background, previous exposure to BIM and professional experience. A total of 30 students (with 6 focusing on civil engineering and 24 focusing on construction management) were divided into 6 project teams and would be assigned a dedicated faculty advisor. For assessment purposes, industry subject matter experts were also invited by faculty to serve as mentors and participate in final project deliverables evaluation. The capstone project took place in spring 2016 and lasted for 16 weeks.

C. Student Learning Outcomes/BIM Competency Assessment

To comprehensively assess student learning outcomes (SLOs) and BIM competency developed through the TBL-facilitated BIM education modules, a digital project manual was required for project teams as their capstone project final deliverables. A panel of three reviewers that were randomly selected from faculty advisors and industry subject matter experts would evaluate student team deliverables. Final assessment results were based on the average of three reviewers' ratings.

To examine the overall SLOs and associated BIM competency development for all 30 students, the reviewers would first evaluate student deliverables against the scales mapped with Bloom's taxonomy (6 indicates the best performance while *1* indicates worst performance), then decided on the percent score threshold at *Low*, *Medium* or *High*. When comparing performance between students, the achieved Bloom's taxonomy scales should take precedence, then the percent score threshold of *Low*, *Medium* and *High* at each scale should be examined. Color codes were used in Table 2 to provide direct visual aids to differentiate performance levels. Student performance distribution, in terms of the percentage of students that fell under one of the three performance levels, was then marked. This table could offer immediate and quantitative insights into a specific SLO or the associated BIM competency. Meanwhile, Fig. 4 also helps the faculty identify hot spots of performance gaps in student preparedness for expected KSA requirements according to the CEM roadmap as shown in Fig. 2. For instance, the baseline performance for the capstone project was set at Bloom's Taxonomy *Scale 4: Analyze*, indicating that students were expected to accomplish *Scale 4* performance for all SLOs and associated BIM competency requirements. However, Fig. 4 clearly indicated there were significant performance gaps (*Scale 3* performance) in *Architectural Design* (**33.3%** at *Low Scale 3*), *Green Building Analysis* (**36.7%** at *Low Scale 3*) and *Project Cost Estimating* (**33.3%** at *Low Scale 3*). Such specificity would assist instructors in creating focused action plans to improve SLOs and competency development in particular areas.

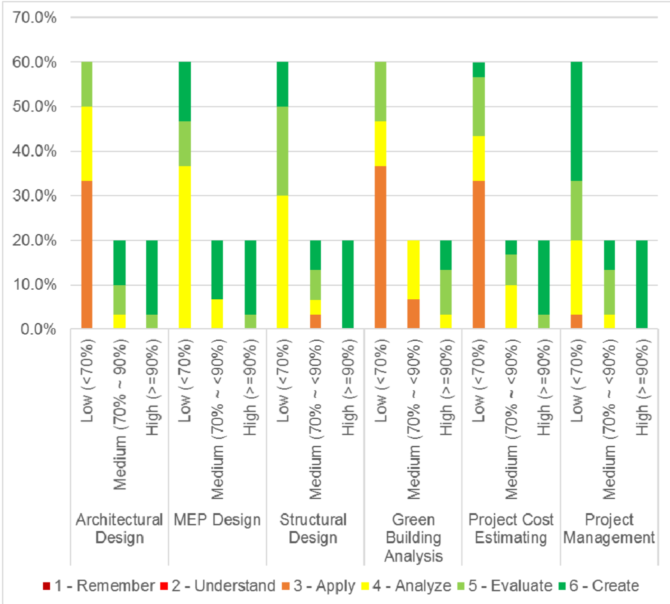

Fig. 4. Distribution of SLOs & associated BIM competency (N=30).

D. Student Feedback

Because Phase IV – post-construction module was not piloted in this research, the faculty advisors decided to use the time saved to conduct an indirect measure of the TBL-facilitated BIM education experience with a short survey. The survey questionnaire consisted of 10 questions using 5-point Likert-type scales to request the 30 students to rate their perceived usefulness of TBL from various perspectives including learning engagement and motivation, effectiveness and efficiency in knowledge acquisition and skill development (Table 2). Considering this was the first time for the CEM capstone project to be delivered using a TBL approach, the survey also included an open-ended comment question for students to offer any constructive feedback on potential future improvement.

The most commonly cited success was the fact that they were able to complete the project on time with satisfactory quality, considering the majority of them had never used any BIM applications before this project. They also acknowledged that TBL in a project-based learning environment was able to uncover issues that were nontypical in conventional lectures and enhanced their working knowledge of BIM real world scenario. The overall student ratings on TBL usefulness were mostly positive as shown in Table 2. Specifically, TBL was highly regarded by students (mean rating of 5-point Likert-scale at 4.52) as a more innovative pedagogy than conventional lectures. TBL was also considered useful in enhancing team awareness (mean at 4.29), motivating learning engagement (mean rating at 4.25), reflecting advantages of teamwork in learning (mean at 4.11), improving student capacity in knowledge application (mean at 4.08) and promoting student preparedness for learning (mean at 4.06).

TABLE 2. STUDENT FEEDBACK ON TBL-FACILITATED BIM EDUCATION CAPSTONE EXPERIENCE (N=30).

Questionnaire Items	Student Rating* Distribution (%)					Value
	1	2	3	4	5	Mean
TBL pedagogy can significantly motivate students to learn	0	0	12.5	50.0	37.5	4.25
TBL pedagogy is more innovative than conventional lecture-based pedagogy	0	0	8.3	31.3	60.4	4.52
TBL pedagogy can promote student preparedness before classes	0	2.1	22.9	41.7	33.3	4.06
TBL pedagogy can enhance students' team awareness	0	4.2	10.4	37.5	47.9	4.29
TBL pedagogy can promote independent thinking and self-learning	0	10.4	18.8	41.7	29.2	3.90
TBL pedagogy effectively reflects advantages of teamwork in learning	6.2	4.2	10.4	31.3	47.9	4.11
TBL pedagogy can improve productivity of students in knowledge acquisition	4.2	10.4	12.5	35.4	37.5	3.92
TBL pedagogy motivates critical thinking by encouraging students investigating extracurricular resources and learning materials	0	12.5	14.6	52.1	20.8	3.81
TBL pedagogy improves students' capacity in knowledge application	0	10.4	12.5	35.4	41.7	4.08
TBL pedagogy can improve students' interpersonal communication skills	0	0	43.7	37.5	18.8	3.75
*Likert Scale: 1 = Not Useful; 2 = A Little; 3 = Medium; 4 = Useful; 5 = Very Useful						

In the open-ended comment question, students made several recommendations to future endeavors in TBL-facilitated BIM education: 1) It is critical for faculty advisors to make it clear on individual preparation requirements, which is the foundation of productive TBL experience; 2) There was a process and the learning curve for students to adapt to TBL. Therefore, before the actual capstone project, certain training on TBL could have been helpful; 3) In TBL, faculty advisors were more like mentors and consultants. Students felt there should be more frequent, both formal and informal communication between students and advisors. Based upon specific project tasks, students were also expecting extra resources pointed out by faculty advisors.

VI. CONCLUSION, LIMITATION AND FUTURE RESEARCH

This research reviewed current BIM education literature and best practices and proposed a TBL-facilitated BIM education framework in response to recent industry needs for a BIM workforce with balanced technical and non-technical competency. This framework leverages the TBL pedagogy to improve students' BIM knowledge, skill and abilities (KSAs) cultivation in real-world BIM project execution process. The goal is to increase students' career preparedness and develop career-specific BIM competency in a streamlined, standardized and systematic manner. The paper also delineated the process of implementing this framework in BIM education module development using a pilot test with an undergraduate capstone project.

The major intellectual merits of this research include several contributions made to the existing body of knowledge in BIM education. First, it pointed out the essence of real-world BIM implementation as a project-based team effort, and made explicit attempts to adopt a team-based pedagogy, TBL, to educate students so they would be prepared for job tasks and performance expected in real BIM project execution. Second, this research proposed and established the TBL-facilitated, project delivery-simulated BIM education framework, and demonstrated the development of a series of phased BIM education modules with the iterative structure. Based upon the program's priority and BIM educational objectives, each BIM education module could accommodate student learning teams with various BIM education topics such as model authoring, performance simulation, spatial coordination, model-based quantity takeoff (QTO) and cost estimating, 4D simulation, photogrammetry-based as-build model generation, to name a few.

It is also recommended that before implementing the framework proposed in this paper, college AEC programs should investigate and assess the BIM pre-requisites in their existing curricula to make sure that sufficient exposure to BIM has been accomplished through tangible investment by instructors in BIM pedagogy development and incentives to encourage student involvement. Some examples may include faculty release time and/or stipends for BIM integration course redesign, BIM workshops, and student competitions, field trips to BIM projects, to name a few.

The major limitation of this research resides in the lack of empirical evidence of the proposed TBL-facilitated BIM education framework. At the same time, it is anticipated that the assessment conducted for student learning outcomes (SLOs) and BIM competency development through the TBL-facilitated BIM education modules may be severely constrained due to the lack of standard measures and best practices on assessing the TBL-facilitated BIM education.

Future research will focus on further developing and pilot-testing the TBL-facilitated BIM education modules in a CEM capstone project and other CEM courses at different academic levels to establish longitudinal assessment data and further uncover how instructional design factors, TBL implementation factors, and BIM execution factors may contribute to the measured SLOs and BIM competency development.

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