Toward Next-Generation Engineering Education: A Case Study of an Engineering Capstone Project Based on BIM Technology in MEP Systems

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Abstract

To respond to the digital building environment and Industry 4.0 in buildinginformation modeling (BIM)-based mechanical, electrical, and plumbing(MEP) systems this study developed a new approach to engineering capstone projects. This article reports on a case study of the development of the innovative capstone project for engineering majors, which is based on team- based learning (TBL) combined with the 360-degree evaluation feedback method to cultivate students' BIM competency. The data collection and ana-lysis involves a combination of qualitative and quantitative methods, which aims to evaluate students' learning outcomes and their BIM competency. The results indicate that TBL, combined with the 360-degree evaluation feedbackin the capstone project, can be highly effective in improving graduates' BIMcompetency. This study discusses the interoperability of BIM software tools, problems in the process of data exchange, and provides suggestions for im-proving the course and BIM team collaboration. The research has identifiedhow professional capabilities for students can be enhanced, enabled through a capstone project, and educators are able to deploy the BIM course to develop engineers that closely meet industry needs. The study provides the case forusing the capstone project to improve and cultivate engineering students' BIM competency in MEP systems. This study has provided a new paradigm for applying TBL and 360-degree evaluation feedback to engineering education.

Keywords: 360-degree evaluation feedback, BIM education, curriculum model, MEP systems,team-based learning

1 | INTRODUCTION

The architecture, engineering, construction, and operations (AECO) industry is an integral part of the construction sector that provides architectural design, engineering design, construction services, and operations [1]. Construction industry 4.0 represents the exploration and application of digital technology in construction, engineering, construction, and operation industries, which is conducive to the sustainable development of society, economy, and environment [2]. As a key part of Industry 4.0 adoption in the AECO industry, BIM (building information modeling) has been playing a major role as the central data repository for collating digital information in MEP (mechanical, electrical, and plumbing) systems [3,4]. BIM has become a bridge between the physical environment and the digital environment, and its application requires collaboration at all levels in AECO [5]. MEP systems include heating, ventilation, and air conditioning (HVAC), electric, electronic, plumbing, and anti-power subsystems [6], which are important components of buildings and related infrastructure [7]. In the past 10 years, the industry's demand for BIM application in MEP systems has been accelerating [8,9]. For example, as visual computer tools, BIM can automatically identify misalignment between MEP systems and provide corresponding solutions [10]. With the increasing demand for so-called digital buildings to leverage BIM technology as part of Industry 4.0 adoption, BIM education needs to be optimally aligned with industry needs.

As BIM becomes further embedded in the AECO industry workflows, BIM education in the AECO industry needs to be updated with the inclusion of the new skills requirements associated with Industry 4.0, and the educational technology needs to be improved accordingly [11]. Enhancing the integration of industrial BIM practice into AECO-related curriculums has been the goal for many higher education institutions [12,13]. At the same time, some have identified that BIM skills are required by different BIM-related professionals in the construction sector and the corresponding educational programs [14,15]. Indeed, Succar and Sher [16] identified a competitive knowledge base for BIM learning, which is used to develop BIM learning modules to satisfy the learning requirements of varied audiences. Whereas Zhang et al. [17] created team-based learning (TBL)-facilitated pedagogical model to enhance civil engineering and management students' career-specific BIM competency.

Contrasting with the dramatic rise in the demand for BIM technology in the AECO sector, there has been a lack of studies on how BIM-based MEP systems can be effectively incorporated into engineering capstone projects for undergraduates. In summary, although the BIM application has become commonplace in terms of MEP systems practice, there is presently a lack of understanding on how BIM-related competencies and wider Industry 4.0 technologies can be incorporated in engineering education programs and especially in engineering capstone projects. It should be noted that this article will use the term competency to include BIM-related knowledge, skills, and abilities [18].

The aim of the research study reported in this article was to develop an innovative engineering capstone project, which combined TBL with 360-degree evaluation feedback to cultivate students' BIM-related competencies in MEP systems.

2 | LITERATURE REVIEW

2.1 | BIM education and capstone in MEP

In the AECO industry, BIM is a key tool for visualizing and coordinating construction work as well as helping to avoid errors and omissions. BIM is used to control information, organizational responsibilities, and management processes from the planning stage through to design, construction, maintenance, and finally to demolition [19,20]. There have been several studies of BIM in the MEP systems context. Yung et al. [21] documented and further developed a BIM-enabled MEP coordination process model based on the ID EF0 language. The model can reduce the costs of manual MEP coordination. Wang and Leite [22] presented a formalized schema that can be used to capture the features of scheduled clashes and associated solutions during MEP coordination, and this approach formalizes support management coordination activities.

In an effort to educate future engineers and managers on how to fully utilize BIM, educators continue to explore new teaching methods. Korman and Huey-King [23] developed an experiential learning system to enhance students' understanding of building systems coordination, which was based on a building coordination exercise that compared the differences in MEP coordination between using the light table approach and BIM technology.

Capstone projects represent a critical juncture in students' development and help their transition from university education to professional work. Capstone project instructors use a range of practices designed not only to coach students through the engineering design process but also to more broadly prepare students for workplace and industry practice, as well as helping to build their confidence and identity as emerging engineering professionals [24,25].

It has been suggested that one of the main challenges facing engineering education in the 21st century is that engineering graduates need to develop the relevant attitudes and skills ultimately required by industry before they even leave university [26]. However, this may not be the case yet in China, where the BIM-enabled capstone approach is still in its infancy. In 2016, China became the 18th full member of the Washington Accord, which outlines a set of graduate attributes that in turn form a set of individually assessable outcomes. Such outcomes are the components that are indicative of graduates' potential to acquire the required competency to practice at the appropriate professional level [27]. The combination of BIM capstone project characteristics and the graduate attributes in the Washington Agreement is shown in Figure 1.

2.2 | TBL

There are many different learning models that have been developed and applied in educational research. The widely used approaches include cooperative problem-based learning (CPBL), problem and project-based learning (PBL), and TBL. Following a comparison of different teaching modes, the BIM capstone project model was selected as the most suitable teaching mode.

CPBL is the combination of problem-based learning and cooperative learning. It consists of three to five students forming a group to solve problems through cooperation. It aims to cultivate students' self-directed learning ability and team problem-solving ability. The CPBL cycle is mainly divided into three stages, namely: problem identification, problem analysis and synthesis, and solution generation [28,29]. For example, Mohd Yusof et al. [30] investigated the application of CPBL in a chemical engineering course, which was designed to motivate students to cultivate learning, thinking, and problem solving in the team as well as promoting cooperation among students and improving learning quality and skills. PBL is a teaching method based on student-centered learning in which students learn (via a problem-oriented and project-based approach by solving complex and realistic problems under the guidance of teachers. The purpose is to cultivate students' ability to solve practical problems and specific professional skills [31,32]. In further research, Zhang et al. [33] explored the capstone project that combines situational teaching with real-world projects to cultivate students' expected BIM ability, and learning feedback from the students believed that PBL was helpful to cultivate their ability.

Michaelsen et al. [34] have described the TBL as an active learning method that has been used in a variety of fields, such as business, engineering, natural sciences, mathematics, medicine, nursing, informatics, and humanities [35]. A TBL approach usually involves teams of five to seven students with a diverse composition of team members, effectively representing an even distribution of human resources within the team [36]. When TBL is adopted as a pedagogical principle for a whole program, the instructor needs to set three distinct phases (i.e., preparation, application, and evaluation), and this cycle is repeated for each topic unit [37]. TBL is a good fit for an effective active learning strategy in the field of engineering education [38,39]. This approach promotes the required professional skills, such as teamwork, creativity, problem solving, and communication.

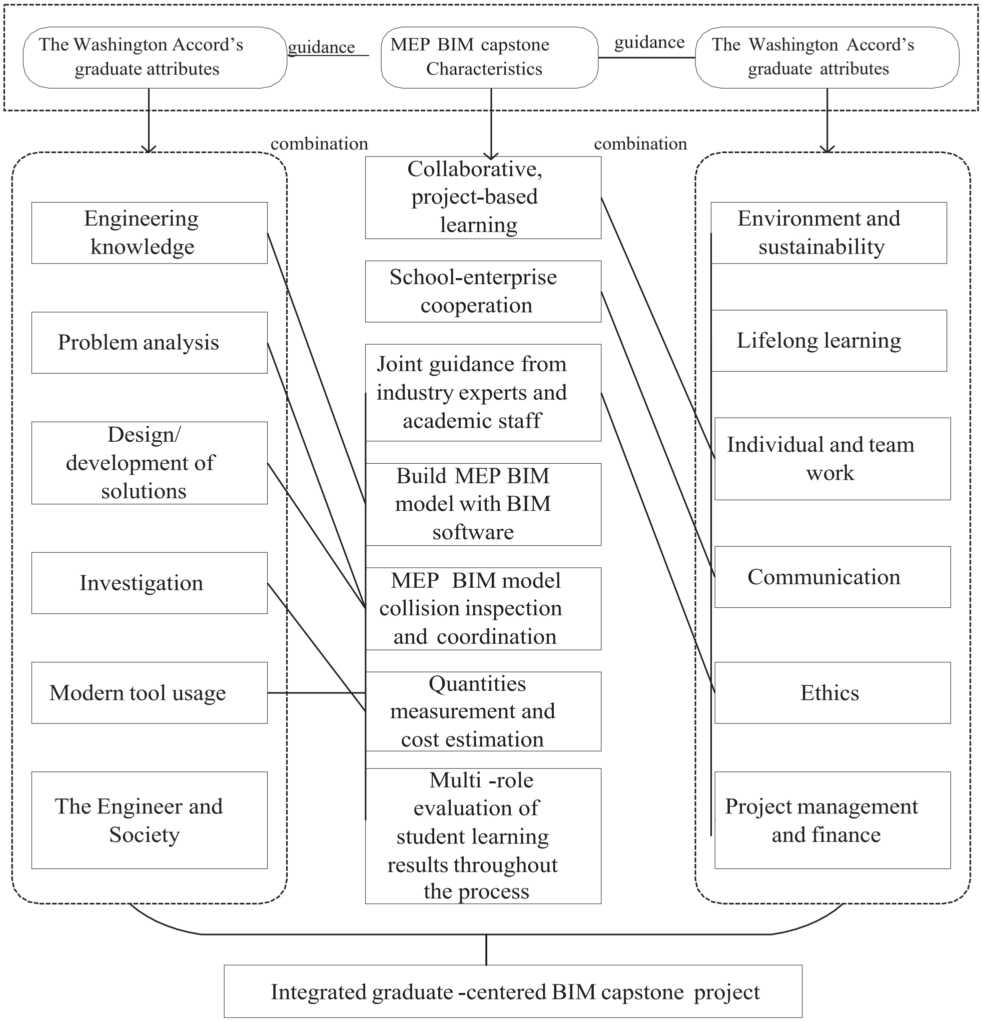


FIGURE 1 Integrated graduate-centered BIM capstone project. BIM, building information modeling; MEP, mechanical, electrical, and plumbing

Moreover, Dehaene et al. [40] developed a multidisciplinary student team design project to support the education of undergraduate electrical engineering students in which students not only gained professional knowledge but also developed teamwork, leadership, and presentation skills. In general, student evaluations of TBL are highly positive [41,42].

According to the above literature review, the advantages and disadvantages of the three models are summarized in Table 1. This comparison shows that TBL is an indispensable component in the BIM capstone project, which can explain how to implement BIM capstone projects through team learning and connect with each stage of the real project. At the same time, the TBL approach can evaluate students' formative ability through the iterative cycle of each stage, which is helpful to cultivate students' ability.

2.3 | 360-degree evaluation feedback in education

360-degree evaluation feedback is also known as multisource feedback, multirater assessment, full-circle appraisal, and peer evaluation. This method of providing developmental feedback is used to assess competency and behavior [47]. The participants in 360-degree evaluation feedback include subordinates, colleagues (i.e., peers), and superiors. It can provide teachers with more valuable information and opportunities for self-reflection, peer-assessment, and self-assessment [48]. The goal is to design a sustainable process that provides the comprehensive and objective assessment of student progress as well as the feedback of the personalized satisfaction and program effectiveness [49].

TABLE 1 Comparison of three learning models

Category	Advantage	Disadvantage
Cooperative problem-based learning (CPBL)	Open teaching, the teaching process to discuss the main concepts, the formation of a cooperative learning atmosphere, improvement of the students' team problem-solving ability [29]	Implementation is difficult to monitor and difficulties in balancing the depth and breadth of the syllabus [30]
Problem and project-based learning (PBL)	Student-centered, combines theoretical knowledge with problems organically, and students learn specific technical content through projects [43]	Resource-intensive, usually every ten students need a tutor. The design and addressing of questions mainly depend on teachers' personal experience, which may be heterogeneous [44]
Team-based learning (TBL)	Flexible implementation, less demand for teachers and lower dependence on teachers [45]	Students master the content through repeated iterations of the three-step process [46]

3 | METHODOLOGY

3.1 | Research framework

The framework supporting the research study is divided into five parts. First, the study reviewed BIM education and capstone projects in MEP systems, TBL, and 360-degree evaluation feedback in education. Second, the pedagogical approach of TBL was de- signed, which is combined with 360-degree evaluation feedback in the BIM capstone. This BIM capstone project approach (i.e., TBL combined with BIM 360- degree evaluation feedback) aims to guide students and teachers in MEP systems teaching and practice, and its teaching content can be adjusted according to the needs of specific engineering disciplines. Third and through adopting a university in China as an example, TBL was combined with 360-degree evaluation feed- back in the BIM capstone, followed by the use of 360- degree evaluation feedback to evaluate students' learning outcomes and their BIM competency. Finally, there was a discussion of the students' team ability, professional abilities, and BIM competency, and the BIM capstone project's benefits and suggestions forimprovements were identified. The research frame- work is shown in Figure 2.

3.2 | Organization of the BIM capstone project teaching

The BIM capstone project is organized as follows:

(1). Teaching objectives: The engineering course relies on graduate-centered capstone projects, and cultivates graduates' cognitive methods, professional ethical awareness, and skills as the teaching goal. It thereby supports graduates' BIM competency and long-term career development prospects.

(2). Team formation: Teams are formed in such a way that, according to the GPA ranking adopted for the first 3 years of the university, the average performance is balanced with teams having a similar ratio of male to female students. A team captain is selected within the team. The class has 50 students and 10 learning teams.

(3). Instructors: A total of seven instructors are involved, including three teachers, one MEP cost estimator tutor, one MEP design teacher, one BIM expert, and four general industry experts.

(4). Teaching resources: A multimedia classroom with 60 computers controlled by the host computer, installed with Revit 2016, Magicad, Navisworks, Guanglianda, GQI, and GBQ pricing software.

(5). Teaching progress plan: The BIM capstone project runs for 16 weeks. According to the corresponding teaching requirements, a capstone progress plan is prepared, and instructors meet with students to solve problems in joint meetings twice a week. Figure 3 provides the Capstone progress plan.

3.3 | Research method

Referring to the experimental design of Yilmaz Ince and Koc [50], this study adopts the experimental research method, where a case study method was used to describe in detail the BIM capstone project. The purpose is to adopt the new capstone project combined with TBL and 360-degree evaluation feedback as an intervention measure to measure its impact on BIM ability. Due to the limited number of students in this major and the same learning resources and environment for all participants as well as the need to meet the requirements of

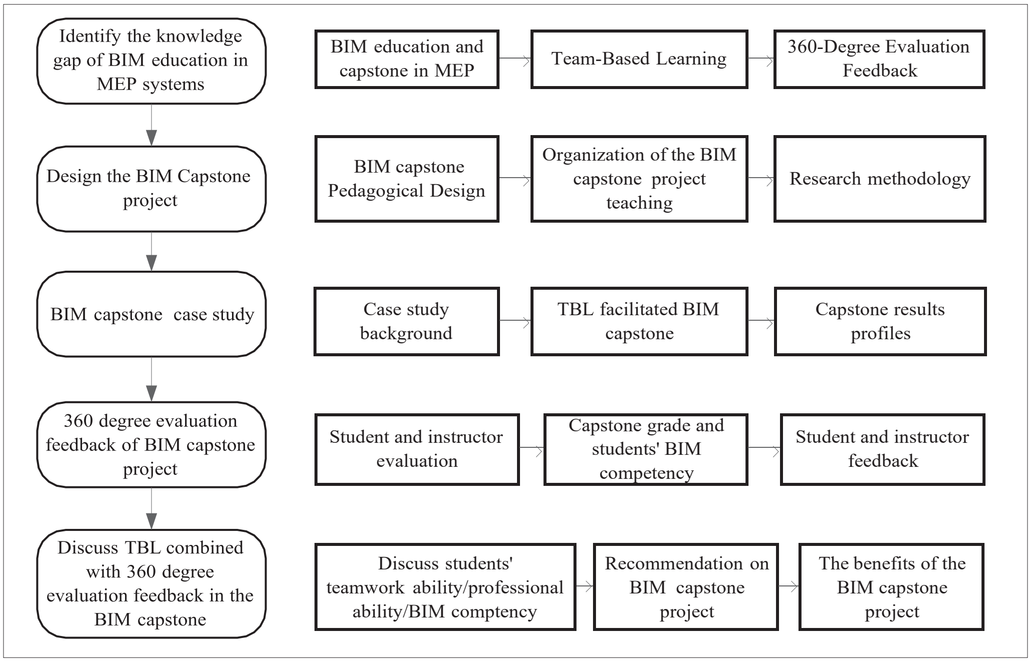


FIGURE 2 Research framework. BIM, building information modeling; MEP, mechanical, electrical, and plumbing

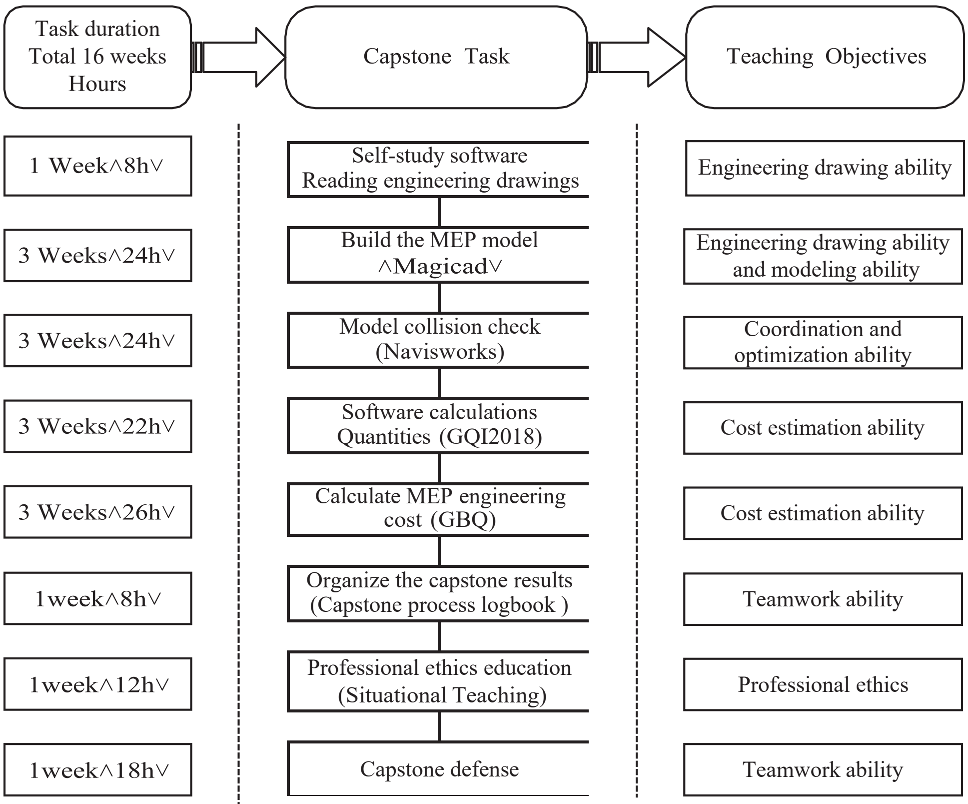


FIGURE 3 Capstone progress plan. MEP, mechanical, electrical, and plumbing

graduation audit and graduate smoothly, it was not possible to form a control group. Therefore, we employed a set of experimental designs for comparative testing to identify the impact of the implementation of the new capstone program. The comparison of the learning effect of the experimental design helps to explore the potential value of new teaching methods and curriculum innovation, which is suitable for the experimental situation of this study [51]. The data collection process of this study includes a semi-structured interview, evaluation criteria for capstone results, capstone scores and comparative test scores, and review of the capstone process logbook.

3.4 | Measures

The results from the evaluation criteria are formulated by the instructor and industry experts according to an agreed-upon evaluation scale (see Supporting Information Appendix A) and are sent to students in the capstone preparation stage. To verify the effectiveness of the BIM capstone project, after completion of the implementation stage, students independently complete the task amount of the first floor of the case (the task lasts for one week). Except for the TBL and 360-degree evaluation feedback, the remaining parts of the teaching model are consistent with the BIM capstone pedagogic design. In addition, through the development of the capstone process logbook, students are required to record their learning experience, personal reflection, and views every day. As a real record of data on the learning process, this approach also provides abundant qualitative data for research. Finally, the semi-structured interview method is used to understand the effect of the teaching mode, the existing problems, and the cultivation of students' ability. Respondents included all participants in the BIM capstone projects. The inclusion of a wider set of interviewees provides a broader and more detailed perspective on the effectiveness of the capstone project approach through capturing the views of the different types of actors involved in the process. Each interview lasted approximately 45 min and was recorded with a voice recorder. After each interview, the audio recordings were imported into NVivo software for transcription and coding.

3.5 | Case study

The capstone case study was based on a teaching building installation project at a university in Sichuan Province in China. The project is a multistory building with a total construction area of 62,750 m^2, building height of 22.2 m, and a total of five floors. The scope of the capstone project requirements included: sanitary water supply and drainage system, electrical system, fire protection system, and HVAC. The case, which involved BIM system visualization, multiprofessional collision inspection, and coordination and optimization according to the MEP model, was convenient for demonstrating engineering cost budget control and cost management.

4 | RESULTS

4.1 | Data analysis

According to the course outcomes, all 50 students who participated in the BIM capstone project passed the course examination successfully, with an excellent average mark of 80% and a pass rate of 100%. The comparative test data of the BIM capstone project are analyzed and shown in Table 2.

After the use of the 360-degree evaluation feedback method combined with the TBL teaching model (including measurement of the minimum and maximum score), the average score of students is higher than that of students without using the proposed method in this study. In this study, the t test of relevant samples was used to test the difference of data, and the significance of the difference is shown in Table 3.

As can be seen from the table, the $df = 49$, $p < .05$. Therefore, at the significance level of 0.05, this data indicate that after the application of the teaching mode based on TBL and 360-degree evaluation feedback method, the BIM capstone project implementation score and individual independent test score have a significant difference. According to the above analysis, the BIM capstone project design based on TBL and the 360-degree evaluation feedback method has been shown to improve students' academic performance.

4.2 | TBL facilitated the BIM capstone project

The BIM capstone project consists of three integrated phases of TBL (i.e., preparation phase, application phase, and evaluation phase), which iterates across the whole project cycle. The integration framework for the BIM capstone project,

TABLE 2 Descriptive statistics

	N	Minimum	Maximum	Mean	Standard deviation
BIM capstone project implementation score	50	60	99	78.32	10.741
Individual independent test score	50	67	100	85.44	9.307

Abbreviation: BIM, building information modeling.

which is based on the TBL model, is summarized as follows (the framework is shown in Figure 4):

(1). Self-study phase: In the capstone preparation phase, students self-study the basic operation of BIM software, such as Magicad, Navisworks, GQI, and GBQ. This approach cultivates lifelong learners who can adapt to new technological advances in the rapidly changing industry.
(2). Application practice phase: According to the needs of the construction industry, students need to increase their awareness of digital technology and enhance their competitiveness. Therefore, learning templates and digital tasks are designed and integrated into engineering project teaching. This approach is helpful for students to understand the engineering project changes brought about by the technological change in the digital work scene.
(3). Evaluation feedback phase: Through the use of the 360-degree evaluation feedback method, the evaluation results are immediately fed back to the students and teachers. The students and industry experts assess the gap between the professional level of the students and the corresponding industry standards. Students can gain practical experience before graduation so that they can solve the problems and challenges they may face in the real work environment.

TABLE 3 Descriptive statistics and t test results for the comparison score

Type test	Individual independent test score	BIM capstone project implementation score
Mean	78.32	85.44
η^2	115.37	86.62
Sample	50	50
df	49	
$P(T \leq t)$	0.000321	
t	1.839	

Abbreviation: BIM, building information modeling.

4.2.1 | Team meeting

In addition to the instructors responding to student queries twice a week, team members organize discussions and facilitate learning on their own after encountering issues and problems during the capstone process. If the problem cannot be resolved afterthe meeting, the team leader records the problem and asks the instructor for help. The interdisciplinary collaboration elements of Industry 4.0 are embedded in the process of team learning, which is conducive to

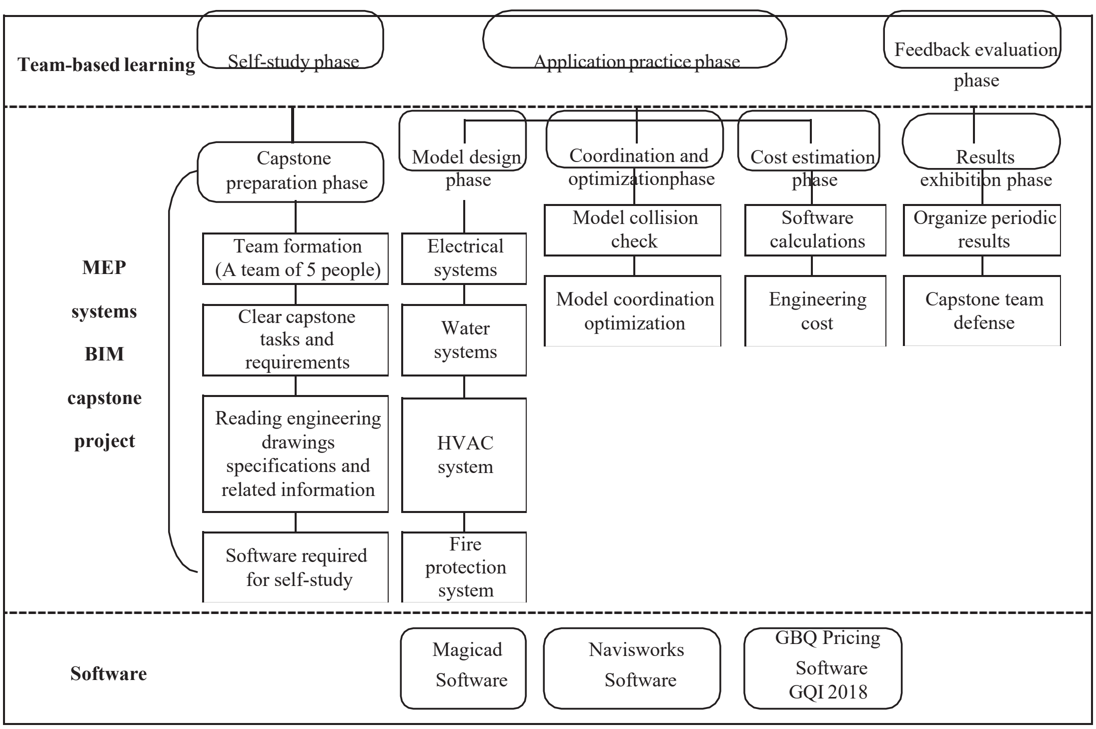
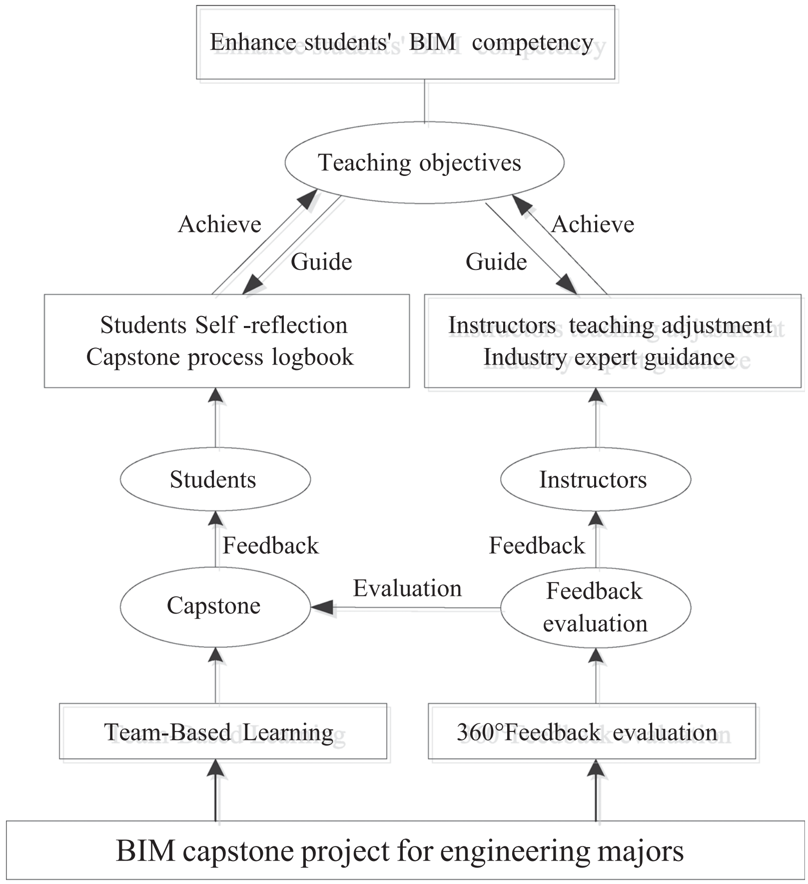


FIGURE 4 TBL facilitated BIM capstone. BIM, building information modeling; HVAC, heating, ventilation, and air conditioning; MEP, mechanical, electrical, and plumbing; TBL, team-based learning

FIGURE 5 Formative evaluation system diagram. BIM, building information modeling



strengthening students' cooperation ability and communication ability. Furthermore, the integration of Industry 4.0's multidisciplinary collaboration elements into the team learning process is conducive to strengthening students' collaboration and communication skills. The BIM capstone student samples are shown in Supporting Information Appendices A and B.

4.3 | 360-degree evaluation feedback of BIM capstone project

Formative evaluation is defined as the iterative process of establishing what, how much, and how well students are learning in relation to the learning outcomes to inform tailored formative feedback and support further learning. Such a pedagogical strategy can be more productive when the evaluation role is effectively shared among the instructor, peers, and the individual learner [52]. This evaluation score for a capstone project does not adopt a routine final evaluation but instead goes through a formative evaluation process. Capstone results evaluation criteria (see Supporting Information Appendix C) are sent to students during the capstone preparation phase. The purpose of this evaluation standard is to ensure that students understand the importance of the learning outcomes. After each phase is completed, the results of the phase are evaluated in accordance with the evaluation criteria, using the 360-degree evaluation feedback method. As a consequence of the collective meetings, students receive the evaluation results at the optimal time. Students reflect on the evaluation feedback themselves and record their reflections in the capstone process logbook. At the same time, the instructor is required to make teaching adjustments to help students correct any issues and mistakes to improve the students' professional skills during this phase. The evaluation system is shown in Figure 5.

The process of delivering 360-degree evaluation feedback is mainly divided into self-evaluation and the evaluation of others (i.e., peer evaluation). In this case, the assessors are students themselves and the student team captains, as well as instructors and industry experts. The evaluation process is divided into three main steps.

During the first step, at the end of each phase of the capstone project, each team is required to collate the results of that phase, and explain and display the results to other students and teachers. After the report is completed, the results of each stage of the evaluation are scored according to the result evaluation criteria (see Supporting Information Appendix C). The evaluator then completes the final result evaluation form (see Supporting Information Appendix D). The evaluation weightings include instructors (40%),

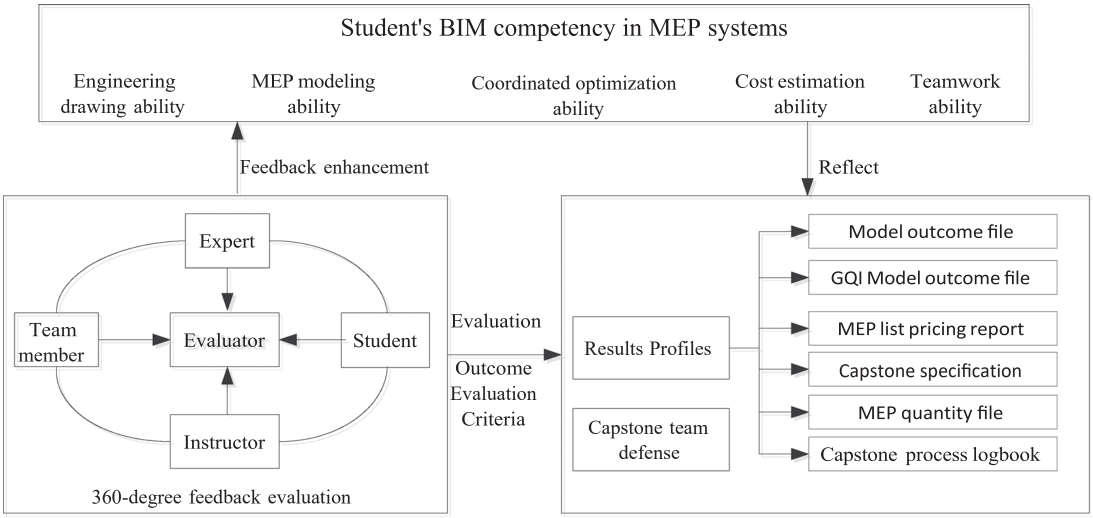


FIGURE 6 360-degree evaluation feedback frame diagram. BIM, building information modeling; MEP, mechanical, electrical, and plumbing

industry experts (30%), student team captains (20%), and student team members (10%). The 360-degree evaluation feedback framework is shown in Figure 6.

During the second step, the instructor and industry experts discuss the team's report and develop specific learning feedback for the student team. At the same time, the student team conducts internal discussions and undertakes overall and personal assessments of the team. After 10 min, the students summarize the self-assessment and team member assessments and report the results back to the instructors and industry experts. The instructors and industry experts also undertake an assessment and provide feedback to the students.

During the third step, students collate the feedback results and record them in the capstone process logbook. Content in the logbook can include learning experiences and areas for improvement.

To enhance the professional skills of students, the capstone project evaluation includes a number of different aspects in all phases of the BIM capstone, including evaluation, feedback, adjustment, and the overall assessment cycle. The multirole evaluation results in the 360-degree evaluation feedback help to understand the gap between students' current performance and learning outcomes, thereby helping to fill in knowledge gaps.

5 | DISCUSSION

5.1 | Teamwork ability

Team learning improves student participation, clarifies roles and tasks in the team, and can help in previewing exercises for future teamwork in post-BIM projects.TBL provides an interactive environment for students to understand the application of BIM technologyin engineering projects. Students' problem-based collaborative learning improves their participation and enthusiasm, thus endowing them with the ability of thinking and autonomous learning [53]. The team-related cooperation of team members is helpful to solve problems successfully and therefore enhances team cooperation and communication ability. Indeed, 70% of the interviewees mentioned that they are influenced by team members and stimulated by the gaps between the teams. Moreover, they adopt a positive learning attitude to improve their mastery of professionalknowledge, and improve teamwork efficiency and learning efficiency.

5.2 | Professional abilities

(1). Engineering drawing ability

Students use software to convert 2D drawings to 3D models. This is helpful to improve students' spatial imagination and master the reading of various standards and related documentation. It has improved students' ability to master and use the basic knowledge of drawing. Indeed, 75% ofthe interviewees mentioned that they could read the drawings of the MEP project, understand the relationship between the drawings, consult the atlas and specifications skillfully, and were able to establish the three-dimensional model in accordance with the requirements of the drawings.

(2). BIM modeling ability

When the BIM model is established, students are required to master common BIM software operation knowledge. Their independent ability of BIM modeling and scheme simulation is cultivated. In this regard, 80% of interviewees mentioned that they had mastered practical BIM technology and improved BIM modeling skills. According to the engineering requirements, the relevant drawing data of the model are exported.

(3). MEP coordination and optimization ability

The problem of collision detection among different disciplines of MEP systems is a key technical difficulty of BIM application. In fact, it is the process of simulating construction. The space problems hidden in the drawings can be easily exposed to solve the problems of mistakes and collisions, which can improve the design quality and reduce the designer's on-site service time. On this matter, students mastered the concept and application of different BIM software and Navisworks. The quality of communication between different majors was improved, and students' communication and coordination abilities were also cultivated.

(4). Cost estimation ability

Students use the BIM model to quickly obtain the engineering parameter information and master the interaction specification between BIM software. They also gained the ability to use BIM tools for quantity estimation and cost budgeting. The BIM construction model was used to estimate the area and material cost of the model in detail, and they made a general and detailed construction budget table to form the project cost plan.

5.3 | BIM competency

Across the 16 weeks capstone project and under the guidance of the teaching staff, the students completed the project according to the capstone assignment requirements. It was found that teamwork ability, professional ability, and professional ethics awareness of the students were all enhanced, and it is suggested that the students will eventually possess greater BIM competency and competitiveness in the job market. Indeed, 80% of the respondents talked about "obviously feeling that they can solve professional problems better than before," or "I have a clearer understanding of the BIM competency that MEP systems need to master," or "I am confident in my future job opportunities."

The interview data from tutors on the program provides different perspectives on the feedback of the students' BIM competency. For example, Tutor 2 described the employment situation of graduates as follows: "From the students' capstone outcomes, we can find that the students are very devoted, and everyone actively discusses and actively learns new knowledge in each meeting, According to the return visit from the graduate employers, the employers affirmed the students' ability." Industry Expert 1 said: "According to the capstone achievement grading standard, students are scored. Judging from the capstone achievements and outcomes, they have mastered the professional skills and meet the needs of employment positions."

The students described a series of views on the acquisition of professional ability and BIM competency. The BIM capstone project had a positive impact on the cultivation of their ability and the student interview data reinforced the skills that students acquired in the capstone. However, the interviewed students and instructors thought that there were still some problems in the BIM capstone project, and corresponding suggestions were provided, which will be further discussed in the next section.

5.4 | TBL

This paper describes the teaching process of how to design TBL, 360-degree evaluation feedback, and a BIM capstone project in a broad sense, as shown in Figure 4, and lists the software learning and implementation process. Through TBL, educators and students can prepare and carry out BIM capstone project in three stages. (a) In a BIM capstone project, students' autonomous learning, peer-directed learning, and teacher-assisted question answering are combined to improve students' participation and problem-solving ability. So as to reduce the number of instructors and effectively integrate educational resources [54]. (b) A BIM capstone project only specifies the achievement requirements and learning objectives and does not set specific questions and answers. It allows students to play freely, which helps to stimulate students' potential and innovative consciousness. To reduce the impact of the differences in the depth and breadth of the syllabus, problem design and teachers' experience on the heterogeneity of students' performance. (c) The use of multisource assessment in TBL can increase the sense of responsibility among team members [46]. In this study, a 360-degree feedback evaluation method is used to evaluate the whole process and the multiple levels in each stage, to provide immediate feedback for students and teachers, and to effectively monitor the implementation of TBL and students' learning effects. (d) In the future, we should combine the elements of CPBL, PBL, and TBL to provide teaching methods that conform to the current BIM teaching design principles, so as to combine the advantages of the three and improve the teaching impact.

5.5 | Implications for research

TBL and multisource feedback are highly effective and widely used methods in the field of education. However, both of these approaches are hitherto used in an ad hoc manner in the teaching process As such both TBL and multisource feedback have not been systematically combined into an integrated BIM educational program and there have been no in-depth case study investigations of such an approach [55]. With the goal of integrating TBL and the 360-degree evaluation feedback method into a teaching case study of the BIM capstone project, this study investigates the benefits of integrating the two methods. One of the most important insights of this study is to describe how the teaching method is based on the workflow of a real construction project along with providing a pedagogical design. The study also embeds visualization technology, BIM and computer-aided software application and evaluation, and clarifies the application principles, core guiding elements and comprehensive application teaching strategies of TBL and the 360-degree evaluation feedback method. The results of this study can also be used to develop a benchmark for integrating TBL and 360-degree evaluation feedback into teaching. A further contribution is to use the case study method to explain how to apply TBL and the 360-degree evaluation feedback method in the BIM capstone project. The reflective experience collected from the case application of this teaching mode provides a reference for future application and can be used to develop new teaching case studies. In addition, the study provides teachers with insights on how to improve engineering students' professional skills.

5.6 | New engineering capstone project: Challenges and benefits

In the interviews, three specific measures were proposed to solve or avoid problems associated with the BIM capstone project and also improve students' BIM competency. Additionally, suggestions were made to help students strengthen their professional abilities, improve the quality of engineering education, and meet the needs of the labor market. The three measures are as follows:

(1). Appropriate suggestions for the application of TBL in BIM-based education include the following: (a) The division of tasks and appointment of team captains require the guidance of instructors to strengthen team training and education; (b) The team should formulate task arrangements and project schedules to identify member responsibilities; and (c) The number of team group meetings should be increased to maintain the frequency and quality of communication within the team.

(2). There is a need to strengthen the cooperation between engineering schools at universities and industrial enterprises. This helps to increase the level of guidance provided by senior engineers from the industry, builds an educational base for professional talent training needs, provides BIM-related skills training for engineering majors, and improves the employability of students. Indeed, around 50% of interviewees believed that the theoretical knowledge of the engineering school at the university alone could not meet the needs of the industry since there was a lack of practical experience and students were not fully qualified for jobs. The guidance and best practices provided by industry engineers should be strengthened to ensure that students can effectively cross the university-industry divide. Industry engineers can also strengthen students' professional ethics awareness and education.

(3). It is proposed to establish an electronic file of student development records and a suggestion box for professional program enhancement, thereby promoting professional development. In this case, 50% of interviewees believed that the capstone process logbook recorded their own reflections and could act as a reminder to avoid repetition as well as record the learning experience of others. However, the paper logbook cannot be viewed until after program graduation so it is recommended to establish individual electronic development records that are easily accessible by students, parents, and engineering schools at universities. At the same time, it is also recommended that engineering schools listen to the suggestions of engineering construction programs, which should be formulated by students, professional instructors, and industry experts.

5.7 | Benefits to the COVID-19 public health crisis

The COVID-19 public health crisis has brought hitherto unknown crises and challenges to global education, and is accelerating global educational reforms to reduce the negative impact of the epidemic on the education system [56]. On this matter, the OECD (Organization for

Economic Co-operation and Development) Global Research Report highlights that the education system has recently undergone profound changes due to the current pandemic [57]:

- During COVID-19 school closures have resulted in the rapid adoption of remote online learning as a new teaching mode.
- The application of educational digital technology has been found to promote blended teaching as well as more collaborative teaching through emphasizing knowledge and resource sharing.
- Online and remote learning requires increased student engagement and there is also a need to ensure the integrity and sustainability of student evaluation.

In response to the COVID-19 pandemic, necessary measures must be taken to ensure that the BIM capstone project approach adapts to the post-COVID-19 teaching and learning environment. Such measures are as follows: (a) The real case selection of the BIM capstone subject should be related to the environment in which students are residing. For example, the teaching building case in this study could be replaced by the residential case, which is closer to the student's daily life; (b) The set of learning outcomes should be structured in an appropriate form for a team, and learning should be promoted through team partners to enhance students' participation. In addition, the team captain can regularly change other members of the same team to enhance students' ability of long-distance communication and collaborative learning; (c) The evaluation subjects can where appropriate increase the number of students' family members, which is closer to the actual situation of students studying at home during the epidemic period so as to ensure the authenticity and diversity of the evaluation; (d) Focus on cultivating students' information literacy and computer ability. For example, in addition to the BIM software operation ability required in this study, students' online resource acquisition ability and online learning skills can also be increased; (e) Expand collaboration among stakeholders through digital technology in education, such as through multidisciplinary collaboration between professions, school and community collaboration, and collaboration between teachers and parents of students.

5.7.1 | Benefits for students

In the process of evaluating others, students are able to cultivate their ability to critically examine a situation as well as exercising decision-making skills. Furthermore, self-evaluation helps students to reflect and guide their own development. The timely feedback of the evaluation results helps students ascertain the differences in the evaluation results and also helps students to analyze the reasons behind issues encountered and mistakes tobe addressed. Furthermore, students are able to accumu-late experience from the mistakes of their peers and gain greater benefits from this peer-to-peer interaction. In addition, through the "microinsertion" method [58], the "small units of ethics" of a week will be integrated into the BIM capstone design project, so as to enhance the moral reasoning of students and educate them to become engineers responsible for society and the environment.

5.7.2 | Benefits for teachers

Adoption of the 360-degree evaluation feedback (i.e., two-way feedback) provides more information to support the instructor's teaching activities and helps to appreciate the learning dynamics of the students on the capstone project [59]. This also helps to inform any adjustments required to the syllabus and program content, thereby ensuring that the knowledge gap of the students is adequately addressed. As identified by industry experts, a large number of modules are often lost when students import GQI software from Navisworks software and in many cases they do not know how to solve such problems. This highlights that the current teaching of professional software for students is lacking in the interoperability teaching between BIM software. In the future, multidisciplinary teaching content and interoperability content between professional software need to be included in the overall provision of professional software teaching.

5.7.3 | Benefits for industrial companies

The BIM capstone project has been developed and implemented by the university and in conjunction with industry companies. Two main sources of graduates have knowledge of BIM in the built environment application. The first is the professional training of existing employees within the industrial company, and the second is via the education provided by engineering and architectural colleges and universities. Moreover, engineering education strengthens the connection with employment, and provides industrial companies with the environment and opportunity to train new employees or test new workflow. Industrial companies can save the cost of post employment training for graduates [11,60]. The technological revolution of Industry 4.0 can be harnessed to help improve the connection between engineering education and industry demand, where the BIM capstone project supports the sustainable development and growth of the bilateral interests of higher education institutions and enterprises.

5.7.4 | Benefits to professional development

Universities have a clear and specific objective on the provision of professional development and training through the instructors' analysis of students' capstone outcomes and the problems addressed in the capstone process. This will help with updating professional development programs. For example, educators participating in this study found that students have not yet reached a balance between teaching theory and software tools. In the future, the school will need to increase the proportion of professional technology courses in the curriculum system to support the teaching and learning of professional software.

6 | CONCLUSIONS, LIMITATIONS, AND FUTURE WORK

Enhanced BIM competencies for the AECO sector are urgently needed if Industry 4.0 is to be effectively adopted across the construction industry; engineering educational programs have a key in realizing this important objective. This empirical research study has identified that the unique combination of TBL and 360-degree evaluation feedback as part of the engineering capstone project plays an important role in cultivating, evaluating, and acquiring educational capacity as part of undergraduate engineering majors. This is the first study to focus on the relationship between 360-degree evaluation feedback and TBL integration to enable BIM competencies in MEP systems for engineering students. The results of the case study investigation highlight that all-round evaluation feedback and practice cultivate BIM competencies. The results also indicate that teamwork ability has an important impact, especially in the cycle of evaluation, feedback and improvement via reflection, which plays a key role in the development of students' BIM competencies.

This study has proposed an innovative BIM capstone project where students are guided to complete the modeling, optimization, and cost estimation of mechanical and electrical installation engineering through BIM-enabled collaboration. The study involved the 360-degree evaluation feedback method to formally evaluate the capstone results, and this was facilitated through assessment according to the program learning outcomes and use of the results evaluation standards set by the Washington Accord's graduate attributes in the IEA. This approach further strengthens the students' BIM competencies and graduate attributes. The results have highlighted the effectiveness of the BIM capstone project and provided pedagogical insights and best practice for engineering education involving BIM technology implementation. This BIM capstone project can be widely used in the field of engineering education, and its teaching content can be adapted according to the needs of the specific engineering discipline, which includes an extension to the (AECO) Industry 4.0 technological paradigm.

The limitation of this study is that the capstone project is only related to MEP modeling, model coordination optimization, and cost estimation and does not involve interdisciplinary joint design work. Also, the data in this study are not intertemporal data. Therefore, future research work should be oriented toward interdisciplinary BIM learning to increase the practicality of TBL and 360-degree evaluation feedback and further expand the teaching content.

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CONFLICT OF INTERESTS

The authors declare that there are no conflict of interests.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request

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