Exploring Industry Solutions and Evaluating Teaching Methods for Delivering BIM in Senior Design Class

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Abstract

Building Information Modeling (BIM) has been adopted by the Architecture, Engineering, and Construction (AEC) industry to simulate the construction environment before it is constructed in the real world. However, the adoption of this technology has been challenging for both the AEC industry and engineering education at the undergraduate level. Some challenges faced by the AEC industry include a lack of BIM professionals, and a lack of guidelines for BIM implementation, so there is a need to emphasize the importance of finding solutions to those challenges, which is critical for successful BIM implementation. The growing demand for BIM professionals is leading universities to adapt their curricula and provide adequate BIM training for the next-generation professionals. The senior design class is a core course for last-year students in many Architecture, Civil, and Construction engineering programs. Students are given opportunities to work on a real building project through multiple class activities, BIM software, and lectures by practitioners. The goal of this research was divided into two parts: 1) Evaluate the teaching methods for delivering BIM topics in a senior design class. A questionnaire survey was distributed to students; 2) Fill the gap about the need for more research to be conducted on the solutions for implementing BIM in the AEC industry. The existing research may have identified the problems, but the solutions are not as thoroughly studied or documented. So, an interview and a panel discussion with AEC industry practitioners were conducted. All invited companies are successful in BIM implementation in the industry, so the solutions that were implemented to overcome the identified challenges were discussed. Also, the practitioners transmitted their opinion on the current Senior Design class curriculum. The findings of this study are expected to (1) learn solutions to challenges encountered by companies in implementing BIM (2) improve the teaching methods for delivering BIM to better equip students with industry-needed skills and knowledge.

Introduction

The construction industry is one of the largest industries in any economy. However, this industry faces a significant challenge due to the high cost of building, workers' low productivity, and lack of innovations [1]. One of the main strategies to enhance the performance of the construction is the use of digital technologies, such as Building Information Modeling. This technology enables simultaneous site planning and building element production, which can reduce project delivery time by 30% to 50% [2]. Nonetheless, many AEC firms have found it difficult to use this tool due to cultural resistance and implementation costs [3]. Therefore, given the advantages of digitalization, there is a need to uncover solutions to break the boundaries of employing BIM in building design projects and construction sites.

For educators, teaching the content of respective academic disciplines is straightforward, but effectively communicating the subject matter to learners can pose a great challenge. The students' success and motivation depend on the teacher's ability to engage students' interest, by using effective teaching methods [4]. One of the methods emphasized by Morley [5] is the need for university students to cultivate "listening" skills. The other method is "hands-on learning", to engage students through instructional practices [6]. As technology continues to advance, a new

way of teaching is also arising, “visualization” or visual learning became essential in today’s education [7]. Another teaching method is the use of “writing and reading” as alternative techniques to improve students’ performance in class [8].

This study aims to gather information from AEC industry practitioners through interviews and a panel discussion to learn about solutions to the challenges faced in the application of BIM in building projects. Additionally, this research used a questionnaire to analyze the effectiveness of teaching BIM in the Senior Design class and the civil, construction, and architectural engineering courses.

Literature review

BIM applications

Building Information Modeling (BIM) is a digital tool that promotes a continual and effective way of updating and sharing project information. One of the key features of this technology is the ability to design models in real-time considering cost, schedule, and safety, which enhances productivity and the quality of the product [9]. BIM has proven to be an invaluable process for the modern AEC industry [10]. The importance of this tool to construction management highlights the technological renaissance period that the construction industry is leaving nowadays, including innovations in all phases of an AEC project [11]. BIM provides information that extends beyond the shape and size of a project because it is composed of eight different dimensions making objects integrate and extending the horizons for more realistic simulations and analysis. The dimensions are composed of 3D graphic representation, 4D scheduling, 5D cost estimating, 6D sustainability, 7D facility maintenance, and 8D safety management. [12]

Challenges on implementing BIM in AEC industry

Researchers in the past decade have shed the light on researching the potential application and advantages of using BIM in industry. On the other side, some case studies have emerged about the barriers and awareness of construction practitioners on adopting BIM in the life cycle of a construction project. The existing research is significant in finding ways to address the challenges faced by the industry. The challenges of applying BIM in the AEC industry can be categorized into four groups: technology, people, process, and Governmental issues [13].

Some of the issues with applying BIM in the “technology” category include the expensive initial cost of installing the technology and the complexity of BIM tools [13]. Also, the low and insufficient interoperability, weak collaboration among different disciplines, and interoperability problems amongst various BIM software [14]. Other concerns such as the requirement of a reliable Wi-Fi connection on the job site and the complexity of dealing with various user interfaces [15]. The challenges of applying BIM related to the “people” category introduce the lack of BIM knowledge and awareness of its benefits [13]. Also, cultural resistance, for instance, is the challenge in persuading the stakeholders to use the technology effectively, as they have a lack of comprehension about why this change is needed [16]. Another important category to

mention is the barriers related to the “process” of using BIM. The lack of expertise and the financial restrictions are the relevant reasons to exist this challenge [13]. Also, the lack of BIM training to increase workers’ knowledge and a lack of effective strategy and clear guidance on introducing BIM in the AEC process [15]. The last category is related to BIM application challenges associated with "governmental and legal issues". Contractual liability and obligation make entities reluctant on implementing BIM [16]. Additionally, the lack of a mature BIM contract and intellectual property rights is a concern [14]. Finally, the lack of government legislation, reducing the company’s motivation on using this technology is a considerable issue [13]. Based on these identified challenges, it is evidenced that despite numerous studies identifying the challenges of implementing BIM. Despite previous studies, solutions still require further research. While it is crucial to understand the challenges, it is equally important to identify potential solutions that can help overcome these challenges [17].

Challenges on implementing BIM education

The adoption of BIM has been struggling for practitioners to keep up with the development of skills to be competent users of BIM. Nevertheless, proficiency in BIM has become a need for all workers in construction. Higher education institutions have investigated ways to infuse these skills into their curriculum [18]. The significance of BIM education in AEC programs is examined and the necessity of BIM integration into the curricula is emphasized [19]. It highlights the significance of BIM training for the phases of design, construction, and facilities management, and the need for BIM education in the design process, construction, and facilities management stages. The significance of industry collaboration in BIM education is covered in [20], which presents the necessity of collaboration between academic institutions and business partners to create a BIM curriculum that satisfies market demands. The effectiveness of higher education's BIM curriculum is determined through an evaluation of students' BIM competencies [21]. It implies that BIM instruction can enhance students' technical proficiency, capacity for teamwork, and communication skills. Improving BIM classes is crucial, it ensures that students receive up-to-date and relevant information on the latest industry standards and technological advancements. Finally, improving BIM classes can enhance students' employability by providing them with the knowledge and skills that employers are increasingly seeking.

Methods of teaching in the education field

Numerous studies have been conducted on the need to increase AEC students’ knowledge by using some tools and teaching methods in the classroom. Some of the important teaching methods using nowadays are visualizing, listening, writing/reading, and physical/hands-on. Since the start of humanity, visualization has been a successful means of communicating in both abstract and concrete ways of ideas, also, understanding a problem in terms of a visual (mental) image is known as “visualizing” the problem [22]. The current generation of students is more visually oriented, so academia needs to find a better way to impart knowledge through a visual approach [23]. Shatri and Buza [24] used visualization as a teaching and learning form to increase the critical thinking of students, the results were a positive influence by increasing this

skill. Furthermore, Nurbekova et. al. [25] conducted a survey and presented a teaching method using visualization for STEM students, stating that this interactive way of learning improved students' motivation and consolidated students' knowledge compared to traditional teaching methods.

Listening, as an example of passive learning is one of the most prevalent teaching methods [26] [27]. Up to 90% of the knowledge students gain comes from listening to teachers and other students [28]. However, some students are often unable to quickly process information while listening due to various problems like difficulties in interpretation and lack of concentration. [29] For them, listening as a way of teaching can be a stressful activity [30]. Porozovs, Liepniece, & Voita [31] also state that students prefer hands-on learning to listen to a lecture. Another method of teaching is using writing and reading. Reading and writing are considered parallel functions, and they complement each other as reading has generally been thought to develop before writing [32]. It has been revealed that active learning could effectively enhance students' performance. [26] Any activity beyond just listening to the lecture is considered active learning [26] [27]. The teaching method of using Physical and hands-on learning has been widely used. These methods consist of providing experiential learning opportunities. Furthermore, hands-on and physical has a very high relevance for teaching and learning when it is used as an educational tool [33].

Methodology

This experimental study aimed to tackle the potential difficulties of implementing BIM in the AEC industry and evaluate the efficiency of teaching BIM in engineering and construction undergraduate courses. The research gathered qualitative data through a 1-hour panel discussion with industry experts and a 10-minute questionnaire among senior design students.

Senior Design Class

The Senior Design Class in the department of civil, construction, and environmental engineering at the University of Alabama (UA) is a 4-credit hour course normally taken during the last term on campus. The students work on a real construction project in groups of four. Each student will receive a team role: Team Lead, Architectural Lead, Structural Lead, or Construction Lead. This course combines lecture and laboratory activities. The lecture is delivered by construction practitioners. They share solutions that their company uses to apply Building Information Modeling (BIM) in their engineering projects. Also, during the semester, there are three presentations and a pin-up meeting where students show their project progress to practitioners and receive feedback from them. The lecture's subject includes four main topics, such as Architecture Analysis, Sustainability Analysis, Structural Analysis, and Construction Analysis. Each topic has subtopics, as shown below:

- Architecture Analysis
    - Using Revit for architecture layout
    - Code Analysis
    - 3D Site Plan/Building view
- Sustainability Analysis

    - LEED
- Structural Analysis
    - Using RISA
    - Using REVIT for structural analysis
    - Load calculations
    - Structural Design
    - Structural Detailing
- Construction Analysis
    - Construction Site Plan
    - Project Execution Plan
    - Cost Estimating
    - Scheduling
    - Safety

The laboratory activities involve the use of design software such as Revit, Lumion, and MS Project, those programs are BIM software that can support design, parametric modeling, data coordination, quantity take-off, rendering, etc. Also, Lumion is used to create the video and the 360 panoramas for the final project, and MS Project is used to create schedules, distribute resources, and manage budgets. To assure the quality of engineering education in this class, this course follows the Accreditation Board for Engineering and Technology, Inc. (ABET) to demonstrate that the program meets quality standards and criteria. One of the criteria is to define the Student Outcomes. This outcome describes what students are expected to learn by the time of graduation, and it prepares graduates to enter the professional practice of engineering. From the seven Student Outcomes that existed on ABET, the Senior Design Class follows the Learning Outcomes numbers 2, 3, 4, 5, and 7. [34]

Industry Interview and Panel Discussion

For the first section of this study, an interview and a panel discussion with five construction practitioners was conducted. Those professionals are engineers and attended the Senior Design Class as lecture. Also, they all work in Architectural, Engineering, and Construction (AEC) companies that have a history of using BIM in their engineering projects. In accordance with regulation, an Institutional Review Board (IRB) Process was submitted under Protocol ID 22-05-5618. This process was executed to ensure safe and ethical treatment for the respondents, as they are treated as a subject. To follow IRB ethics, the interview and the discussion were confidential and completely voluntary. The interview started by distributing a sheet asking their job title and four questions about their company: What is the number of employees in your company? What is your company type? Which sector does your company work in? For how long has your company been using BIM? Following that, a 1-hour panel discussion started, and the interviewer asked questions about the implementation of BIM in their company. Some of the questions included the following (Table 1).

Table 1: Interview and discussion questions

Question Number	Question
Q.1	Which solutions does your company use to break the barriers to applying BIM?

Q.2	Which dimensions of BIM does your company use?
Q.3	Which BIM software and platforms does your company use?
Q.4	Which methods are you using to make your employees understand BIM and its benefits?
Q.5	Does your company provide any BIM training?
Q.6	Which suggestions do you have to improve our current syllabus on Senior Design Class?

Questionnaire for the Senior Design Class

The second section of this study was a 10-minute questionnaire survey that was provided to students by the end of the semester, using an online survey software called Qualtrics. The goal of this questionnaire was to assess students' feedback about the Senior Design Class and their opinion about how efficiently BIM was delivered during their undergraduate courses. Also, some personal questions about their background were asked. The survey was sent to 12 participants that attended the Senior Design Class, and all of them answered the questions. To ensure students' privacy and allow the distribution of this survey, an IRB Process was also submitted under Protocol ID 22-10-5996. This questionnaire was divided into three parts. Part 1 inquiries into students' backgrounds to understand their prior experiences, by asking about their minor, major, and internship experience. Part 2 consisted of questions related to their opinion about the Senior Design class (Table 2). Part 3 is composed of students' opinions about the teaching methods of delivering BIM topics during their bachelor's (Table 3).

Table 2: Part 2 from Senior Design Class questionnaire

Question Number	Question
Q.1	At the beginning of the semester, how well do you understand what is expected of you in preparing for the final design project?
Q.2	How would you rate the level of difficulty in learning each topic below in a 5-point Likert scale (Very easy, easy, neutral, difficult, very difficult): Using Revit for Architecture Code Analysis 3D Site Plan/Building view LEED (Sustainability) Using RISA Using Revit for structural analysis Load Calculations Structural Design Structural Detailing Construction Site Plan Project execution Plan Cost Estimating Scheduling Safety

Q.3	Open-ended question: What additional comments, insights, or questions/ concerns do you have about this class?

Table 3: Part 3 from Senior Design Class questionnaire

Question Number	Question
Q.1	How often is each teaching method used in your courses in a 5-point Likert scale (Never, Sometimes, Often, Usually, Always): Visualizing Immersive Learning Listening Writing and Reading Physical/Hands-on
Q.2	In your opinion, how effectively could each teaching method help with learning BIM in a 5-point Likert scale (Never, Sometimes, Often, Usually, Always): Visualizing Immersive Learning Listening Writing and Reading Physical/Hands-on
Q.3	Open-ended question: What do you think about the integration of BIM in our undergraduate curriculum?

Results and Discussions

Industry Interview and Panel Discussion

The interview with industry professionals was conducted to understand the strategies and solutions that have been successful in overcoming challenges in applying BIM and to identify best practices for BIM implementation in the industry and academia. The outcomes obtained from interviewing professionals following the questions presented in Table 1 are as follows: At the beginning, the practitioners discussed how they solve the challenges of implementing BIM in their companies. They shared that the architectural clients were urging them to use BIM, as the architects were the earlier adopter of this technology. Also, after taking extended courses related to BIM, the engineering team realized that they could significantly improve their projects by making them better, faster, and more cost-effective through the use of BIM. Furthermore, the

limitation of 2D modeling, such as inaccuracies in drawings and communication gaps, led practitioners to start 3D modeling. Moreover, as the construction site workers were requesting more levels of detailing, the project team had to improve their work, and using BIM was the best solution. Finally, practitioners highlighted the use of BIM 360, as the live model can help a lot with sharing information. Following the interview, the practitioners were asked about the BIM dimensions they used in their engineering projects. The dimensions most used by all companies interviewed are 3D (architectural, structural, MEP), 4D (Time-based simulation, scheduling, and clash detection), and 5D (quantity surveying and budgeting). They also pointed out that using these modeling tools, helped a lot to communicate with fabricators, as the company was able to send projects with a high level of detail, which reduced the number of errors from the fabrication side. Regarding the question about providing BIM training, practitioners pointed out that the company invests in basic BIM training. However, they shared a preference for hiring students with a high level of BIM competence, so they are constantly looking for newly graduated students with proficiency in BIM. At the end of the interview, the practitioners gave their opinion about the senior design class. They claimed that they believe students sometimes struggle to understand the project scope, so they suggested developing a set of drawings about how the project is supposed to look when finished. Additionally, they discussed the need of providing students with more information on structural detailing and drawings, because some structural designing information was missing.

Questionnaire for the Senior Design Class

The questionnaire conducted in this study aimed to assess the effectiveness of the current teaching methods for delivering BIM topics in the senior design class. By gathering feedback from students. The outcomes obtained from the students' questionnaire based on the questions presented in Table 2 and Table 3 are as follows. Based on the results gathered from a total of 12 completed surveys, the results from Part 1 of the questionnaire revealed that 8 students do not have a minor, 9 students have a Civil Engineering major and 10 students had internship experience.

Part 2 of the questionnaire which was related to students' opinions on the Senior Design Class reveals that students have a neutral understanding of how the project will look by the end of the semester (Figure 1). However, it is important to highlight that 3 students choose that they understand very poorly, against only 1 student who understood very well. It means that at the beginning of the semester, more information and a detailed explanation of the project scope are needed. For future research, an alternative to facilitate the understanding is by showing some animations from the final project, thereby, students will better visualize what is expected from them.

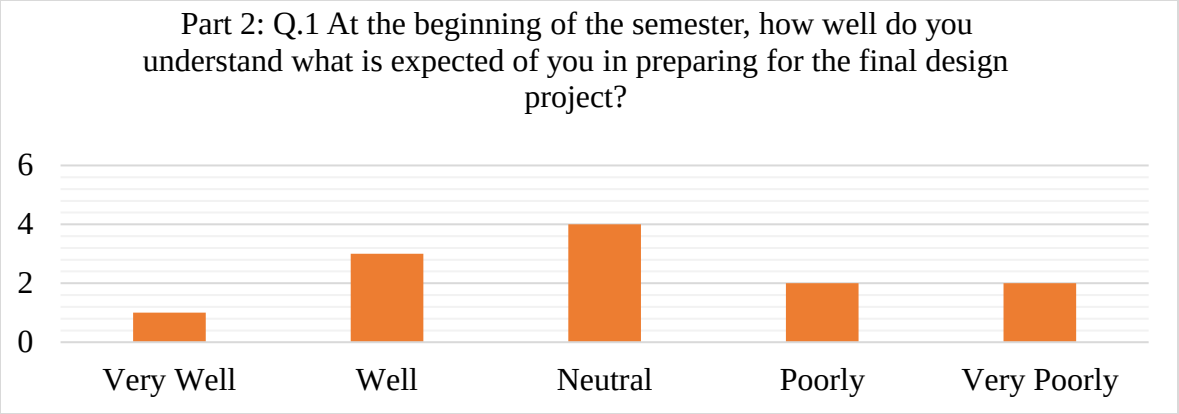

Figure 1: Students' perception of understanding project expectations at the beginning of the semester

Figure 2 presents an average result that the students have a neutral understanding of the topics taught. An important analysis that needs to be highlighted is the percentage of students that chose the “difficult” and “very difficult” scales. As shown in Figure 2, more than 25% of students chose both scales for the following topics: Using RISA, Using REVIT for Structural Analysis, Load Calculation, Structural Design, Structural Detailing, and Cost Estimating. It means that for those topics, there is a need to find a better teaching method to facilitate the understanding of the topics.

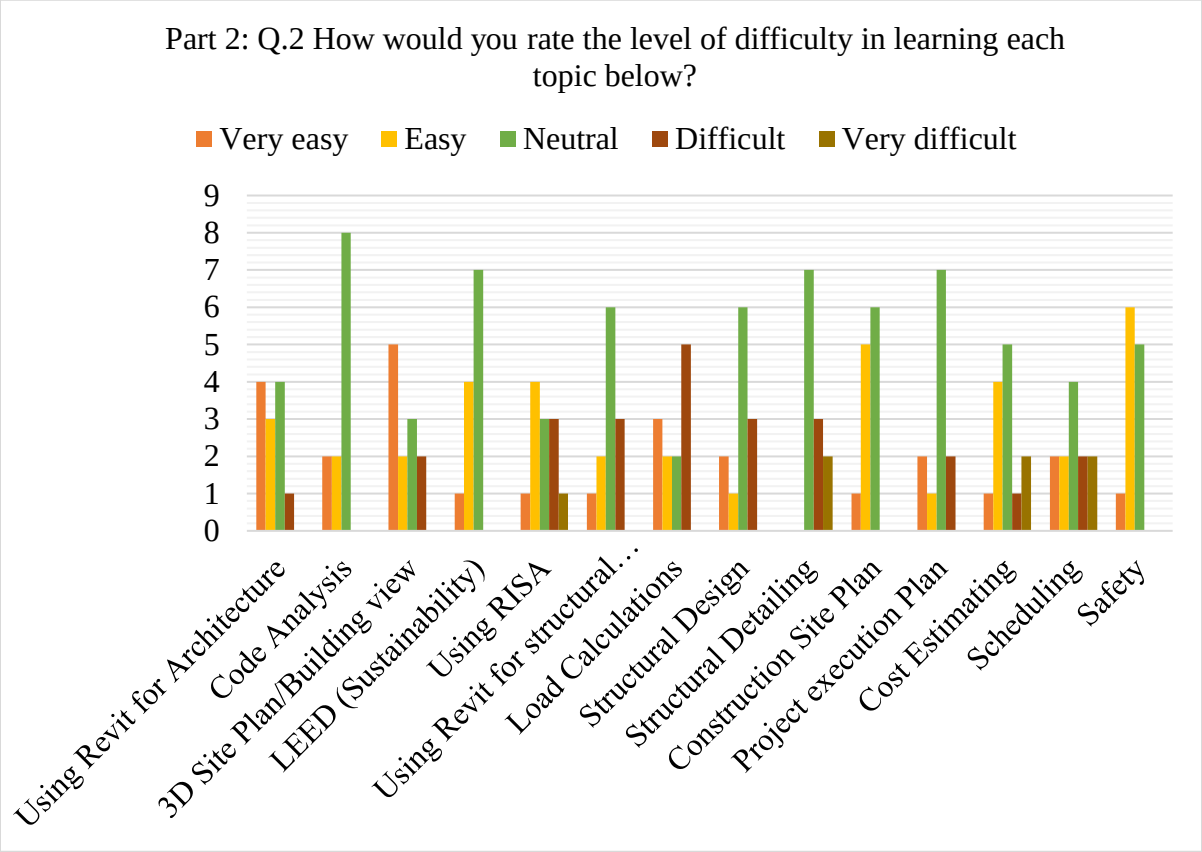

Figure 2: Level of difficulty for each topic

The open-ended question demonstrates students' general comments about the course. Some suggestions were received such as covering the Mechanical, Electrical, and Plumbing (MEP) in a future class. In addition, the need for more clarification on the topics mentioned in Figure 1 was also emphasized by the student's responses.

Part 3 of this questionnaire sought students' opinions on the effectiveness of BIM teaching methods in their undergraduate courses. Analyzing Figures 3 and 4, it is verified that the method of "Visualizing" was sometimes used during their undergraduate courses; however, students feel it would have a high level of efficiency if it was more included in their bachelor's. The method of "Immersive Learning" was sometimes used, and students believe that using this method would have average effectiveness if included in their undergraduate classes. The method of "Listening" was always used in classes, however, students assume that it has an average effectiveness. The method of "writing and reading" was often used and students believe that this method also has an average effectiveness for their learning. The method of "Physical/hands-on" was only sometimes used, however, students agree that it has high effectiveness by using it in undergraduate courses.

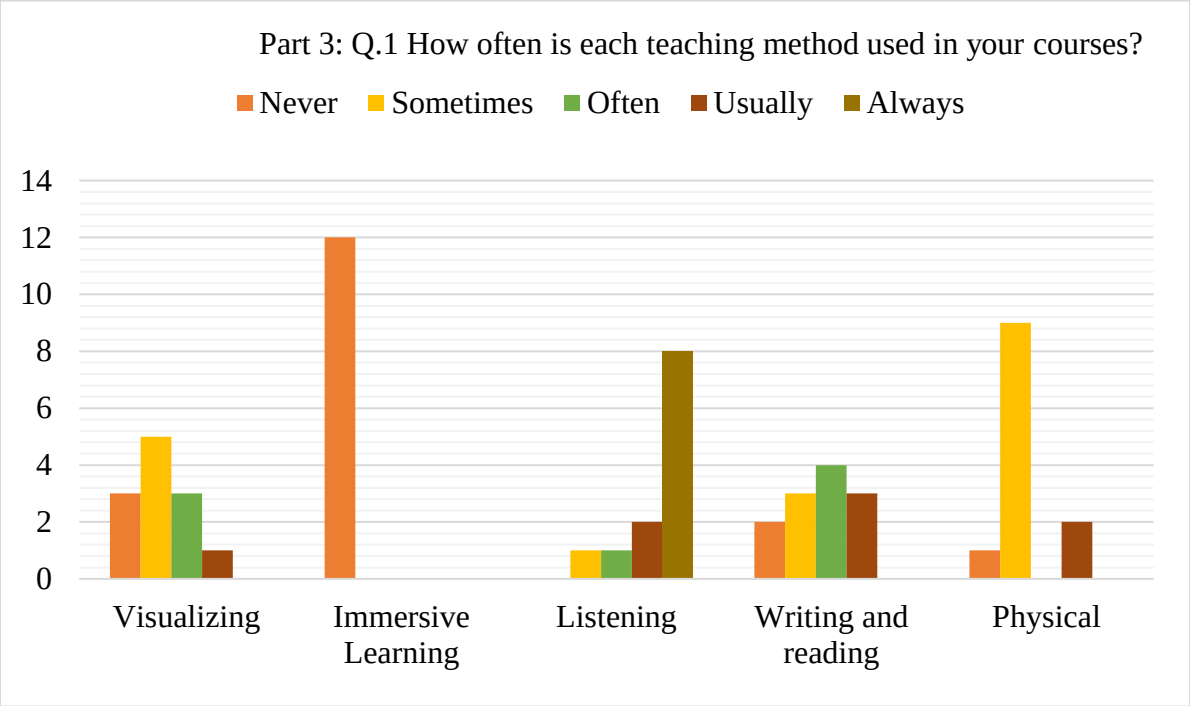

Figure 3: Teaching methods used in BIM courses

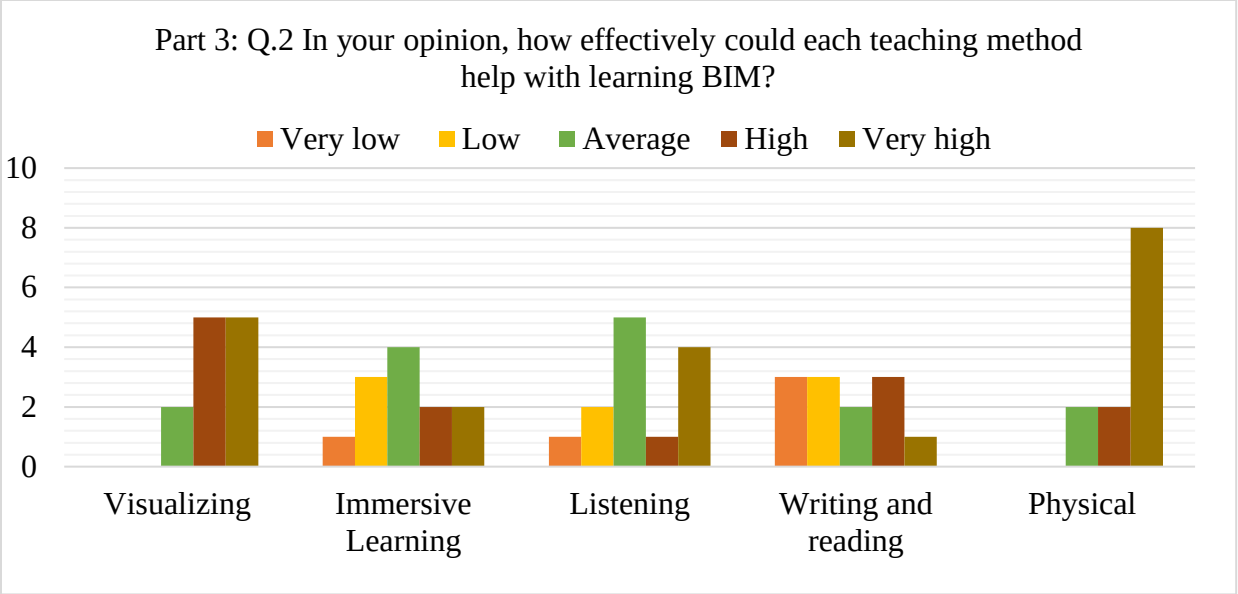

Figure 4: Students' perception of the effectiveness of various teaching methods

The open-ended question in this section of the questionnaire revealed some suggestions from students about implementing BIM in the Civil, Construction, and Architectural Engineering classes. They said that BIM should be integrated into more classes, finding opportunities to take theories being taught in classes and applying them through a BIM assignment such as homework or projects. Also, they stated that BIM should be taught earlier in their bachelor's, as the earlier it can be implemented, the better students can be prepared for their careers. Finally, students emphasized the importance of gaining more proficiency in BIM software during their undergraduate education.

Conclusion

This study thoroughly identified solutions that the AEC industries have developed for incorporating BIM in their engineering projects. Also, the study considered the perspective of senior students regarding how BIM was delivered during a Senior Design Class and throughout their undergraduate education at UA. It is also concluded that the AEC industry is utilizing this technology because it was proved that BIM is a solution to transform the traditional practice of executing projects into a better-revolutionized process. Practitioners also said that the quality of teaching BIM in undergraduate studies is crucial to the success of students, as the industry is always looking for newly graduated students that already have BIM competencies at a considerable level.

It is relevant to note that based on the practitioners' interview and student's questionnaire, it was observed that they felt the same issue in the Senior Design Class, related to the student's difficulty in comprehending the final project scope. Also, both students and practitioners recognize the challenges of understanding the content related to structural engineering projects. This analysis demonstrates the value of using specific teaching techniques to help students to have a better understanding of the project requirement and class expectations. Based on the findings and discussions, the researchers also concluded that the teaching methods of

“visualization”, “immersive learning”, and “physical/hands-on” should be further integrated into classrooms. The study also suggested undergraduate programs should offer more BIM-integrated classes during undergraduate education as the industry affirms the importance of students having some knowledge of using BIM. Moreover, more BIM software must be included, and more content needs to be covered, including MEP.

The present study has some limitations that should be acknowledged, the sample size was relatively small, and the study was conducted in one university in the US, which may limit the generalizability of the results. The results may not be applied to other regions, and the small sample size may not accurately represent the experiences and perspectives of individuals in a larger population. For future research, a large sample size should be used. Furthermore, other educational tools and teaching methods such as animations, artificial intelligence, and videos contents could be integrated to improve BIM curricula in future studies.

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