Ruiz, D.M., Sánchez, O., Gómez-Cabrera, A, & Alvarado, Y.A. (2024). BIM-based capstone project of an ABET-accredited civil engineering program. In *Proceedings of the IX Ibero-American Congress of Construction Management and Technology* (IX ELAGEC2024). Herrera, RF, Salazar, LA, (Editors)

BIM-BASED CAPSTONE PROJECT OF AN ABET-ACCREDITED CIVIL ENGINEERING PROGRAM

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ABSTRACT

Integrating Building Information Modeling (BIM) in construction education can potentially improve students' skills in engineering and related programs. ABET (Accreditation Board for Engineering and Technology) accreditation ensures that engineering programs meet appropriate quality standards, preparing students for professional contexts. This paper explores how implementing BIM in an ABET-accredited civil engineering program can benefit students' educational experience during the development of their Capstone Project, potentially leading to a substantial improvement in their competencies. Analysing the capstone project that incorporates various disciplines such as structural engineering, sanitary engineering, construction planning, and geotechnical engineering, it is evident how BIM facilitates the connection between these disciplines and enhances the understanding of the impact of students' decisions on the project. Significant advantages of incorporating BIM in project development include improved interdisciplinary collaboration, enhanced estimating accuracy, streamlined clash detection, and optimised schedules and budgets. These findings reveal that integrating BIM in capstone projects can provide more comprehensive and practical training in line with the demands of the professional sector.

KEYWORDS

BIM; ABET; civil engineering; capstone project; engineering education.

INTRODUCTION

Adopting Building Information Modeling (BIM) methodology in civil engineering education programs is a significant innovation in training future construction professionals. This methodology allows students to interact with construction projects in virtual environments (Wong et al., 2020). They can analyse various scenarios and configurations without committing financial resources (Lu et al., 2016). Creating a detailed digital replica facilitates understanding of the interaction between different construction project components. This allows students to reflect on construction processes and the interrelationship between project elements, influencing the design process. Additionally, BIM allows students to explore various design and construction alternatives with moderate effort, encouraging reflection on the impact of decisions on critical aspects of the project, such as functionality, sustainability and the required budget (Lee et al., 2019). The collaborative possibilities in BIM environments also prepare future professionals to adapt to collaborative workflows essential for developing construction projects that involve a wide diversity of professionals, all interacting for the project's success.

In engineering education, several accreditation systems/frameworks serve as benchmarks for quality and consistency, ensuring that programs meet rigorous standards to produce competent professionals. These systems include ABET, CDIO, and Eur-Ace, each with its own unique focus and criteria (Winkens et al., 2023). CDIO (Conceive, Design, Implement, Operate) is an innovative educational framework that emphasizes hands-on, project-based learning to produce engineers who are technically proficient and capable of leading engineering projects. This approach is particularly conducive to innovation and creativity in engineering education. On the other hand, Eur-Ace (European Accreditation of Engineering Programs) is a Europe-wide accreditation system that ensures that engineering programs meet high quality standards. Eur-Ace is recognized throughout Europe and sets rigorous standards for engineering education, emphasizing a broad-based curriculum that combines a strong theoretical foundation with practical skills to ensure that graduates are well prepared for the engineering profession. The Eur-Ace accreditation process is outcome-based, focusing on problem-solving skills, design and project management skills, and a strong ethical understanding of their professional responsibilities. In addition, the ABET (Accreditation Board for Engineering and Technology) system outlines the educational objectives of an undergraduate engineering programme (Iqbal Khan et al., 2016). These objectives prepare graduates to enter the professional practice of engineering and are summarised in seven items: (1) ability to identify, formulate, and solve complex engineering problems; (2) ability to apply engineering design to produce solutions that meet specific needs; (3) ability to communicate effectively with diverse audiences; (4) ability to recognise ethical and professional responsibilities in engineering situations and to make informed judgments; (5) ability to work effectively in a team whose members contribute jointly; (6) ability to develop and conduct appropriate experiments, analyse and interpret data; and (7) ability to acquire and apply new knowledge as needed (Koehn, 2004; Gallego et al., 2023).

Despite the excellent of CDIO and Eur-Ace, ABET accreditation was chosen for the Civil Engineering program at Pontificia Universidad Javeriana because of its long-standing reputation and global recognition. ABET is widely regarded as the gold standard in engineering education accreditation. It is recognized not only in the United States, but also internationally, with a strong presence in Latin America. ABET's focus on outcomes-based education aligns with producing graduates who are well prepared to enter the global workforce. ABET's rigorous criteria ensure that the curriculum is continually updated to reflect the latest advances in engineering and technology, with emphasis on continuous improvement and in lifelong learning. This is especially important in a rapidly evolving field like civil engineering, where new challenges and technologies emerge on a regular basis.

The undergraduate program in Civil Engineering at Pontificia Universidad Javeriana is accredited by ABET, but its curriculum is also based on CDIO. In this way, it was possible to combine both accreditation and the CDIO framework. In fact, the simultaneous consideration of ABET and CDIO helps to improve the quality of undergraduate engineering programs. As noted by Forcael (2021), a relationship between the competencies that today's engineers must have according to the student outcomes established by ABET meet the requirements of the CDIO curriculum. In this context, one of the most important aspects of CDIO used in the curriculum of the ABET Civil undergraduate program was project-based learning. Project-based learning has been a crucial tool to achieve these objectives, leading to the development of capstone projects that have demonstrated extensive benefits in the learning process (Meah et al., 2020). In this context, the adoption of BIM presents an opportunity to enhance students' educational experience in engineering programs related to the construction industry (Zhang et al., 2016). This methodology provides them with interdisciplinary and collaborative skills essential for their performance in the professional environment (Mynderse et al., 2021).

The adoption of ABET accreditation in Civil Engineering programs has led to the development of curriculum reforms (Alhorani et al., 2021), prioritising the completion of an "Integrative Project" or "Emphasis Project" as a graduation requirement. Both project types align perfectly with ABET's requirements and are collectively known as the "Capstone Project" (Szatmary, 2023). These projects aim to provide students with hands-on experience in designing infrastructure works, enabling them to apply robust scientific and technical knowledge to solve engineering problems throughout the life cycle of civil infrastructure projects while also considering ethical, social, and environmental responsibilities (Goldberg, 2006). Additionally, these projects incorporate aspects of leadership and teamwork in interdisciplinary groups. Within this framework, BIM technology is a crucial element that bridges the gap between the desired graduate profile and ABET accreditation standards (Blumenfeld et al., 2023). BIM can potentially transform the educational process by offering a digital and collaborative platform that integrates various engineering disciplines (Chen et al., 2020). This integration aligns with the capstone project's requirements, involving interaction among civil engineering disciplines (Zhang et al., 2022). Thus, incorporating BIM into ABET-accredited programs ensures that students understand theoretical concepts and gain practical experience with industry-standard software and methodologies (Blumenfeld et al., 2023).

Integrating BIM into capstone projects offers several key advantages, including improved accuracy of budget and schedule estimations (Pérez et al., 2024; Solnosky et al., 2014). This is made possible through highly detailed models that allow for the breakdown of work packages required in construction processes, providing students with a comprehensive understanding of construction procedures and project components (Nusen et al., 2021; Oreto et al., 2021). Another essential feature of BIM for integrative projects is its ability to detect clashes. This allows future professionals in interdisciplinary roles to identify collisions between elements from different disciplines early on, thus preventing costly design changes during the construction phase (Akhmetzhanova et al., 2022; Chahrour et al., 2021). This experience enhances their communication and coordination skills, essential for effective teamwork in construction projects (Oh et al., 2015; Singh et al., 2011). Additionally, BIM nD digital simulations of the construction process facilitate the development of optimised schedules through improved planning and resource allocation (Lee et al., 2020), allowing for analysing various construction methods with potentially higher efficiency levels.

Integrating BIM into capstone projects in civil engineering programs helps students develop diverse competencies essential for their professional performance. BIM's potential aligns with the objectives promoted by ABET accreditation, ensuring that future professionals can effectively function in their work environments. Despite the recognised potential of integrating BIM in ABET-accredited programs, there is a noticeable lack of studies analysing the benefits of BIM in achieving the objectives promoted by ABET accreditation in Civil Engineering undergraduate programs. Therefore, this study has two research aims: (1) to propose the structuring of a BIM-base capstone project for an ABET-accredited civil engineering program and (2) to analyse the benefits of adopting BIM in ABET-accredited civil engineering programs. The results provide a theoretical foundation for institutions to adopt BIM in capstone projects based on reported experiences efficiently.

METHODOLOGY FOR DEFINING AND EVALUATION OF CAPSTONE PROJECT

In 2014, the School of Engineering of Pontificia Universidad Javeriana, aware of the challenges faced by graduates in a globalized world, decided to design a quality management system for teaching and learning processes and to apply for international accreditation ABET. To reach this step, it had already obtained high quality national accreditations from the country's Ministry of Education. At that time, the capstone project consisted of a research experience for undergraduate civil engineering students. In order to comply with ABET guidelines, this project was completely modified to become an infrastructure design project. Figure 1 provides a summary of the methodology used to design, implement, and continuously improve the capstone project. In addition, all steps of the methodology are explained and key decisions (e.g., inclusion of new areas of civil engineering such as BIM or socio-environmental studies) are included.

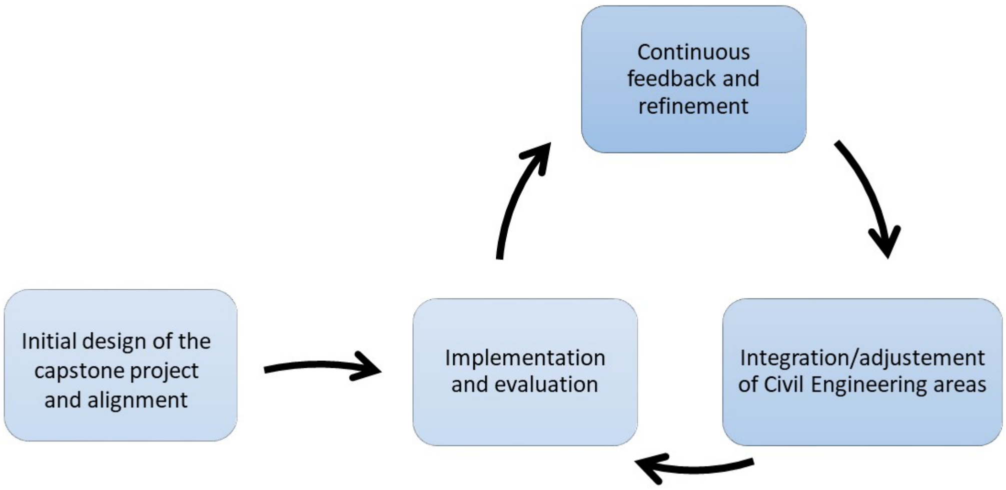

Figure 1. Summary of the methodology for designing, implementing, and continuously improving the capstone project.

- *Initial design and alignment with ABET and the institutional guidelines:* In 2015 the faculty discussed different points of view with professors from Spanish universities that had recently implemented ABET and the Capstone Project in their civil engineering undergraduate program. The discussions for the new project also included the industry perspective and educational goals according to ABET requirements. The faculty ensured that the project would address the fundamental challenges of civil engineering at the moment and defined that the capstone project framework would include the following core areas: structures, geotechnical, hydrotechnical, and construction (schedule and budget). It is important to note that in 2015, BIM technology was not as important in the civil engineering sector in Colombia as it is today. The group of professors who defined the capstone project decided that the project should be as close as possible to a civil engineering consulting project, as it was consistent with the graduate profile of the undergraduate program: Consulting Engineer. Therefore, it was determined that all areas should interact with each other, as structural decisions affect, for example, geotechnical and construction decisions.

- *Implementation and evaluation:* During the implementation phase, course coordinators monitored the progress of the capstone projects through regular check-ins, interim reviews, and assessments. They observe how well students apply their knowledge of structures, geotechnics, hydrotechnics, and construction. They also evaluate the clarity and scope of the project through student feedback, faculty review, and industry consultation. Indicators for improvement include student performance metrics and feedback from civil engineering evaluators. In addition, the course coordinators identified recurring difficulties in integrating different engineering disciplines and teamwork that suggested adjustments to the project. It was decided that the advisors and evaluators would be professionals who had been involved in the design and construction of the real infrastructure that the students would be designing. In addition, it was decided to include professors from different fields as course advisors so that there would be a 5:1 student-professor ratio for each civil engineering field. Similarly, architecture was included so that the projects would include technical designs adapted to the needs of the client/user as addressed in CDIO. The pandemic also affected the development of the capstone project. In this way, new technologies such as BIM 360 (Autodesk) were very useful for the virtual (remote) work of students and consultants. In a complementary way, managers (students) were defined for each project. These managers would be in charge of supervising the development of the projects and would report every two weeks to the course coordinators (professors) on the progress and difficulties of the students dedicated to the design of the technical areas. After a few semesters, this manager became responsible for the BIM aspects of the capstone project.

- *Continuous feedback and refinement:* At the end of each project cycle, the coordinators, the civil engineering department head, and the director of the undergraduate civil engineering program will conduct a comprehensive review involving students and faculty in accordance with the quality assurance assessment program defined for ABET accreditation. In this review, these individuals make observations about the overall effectiveness of the capstone project in achieving learning outcomes and meeting the needs of the civil engineering discipline. They analyze feedback and performance data to identify strengths and weaknesses in the capstone project. Key indicators include student satisfaction, the effectiveness of new areas in improving project quality, and the ability of projects to comprehensively address real-world issues. All of this analysis allows to refine and improve the project structure, incorporate additional resources and areas as needed, and update the curriculum. Problems were identified in the management practices and teamwork of the student groups. During the evaluation process, the evaluators also noted that the students had problems in integrating different disciplines, for example, inconsistencies were noted between the structural project and the geotechnical and hydrotechnical project.

- *Integration of additional areas:* For Outcome 5 (the ability to work effectively as part of a team whose members share leadership, create a collaborative and inclusive environment, set goals, plan tasks, and meet objectives), only 64% of students scored Excellent prior to implementing BIM in the capstone project. This implies that the civil engineering program needs to make improvements considering that the rubric has the following categories: Excellent, Satisfactory, In Process, Unsatisfactory. As a result, in the first semester of 2018, BIM has been included in the capstone project to promote good management practices, teamwork, integration of different disciplines, and leadership. In the same way, and with the new global trends, BIM allowed to link aspects of digital transformation. This digital transformation was requested by the construction industry, which hires graduates of the Civil Engineering program of Pontificia Universidad Javeriana. In addition, in 2015, there were two aspects that influenced the capstone project: the promulgation of the Sustainable Development Goals (SDGs) and the promulgation of the encyclical Laudato SI by Pope Francis. For this reason, and because it is a civil engineering program at a Jesuit university, two additional areas were included in the capstone project: social and environmental issues. Additionally, in 2017, the Engineering Accreditation Commission announced its decision to use a new student outcomes model, replacing the model that had been in place since 2000. The previous model consisted of eleven (11) learning outcomes (listed from A to K), while the new model (2017) proposed seven (7) learning outcomes, numbered from 1 to 7. A change in the model suggested the need to include global, cultural, social, environmental and economic factors. Therefore, the changes made in the capstone project due to the SDGs and Laudato SI were aligned with the adjustments made in ABET. On the basis of this context, in the second semester of 2017, the social and environmental fields have been included in the capstone project.

To evaluate students' perceptions of the benefits of using BIM in construction project development, a three-phase research methodology was implemented: (1) exploratory interviews, (2) questionnaire design, and (3) analysis of the results. In the first phase, semi-structured interviews were conducted with five students who had participated in a building project during their third year of study. These interviews aimed to identify the primary benefits students perceived from using BIM in their projects. Participants were intentionally selected to ensure a diverse range of experiences and perspectives on BIM usage. The qualitative analysis of these interviews identified seven key perceived benefits, which served as the foundation for the questionnaire development.

In the second phase, the seven benefits identified during the previous stage were used to design a questionnaire comprising three main sections. The first section focused on collecting categorical information from students, such as their level of study, major, city, and BIM training background. The second section aimed to assess the students' perceived levels of the seven identified benefits after completing the capstone project. A 5-point Likert scale was employed for this purpose, where 1 represented "not perceived at all" and 5 represented "extremely perceived." The questionnaire was given to a group of 29 students who had taken part in a BIM-based capstone project. The questionnaire was created using Microsoft Forms and distributed online. In the third phase, the responses collected were analyzed to determine how the benefits were perceived overall. To measure the relative perception of each benefit, the Relative Importance Index (RII) was used (see Equation 1). The RII allowed for the ranking of benefits based on the level at which they were perceived by the students, providing a clear hierarchy of the most significant benefits according to the participant's experiences in the capstone project.

$$RII = \left(\frac{\sum_{i=1}^{N} w_i}{N * w_{max}}\right) \qquad \textbf{Fórmula 1}$$

Where w_i is the classification weights, assigned by the evaluator i; N is the total number of valid questionnaires ($N = 29$); and w_{max} is the maximum possible weights for classification ($w_{max} = 5$).

BIM-BASED CAPSTONE PROJECT STRUCTURE

One of the graduation requirements for the Civil Engineering program at an ABET-accredited institution is completing a Capstone Project. For example, at Pontificia Universidad Javeriana, the Capstone Project course is designed to develop students' competencies in problem-solving, designing complex engineering solutions, recognising ethical and professional responsibilities within the context of Civil Engineering, and working independently and as part of a team. Throughout the project, students must apply their previously acquired knowledge to integrate various areas of Civil Engineering. This project spans two academic semesters. In the first semester, students gather all necessary information and propose a preliminary design, which several professors must approve as a prerequisite for continuing to the next semester. In the second semester, students enrol in the "Capstone Project" course, where the goal is to produce a detailed project design. By the end of this phase, students must submit a comprehensive set of design plans, a budget, Gantt charts with the project timeline, and calculation reports. Throughout both phases of the Capstone Project, students receive support from faculty members and industry professionals who serve as advisors. Advisors meet with students weekly to address any questions and provide general guidance on the project. These sessions include advisors from various disciplines. Given the workload, each work area (such as Structures, Geotechnics, Construction, Hydrotechnics, etc.) typically requires two students who act as "area managers."

The primary objective of the Capstone Project is to complete a detailed engineering design for an infrastructure project selected. This project is conducted through two courses (totalling six academic credits) spread across two academic semesters, with 64 contact hours with professors and over 300 hours of individual student work. The project encompasses geotechnical, structural, and hydrosanitary designs and the preparation of bidding and construction documents, including schedules, budgets, and technical specifications required for constructing the infrastructure facilities. The initial information provided to students includes topographic surveys, basic architectural proposal plans, and detailed soil studies (including laboratory test results and borehole logs). The detailed engineering process involves geotechnical, structural, and socio-environmental studies, budget estimation, descriptions of construction processes, and BIM modelling. This entire process is integrally and holistically articulated with BIM, and each area of work utilises licensed software such as SAP 2000, ETABS, Rocscience, Plaxis, Autodesk Revit, and Microsoft Office, among others. The design process carried out by the students involves the appropriate use of design and construction codes, as well as adherence to national and international regulations. This exposure provides students with a realistic design environment typically encountered in consulting firms. Specifically, students in the Integrative Project engage in the following activities:

- Identify the stages of the civil engineering design process to solve problems by developing a project schedule and budget. They explain the implications of technical, environmental, economic, regulatory, or cultural requirements and constraints for project execution.
- Propose design alternatives for a civil engineering project, analysing the implications of technical, environmental, economic, regulatory, or cultural requirements and constraints.
- Assess the applicability and constructability of proposed solutions for a civil engineering project, considering the technical, environmental, economic, regulatory, or cultural requirements and constraints.
- Design an infrastructure project that meets the client's needs while considering environmental, social, economic, construction, political, ethical, health, sustainability, and safety limitations.
- Present a 3D model with the final proposed solution, including all components, general construction details, notes, and technical specifications.

- Apply the principles and concepts necessary to form the capstone project team, demonstrating collective leadership and creating a collaborative and integrative environment within the context of BIM methodology.

Within this framework, students, working in groups of 6 to 10, tackled various design projects between 2015 and 2021. These projects included residential buildings, laboratory buildings for an engineering faculty, industrial plants, metro stations for the Bogotá Metro system, water treatment plants, and roadway projects. Figure 2 shows examples of the projects developed by the students in REVIT.

Figure 1. BIM-based capstone project examples. a) Example of the design of the new laboratory building of the School of Science of the Pontificia Universidad Javeriana, (area of 20,000 square meters); b) Structural system of the new science school laboratory building; c) & d) Example of one of the stations of the new metro of Bogotá; e) Industrial plant example for factory

BIM INTEGRATION INTO THE CAPSTONE PROJECT

Throughout the Capstone Project, students applied BIM methodology and its tools to manage, analyse, and document the engineering design of infrastructure projects, typically buildings. Implementing BIM methodology in the project involved detailed control of actions, requirements, and progress through various aspects, referred to as BIM dimensions. These dimensions encompass detailed modelling by speciality (BIM 3D), documentation (BIM 2D), project scheduling (BIM 4D), and detailed quantity extraction for budgeting (BIM 5D). The development of the BIM model aimed to achieve detailed engineering designs in line with the specified level of development for each area. The required deliverables for students include: (1) BIM planning, (2) BIM management, and (3) BIM documentation.

BIM PLANNING

- *BIM execution plan (BEP):* Based on the project schedule and tailored to the scope of the Capstone Project and the BIM Kit from BIM Forum Colombia (available for free on the BIM Forum Colombia website), the BEP should include, at a minimum, general project information, BIM goals, BIM uses with their respective responsibilities, and the formats and management of information exchange.
- *Responsibility matrix for modeled elements:* This matrix covers the project's design stages according to scope. This matrix should include a specific Level of Development (LOD) for each model component, as required in each area. The LOD definitions should be based on the LOD Specification document from BIMForum and the Omniclass codes for each element to standardise the process. Additionally, the matrix should adhere to the "BIM Modeling Guide" from the BIM Kit of BIM Forum Colombia.

BIM MANAGEMENT

- *Utilization of a collaborative platform for monitoring and control:* Adopting a collaborative tool for team organisation enables the creation of a dedicated dashboard for each group. This platform facilitates the weekly documentation of periodic team meetings, tracking of commitments, and task management, all linked to the semester's work schedule. Additionally, scanned minutes of weekly commitments, reviewed and signed by advisory professors, are uploaded here. The platform also supports collaborative work across various project areas by linking cloud-based files, ensuring access to the latest versions. Comprehensive reports detailing the status of activities, delay percentages and other relevant metrics are generated to provide clear evidence of project management and progress tracking.
- *Cloud-based platform for project information organisation:* All project-related information must be stored in a cloud-based platform, organised into folders according to the information organisation diagram. This folder structure is the weekly working directory for all specialist students, ensuring consistent and systematic access to project files. The cloud platform's organisation is crucial for maintaining up-to-date and easily accessible records, enhancing the team's overall efficiency and collaboration.

BIM DOCUMENTATION

- *BIM model*: The BIM model should encompass all parametric elements, including all specialities (central and local models) and the alternate and collaborative models of each speciality in RVT format. These BIM models must contain all labels and detailed plans for the various specialities, ready for printing. Regular reviews ensure consistency between the BIM models and the presented plans. Additionally, the models must adhere to the guidelines outlined in the BIM execution plan.

- *BIM model with clash detection:* Students must create a BIM model in NWF format along with the corresponding NWC files, performing clash detection analysis for each speciality and identifying unresolved conflicts. They must prepare a report explaining the implications of not addressing these conflicts (cost, time, design, etc.) and propose solutions. The final BIM model in NWF format should show all resolved clashes, with traceability of changes indicated as Resolved, Approved, and/or Reviewed.
- *Quantity takeoff tables in BIM model:* The BIM model in RVT format should include updated quantity takeoff tables aligned with the detailed engineering. The correspondence between these tables and those used in the budget calculation files should be reviewed to ensure accuracy.
- *Simulation of construction sequence:* Students must simulate the entire construction sequence for excavation, foundation, and structure, as well as all sections included in the project schedule (preliminaries, structure, hydrosanitary installations, fire protection network, etc.). This simulation should detail each process, including strategic planning elements, and must correspond to the project schedule delivered in Microsoft Project. The simulation is delivered in NWF and Windows AVI formats, with the video displaying the date, day number, week number, complete model, and construction sequence of all systems and chapters.
- *4D simulation videos:* Students must create five 4D simulation videos in Windows AVI format to explain the building's construction process: one for geotechnics, one for environmental, one for structure, one for hydraulics, and one for strategic planning.
- *Technical drawings for each area:* Technical drawings for each area (Geotechnics, Structures, Environmental, Hydraulics, Construction, and BIM) should be extracted from the BIM models, demonstrating complete concordance. All drawings for each speciality must be included within the same model for that discipline.
- *Stereo panoramic views:* Students must provide a minimum of 10 stereo panoramic views (two for each speciality: structural, geotechnics, environmental, hydraulics, project scheduling, and budgeting) that illustrate and explain the design/strategy implemented in the detailed engineering phase. These views should meet the specific requirements of each speciality and be presented on a plan (2D/3D view) indicating the location of each view with corresponding QR codes.

BENEFITS OF USING BIM IN THE CAPSTONE PROJECT OF AN ABET-ACCREDITED PROGRAMME

In the undergraduate Civil Engineering program at Pontificia Universidad Javeriana, accredited by ABET, the integration of BIM into the Capstone Project has enhanced students' academic training while providing numerous educational and professional advantages. The Civil Engineer profile at Pontificia Universidad Javeriana outlines that graduates will possess a robust technical foundation across all areas of their profession. They will have the analytical skills necessary to solve engineering problems related to the lifecycle of civil infrastructure projects, supported by knowledge of the social, economic, and environmental frameworks and an understanding of the ethical commitments of professional practice. Additionally, graduates will be capable of leading projects and interacting effectively in interdisciplinary teams, with an attitude of autonomous learning and a strong will to serve. Table 1 shows the main benefits of BIM adoption in the Capstone Project.

Table 1. Benefits of using BIM in the capstone project.

Id	Benefit	Description
B_1	Enhanced Project Visualization and Understanding	BIM tools have improved the comprehension and visualisation of infrastructure construction projects. By allowing students to visualise projects in 3D, BIM facilitates a clearer understanding of the complex interactions between different structural components. This three-dimensional visualisation surpasses traditional 2D plans, providing a more realistic and detailed project perspective. Through exploring digital models, students have identified potential design issues and gained a better understanding of construction solutions.
B_2	Promoted Collaboration and Teamwork	BIM technology has fostered a collaborative approach to project development, mirroring industry practices. The collaborative dynamics of BIM have enabled students to learn teamwork, sharing information, and coordinating efforts to achieve an integrated design. This skill is crucial today, as future civil engineers must be prepared for a work environment where interdisciplinary collaboration is essential for project success.
B_3	Development of Advanced Technical Competencies	BIM has equipped students with advanced skills and techniques highly demanded in the construction industry, such as proficiency in Autodesk Revit, Navisworks, and Civil 3D. Based on the university's interactions with the industry over the past decade, it has been established that mastery of these techniques and software is highly valued in the construction job market. The familiarity with these tools provided by the university can enhance the employability of future graduates, as they are better prepared to tackle the technological challenges of modern engineering.
B_4	Emphasis on Sustainability	A critical aspect of the latest ABET criteria update is sustainability. BIM technology, being integral not only in the design phase but also in the planning, construction, and maintenance of infrastructure, has taught students to manage the entire lifecycle of a project. This includes optimising resources and improving the sustainability of construction projects. Integrating BIM tools in an ABET-accredited undergraduate Civil Engineering program has provided numerous advantages, from improved project understanding and visualisation to developing advanced technical skills and preparation for future innovation.

Id	Benefit	Description
B_5	Improved Project Management Skills	BIM facilitates better project management by integrating various components into a cohesive model. This integration allows students to practice effective project management techniques, such as scheduling, cost estimation, and resource allocation, providing real-world experience in managing complex projects.
B_6	Preparation for Industry Innovations	BIM technology keeps students abreast of the latest industry innovations and practices. By working with cutting-edge tools and methodologies, students are better prepared for future technological advancements and can contribute to the ongoing evolution of the construction industry.
B_7	Strengthened Ethical and Professional Responsibility	The use of BIM in the curriculum reinforces the importance of ethical considerations in engineering practice. Students learn to design and manage projects responsibly, considering social, economic, and environmental impacts. This ethical grounding ensures that graduates are technically proficient and mindful of their professional responsibilities.

Integrating BIM tools in the ABET-accredited Civil Engineering program at Pontificia Universidad Javeriana offers substantial benefits. It enhances project visualisation, fosters collaboration, develops advanced technical skills, emphasises sustainability, improves project management, prepares students for industry innovations, and strengthens ethical responsibility. This comprehensive approach ensures that graduates are well-equipped to meet the current and future demands of the construction industry, providing a high-quality education that aligns with industry standards.

PERCEIVED LEVEL OF BIM BENEFITS

Table 1 presents the Relative Importance Index (RII) results, calculated from the seven benefits identified through interviews with five selected students. These benefits were recognized as key advantages of implementing BIM in the capstone project. The indices were derived from responses to 29 questionnaires, where students rated each of the seven benefits using a 5-point Likert scale. The analysis highlights that the three most significant perceived benefits of incorporating BIM into the capstone project are: (1) Enhanced Project Visualization and Understanding, (2) Promoted Collaboration and Teamwork, and (3) Development of Advanced Technical Competencies.

Table 2. Benefits of using BIM in the capstone project.

Id	Benefit	RII	Rank
B_1	Enhanced Project Visualization and Understanding	0.917	1
B_2	Promoted Collaboration and Teamwork	0.793	6
B_3	Development of Advanced Technical Competencies	0.821	5
B_4	Emphasis on Sustainability	0.752	7
B_5	Improved Project Management Skills	0.834	3
B_6	Preparation for Industry Innovations	0.828	4
B_7	Strengthened Ethical and Professional Responsibility	0.855	2

Enhanced Project Visualization and Understanding (B1) is the benefit with the highest relevance index, showing an RII of 0.917. This means that students believe that BIM improves their ability to visualize and understand construction features and processes during the project's construction phase. This is consistent with BIM's ability to create detailed three-dimensional models in virtual environments, allowing the integration of project elements from various design disciplines. This integration helps to identify design flaws, reducing errors and improving planning efficiency. The high relevance index in this area suggests that BIM is particularly valuable in an educational context, where spatial understanding and the ability to interpret complex plans are essential skills. Additionally, BIM's capability to enhance project comprehension is particularly beneficial in academia, where creating a construction project prototype in a laboratory can be prohibitively expensive. The ability to navigate, section, and analyze three-dimensional models allows students to understand the interactions between different project components better.

Strengthened Ethical and Professional Responsibility (B7) was identified as the second most significant benefit, with a Relative Importance Index (RII) of 0.855. This benefit was highly valued by the students, who felt that integrating BIM into their capstone project significantly helped them develop a stronger sense of ethical and professional responsibility. This result is consistent with the attributes of BIM that enhance transparency and traceability in projects, which are crucial for professionals in the construction industry. This industry is often faced with ethical challenges that can compromise the successful delivery of projects. Furthermore, the high score in this area indicates a growing awareness among students of the importance of ethics throughout the lifecycle stages of construction projects. This outcome demonstrates the students' acknowledgment of ethical participation within teams, where inappropriate conduct can jeopardize not only individual situations but also the overall success of the group.

Improved Project Management Skills (B5) ranked third, with a Relative Importance Index (RII) of 0.834. The students who took part in the survey believed that using BIM significantly improved their ability to manage projects more effectively, especially in terms of cost and schedule management during both the design and construction phases. This improvement is important because it demonstrates the enhancement in planning, monitoring, and controlling various project activities, facilitated by the detailed information and virtual environment provided by BIM. Students mentioned that BIM's capabilities in automating estimation processes and analyzing different project scenarios contribute to more efficient project management. This is significant, considering that project management is a crucial skill for professionals in the construction industry. BIM assists in planning and enhances communication and coordination among project stakeholders, improves resource allocation efficiency, and optimizes time management. The positive perception of this aspect highlights the potential usefulness that students see in BIM for accurate scheduling and budgeting during the design and construction stages.

CONCLUSIONS

This study makes theoretical contributions to the field of civil engineering education and the implementation of BIM in ABET-accredited academic programs. First, it establishes a theoretical framework that links BIM use with enhancing educational quality in ABET-accredited programs. The study shows how BIM facilitates three-dimensional visualisation and interdisciplinary coordination, thereby improving students' ability to analyse and solve complex engineering problems throughout the lifecycle of an infrastructure project. Second, the study proposes a structured model for integrating BIM into Capstone Projects within ABET-accredited civil engineering programs. This model encompasses BIM planning, management, and documentation, providing a comprehensive approach for practical implementation. Additionally, the study highlights how BIM can be utilised for clash detection, construction sequence simulation, and resource management, offering students a learning experience that mirrors current industry demands and practices. Finally, the study provides a theoretical foundation supporting the adoption of BIM in engineering programs, emphasising its benefits in sustainability, project management efficiency, and preparation for future innovations in construction. By integrating BIM into the educational process, the study underscores the potential of this technology to enhance the academic and professional readiness of civil engineering students, aligning their training with the evolving needs of the construction industry.

The findings make practical contributions to civil engineering education by integrating BIM in Capstone Projects of ABET-accredited programs. First, the implementation of BIM has demonstrated improvements in interdisciplinary collaboration. By enabling students from various specialities, such as structural engineering, environmental engineering, construction planning, and geotechnical engineering, to work on a shared model, BIM enhances the connection between these disciplines and fosters a comprehensive understanding of the impact of their decisions on the project. Second, BIM has proven to improve the accuracy of budget and schedule estimations. The detailed models allow for the breakdown of necessary work packages in construction processes, providing students with a thorough understanding of construction procedures and project components. Furthermore, BIM's ability to detect early conflicts between elements from different disciplines prevents costly changes during construction, improving essential communication and coordination skills for effective teamwork in construction projects. Finally, BIM facilitates nD digital simulations of construction processes, enabling students to develop optimised schedules through better planning and resource allocation. This allows them to analyse various construction methods with potentially higher levels of efficiency. Integrating BIM in capstone projects thus provides a more comprehensive and practical education aligned with the demands of the professional sector.

FUTURE RESEARCH

This study has several limitations that could be addressed in future research. The implementation of BIM in capstone projects was examined within a single ABET civil engineering program, which may limit the generalizability of the findings to other programs and educational contexts. In addition, the research was conducted over a specific time period and does not account for potential variation over time or across student cohorts. Another limitation is the reliance on specific tools and software, such as Autodesk Revit and Navisworks, which may not represent the full range of BIM tools available and used in the industry. For future research, it is suggested that comparative studies be conducted among different ABET civil engineering programs that have integrated BIM into their capstone projects. This would help evaluate the effectiveness of different implementation methods and their impact on student learning outcomes. In addition, it would be valuable to examine how the use of different BIM tools influences the development of students' technical competencies and professional readiness. In addition, it is recommended that the impact of BIM integration on project sustainability and how this technology can promote more environmentally responsible and efficient construction practices be explored.

ACKNOWLEDGMENTS

We gratefully acknowledge the financial support from the Pontificia Universidad Javeriana, Colombia, through "Apoyo a proyectos de investigación liderados por profesores que se encuentran en su primera etapa de su carrera en Investigación 2023" with the project ID 20699. The authors are grateful for the support of the Department of Civil Engineering from the Pontificia Universidad Javeriana.

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