

## Article

# Bridging the Gap: Enhancing BIM Education for Sustainable Design Through Integrated Curriculum and Student Perception Analysis

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## Abstract

Building Information Modeling (BIM) is a transformative tool in Sustainable Design (SD), providing measurable benefits for efficiency, collaboration, and performance in architectural, engineering, and construction (AEC) practices. Despite its growing presence in academic curricula, a gap persists between students' recognition of BIM's sustainability potential and their confidence or ability to apply these concepts in real-world practice. This study examines students' understanding and perceptions of BIM and Sustainable Design education, offering insights for enhancing curriculum integration and pedagogical strategies. The objectives are to: (1) assess students' current understanding of BIM and Sustainable Design; (2) identify gaps and misconceptions in applying BIM to sustainability; (3) evaluate the effectiveness of existing teaching methods and curricula to inform future improvements; and (4) explore the alignment between students' theoretical knowledge and practical abilities in using BIM for Sustainable Design. The research methodology includes a comprehensive literature review and a survey of 213 students from architecture and construction management programs. Results reveal that while most students recognize the value of BIM for early-stage sustainable design analysis, many lack confidence in their practical skills, highlighting a perception–practice gap. The paper examines current educational practices, identifies curriculum shortcomings, and proposes strategies, such as integrated, hands-on learning experiences, to better align academic instruction with industry needs. Distinct from previous studies that focused primarily on single-discipline or software-based training, this research provides an empirical, cross-program analysis of students' perception–practice gaps and offers curriculum-level insights for sustainability-driven practice. These findings provide practical recommendations for enhancing BIM and sustainability education, thereby better preparing students to meet the demands of the evolving AEC sector.

**Keywords:** building information modeling; BIM; sustainable design; AEC education; student perceptions; curriculum integration; project-based learning; PBL



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## 1. Introduction

As the global construction industry increases its focus on environmental responsibility, Sustainable Design (SD) is becoming a central priority in architectural, engineering, and construction education. Growing concerns over climate change and resource depletion have prompted institutions worldwide to incorporate sustainability and digital innovation into

their curricula, preparing graduates to meet the complex demands of a rapidly evolving sector [1].

One of the most widely adopted digital tools in this context is Building Information Modeling (BIM), which facilitates integrated design, energy analysis, daylight simulation, and comprehensive sustainability assessments from the earliest stages of the project [2,3]. BIM empowers students to model and analyze building performance in a virtual environment, thereby enhancing both technical knowledge and critical skills such as communication, teamwork, and interdisciplinary problem-solving [4,5]. Notably, the global BIM market was valued at USD 8.6 billion in 2023 and is projected to reach USD 24.8 billion by 2030, reflecting a compound annual growth rate (CAGR) of 16.3% [1]. According to Allied Market Research (2024), this trend highlights the growing adoption of BIM technologies worldwide and their expanding role in both education and industry [6]. The BIM adoption is driven by clear evidence of its benefits. Empirical studies report that BIM adoption may reduce labor requirements, improve productivity, and shorten construction timelines under specific conditions, all while supporting more sustainable outcomes through energy, material, and carbon optimization [5]. These capabilities position BIM as a cornerstone for advancing sustainable design in both academic and professional settings.

Despite its potential, integrating BIM and sustainability in higher education remains a persistent challenge. In architecture and construction management academic programs, the two subjects are still taught separately, which often limits students' ability to apply sustainable concepts holistically using BIM tools in real-world projects [3,7]. Teaching BIM and sustainability as separate subjects may result in graduates possessing theoretical knowledge but lacking practical expertise in integrating BIM with sustainability objectives [8]. Furthermore, technical barriers, such as software interoperability and the integration of performance metrics, combine with pedagogical obstacles, including fragmented curricula, limited faculty expertise, and the complexity of both domains, to inhibit effective learning [9,10].

Recognizing these gaps, recent educational research and industry feedback have called for curricula that integrate project-based learning (PBL), foster interdisciplinary collaboration, employ real-world case studies, and encourage direct engagement with industry professionals [3,11]. These approaches have been shown to increase student motivation, deepen learning, and better align academic outcomes with the needs of a rapidly evolving Architectural, Engineering, and Construction (AEC) sector [12].

In response to these goals, this study investigates the integration of BIM and Sustainable Design in higher education, focusing on students' perceptions, competencies, and readiness to apply BIM for sustainability in practice. To achieve the study objectives, four research questions (RQ1–RQ4) were developed based on a synthesis of the literature review and preliminary classroom observations. Each question targets a specific learning dimension measured in the student survey, ensuring a precise alignment between theoretical objectives and empirical data collection.

Previous research on BIM and sustainability education has primarily centered on software skills or abstract sustainability concepts taught in discipline-specific settings. This research extends the literature in three distinct contributions: (1) it provides an empirical, cross-program comparison of perception–practice gaps between Architecture and Construction Management students; (2) it offers curriculum-level insights by linking survey results to actionable recommendations for course and program improvement; and (3) it positions these insights within an evidence-based framework for curriculum integration, bridging quantitative perception data with qualitative educational analysis.

By integrating recent research with empirical survey findings, the study advances beyond descriptive inquiry to propose actionable strategies for aligning BIM and sustainability

education with industry expectations, ensuring that future graduates are equipped to address the sustainability and digitalization challenges of contemporary construction practice.

## 2. Background

### 2.1. Research Trends in BIM and Sustainable Design

Recent survey studies confirm that BIM is being used more frequently to facilitate sustainable building design in both professional practice and educational settings [13,14]. Their analysis shows that BIM enables more accurate simulations for energy efficiency and material selection, a trend that aligns with the industry's shift toward performance-driven design practices. Additionally, research on the integration of BIM and sustainable design has focused on several key areas, including energy performance analysis, material optimization, and Life Cycle Assessment (LCA). Recent studies have increasingly emphasized BIM's role in holistic building performance optimization, with energy simulations, daylighting, and embodied carbon analysis now standard in both research and practice [15–17]. These tools enable architects and engineers to make design decisions that minimize energy consumption, reduce waste, and optimize resource usage during the entire lifecycle of the building [18]. Benner et al. (2019) highlighted the rise of data-driven BIM approaches for sustainability certification, like LEED [19], while Sanchez-Lite et al. (2022) demonstrated how digital models are used for ongoing sustainability performance monitoring [20].

The education sector has also recognized the need to integrate BIM and sustainable design into its curricula. Recent surveys indicate a surge in the adoption of BIM-enabled sustainability coursework across architecture and construction programs worldwide. [21,22]. Several studies have reported on the integration of BIM in construction management and architecture programs, where students learn to apply BIM tools to assess the sustainability of their designs [8,23]. For example, Project-Based Learning (PBL) has been identified as an effective method for teaching students how to integrate BIM and sustainability. Jin et al. (2018) and Ma and Tao (2023) both demonstrated that interdisciplinary PBL environments using BIM foster deeper understanding and collaboration around sustainable solutions [24,25]. In PBL environments, students work on real-world scenarios, allowing them to apply BIM tools to solve sustainability challenges, such as energy optimization, water management, and the use of sustainable building materials [26].

Figure 1 shows a steady rise in publications on BIM and Sustainable Design in education from 2020 to a peak in 2024, reflecting growing academic interest in this intersection. The early 2025 decline likely results from ongoing indexing. This trend supports the systematic literature search findings, confirming that BIM-sustainability integration has become an emerging focus in educational research.

Furthermore, some studies have highlighted the potential of energy simulation software integrated with BIM to help students and practitioners assess energy needs, reduce carbon footprints, and analyze renewable energy options [27,28]. Hopfe et al. (2022) further illustrated the growing use of advanced simulation tools in undergraduate teaching for building performance analysis [29]. For instance, tools like Green Building Studio and Autodesk Revit are frequently used in educational settings to teach students about building performance simulation, which is critical for understanding sustainable design [30].

While these trends highlight the growing adoption of BIM in the context of sustainable design, there remain challenges to its full integration. Many studies point to the lack of standardization and software interoperability as key barriers [1,3]. Tran et al. (2024) provided a comprehensive review of persistent challenges, citing not only technical issues but also curriculum misalignment and the need for better digital literacy among both students and educators [31], which could be linked to student motivation [32]. Furthermore, research has identified that many educational programs still treat BIM and sustainability

as separate subjects, which can prevent students from fully understanding how these two domains intersect and how BIM can be a tool to enhance sustainability in construction [7,26].

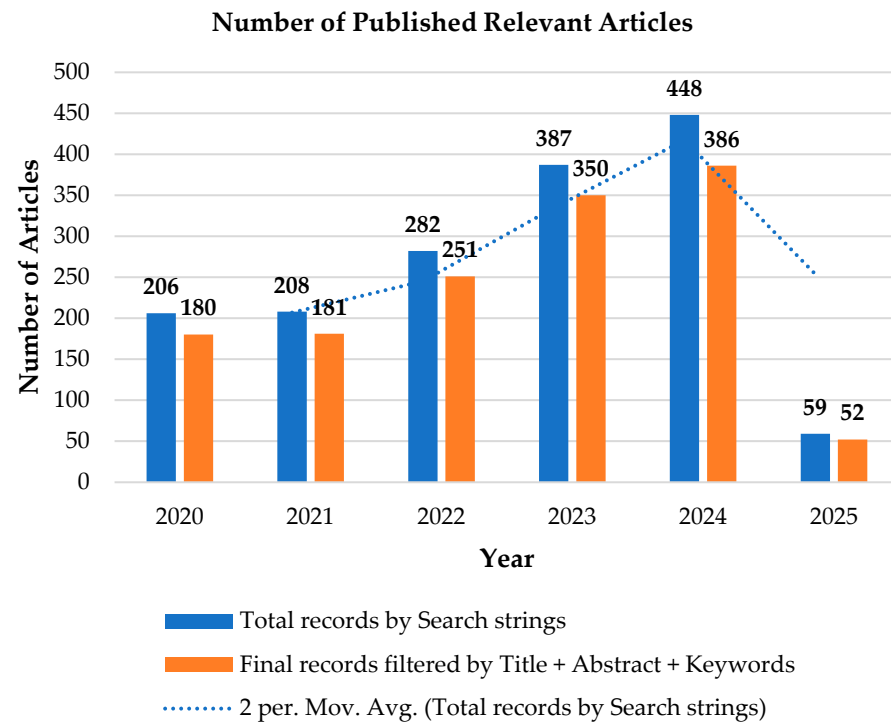


**Figure 1.** Annual Distribution of Total vs. Relevant Articles on BIM and Sustainable Design in Education (2020–early 2025).

To further illustrate the evolving academic interest in BIM within sustainability-focused education, Figure 2 presents a keyword co-occurrence network generated using *VOSviewer*. The dataset was developed by analyzing titles, abstracts, and author keywords from 1589 documents retrieved from the Web of Science, OpenAlex, and Scopus databases (2020–2025). Co-occurrence analysis identifies frequently associated terms that appear together across these publications. The resulting visualization reveals clusters where “Building” most frequently appears as a central node, reflecting BIM’s association with building-centric research terms. It is closely linked to “sustainable design,” “education,” “energy modeling,” and “curriculum.” This indicates that the literature increasingly connects BIM with sustainability pedagogy and performance-based design. The inclusion of related terms, such as “LEED,” “simulation tools,” and “project-based learning,” further demonstrates how the discourse has shifted toward experiential and data-driven educational strategies. The color gradient reflects temporal evolution, with lighter tones representing newer research trends such as “digital literacy” and “parametric modeling.”

## 2.2. Educational Practices and Pedagogies

Integrating BIM with sustainable design education presents both opportunities and challenges for educators. Several studies have explored pedagogical approaches, particularly Project-Based Learning (PBL) and case studies, when teaching BIM in sustainable design contexts [33,34]. For example, Atabay et al. (2020) assessed the outcomes of embedding both BIM and green building concepts within engineering programs, finding notable gains in students’ analytical and collaborative skills [33]. According to Shen et al. (2012), PBL encourages students to engage in real-world problem-solving, where they can apply BIM to develop sustainable building solutions, such as conducting energy modeling and selecting sustainable materials [23]. Recent research by Lee et al. (2023) and Tijó-López et al.



principles to offer students a holistic education that prepares them to address real-world sustainability challenges in the construction industry [23,26,39].

### 2.3. Challenges and Barriers in BIM and Sustainable Design Integration

Although BIM for sustainable design offers considerable potential, several barriers continue to hinder its widespread adoption, both in the AEC industry and in education, including curriculum misalignment, inadequate hands-on opportunities, and a misalignment between the skills students acquire during their studies and those required by employers in the construction industry [40]. McCord et al. (2023) especially emphasize that educational programs must continuously adapt based on industry feedback to remain relevant [41]. Technical challenges, such as software interoperability and the need for cross-platform integration, remain major obstacles in implementing BIM tools in the context of sustainable design [1,2]. Cascone (2023) critically reviewed recent digital technologies, emphasizing the ongoing fragmentation of BIM-based sustainability assessment workflows [42]. Several BIM software tools used in practice today, such as Autodesk Revit and Green Building Studio, do not seamlessly integrate with other performance simulation tools, which limits their effectiveness in optimizing sustainability during the early stages [43,44].

In education, faculty preparedness is another critical challenge. Many faculty members lack the expertise to teach both BIM tools and sustainability principles, making it difficult to provide students with a comprehensive understanding of how these areas intersect [1,8]. Obi et al. (2022) showed that upskilling educators in BIM and sustainability competencies directly improves student outcomes in undergraduate programs [45]. Lack of standardized curricula and the fragmented nature of BIM and sustainability education further contribute to the challenge, as students may not receive a coherent education that links these two critical areas [3].

Additionally, the adoption of BIM for sustainable design within the industry has remained limited, primarily due to high initial costs, technical barriers, and the absence of consistent standards and policies [1,46]. As Dalla Valle (2021) noted, despite strong evidence of BIM's long-term benefits for sustainability, the lack of standardization continues to hinder widespread integration across projects [46]. These industry-level challenges extend beyond professional practice and have direct implications for education. Limited adoption of BIM-based sustainability practices in the field constrains faculty exposure, case study availability, and access to up-to-date software or workflows in academic programs. Consequently, students may learn BIM and sustainability concepts in isolation rather than through integrated, practice-based exercises that mirror real-world applications. This disconnect reflects a persistent mismatch between what universities teach and what the construction industry expects of graduates [2,3,10]. Addressing these issues requires improved coordination between academia and industry to align curricula with current sustainable construction tools, standards, and practices [24,34]. In doing so, academic curricula can help close the perception–practice gap identified in this study [21].

Figure 3 illustrates the conceptual relationship between BIM and SD within the educational context. BIM serves as a central integrative framework that connects diverse sustainability domains, such as energy analysis, carbon footprint assessment, natural resource management, and lifecycle performance, with collaborative project delivery and standardized frameworks. By visualizing these interconnections, the diagram highlights how BIM acts as both a technological and pedagogical bridge, enabling students to understand sustainability not as an isolated topic but as an interconnected process embedded within the design, construction, and operation of the built environment. This integrative approach underscores the importance of embedding BIM-based sustainability principles throughout the curriculum to foster systems thinking and multidisciplinary collaboration.

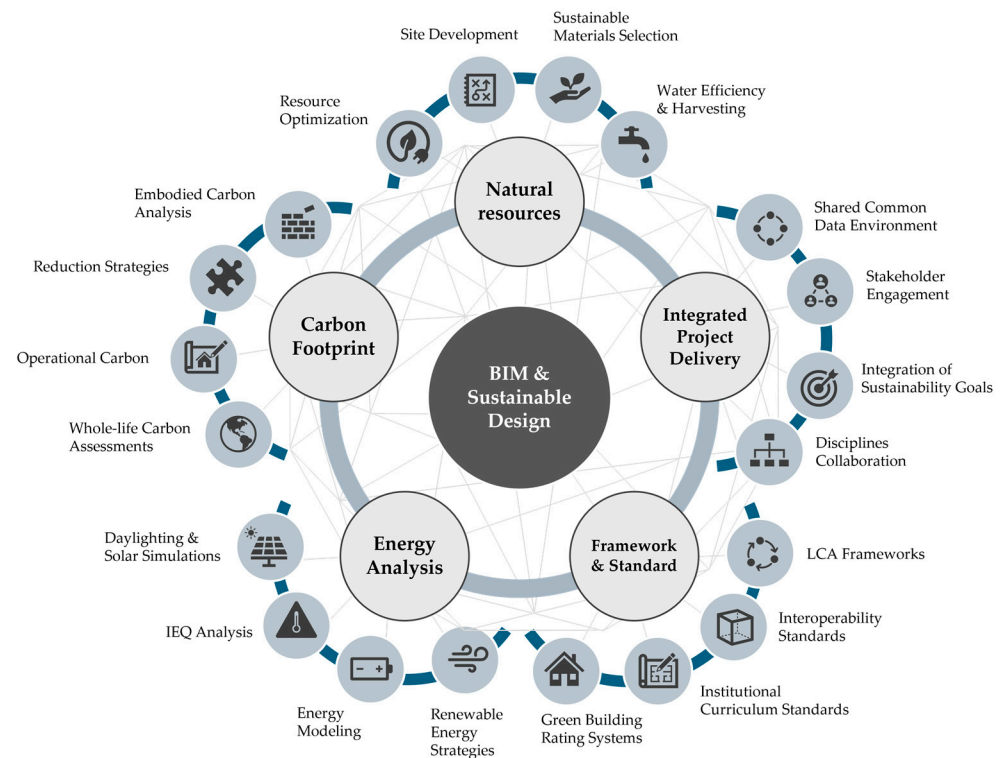


**Figure 3.** The Connection Between BIM and Sustainable Design in Education, adapted from Sharon (2025) [47].

#### 2.4. Research Gaps

Despite increasing attention to BIM-enabled sustainability education, several critical research gaps remain. First, prior studies have predominantly examined BIM integration from either a technical or pedagogical perspective. Still, few have empirically explored how students perceive their readiness to apply BIM for sustainable design in real-world contexts [3,5,7]. Second, there is limited comparative research across academic disciplines, particularly between architecture and construction management, that assesses perception–practice gaps or curricular disparities [8,10,22]. Third, while many studies have discussed best practices conceptually, quantitative and mixed-method approaches that connect student perceptions to curriculum outcomes are scarce [25]. Finally, there is a lack of frameworks that bridge empirical findings with curriculum design strategies, linking educational outcomes with industry readiness [19]. By addressing these gaps, the present study contributes empirical evidence on student perceptions and provides actionable insights for integrating BIM and sustainability education more effectively within higher education programs.

### 3. Methodology

#### 3.1. Research Design

The research design comprised three interrelated components: a systematic literature search, a snowball reference search, and a cross-sectional student survey. This multimodal strategy was employed to triangulate evidence, validate findings, and ensure both breadth and depth in the analysis of BIM and sustainable design integration.

Figure 4 illustrates the research methodology flowchart, presenting a logical and iterative progression of the study from defining goals to identifying future directions. The process begins with the formulation of research goals and objectives, which guide the literature review. This review identifies existing knowledge and highlights research gaps, which in turn inform the development of research questions and validation. These questions

shape the research design, which outlines the data collection strategy, comprising surveys, simulations, and case studies. Collected data undergo validation and reliability checks to ensure accuracy, supporting the derivation of meaningful results and findings. These findings yield both scholarly and practical contributions, ultimately suggesting future research directions. The flowchart emphasizes interdependence between components, reflecting a quantitative survey-based approach supported by descriptive and thematic analyses to ensure both theoretical rigor and empirical validation. Each stage of data collection and analysis was designed to correspond directly with one of the four research questions, as summarized in Table 1.

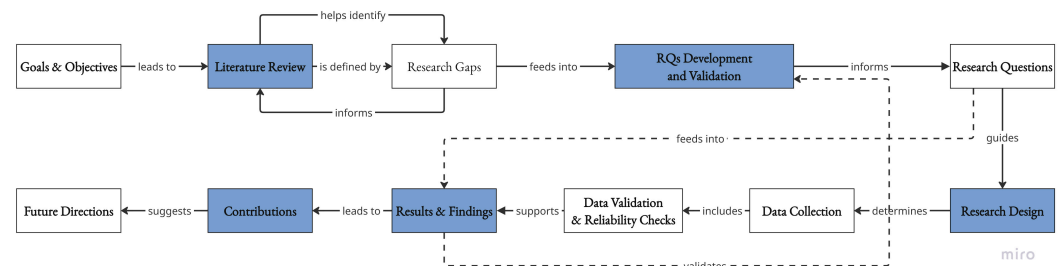


**Figure 4.** Research Methodology Flowchart.

**Table 1.** Alignment between Research Objectives, Research Questions, and Survey Items.

| Objective                                                                                                                      | Research Question (RQs)                                                                                                                                                 | Survey Items            |
|--------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------|
| O1: Assess students' current understanding of BIM and Sustainable design.                                                      | RQ1: How can BIM tools be effectively integrated into early design stages to optimize sustainability metrics in architectural projects?                                 | Q6, Q7, Q11, Q16, Q18   |
| O2: Identify gaps and misconceptions in applying BIM to sustainability.                                                        | RQ2: What role does BIM play in facilitating interdisciplinary collaboration among architects, engineers, and sustainability experts?                                   | Q14, Q17, Q19, Q20, Q21 |
| O3: Evaluate the effectiveness of existing teaching methods and curricula to inform future improvements.                       | RQ3: How can a standardized curriculum that integrates BIM with sustainable design principles improve students' ability to apply these concepts in real-world projects? | Q9, Q10, Q22            |
| O4: Explore the alignment between students' theoretical knowledge and practical abilities in using BIM for sustainable design. | RQ4: What are the barriers and challenges in translating BIM knowledge into practical, sustainable design applications in the construction industry?                    | Q13, Q21                |

*Note:* Table clarifies how each RQ is derived from the objectives and supported by corresponding survey questions (Appendix A).

### 3.2. Systematic Literature Search and Data Collection

A systematic literature search was first conducted using three major research databases, Web of Science (WoS), OpenAlex, and Scopus. The search query included “Building Information Modeling” or “BIM” and “Sustainable Design” or “Sustainability in Construction,” combined with terms such as “Student Perception,” “Student Learning Outcome,” “Education,” and “Curriculum Development.” Inclusion criteria focused on English-language articles published since 2020; wire feeds, blogs, and non-peer-reviewed sources were excluded to ensure scholarly relevance.

- Total Articles Found: 1589 (WoS, OpenAlex, Scopus combined).
- Relevant Titles & Abstracts: 523 (31 from WoS, 488 from OpenAlex, four from Scopus).
- Shortlisted Top 20: 44 articles (across all databases).

- Full Review Selection: 28 articles (13 OpenAlex, 15 Scopus) were retained for in-depth analysis based on direct relevance to research questions on BIM and sustainable design education.

To complement the database search, a snowball reference search was conducted, examining the reference lists of shortlisted articles to identify further relevant studies not captured in the initial queries. This strategy yielded 20 additional articles, resulting in a final pool of 48 for comprehensive review. Notably, foundational works predating the primary search window (pre-2020) were also included when they provided significant theoretical context or influenced current BIM and sustainable design pedagogy. This approach ensured historical continuity and theoretical depth in the literature review search.

The selection of pertinent literature was guided by its direct relevance to the objectives of this study. Only papers strongly aligned with the research focus were included. Screening was conducted by two authors, one serving as the primary reviewer and the other providing secondary support. For most publications, inclusion decisions were straightforward; however, for studies where eligibility was uncertain, both authors jointly evaluated quality, publication date, and thematic relevance to minimize potential bias. Studies identified as having a high risk of bias were excluded. After screening, 48 articles met the inclusion criteria and were retained for comprehensive analysis; however, to maintain logical coherence and conciseness, only the most pertinent works are presented in this paper.

### *3.3. Survey Design and Implementation*

The empirical component of this study employed a cross-sectional, quantitative survey to collect data on students' perceptions, experiences, and preparedness regarding the integration of BIM and SD in higher-education curricula. The survey was designed to capture current trends in student understanding and to identify perceived barriers to applying BIM for sustainability in practice.

The survey instrument was informed by insights from the systematic literature search (SLS) summarized in Section 2. It was developed through iterative review by three faculty experts in BIM and sustainable construction education. A pilot test with five students was conducted to verify clarity and content validity, after which minor wording adjustments were made.

#### *3.3.1. Sampling Strategy and Population*

The study adopted a non-probability, purposive sampling strategy targeting students enrolled in architecture- and construction-related programs. This approach was selected to ensure that respondents possessed at least basic exposure to BIM concepts or sustainability coursework, consistent with the research objectives. The survey was distributed electronically via Qualtrics between 12 April 2024, and 20 April 2025, to two departments (architecture and construction management) at a university in the Southeastern United States.

A total of 295 invitations were sent to eligible students. Of the 295 students invited, 284 responded and agreed to participate. After screening for completeness and consistency, 213 valid responses were retained for analysis, representing an effective response rate of 72 percent. This sample size is considered adequate for descriptive statistical analysis and thematic interpretation in exploratory education studies.

#### *3.3.2. Ethical Considerations*

Before deployment, the study protocol received approval from each institution's Institutional Review Board (IRB). Participation was voluntary and anonymous; respondents provided informed consent before accessing the questionnaire. No identifying information

was collected, and data were stored on password-protected university servers in accordance with institutional data-privacy policies.

#### 3.3.3. Data Validation

Responses were checked for completeness and logical consistency. Cases with contradictory or incomplete answers were excluded. Internal reliability of key Likert-scale items was confirmed through Cronbach's  $\alpha > 0.8$ , indicating satisfactory internal consistency among perception-related variables.

#### 3.3.4. Section Transition

The detailed composition of the survey instrument, including question categories, scaling structure, and alignment with the research questions, is presented in Section 4.3 (Survey Instrument and Structure).

## 4. Data Analysis

### 4.1. Data Analysis Approach

Both quantitative and qualitative analysis techniques were employed. Descriptive statistics (means, frequency distributions, and percentages of agreement/disagreement) were calculated for all Likert-scale items to gauge overall trends in student perceptions. These statistics helped answer the research questions by revealing, for instance, the proportion of students who believe BIM is helpful for specific sustainable design tasks (RQ1) or the percentage who feel well-prepared by their curriculum (RQ3). Where relevant, comparisons were made between subgroups, such as responses from Construction Management students versus Civil Engineering students, to determine if any significant differences emerged based on academic background.

Qualitative data from open-ended questions were thematically analyzed. Common themes that emerged included calls for more hands-on practice, desires for interdisciplinary project opportunities, and observations about software challenges. These qualitative insights provided context to the quantitative results, illustrating why students felt a certain way. For instance, if a student disagreed that their curriculum was adequate, their open-ended comment might mention "we only had one class project using BIM for energy analysis, which was not enough to feel proficient." Such comments were categorized under themes like "Limited coursework exposure," a barrier that complements the quantitative finding of low confidence.

To analyze the open-ended responses, a three-phase thematic analysis was conducted following the procedures recommended by Braun and Clarke (2006) [48]. In the first phase, all responses were imported into NVivo 14 and reviewed line-by-line to generate initial codes that captured recurring ideas (e.g., hands-on practice, interdisciplinary collaboration, software limitations). In the second phase, codes with conceptual similarity were grouped into categories that reflected broader patterns of meaning, such as "curricular barriers" or "learning preferences." In the final phase, these categories were refined into overarching themes aligned with the four research questions (RQ1–RQ4). Two researchers independently coded a random subset of responses to verify consistency, and discrepancies were resolved through discussion. This systematic process enhanced the credibility and transparency of the qualitative findings.

The results were then organized according to the four research questions, addressing each one directly. In the following section, the survey findings are presented alongside a discussion and interpretation, including comparisons with the existing literature. This integrated presentation helps highlight where students' perceptions align with established

educational outcomes and where notable gaps or contradictions exist, thereby fulfilling the study's aim of confronting perceptions with practice.

#### 4.2. Demographic Background of Participants

A total of 213 valid responses were analyzed, representing students from two accredited universities in the Southeastern United States. The sample was predominantly undergraduates (approximately 96% were pursuing a bachelor's degree) with a small number of graduate students (4%). In terms of discipline, the majority (about 93%) were Construction Management majors, reflecting the large enrollment of that program in the sample. Roughly 6% were Architecture students, and the remaining responses came from other disciplines such as Civil Engineering (1%). The sample's demographic composition was 87% male and 13% female. It included a diverse range of backgrounds, with approximately 65% of respondents identifying as Caucasian, 10% as African American, 13% as Hispanic, and the remainder reporting as multi-racial or in other categories. A significant portion of participants (approximately 75%) had some prior work experience in the construction industry, although it was typically limited, with most having 1–4 years of experience (approximately 13% having 5–10 years). For most respondents, this “experience” refers primarily to internships, cooperative education placements, and academic capstone projects rather than full-time professional employment. These opportunities allowed students to gain exposure to real construction workflows, project documentation, and limited BIM applications under supervision. This early experiential learning helps contextualize their classroom knowledge but does not yet equate to industry-level proficiency. Figure 5 illustrates the proportion of students across degree levels, disciplines, and prior experience categories.

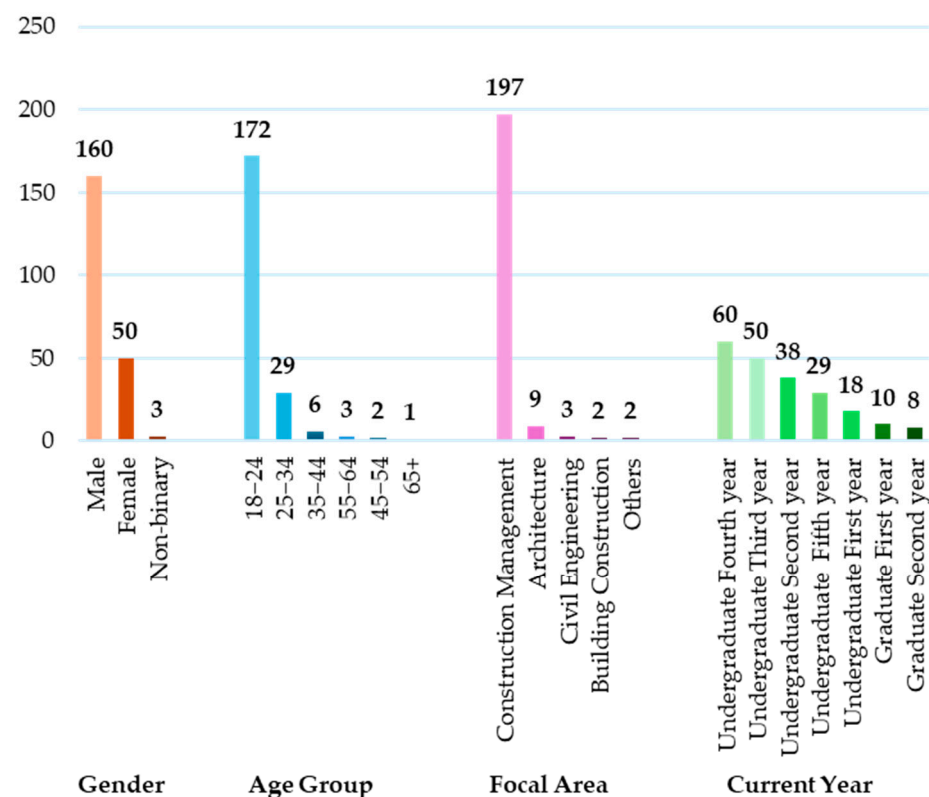


**Figure 5.** Distribution of participants' socio-demographic background ( $n = 213$ ). The X-axis categorizes respondents by gender, age group, focal area of study, and current academic year, while the Y-axis represents the number of respondents in each category, Q1, Q2, Q4, and Q5.

#### 4.3. Survey Instrument and Structure

The survey instrument was designed to align directly with the four research objectives and corresponding research questions outlined in Section 1. Its purpose was to evaluate students' knowledge, perceptions, and perceived preparedness in applying BIM for SD within their academic programs.

##### 4.3.1. Structure and Content

The questionnaire consisted of 25 items divided into five thematic parts, each mapped to specific research questions (RQ1–RQ4):

- Part I-Demographic Information: Collected participants' program of study, year level, gender, age group, and prior industry or academic project experience. These variables provided context for interpreting patterns in perception and preparedness.
- Part II-Knowledge and Familiarity with BIM Tools (RQ1): Assessed students' prior exposure to BIM software (e.g., Revit, Navisworks, ArchiCAD) and understanding of BIM's potential for improving sustainability outcomes.
- Part III-Perceptions of BIM's Role in Sustainability (RQ2 & RQ3): Examined students' views on how BIM supports sustainability, such as energy modeling, material optimization, and interdisciplinary collaboration, and the extent to which their curriculum fosters these competencies.
- Part IV-Barriers, Challenges, and Learning Preferences (RQ4): Identified perceived obstacles to using BIM for sustainability (e.g., limited access, lack of training, insufficient hands-on experience) and preferred instructional strategies (e.g., project-based learning, case studies, guest lectures).
- Part V-Future Perceptions: Captured students' expectations about BIM's role in achieving future sustainability goals and invited open-ended reflections on potential curriculum improvements.
- In total, the instrument included 25 questions, 21 closed-ended (Likert-scale, multiple-choice, or ranking) and four open-ended items designed to elicit qualitative insights. The open-ended items encouraged participants to elaborate on challenges, preferences, and experiences that could not be captured through scaled responses.

##### 4.3.2. Response Formats

The questionnaire employed a five-point Likert scale (1 = Strongly Disagree; 2 = Disagree; 3 = Neutral; 4 = Agree; 5 = Strongly Agree) for all attitude and perception items. This format was used consistently across all attitudinal questions to ensure comparability and interpretive reliability. It was selected for its ease of use, balance between discrimination and response fatigue, and consistency with prior perception-based research in construction and sustainability education. Responses were analyzed using descriptive statistics (mean, frequency distribution) to identify trends across the four research questions. In addition, multiple-choice and ranking questions were included to capture preferences and perceived barriers. Four open-ended questions provided qualitative feedback, allowing respondents to elaborate on their views regarding curriculum integration and practical challenges. These qualitative responses were thematically analyzed using *NVivo 14*, as described in Section 4.1.

##### 4.3.3. Instrument Validation and Reliability

To ensure content validity, the questionnaire goes through expert review by two faculty members specializing in BIM and sustainability education. Pilot testing with five students confirmed the clarity of question wording, logical sequencing, and appropriate survey length. Minor revisions were made to improve flow and remove ambiguity.

Reliability testing of perception-related items yielded a Cronbach's  $\alpha = 0.80$ , indicating strong internal consistency among the Likert-scale constructs. According to Nunnally and Bernstein (1994), reliability coefficients above 0.70 are considered acceptable for social science research, while values above 0.80 indicate good reliability [49]. This result, therefore, confirms that the survey instrument achieved satisfactory reliability for perception-based educational research. The final instrument balanced brevity with comprehensiveness, allowing completion in approximately 10 min while maintaining measurement accuracy across both quantitative and qualitative components.

#### 4.3.4. Link to Research Framework

Each survey section was mapped to the study's objectives and research questions as summarized earlier in Table 1 (Alignment between Research Objectives, Research Questions, and Survey Items). The complete questionnaire, including all item wording and sequencing, is provided in Appendix A to ensure transparency and reproducibility.

#### 4.4. Data Validation and Verification

To ensure content validity, the survey was reviewed by two faculty members knowledgeable in BIM and sustainable construction, and their feedback was used to refine question wording. A small pilot test was then conducted with a group of 5 students, whose responses and comments helped to clarify questions further and adjust the length of the survey. Data validation and reliability checks were built into the methodology. The final questionnaire included attention-check items, and the collected data underwent screening for consistency of responses. For example, inconsistent responses (e.g., a student indicating both very high and very low self-assessed BIM skill in different sections) were flagged and reviewed. In this dataset, only a few responses had to be removed due to inconsistency, indicating good attention from the participants. The internal consistency of key Likert scale items was evaluated using Cronbach's  $\alpha$ , and the survey achieved an  $\alpha$  value above 0.8 for the set of items related to perceptions of BIM's role in sustainability, suggesting that these items reliably captured a single underlying construct (students' perceived value of BIM for sustainable design). The structured nature of the survey and these checks helped improve the reliability of the findings.

## 5. Results & Discussion

### 5.1. Results

#### 5.1.1. Integrating BIM in Early Design for Sustainability Optimization (RQ1)

The relevant survey responses assess students' agreement on whether BIM can aid various aspects of sustainable design. The aspects include building orientation, massing, daylighting analysis, water harvesting, sustainable materials, sustainable equipment, and site and logistics management.

The survey results indicate that a large majority of students recognize the value of BIM in supporting sustainable design strategies. Across eight sustainable features, ranging from building orientation to energy modeling, more than 75% of respondents consistently agreed or strongly agreed that BIM aids in each area. The strongest consensus was observed in features like water harvesting, sustainable materials, and daylighting analysis, which received the highest percentages of "Strongly Agree" responses. Meanwhile, features such as building orientation and sustainable equipment also garnered high levels of agreement with minimal disagreement, indicating a broad appreciation for BIM's role in spatial and systems coordination. While 5% to 14% of respondents were neutral or disagreed, the majority viewed BIM as a valuable tool for enhancing energy efficiency, environmental performance, and design integration in sustainable construction.

Figure 6 summarizes students' perceptions of BIM's contribution to sustainable design features such as energy efficiency, material selection, and environmental performance analysis that address RQ1.

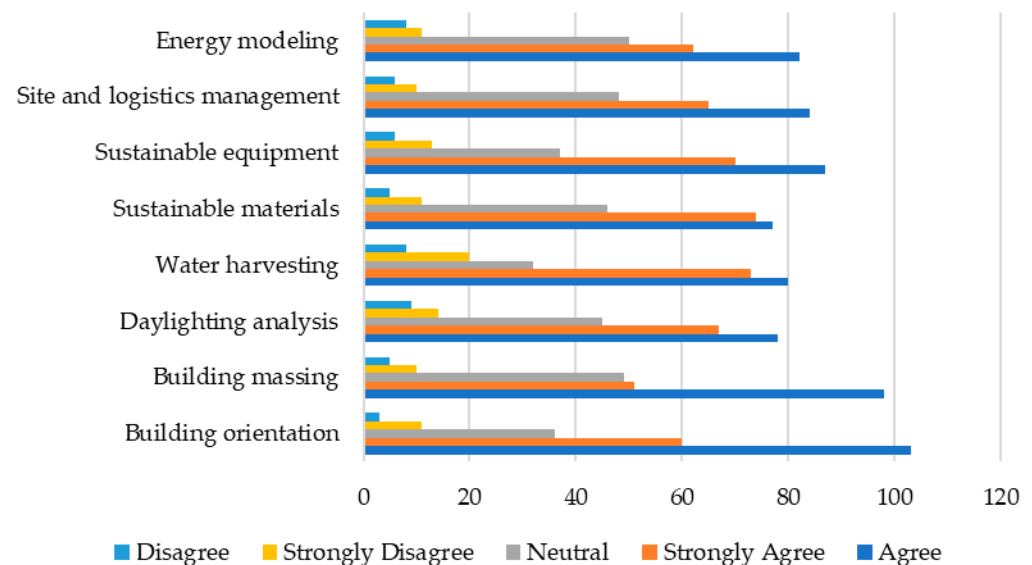


**Figure 6.** Student Perceptions of BIM's Contribution to Sustainable Design Features. Distribution of student perceptions of BIM's contribution to sustainable design features (Q11). The Y-axis lists individual sustainability aspects (e.g., building orientation), and the X-axis shows the percentage of respondents selecting each Likert-scale category (1 = Strongly Disagree to 5 = Strongly Agree).

#### 5.1.2. BIM's Role in Enhancing Interdisciplinary Collaboration (RQ2)

To answer the research question, this study investigated a combination of survey responses that highlight students' experiences with interdisciplinary and collaborative learning. The results indicate that students value teamwork, group projects, and exposure to industry professionals as key elements supporting cross-disciplinary engagement. Reflections on applying theory to practice, along with the identification of challenges such as limited curriculum integration and industry exposure, further illustrate both the strengths and remaining gaps in fostering collaborative learning through BIM and sustainable design education (Figure 7).

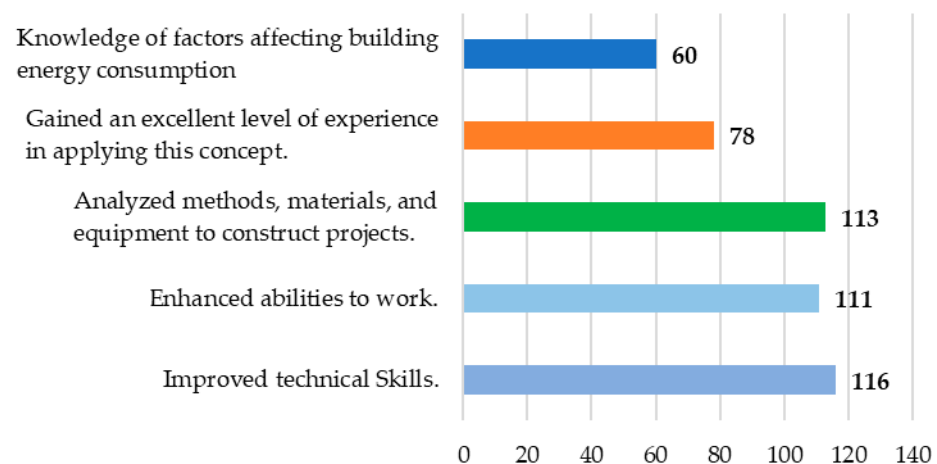


**Figure 7.** Student-Perceived Benefits of Learning BIM in Sustainable Design Education (Q14). The Y-axis represents different instructional methods, and the X-axis shows the number of respondents selecting each strategy.

The survey results on the “Benefit of understanding BIM with Sustainable Design in your program” reveal key insights into how students perceive the value of integrating these two concepts into their academic experience.

The most frequently selected benefit was “Improved technical skills” with 116 mentions, indicating that students strongly associate BIM with gaining core competencies in digital tools and modeling processes essential for modern sustainable design. Closely following are “Analyzed methods, materials, and equipment to construct projects” (113 mentions) and “Enhanced abilities to work” (111 mentions), both of which reflect the perceived improvement in applied knowledge and interdisciplinary collaboration, a crucial outcome for PBL in construction and design. Additionally, “Gained an excellent level of experience in applying this concept” (78 responses) and “Knowledge of factors affecting building energy consumption” (60 responses) show that a considerable number of students feel they have been equipped not only with practical application opportunities but also with an understanding of energy-related sustainability metrics.

As a result, these findings suggest that students perceive substantial value in learning BIM within the context of sustainability, particularly for developing technical skills, analyzing materials, and gaining collaborative work experience. This supports the case for strengthening hands-on, project-oriented BIM + sustainability modules within the curriculum to better align academic outcomes with industry expectations.

Figure 8 presents the results from the survey question “Which of the following learning strategies are helping to understand BIM in sustainable design?” These results offer valuable insights into the types of instructional methods students find most effective for developing their understanding of BIM within a sustainability context.

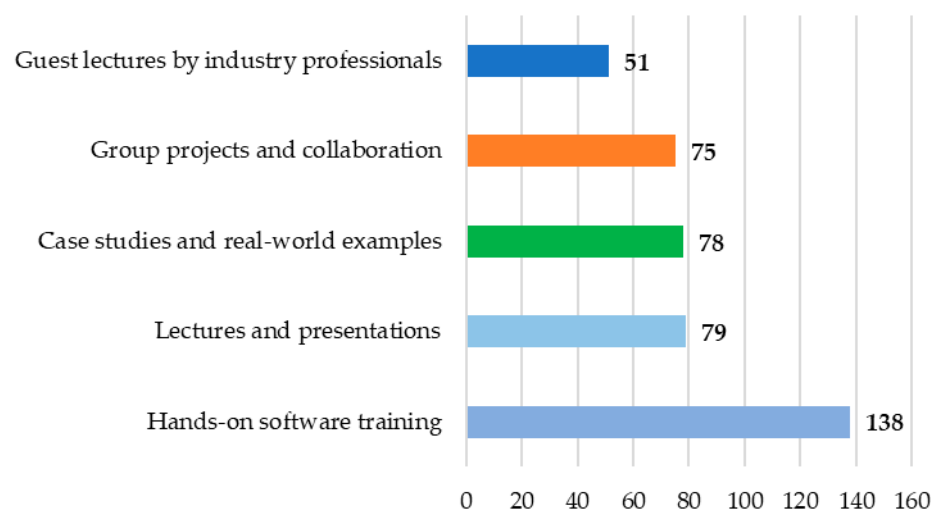


**Figure 8.** Student-Preferred Learning Strategies for Understanding BIM in Sustainable Design (Q10). The Y-axis lists the instructional strategies, and the X-axis shows the number of respondents selecting each option.

The most frequently cited strategy was “Hands-on software training”, selected by 138 students, clearly underscoring the importance of experiential, skill-based learning in mastering BIM tools. This reflects students’ strong preference for active engagement with digital platforms over passive instruction, aligning with industry expectations for technical proficiency.

Following that, “Lectures and presentations” (79 responses), “Case studies and real-world examples” (78 responses), and “Group projects and collaboration” (75 responses) received nearly equal recognition. These results highlight students’ appreciation for a well-rounded educational approach that combines theoretical foundations with exposure

to practical applications and opportunities for teamwork. The inclusion of “Guest lectures by industry professionals” (51 responses) also indicates that students value learning from real-world practitioners who can bridge the gap between academic concepts and professional practice.

Accordingly, the data suggests that students favor active, applied, and collaborative learning experiences to enhance their understanding of BIM and sustainable design. These insights highlight a pressing need for academic programs to prioritize hands-on software training, integrate real-world case studies, foster interdisciplinary collaboration, and engage industry professionals to enhance their educational experience.

The results from the survey question, “Does your theoretical knowledge of BIM and sustainable design align with your practical ability to apply these concepts in real-world construction projects?” highlight a noticeable gap between academic learning and practical application among students (Figure 9).

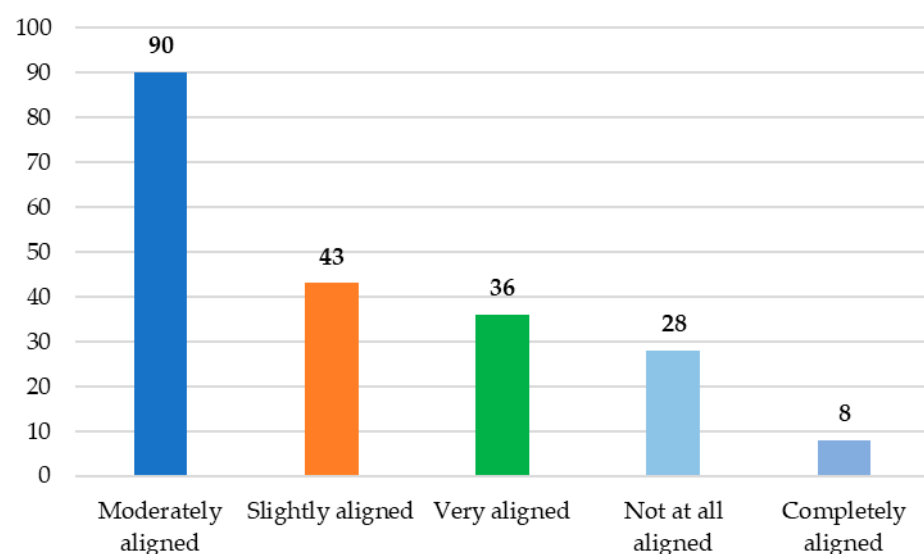


**Figure 9.** Student Perceptions of Alignment Between Theoretical Knowledge and Practical Application of BIM in Sustainable Design (Q19). The X-axis presents the alignment categories, and the Y-axis indicates the number of respondents selecting each option.

Most responses fell within the “Moderately aligned” (90 students) and “Slightly aligned” (43 students) categories, which together represent over 60% of the total respondents. This indicates that while students gain foundational knowledge in BIM and sustainable design, many feel only partially confident in applying that knowledge in practical, real-world scenarios.

Only eight students reported that their theoretical and practical skills are “Completely aligned,” while 36 selected “Very aligned,” reflecting that a smaller proportion of students feel well-prepared to integrate these concepts into practice. Conversely, 28 students felt “Not at all aligned,” which suggests that a significant minority of learners experience a complete disconnect between what is taught and what is practically usable.

These findings underscore the need for curricula that better bridge the gap between theory and application, particularly by increasing exposure to hands-on BIM training, real-world project simulations, and interdisciplinary collaboration. Such enhancements would not only improve student preparedness but also foster greater confidence and competence in leveraging BIM for sustainable design in professional contexts.

The analysis of responses to the survey question, “Can you provide an example of a real or simulated project where you successfully applied BIM for sustainable design

principles?” reveals a range of student experiences and preparedness levels regarding the integration of BIM with sustainable design practices. A portion of the students demonstrated the direct application of BIM in real or simulated projects, citing specific examples such as using BIM to coordinate LEED-based design, create Heating, Ventilation, and Air Conditioning (HVAC) systems, or integrate solar panels and rainwater harvesting systems. These responses indicate that some students are successfully bridging theory and practice by applying digital modeling tools to achieve tangible sustainability outcomes. This group demonstrates growing competence in utilizing BIM to address complex environmental and energy-related considerations within design workflows. However, a considerable number of students responded with “no”, suggesting they have not had the opportunity or confidence to engage in such applications. This highlights a potential gap in hands-on or PBL within current curricula, where exposure to real-world interdisciplinary simulations is limited. Therefore, as the presence of meaningful project examples demonstrates positive curriculum outcomes for some, the overall variation in response quality highlights a need for stronger experiential learning, structured reflection, and real-world simulation in BIM and sustainable design education. Such improvements would ensure more students can confidently describe how they have applied these concepts in practice.

### 5.1.3. Curriculum Integration of BIM and Sustainable Design for Applied Learning (RQ3)

Figure 10 presents student responses to the question: “Which are the most important resources for an understanding of BIM and sustainable design?” and provides valuable insights into perceived educational impact.

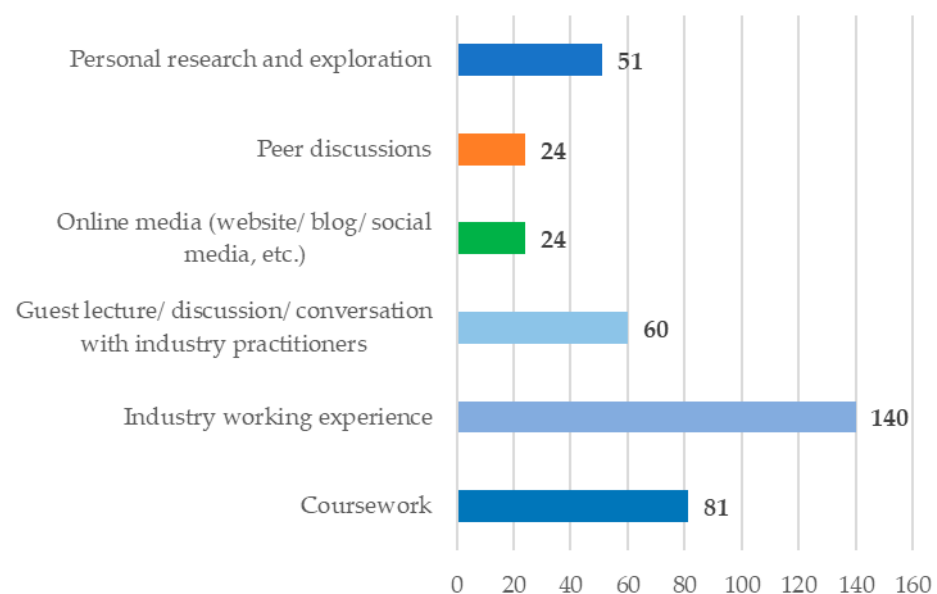


**Figure 10.** Most Valued Learning Resources for Understanding BIM and Sustainable Design According to Students (Q10). The Y-axis lists the resource categories, and the X-axis shows the number of respondents selecting each option.

The most cited resource, by far, is industry work experience, with 140 mentions, accounting for most student preferences. This suggests that real-world, hands-on exposure is seen as the most effective way to understand and apply BIM and sustainability concepts. Following this, 81 students selected coursework, indicating that while academic instruction is essential, it may not be sufficient on its own without practical application.

Guest lectures and industry conversations (60 mentions) also ranked high, reinforcing the value students place on direct interaction with professionals. Personal research and exploration (51 mentions) also played a notable role, showing that motivated learners

seek out their learning opportunities. Meanwhile, online media and peer discussions were less frequently selected (24 mentions each), showing limited reliance on informal or alternative sources.

These results highlight a clear message: while formal education is foundational, students place the most outstanding value on experiential learning through industry exposure and real-world interaction. To improve curriculum effectiveness, programs should focus more on integrating internships, practitioner engagement, and the application of PBL into BIM and sustainability education.

The survey results for the question “To what extent do you feel your coursework has prepared you to apply BIM concepts to real-world sustainable design projects?” reveal a nuanced but critical insight into current educational effectiveness.

According to Figure 11, most students (145 out of 213 responses, or approx. 68%) rated themselves as only moderately or slightly prepared, indicating that while some foundational understanding exists, it may not be sufficient for confident real-world application. Only 34 students (16%) felt very prepared, and a mere seven students (3%) reported being extremely prepared, highlighting a significant gap in deep, practice-ready competence. Meanwhile, 27 students (13%) reported being completely unprepared, suggesting that some students may be completing their coursework without gaining meaningful exposure to BIM in sustainable design contexts.

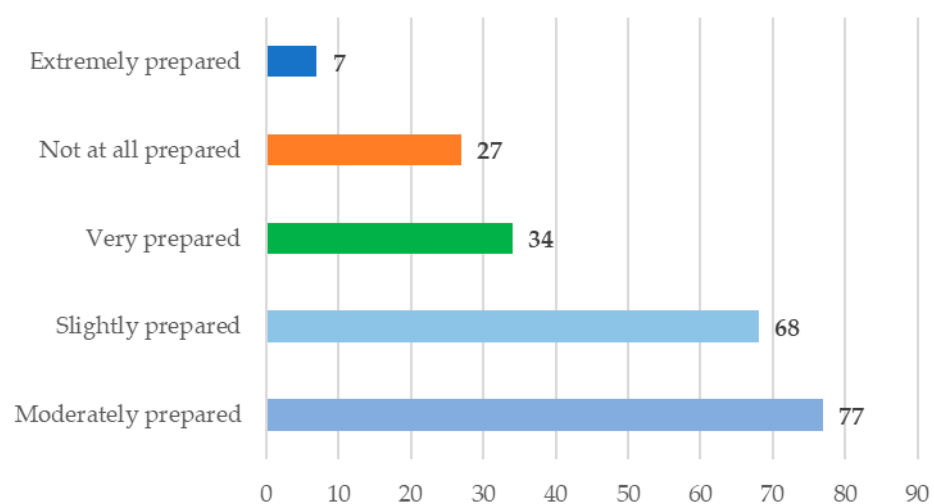


**Figure 11.** Student Perceptions of Coursework Preparedness in Applying BIM to Sustainable Design Projects (Q9). The Y-axis lists the preparedness levels, and the X-axis indicates the number of respondents selecting each option.

Table 2 shows the qualitative themes derived from open-ended responses to survey items (Q22), which invited students to reflect on their experiences, challenges, and suggestions for improving BIM and Sustainable Design education. Responses were coded using *NVivo 14* following a three-phase thematic analysis (initial, axial, and selective coding) as outlined in Section 4.1. The resulting themes represent recurring patterns in students’ written reflections rather than numerical frequency counts. Interestingly, the open-ended responses to Q22 revealed five dominant themes that reflect students’ distinct perspectives and expectations about the future of BIM in sustainable design. A majority expressed confidence in the growth and widespread adoption of BIM, noting that “more software and applications are being applied for sustainable design” and that its use will “only increase” in the future (“more software and applications...”; “will only increase”). In addition, students frequently emphasized BIM’s essential role in achieving sustainability objectives, describing it as a “must to keep in front of all the tools for sustainable design” and as

a “necessary component” for greener practices (“I think it is a must...”; “necessary for sustainability”). However, the data also revealed a thread of skepticism or uncertainty, with several respondents simply stating, “not sure,” “no,” or expressing unclear sentiments about BIM’s relevance (“unsure,” “no,” “not sure”). Meanwhile, other students pointed to more specialized uses, recognizing BIM’s potential in energy modeling and performance optimization (“energy savings analysis”) and anticipating continued technological advancements through new software and applications that support sustainability workflows (“more software and applications are applying...”). The outcomes underscore the importance of enhancing BIM education through experiential learning and integrated curriculum design, which not only reinforces theoretical knowledge but also cultivates real-world competency in sustainable design practices.

**Table 2.** Emergent qualitative themes from open-ended survey responses (Q22) on students’ experiences and recommendations for integrating BIM and Sustainable Design in education.

| No. | Description                                        | Sample Keywords/Phrases                            | Frequency |
|-----|----------------------------------------------------|----------------------------------------------------|-----------|
| 1   | BIM use will increase in future SD applications    | increase, grow, more, progress, expanding          | 30        |
| 2   | BIM will be essential for sustainability goals     | sustainable, essential, necessary, must, important | 26        |
| 3   | BIM aids energy modeling and performance tracking  | energy, performance, efficiency, savings           | 8         |
| 4   | Emergence of new tools and applications for BIM-SD | software, applications, tools, technology          | 8         |
| 5   | Skeptical or unsure about BIM-SD trends            | no, not, unsure, do not know                       | 18        |

*Note:* Table 2 uses the results of the open-ended survey question to highlight key themes in students’ views on the future of BIM in sustainable design.

Accordingly, these results indicate a need to enhance and standardize BIM and sustainability curricula, particularly by integrating more hands-on projects, real-world applications, and interdisciplinary collaboration. Doing so would not only bridge the gap between theory and practice but also better align student preparedness with industry expectations for sustainable, technology-driven design solutions.

#### 5.1.4. Barriers to Applying BIM in Sustainable Design Practice (RQ4)

The research question concerns the barriers and challenges students face in translating their BIM knowledge into practical, sustainable design applications in the industry. The survey addressed this via a multiple-choice question asking respondents to select all applicable barriers from a list (and an “Other” option for additional input). Table 3 provides descriptive statistics for each barrier. Again, each barrier is treated as a binary variable (1 = selected as a challenge, 0 = not selected). Hence, the “Mean” represents the proportion of students who identified that barrier, and “Sum” is the count of students (out of 213) who selected it.

The most prevalent barrier is a lack of hands-on experience: 128 students (60% of the sample) reported this as an obstacle to applying BIM for sustainable design. This finding resonates strongly with RQ3’s results (where few felt they had sufficient practical training). The next most common hurdles are limited access to BIM software (selected by 74 students, approx. 35%) and insufficient industry exposure to real projects (69 students, approx. 32%). These findings suggest that many students have not had ample opportunities or resources to practice BIM in realistic settings. This is due to limited software availability and a

lack of internships and industry linkages, which hinders their ability to apply BIM skills in practice.

**Table 3.** Barriers Preventing Effective Use of BIM in Sustainable Design.

| No.                                             | N   | Min | Max | Mean   | Std    | Variance | Sum |
|-------------------------------------------------|-----|-----|-----|--------|--------|----------|-----|
| Lack of hands-on experience                     | 213 | 0   | 1   | 0.6009 | 0.4897 | 0.2398   | 128 |
| Limited access to BIM software                  | 213 | 0   | 1   | 0.3474 | 0.4761 | 0.2267   | 74  |
| Insufficient industry exposure                  | 213 | 0   | 1   | 0.3239 | 0.4680 | 0.2190   | 69  |
| Limited Integration of BIM in Curriculum        | 213 | 0   | 1   | 0.2535 | 0.4350 | 0.1892   | 54  |
| Time constraints (e.g., project time/schedule)  | 213 | 0   | 1   | 0.2347 | 0.4238 | 0.1796   | 50  |
| Inadequate training resources (instr./guidance) | 213 | 0   | 1   | 0.1690 | 0.3748 | 0.1404   | 36  |
| Complexity of sustainable design principles     | 213 | 0   | 1   | 0.1549 | 0.3618 | 0.1309   | 33  |
| without                                         | 213 | 0   | 1   | 0.1268 | 0.3327 | 0.1107   | 27  |
| Technological infrastructure limitations        | 213 | 0   | 1   | 0.1033 | 0.3043 | 0.0926   | 22  |
| Others                                          | 213 | 0   | 1   | 0.0376 | 0.1901 | 0.0361   | 8   |

*Note:* Number of responses (N), minimum and maximum observed ratings, mean, standard deviation (Std), variance, and “Sum” = number of respondents who selected the barrier (multiple selections were allowed, so totals sum to more than 213).

About a quarter of respondents (approx. 25%) indicated “limited integration of BIM in the curriculum” as a challenge, which aligns with the notion that their coursework may not have entirely woven BIM with sustainability (as evidenced by moderate preparedness ratings). A similar proportion (23.5%) cited time constraints (likely to refer to the limited time available within courses or projects to delve into BIM for sustainability) as a limiting factor.

Factors such as inadequate training resources or guidance (17%) and the complexity of sustainable design principles themselves (15%) were less frequently chosen, suggesting that while these issues exist for some, they are not the primary roadblocks for most students. Lack of feedback and assessment in BIM tasks (selected by only 13%) and technological infrastructure limitations (10%) were the least commonly reported predefined barriers. Very few students (only eight individuals, approx. 4%) wrote in an “Other” barrier beyond the provided categories, implying the list captured the most common issues. The open-ended comments for “Others” varied but did not reveal any single prominent additional barrier.

Concurrently, the descriptive statistics for RQ4 indicate that the key challenges are both experiential and institutional: students feel they lack sufficient hands-on practice and real-world exposure, and many note shortcomings in resources or the integration of curriculum. These barriers highlight why, even with generally positive attitudes about BIM’s potential (RQ1), students are not fully confident in practice (RQ3); they have not had sufficient practical immersion. Notably, these trends were consistent across different student subgroups; for example, “lack of hands-on experience” was the top barrier regardless of whether the student was in a significant year. Addressing these issues (e.g., by providing more lab work, software access, industry partnerships, and integrating BIM throughout the curriculum) would likely enhance students’ ability to apply BIM for sustainable design in the construction industry.

## 5.2. Discussion of Findings

### 5.2.1. Interpreting Knowledge and Confidence Gaps in Early-Stage BIM for Sustainability

The student perceptions correspond well with the literature on BIM’s application in early design for sustainability. Prior research confirms that many sustainability outcomes (energy use, thermal comfort, daylight availability) are primarily decided by early design choices. BIM enables architects and engineers to evaluate these choices quantitatively during conceptual design by linking the 3D model with analysis tools. For example, Abdelhameed (2017) demonstrated an approach where a BIM model was used in initial

design phases to analyze site layout, building orientation, and form for energy efficiency before finalizing details [2]. By iteratively testing alternatives in BIM (e.g., rotating a building mass to improve solar gain, or comparing different massing options), designers can make informed decisions that significantly improve sustainability metrics early on. Findings related to RQ1 indicate that students understand BIM's sustainability potential but lack early-design application experience. The fact that students overwhelmingly recognize BIM's value in these tasks is encouraging; it implies that current curricula or their own experiences (perhaps through internships or self-learning) have conveyed BIM's early-stage capabilities. Many respondents, for instance, cited BIM's ability to conduct energy modeling and daylight simulations as a reason for their agreement (based on open-ended feedback), showing an understanding that these integrations can optimize a building's performance from the ground up.

However, recognizing a tool's value is not the same as being able to use it effectively. One concern is whether students have had sufficient hands-on practice with early-stage BIM sustainability analyses. Some students noted that while they learned about tools like Autodesk Insight (for energy modeling) in theory, they never used them in a project setting. This highlights a potential gap between knowing and doing; students might conceptually appreciate BIM's role early in design but may not be adept at executing such analyses themselves. Educational strategies should therefore focus on embedding more practical exercises in early design stages. For instance, instructors could incorporate a preliminary design assignment that requires students to use BIM to compare the energy implications of two massing options for the same project. This would reinforce classroom teaching with experiential learning, helping to solidify the integration of BIM tools in the early design phase. Studies have shown that when students engage in simulation-based exercises, their understanding of sustainable design principles improves, and they become more proficient in using BIM to make informed design trade-offs. Our findings suggest that students are ready and eager for this kind of applied learning; they want to use BIM early and see the benefits, so the onus is on curricula to provide those opportunities. Embedding "what-if" sustainability analyses in BIM environments may help narrow the gap between perception and practice. for RQ1. Therefore, BIM can be effectively integrated into early design education by providing students with guided, hands-on experiences in using BIM-based analysis tools to inform design decisions, thereby translating their positive perceptions into practical skills.

#### 5.2.2. BIM as a Collaborative Learning Platform with Curriculum and Pedagogical Implications

These findings align with the well-documented collaborative nature of BIM. In professional practice, BIM serves as a centralized platform where architects, engineers, contractors, and consultants can contribute and extract information from a single, integrated model. This shared digital environment breaks down traditional silos by enabling real-time coordination: architects can view structural or mechanical components in the model, engineers can visualize architectural design intents, and sustainability experts can integrate performance data, all in one place. As a result, BIM projects often experience improved communication and fewer misunderstandings among disciplines. These facts support the students' perception that BIM facilitates interdisciplinary collaboration. Even if they have not personally worked together with, for example, an architect and an energy modeler, they have learned that BIM provides a "common language" (in 3D and data) for such collaboration.

In the educational context, however, providing actual interdisciplinary BIM experiences can be challenging. Architecture and engineering programs are frequently separate, with distinct courses and project work. Some pioneering educational efforts have attempted to create joint classes or projects, for example, pairing architecture students with construc-

tion management students to design and construct a virtual building. Luo and Wu's integrated PBL study is one such example, where students from two different classes, for instance, one focused on design, one on engineering, collaborated on a sustainable building project using BIM [30]. They found that this approach not only improved students' BIM skills but also cultivated stronger teamwork and communication across disciplines, essentially training students in the kind of interdisciplinary collaboration that the industry now expects. Our study's results show that students value this aspect of BIM; even without many formal opportunities, they intuitively or experientially understand that a BIM-centric workflow is more collaborative. Some students wrote that they "wished we did more group projects with mixed majors to simulate real BIM collaboration," highlighting a desire for interdisciplinary learning opportunities.

To leverage BIM's collaborative potential in academia, curriculum developers should consider creating multidisciplinary project experiences that incorporate BIM. This could involve interdepartmental courses where architecture, construction management, and engineering students collaborate on a common project, each utilizing BIM to contribute their respective components (design, cost estimation, energy analysis, etc.). If organizing a joint course is not feasible, another strategy is to utilize BIM collaboration software (such as Autodesk BIM 360 or Revit's work-sharing feature) within a single class and assign students different roles on a project team. Even if all students are from the same program, assigning roles (e.g., "you are the sustainability consultant, you are the structural engineer") and having them coordinate in BIM can effectively mimic the interdisciplinary process. The literature suggests that such collaborative assignments not only build technical skills but also "soft" skills, such as communication and teamwork, which are critical for achieving sustainable design outcomes that require input from various experts. By practicing collaboration via BIM in school, students can better transition to industry teams where BIM is the cornerstone of project coordination.

### 5.2.3. Integrating BIM and Sustainability Through Curriculum Design and Pedagogical Strategies

The notion of a "standardized curriculum" integrating BIM and sustainable design is supported by numerous calls in academic literature to break down curricular silos. Lee et al. (2019) proposed a systematic course development for BIM in construction engineering education to ensure students build competencies in a structured way [39]. While their focus was generally on BIM, later educators have extended this systematic thinking to include sustainability. The authors of this study document the development of an integrated curriculum for construction engineering where each year's courses link BIM and sustainability concepts, from basic principles to advanced project-based applications. The benefit of a standardized or well-planned sequence is that students continually reinforce and deepen their skills. Our findings, which reveal uncertainty in preparedness when BIM and sustainability are taught separately, align with the caution of these researchers: unconnected courses leave students to make the connections on their own, which many will not do effectively. Conversely, when the curriculum is intentionally designed to integrate these topics, students experience repeated, contextualized practice of BIM in sustainable design scenarios, leading to greater competence. This was evidenced by the students who took the integrated elective; their higher confidence aligns with what Kim (2014) observed: students who underwent the Green-BIM integrated teaching showed improved learning outcomes and felt more capable in sustainability tasks [28].

A standardized integrated curriculum could take many forms, but specific strategies are commonly recommended. One strategy is to introduce sustainability problems in BIM classes and vice versa. For example, when teaching BIM, assignments include tasks that require students to model a building and then perform an energy analysis on it, rather

than just modeling for visualization purposes. When teaching sustainable design concepts, students are required to implement a solution in a BIM model, rather than just writing about it. This approach aligns with experiential learning theory, suggesting that application solidifies understanding. Recent research has shown that such practical integration leads to improved student competencies. Atabay et al. (2020) found that when students used BIM to conduct sustainability analyses as part of their coursework, their test scores on sustainability concepts improved compared to a control group that learned sustainability concepts without the use of BIM [33]. This improvement was attributed to the concrete experience provided by the BIM exercise. Our survey results support this: those who had an integrated learning experience (even one elective) felt more able to apply concepts, implying better learning outcomes.

Another aspect of standardizing the curriculum is ensuring consistency, rather than leaving integration to chance, which may occur with a particular instructor or elective. Currently, as some students lamented, if you have a specific professor who likes BIM, you get that exposure; otherwise, you might not. This patchwork can be remedied by program-level curriculum design. Academic departments could develop a curriculum map that identifies where and how BIM and sustainability learning outcomes intersect, ensuring that each student encounters these intersections multiple times throughout their education. Some universities have begun formulating such interdisciplinary curriculum guidelines, sometimes supported by accreditation bodies or industry advisory boards, stressing the importance of BIM and sustainability competencies [21].

The improvement in students' ability when taught under an integrated curriculum is ultimately evident in their project work and the confidence they demonstrate in tackling real-world projects. In our study, the group of students with integrated course experience could point to concrete projects in their portfolio (e.g., "I modeled a net-zero energy library in Revit and analyzed its performance") as evidence of their ability, which will undoubtedly help them in job interviews and the workplace throughout their education. By eliminating gaps and redundancies (where BIM and sustainability might otherwise be taught separately), such a curriculum produces a more cohesive learning experience. Students emerge not just with fragmented knowledge of BIM or green building, but with a synthesized skill set, such as knowing how to use a BIM model to conduct an energy simulation and then make design decisions based on the results. Our findings suggest support for moving in this direction, as students themselves recognize the value of integration and demonstrate higher competence when they experience it.

#### 5.2.4. Barriers and Institutional Challenges in Translating BIM Knowledge to Sustainable Practice

Results associated with RQ4 reveal that perceived barriers primarily stem from limited institutional support and training. The challenges identified by the students mirror those reported in academic research and by educators. One well-documented challenge in BIM education is the steep learning curve associated with the software and its processes. It takes considerable time for students (and instructors) to become proficient in BIM tools. Adding the complexity of sustainability analysis, which may involve multiple software platforms or advanced simulation concepts, can overwhelm an already tight course schedule. As a result, instructors might focus on either BIM or sustainability, but not both in depth, leaving students with a less integrated skill set. This is a curricular barrier. Furthermore, faculty expertise can be a barrier: not all instructors are equally comfortable with both BIM technology and sustainability content. If a program lacks faculty who specialize in the overlap, students may not receive cutting-edge instruction in that area. This aligns with the literature's call for faculty development and training to keep pace with technological and pedagogical advancements.

Another barrier is the limited academic-industry linkage. Academic construction sometimes lags behind the industry in adopting new practices. As BIM workflows for sustainability become industry-standard, academia must catch up. Students in our survey hinted at this by suggesting more industry involvement. Prior studies also note that partnerships with industry (through guest lectures, sponsored projects, internships) can alleviate some educational shortcomings by providing students with practical contexts and access to current technology. For instance, if a university lacks specific software, an industry partner might provide temporary licenses or datasets for students to work with. Additionally, industry projects inherently present interdisciplinary, real-world challenges, exposing students to precisely the kind of complexity that purely academic projects might simplify.

Translating BIM knowledge into practice requires overcoming the barrier of isolation: knowledge needs context for application. One way to surmount this is through capstone projects or integrative assignments that simulate real project delivery. Many programs include a capstone course in the final year, ensuring that BIM and sustainability are part of that capstone. This could force students to reconcile theory with practice. For example, requiring a LEED certification analysis of the capstone project using BIM models would push students to apply what they learned in both domains. The barrier here is often that capstone instructors have to coordinate multiple aspects (design, engineering, management); however, if done well, it is an intense culmination of learning.

Time constraints in curricula are indeed a challenge, but some educators have responded by streamlining content and eliminating redundancies. If BIM is taught across multiple courses, perhaps the intro courses can offload specific topics to later ones (or vice versa) to make room for sustainability integration. There is also the possibility of utilizing extracurricular avenues, such as student competitions (like the Solar Decathlon or Green Building competitions), which require BIM, to encourage students to practice skills beyond the classroom. A few students in our survey mentioned participating in such competitions; they found them very helpful, although they joined for the experience rather than because it was embedded in the curriculum.

Lastly, it is essential to address the psychological barrier: confidence. Our data show that not all students feel confident, and this often stems from a lack of repetition and success in completing tasks. By gradually increasing the difficulty of BIM tasks related to sustainability throughout the curriculum (scaffolding), students can build confidence. Early on, a simple exercise (like analyzing daylight in one room) can later lead to a full-building energy model in a design studio project. Each successful step can reduce the intimidation factor. Educators, as Fadeyi (2017) observed, found that students who engaged in incremental BIM-sustainability assignments felt more ownership of sustainable design problems and were less daunted by the technology at the end of the term [27]. This supports the idea that systematically structured experiences help break down barriers to practical application.

As a result, the barriers to translating BIM knowledge into sustainable design practice are real but addressable. They include limited practical exposure, curricular separation of topics, technical/software difficulties, and insufficient collaboration with industry or across disciplines. Our findings reinforce recommendations for overcoming these challenges: integrating BIM and sustainability throughout the curriculum (to provide practical experience), fostering collaboration (both among different student groups and with industry mentors), investing in up-to-date tools and faculty training, and providing students with opportunities to apply their skills in realistic scenarios. By doing so, educational institutions can turn out graduates who not only understand BIM's role in sustainability in theory but can also confidently implement BIM-based solutions to real sustainability challenges in construction projects.

## 6. Recommendations & Future Research

### 6.1. Recommendations

The results of this survey provide valuable insights into the current state of BIM and sustainable design education. While students have a solid understanding of the theoretical aspects of BIM and its role in sustainable design, there are apparent gaps in their ability to apply this knowledge in real-world projects. The analysis recommends that BIM-based curricula should be revised for the following reasons:

- To provide more hands-on experience with BIM tools, especially in sustainable design contexts.
- To better prepare students for real-world applications, BIM curricula need to incorporate more hands-on projects, particularly those focused on energy modeling, life cycle assessment, and material optimization.
- Industry exposure is critical for students to understand how BIM is applied in real-world sustainable design scenarios. Integrating internships, guest lectures, and industry collaboration into the curriculum would significantly improve students' preparedness.

This data analysis and subsequent recommendations aim to help educators refine their teaching methods and equip students with the necessary tools to effectively utilize BIM in advancing sustainability goals within the construction industry. The findings also underscore the need for a more integrated approach to teaching BIM and sustainable design, which combines technical proficiency with sustainability principles. By bridging the gap between theoretical knowledge and practical application, educational programs can better prepare students to tackle the challenges of sustainable design in the AEC industry.

### 6.2. Future Research Directions

Building on the findings of this study, future research should focus on evaluating the long-term impact of BIM-sustainability education and expanding its interdisciplinary scope. Longitudinal studies tracking graduates' professional application of BIM and sustainability principles would provide evidence of how effectively integrated curricula translate into real-world competence. Research could assess whether graduates continue to perceive gaps between academic preparation and professional practice over time, thereby validating the long-term effectiveness of curriculum interventions.

Additionally, further investigation is needed into practical strategies for teaching BIM during the conceptual and early design stages, where sustainability outcomes are most influenced. Experimental studies could test the use of advanced BIM tools (like generative design or parametric modeling) to enhance students' design thinking, decision-making, and engagement with sustainability concepts.

Cross-disciplinary collaboration also remains an important research area. Future studies could compare learning outcomes between joint architecture–engineering or construction courses and traditional discipline-specific courses to determine the educational value of integrated project experiences.

Finally, as technology and industry practices continue to evolve, research should examine the integration of emerging BIM-based tools, such as cloud collaboration platforms, parametric modeling environments, and AI-assisted workflows, into sustainability education. These investigations would guide the development of adaptive, data-driven curricula that better prepare students for the digital and sustainable future of the construction industry.

## 7. Conclusions

The construction industry is undergoing a notable shift toward more sustainable, digital, and performance-driven practices. This shift, driven by climate change, regulatory

pressures, and the demand for resilient infrastructure, underlines the growing importance of integrating BIM with sustainability principles in higher education curricula.

This study contributes to the body of knowledge by investigating the gap between students' perceptions and the practical application of BIM in sustainable design, revealing consistent patterns of strengths, weaknesses, and learning needs across both Architecture and Construction Management programs. While the scope of this research was limited to two departments, underlying issues such as the need for more hands-on training, interdisciplinary collaboration, and stronger industry engagement are challenges that extend well beyond the case study context. In other words, the identified gaps represent persistent barriers in construction-related education globally. Because of this broader relevance, these findings are essential for higher education institutions seeking to align curricula with the evolving demands of the construction industry, particularly in terms of ensuring that graduates hold integrated BIM and sustainability competencies.

By linking perception analysis with curriculum recommendations, this study provides actionable guidance for integrating BIM and sustainability in higher education. To address these challenges, the results underscore the value of embedding applied BIM-sustainability projects early in the curriculum, supported by experiential and collaborative learning, early-stage performance simulations, and real-world case studies. In addition, the study reinforces the importance of partnering with universities for the industry to co-develop training ecosystems that mirror real-world practices and provide feedback loops that enhance graduate readiness. Similarly, for policymakers and accreditation bodies, the findings suggest that BIM and sustainability learning outcomes should be explicitly incorporated into program standards to prepare the future workforce better.

By providing evidence-based insights into effective teaching methods and barriers to practical application, this research contributes meaningfully to the broader impact on how to equip graduates with the interdisciplinary skills and technological literacy needed for a sustainable built environment. Looking ahead, future studies should expand this analysis to diverse institutions, disciplines, and geographic contexts to validate these findings and refine implementation strategies. Ultimately, enhancing BIM education should be considered a strategic priority for preparing the next generation of sustainability-literate professionals who can drive the green transformation of the built environment.

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## Appendix A. Survey Questionnaires

Title of Research Study: Analyzing Students' Understanding and Application of Building Information Modeling (BIM) in Sustainable Design (SD) within Academic Curriculum

Consent Form: This study aims to understand students' literacy, acceptance, and use of BIM technology in SD within Architecture, Engineering, and Construction (AEC) education. The survey results will assist faculty in identifying curriculum requirements and improving integration of BIM for sustainability.

Duration: Approximately 5–10 min

Risks: None. All responses are anonymous; no identifiable information is collected.

Voluntary Participation: Participants may withdraw at any time without penalty.

Benefits: Findings will guide improvements in BIM and sustainable design education.

Compensation: None.

Eligibility: Participants must be 18 years or older.

By selecting "I agree to participate", participants provide their informed consent.

### Section A–Demographic Questions

Q1- What is your age?

(a) 18–24 (b) 25–34 (c) 35–44 (d) 45–54 (e) 55–64 (f) 65+

Q2- What is the focal area of your current study?

(a) Architecture (b) Construction Management (c) Civil Engineering

(d) Building Construction (e) Other

Q3- In which year are you currently enrolled?

(a) Undergraduate (1st–5th year) (b) Graduate (1st–2nd year)

Q4- Gender:

(a) Male (b) Female (c) Non-binary (d) Prefer not to say

Q5- Race/Ethnicity:

(a) White (b) Black/African American (c) Latino/Hispanic (d) Asian

(e) American Indian/Alaska Native (f) Other (g) Prefer not to say

### Section B–Perception Questions

Q6- How would you rate your current understanding of BIM (VDC/DDC)?

(a) Very Limited (b) Limited (c) Moderate (d) Good (e) Excellent

Q7- Do you believe BIM significantly enhances sustainable design and construction?

(a) Definitely Not (b) Probably Not (c) Might or Might Not (d) Probably Yes

(e) Definitely Yes

Q8- Can you explain the connection between BIM and sustainable design?

(a) No (b) Maybe (c) Yes (d) Yes, confidently

Q9- To what extent has your coursework prepared you to apply BIM in real-world sustainable design projects?

(a) Not at all (b) Slightly (c) Moderately (d) Very (e) Extremely

Q10- Which resources contribute most to your understanding of BIM and sustainable design?

(a) Coursework (b) Industry Experience (c) Guest Lectures (d) Online Media

(e) Peer Discussion (f) Personal Research (g) Other

Q11- Do you agree that BIM supports the following sustainable design aspects?

(Building orientation, massing, daylighting, water harvesting, sustainable materials, equipment, site/logistics, energy modeling)

(a) Strongly Disagree (b) Disagree (c) Neutral (d) Agree (e) Strongly Agree

Q12- How familiar are you with BIM tools for sustainable design (e.g., Tally, Radiance, Insight, Revit, Athena)?

(a) Not at all (b) Slightly (c) Moderately (d) Very (e) Extremely

Q13- How often do you use BIM in the following sustainability areas?

(Site Development, Water Efficiency, Energy Efficiency, Materials & Resources, Indoor Quality, Project Management, Emissions & Equipment)

(a) Never (b) Sometimes (c) Half the Time (d) Most of the Time (e) Always

Q14- What benefits have you gained from understanding BIM and Sustainable Design?

(a) Improved Technical Skills (b) Enhanced Teamwork

(c) Ability to Analyze Materials/Equipment (d) Improved Energy Knowledge (e) Other  
Section C–Learning Effectiveness

Q15- Have you completed any BIM-related coursework or projects for sustainable design?

(a) Yes (b) No

Q16- If yes, how effective were the learning methods?

(a) Not Effective (b) Slightly (c) Moderately (d) Very (e) Extremely

Q17- Which learning strategies best supported your understanding?

(a) Lectures (b) Software Labs (c) Group Projects (d) Case Studies (e) Guest Lectures  
(f) Other

Q18- Did you receive sufficient hands-on training in BIM software for sustainable design?

(a) Yes (b) Maybe (c) No

Section D–Perception vs. Practice

Q19- Does your theoretical knowledge align with your practical ability to apply BIM for sustainability?

(a) Not at all (b) Slightly (c) Moderately (d) Very (e) Completely

Q20- Provide an example of a project where you applied BIM for sustainable design:

[Open-ended Response]

Q21- What barriers limit your ability to apply BIM for sustainable design?

(a) Lack of Experience (b) Limited Software Access (c) Insufficient Industry Exposure  
(d) Time Constraints (e) Complexity of Principles (f) Lack of Feedback

(g) Limited Curriculum Integration (h) Inadequate Resources (i) Other

Q22- What do you think about the future trend of BIM and sustainable design?

[Open-ended Response]

Section E–Knowledge Assessment (Optional)

Q23- What does “BIM” stand for?

(a) Building Information Modeling (b) Building Integration Management

(c) Building Inspection Model (d) Business Information Model

Q24- Name two sustainability metrics commonly used in sustainable design.

(a) LEED (b) Energy Modeling (c) HVAC (d) ROI (e) Other

Q25- If this survey is completed as part of class credit, please include your course name and section (e.g., Spring 2025 CM 4710–Section 01).

[Open-ended Response]

*Note:* The survey was approved by the Institutional Review Board (IRB) and administered online using Qualtrics between 12 April 2024, and 20 April 2025. All responses were anonymous and voluntary.

## References

1. Afzal, M.; Li, R.Y.M.; Ayyub, M.F.; Shoaib, M.; Bilal, M. Towards BIM-Based Sustainable Structural Design Optimization: A Systematic Review and Industry Perspective. *Sustainability* **2023**, *15*, 15117. [[CrossRef](#)]
2. Abdelhameed, W. Sustainable Design Approach: A Case Study of BIM Use. *E3S Web Conf.* **2017**, *23*, 02001. [[CrossRef](#)]
3. Abdirad, H.; Dossick, C.S. BIM Curriculum Design in Architecture, Engineering, and Construction Education: A Systematic Review. *J. Inf. Technol. Constr. ITcon* **2016**, *21*, 250–271.

4. Bynum, P.; Issa, R.R.A.; Olbina, S. Building Information Modeling in Support of Sustainable Design and Construction. *J. Constr. Eng. Manag.* **2013**, *139*, 24–34. [[CrossRef](#)]
5. Wu, W.; Luo, Y. (Vivien) Pedagogy and Assessment of Student Learning in BIM and Sustainable Design and Construction. *J. Inf. Technol. Constr. ITcon* **2016**, *21*, 218–232.
6. Allied Market Research, A.M.R. Allied Market Research. Available online: <https://www.alliedmarketresearch.com/building-information-modeling-market> (accessed on 14 October 2025).
7. Zhang, J.; Schmidt, K.; Li, H. BIM and Sustainability Education: Incorporating Instructional Needs into Curriculum Planning in CEM Programs Accredited by ACCE. *Sustainability* **2016**, *8*, 525. [[CrossRef](#)]
8. Nguyen, T.D.; Adhikari, S. Perception of Students' Understanding of BIM with Sustainable Design. In Proceedings of the 2022 ASEE Annual Conference & Exposition, Minneapolis, MN, USA, 26–29 June 2022.
9. Gerber, D.J.; Khashe, S.; Smith, I.F.C. Surveying the Evolution of Computing in Architecture, Engineering, and Construction Education. *J. Comput. Civ. Eng.* **2015**, *29*, 04014060. [[CrossRef](#)]
10. Wu, W.; Issa, R.R.A. BIM Education and Recruiting: Survey-Based Comparative Analysis of Issues, Perceptions, and Collaboration Opportunities. *J. Prof. Issues Eng. Educ. Pract.* **2014**, *140*, 04013014. [[CrossRef](#)]
11. Porter, D. Integrating BIM into Construction Management Education. In Proceedings of the EcoBuild Proceedings of the BIM-Related Academic Workshop, Salford, UK, 30 June–2 July 2010.
12. Pikas, E.; Sacks, R.; Hazzan, O. Building Information Modeling Education for Construction Engineering and Management. II: Procedures and Implementation Case Study. *J. Constr. Eng. Manag.* **2013**, *139*, 05013002. [[CrossRef](#)]
13. Alasmari, E.; Martínez-Vázquez, P.; Baniotopoulos, C. Building Information Modeling (BIM) towards a Sustainable Building Design: A survey. In Proceedings of the 3rd Coordinating Engineering for Sustainability and Resilience, CESARE 2022, Irbid, Jordan, 6–9 May 2022.
14. Al-Atroush, M.E.; Ibrahim, Y.E. Role of Cooperative Programs in the University-to-Career Transition: A Case Study in Construction Management Engineering Education. *Int. J. Eng. Educ.* **2022**, *38*, 181–199.
15. Ferdosi, H.; Abbasianjahromi, H.; Banihashemi, S.; Ravanshadnia, M. BIM Applications in Sustainable Construction: Scientometric and State-of-the-Art Review. *Int. J. Constr. Manag.* **2023**, *23*, 1969–1981. [[CrossRef](#)]
16. Khahro, S.H.; Kumar, D.; Siddiqui, F.H.; Ali, T.H.; Raza, M.S.; Khoso, A.R. Optimizing Energy Use, Cost, and Carbon Emission through Building Information Modelling and a Sustainability Approach: A Case-Study of a Hospital Building. *Sustainability* **2021**, *13*, 3675. [[CrossRef](#)]
17. Sanchez, B.; Ballinas-Gonzalez, R.; Rodriguez-Paz, M.X.; Nolasco-Flores, J.A. Usage of Building Information Modeling for Sustainable Development Education. In Proceedings of the 2020 ASEE Virtual Annual Conference, Virtual Online, 22–26 June 2020.
18. Liu, T.; Chen, L.; Yang, M.; Sandanayake, M.; Miao, P.; Shi, Y.; Yap, P.-S. Sustainability Considerations of Green Buildings: A Detailed Overview on Current Advancements and Future Considerations. *Sustainability* **2022**, *14*, 14393. [[CrossRef](#)]
19. Benner, J.; McArthur, J.J. Data-Driven Design as a Vehicle for BIM and Sustainability Education. *Buildings* **2019**, *9*, 103. [[CrossRef](#)]
20. Sanchez-Lite, A.; Zulueta, P.; Sampaio, A.Z.; Gonzalez-Gaya, C. BIM for the Realization of Sustainable Digital Models in a University-Business Collaborative Learning Environment: Assessment of Use and Students' Perception. *Buildings* **2022**, *12*, 971. [[CrossRef](#)]
21. Nguyen, T.D.; Adhikari, S. Integrating BIM into Sustainable Design: Perception and Awareness of Architecture and Construction Management Students. In Proceedings of the 2024 ASEE Annual Conference & Exposition, Portland, OR, USA, 23–26 June 2024.
22. Tijo-Lopez, S.; Mejía, G.; Portilla-Carreño, O. Inclusion of BIM and Sustainability in Construction Education through Capstone Design Projects. In Proceedings of the Construction Research Congress 2024, Des Moines, IA, USA, 20–23 March 2024; pp. 315–324. [[CrossRef](#)]
23. Shen, Z.; Jensen, W.G.; Fischer, B.A.; Wentz, T.G. Using BIM to Teach Design and Construction of Sustainable Buildings. In Proceedings of the 2012 ASEE Annual Conference & Exposition Proceedings, San Antonio, TX, USA, 10–13 June 2020; pp. 25.1420.1–25.1420.11.
24. Jin, R.; Yang, T.; Piroozfar, P.; Kang, B.-G.; Wanatowski, D.; Hancock, C.M.; Tang, L. Project-Based Pedagogy in Interdisciplinary Building Design Adopting BIM. *Eng. Constr. Archit. Manag.* **2018**, *25*, 1376–1397. [[CrossRef](#)]
25. Ma, J.; Tao, Y. Learning Outcomes of Civil Engineering Students in PBL Based on Building Information Modeling. *Int. J. Emerg. Technol. Learn. IJET* **2023**, *18*, 89–102. [[CrossRef](#)]
26. Adhikari, S.; Zhang, R.; Bedette, K.; Clevenger, C. Sustainability Related Issues among Construction Students: Analyzing Through Source of Knowledge, Education Preparation, and Future Aspiration. In Proceedings of the ASC 2021. 57th Annual Associated Schools of Construction International Conference, Online, 5–9 April 2021; EPiC Series in Built Environment, EasyChair. Volume 2, pp. 635–643.
27. Fadeyi, M.O. The Role of Building Information Modeling (BIM) in Delivering the Sustainable Building Value. *Int. J. Sustain. Built Environ.* **2017**, *6*, 711–722. [[CrossRef](#)]

28. Kim, J.J. Effectiveness of Green-BIM Teaching Method in Construction Education Curriculum. In Proceedings of the 2014 ASEE Annual Conference & Exposition, Indianapolis, IN, USA, 15–18 June 2014; pp. 24.459.1–24.459.11.
29. Hopfe, C.J.; McLeod, R.S.; Gustin, M.; Brembilla, E.; McElroy, L. Teaching Data Analysis for Building Performance Simulation—Series: Building Simulation and Calculation Tools in Teaching. *Bauphysik* **2022**, *44*, 285–290. [\[CrossRef\]](#)
30. Luo, Y.; Wu, W. Sustainable Design with BIM Facilitation in Project-Based Learning. *Procedia Eng.* **2015**, *118*, 819–826. [\[CrossRef\]](#)
31. Tran, T.V.; Tran, H.V.V.; Nguyen, T.A. A Review of Challenges and Opportunities in BIM Adoption for Construction Project Management. *Eng. J.* **2024**, *28*, 79–98. [\[CrossRef\]](#)
32. Nushi, V.; Basha-Jakupi, A. The Integration of “Building Information Modeling” (BIM) in Sustainable Architecture and Construction Education: Case Study in Pristina University. *Igra Ustvarjalnosti* **2017**, *5*, 52–57. [\[CrossRef\]](#)
33. Atabay, S.; Pelin Gurgun, A.; Koc, K. Incorporating BIM and Green Building in Engineering Education: Assessment of a School Building for LEED Certification. *Pract. Period. Struct. Des. Constr.* **2020**, *25*, 04020040. [\[CrossRef\]](#)
34. Maharika, I.F.; Irsan, A.; Athas, S.I.A.; Susanto, A.; Abma, V.; Yuriandala, Y. Building Information Modelling (BIM) Adoption Model for Architectural Education. *J. Des. Built Environ.* **2020**, *20*, 22–42. [\[CrossRef\]](#)
35. Lee, H.; Moon, H.; Lee, J. Establishing a Customized Framework of BIM Education Programs for Owners in South Korea. *WIT Trans. Ecol. Environ.* **2023**, *293*, 293–303. [\[CrossRef\]](#)
36. Gonzalez Alfaro, P.H.; Dimovski, N.; Lamartina, L.; de Sá, P.J. BIM Methods and CDE in Professional Education for Sustainable Design and Production. *IOP Conf. Ser. Earth Environ. Sci.* **2022**, *1123*, 012025. [\[CrossRef\]](#)
37. Carvalho, J.P.; Bragança, L.; Mateus, R. A Systematic Review of the Role of BIM in Building Sustainability Assessment Methods. *Appl. Sci.* **2020**, *10*, 4444. [\[CrossRef\]](#)
38. Kiani Mavi, R.; Gengatharen, D.; Kiani Mavi, N.; Hughes, R.; Campbell, A.; Yates, R. Sustainability in Construction Projects: A Systematic Literature Review. *Sustainability* **2021**, *13*, 1932. [\[CrossRef\]](#)
39. Lee, S.; Lee, J.; Ahn, Y. Sustainable BIM-Based Construction Engineering Education Curriculum for Practice-Oriented Training. *Sustainability* **2019**, *11*, 6120. [\[CrossRef\]](#)
40. Haruna, A.; Shafiq, N.; Montasir, O.A. Building Information Modelling Application for Developing Sustainable Building (Multi-Criteria Decision Making Approach). *Ain Shams Eng. J.* **2021**, *12*, 293–302. [\[CrossRef\]](#)
41. McCord, K.H.; Ayer, S.K.; Lamanna, A.J.; Eicher, M.; London, J.S.; Wu, W. Construction Education Needs Derived from Industry Evaluations of Students and Academic Research Publications. *Int. J. Constr. Educ. Res.* **2023**, *19*, 77–98. [\[CrossRef\]](#)
42. Cascone, S. Digital Technologies and Sustainability Assessment: A Critical Review on the Integration Methods between BIM and LEED. *Sustainability* **2023**, *15*, 5548. [\[CrossRef\]](#)
43. Chong, H.-Y.; Lee, C.-Y.; Wang, X. A Mixed Review of the Adoption of Building Information Modelling (BIM) for Sustainability. *J. Clean. Prod.* **2017**, *142*, 4114–4126. [\[CrossRef\]](#)
44. Passe, U. A Design Workflow for Integrating Performance into Architectural Education. *Build. Cities* **2020**, *1*, 565. [\[CrossRef\]](#)
45. Obi, L.I.; Omotayo, T.; Ekundayo, D.; Oyetunji, A.K. Enhancing BIM Competencies of Built Environment Undergraduate Students Using a Problem-Based Learning and Network Analysis Approach. *Smart Sustain. Built Environ.* **2022**, *13*, 217–238. [\[CrossRef\]](#)
46. Dalla Valle, A. Emerging Trends and Developments in BIM, Green BIM and LCA. In *Change Management Towards Life Cycle AE(C) Practice*; Dalla Valle, A., Ed.; Springer International Publishing: Cham, Switzerland, 2021; pp. 11–18, ISBN 978-3-030-69981-9.
47. Sharon, M. Role of Architectural BIM in Sustainable Building Design. Available online: <https://vocal.media/education/role-of-architectural-bim-in-sustainable-building-design> (accessed on 19 June 2025).
48. Braun, V.; Clarke, V. Using Thematic Analysis in Psychology. *Qual. Res. Psychol.* **2006**, *3*, 77–101. [\[CrossRef\]](#) [\[PubMed\]](#)
49. Nunnally, J.C.; Bernstein, I.H. *Psychometric Theory*; McGraw-Hill: New York, NY, USA, 1994; ISBN 978-0-07-047849-7.

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