A QUALITY FRAMEWORK DEVELOPED FOR ARTIFICIAL INTELLIGENCE INTEGRATION IN ARCHITECTURAL ENGINEERING EDUCATION

UM MARCO DE QUALIDADE DESENVOLVIDO PARA A INTEGRAÇÃO DA INTELIGÊNCIA ARTIFICIAL NA EDUCAÇÃO EM ENGENHARIA ARQUITETÔNICA

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Resumo. A rápida disseminação da Inteligência Artificial (IA) na prática arquitetônica impõe desafios significativos à educação em engenharia arquitetônica, exigindo que as instituições avancem além da adoção fragmentada de ferramentas em direção a uma integração estruturada e pedagogicamente fundamentada. Este estudo examina a prontidão institucional para a integração da IA por meio de um estudo de caso de um programa de engenharia arquitetônica na Universidade de Taif, com base em benchmarking curricular internacional e nas perspectivas de múltiplas partes interessadas. Utilizando uma abordagem de métodos mistos, a pesquisa explora as percepções de estudantes e docentes sobre a IA, os padrões existentes de integração curricular e os facilitadores e limitações institucionais que moldam sua adoção. Os achados revelam um forte reconhecimento do valor educacional da IA, particularmente no apoio à criatividade em design, à análise orientada por desempenho e à relevância profissional. No entanto, a integração da IA permanece desigual, limitada por baixa coerência curricular, capacidade docente insuficiente, lacunas de infraestrutura e uma governança estratégica e ética ainda pouco desenvolvida. Em resposta, o estudo propõe o marco AI-ArchEDUQUAL como um modelo de avaliação orientado à qualidade para analisar a prontidão institucional em seis dimensões inter-relacionadas. O marco oferece uma base estruturada para avaliação diagnóstica, planejamento estratégico e futuras pesquisas comparativas na formação em engenharia potencializada por IA.

Palavras-chave: Inteligência artificial na educação; Formação em engenharia arquitetônica; Integração curricular; Prontidão institucional; Qualidade educacional.

Abstract. The rapid diffusion of Artificial Intelligence (AI) in architectural practice poses significant challenges for architectural engineering education, requiring institutions to move beyond fragmented tool adoption toward structured and pedagogically grounded integration. This study examines institutional readiness for AI integration through a case study of an architectural engineering program at Taif University, informed by international curriculum benchmarking and multi-stakeholder perspectives. Using a mixed-methods approach, the research explores student and faculty perceptions of AI, existing patterns of curricular integration, and institutional enablers and constraints shaping adoption. The findings reveal strong recognition of AI's educational value, particularly in supporting design creativity, performance-based analysis, and professional relevance. However, AI integration remains uneven, constrained by limited curriculum coherence, insufficient faculty capacity,

infrastructural gaps, underdeveloped strategic and ethical governance. In response, the study proposes the AI-ArchEDUQUAL framework as a quality-oriented evaluative model for assessing institutional readiness across six interrelated dimensions. The framework provides a structured basis for diagnostic assessment, strategic planning, and future comparative research in AI-enhanced engineering education.

Keywords: Artificial intelligence in education; Architectural engineering education; Curriculum integration; Institutional readiness; Educational quality.

1. INTRODUCTION

The rapid advancement of Artificial Intelligence (AI) is reshaping professional practice in architecture and the built environment, raising fundamental questions about how architectural engineering education should respond to these transformations. Although AI-driven tools—such as generative design systems, data-driven simulation platforms, and intelligent modelling environments—are increasingly embedded in professional workflows, their integration within architectural engineering curricula remains uneven, fragmented, and largely ad hoc, particularly in non-Western educational contexts.

Recent scholarly discourse has moved beyond viewing AI as a purely technological enhancement to examining its implications for pedagogy, curriculum design, learning outcomes, and professional identity formation in architecture and engineering education (Zawacki-Richter et al., 2019; Alalouch, 2018; Jin et al., 2024). However, much of the existing literature focuses on isolated tools, studio-based experiments, or conceptual discussions of AI's potential, with limited attention to institutional readiness, curriculum-system alignment, and quality assurance mechanisms that enable sustainable and scalable integration (Sadek and Abdel Gelil Mohamed, 2023; Paananen et al., 2024).

Within architectural engineering education, AI offers significant opportunities to support exploratory design thinking, performance-driven decision-making, and sustainability-oriented analysis, aligning with contemporary professional expectations (Eastman et al., 2018; Adewale et al., 2024). At the same time, its educational adoption introduces critical challenges related to curriculum coherence, faculty preparedness, infrastructure capacity, ethical governance, and alignment with intended learning outcomes. These challenges suggest that AI integration should be understood not as a technical upgrade, but as a broader pedagogical and organisational transformation requiring structured evaluation and strategic planning.

This gap is particularly evident in the Middle East, where ambitious digital transformation agendas—such as Saudi Vision 2030—emphasize innovation and future-oriented skills, yet empirical research on how architectural engineering programs operationalize AI within formal curricula remains limited. Responding to this gap, the present study conceptualizes AI integration as a quality-driven educational challenge and investigates institutional readiness for AI adoption through an empirical case study of Taif University, informed by international curriculum benchmarking and a structured evaluative perspective.

1.1 Artificial Intelligence and Architectural Engineering Education: From Tools to Pedagogy

In architectural engineering education, AI has expanded the scope of design thinking from representational modelling toward data-informed reasoning and performance-based decision-making. Applications such as generative design, BIM-based analytics, and environmental simulation enable students to explore complex design alternatives, evaluate trade-offs, and engage with sustainability objectives at early design stages (McLean, 2018; Silver, 2020). These capabilities suggest a shift from intuition-driven design education toward analytical–creative hybrid pedagogies.

However, the educational value of AI does not lie in the tools themselves, but in how they are embedded within learning structures. Without coherent curricular alignment, AI risks becoming an add-on skill rather than a transformative educational resource. Studies have shown that when AI tools are introduced without adequate pedagogical framing, students may focus on output generation rather than critical reasoning, ethical reflection, or design intent (Kee et al., 2024; Tan and Luhrs, 2024).

Consequently, architectural engineering education faces a dual responsibility: to equip students with AI-related competencies demanded by professional practice, while simultaneously preserving core disciplinary values such as contextual reasoning, human-centered design, and ethical responsibility.

Achieving this balance requires institutional strategies that integrate curriculum design, faculty development, infrastructure investment, and assessment mechanisms into a unified framework.

1.2 Research Purpose and Questions

Considering the identified gaps, this study aims to systematically examine the readiness of an architectural engineering program to integrate Artificial Intelligence within its educational framework, using Taif University as an empirical case study. The research does not seek to evaluate AI tools in isolation, but rather to assess the institutional conditions that enable or hinder meaningful AI integration in architectural engineering education.

The specific purposes of the study are to:

- Examine the current level of AI awareness, usage, and perception among students, faculty members, and academic decision-makers within an architectural engineering program.
- Identify curricular, organizational, technical, and ethical barriers affecting the integration of AI into architectural engineering education.
- Benchmark the program against international practices in AI-integrated architectural curricula.
- Develop a structured evaluative framework that can support quality assurance and strategic planning for AI integration at the institutional level.

Based on these objectives, the study addresses the following research questions:

- RQ1: To what extent are AI concepts and tools currently integrated into the architectural engineering curriculum at Taif University?
- RQ2: What are the perceptions of students, faculty members, and decision-makers regarding the educational value and challenges of AI integration?

- RQ3: What institutional barriers and enabling factors influence the effective adoption of AI in architectural engineering education?
- RQ4: How do international architectural programs integrate AI into their curricula, and what lessons can be adapted to the local context?
- RQ5: How can institutional readiness for AI integration in architectural engineering education be systematically evaluated through a quality-oriented framework?

2. RESEARCH METHODOLOGY

This study employed a mixed-methods research design to examine the readiness of an architectural engineering program for integrating Artificial Intelligence (AI) into education. The mixed-methods approach was adopted to capture both quantitative trends related to AI awareness and usage, and qualitative insights into institutional, curricular, and organizational factors influencing AI integration.

The research was conducted through four interrelated phases.

- An analytical literature review was undertaken to examine how AI has been addressed within architectural and engineering education, identify dominant themes and limitations in existing studies, and inform the design of the empirical instruments. This review served as a conceptual foundation rather than a descriptive background.
- An international curriculum benchmarking exercise was conducted. Architectural and architectural engineering programs from selected leading universities (including MIT, NUS, University of Cambridge, Izmir University of Economics, and KFUPM) were analyzed to identify prevailing approaches to AI integration, curricular structures, and pedagogical strategies. The benchmarking results provided a comparative reference for the local case study.
- Empirical data were collected using surveys and semi-structured interviews. Structured questionnaires were distributed to all faculty members in the Architectural Engineering Program at Taif University (n = 15, with 14 valid responses) and to undergraduate students across all academic levels (n = 452, with 149 valid responses). The surveys assessed AI awareness, prior exposure to AI tools, perceived educational value, and barriers to integration. In parallel, semi-structured interviews were conducted with academic decision-makers to explore strategic priorities, infrastructure readiness, faculty development, and policy considerations related to AI adoption.
- Data analysis and framework development were undertaken. Quantitative data were analyzed using descriptive statistics to identify key patterns and trends. Qualitative interview data were analyzed thematically using an inductive coding approach, allowing themes to emerge directly from participant responses. Findings from all phases were triangulated to enhance validity and reliability.

Ethical approval was obtained in accordance with Taif University's research regulations. Participation was voluntary, informed consent was secured, and all data were anonymized prior to analysis. The integrated findings informed the development of the AI-ArchEDUQUAL (Artificial Intelligence in Architectural Education Quality) framework, which conceptualizes

institutional readiness for AI integration across six dimensions. While the framework is exploratory in nature, it provides a structured basis for future empirical validation and cross-institutional comparison.

3. REQUIREMENTS FOR INTEGRATING ARTIFICIAL INTELLIGENCE INTO ARCHITECTURAL CURRICULA

3.1 Curriculum Integration and Pedagogical Alignment

Integrating Artificial Intelligence (AI) into architectural engineering curricula requires a coherent curricular structure that links computational intelligence with architectural reasoning and design pedagogy. Rather than introducing AI as a standalone technical component, prior studies emphasize the importance of embedding AI concepts progressively across theoretical courses, analytical modules, and design studios.

This approach enables students to understand how data-driven methods, generative systems, and performance-based analysis support architectural decision-making and creative exploration. When integrated in a scaffolded manner, AI contributes to continuous skill development and enhances both analytical and design competencies (Fernández and Rodríguez, 2023).

3.2 Development of Digital and Computational Competencies

Effective AI integration depends on students' acquisition of foundational digital competencies, including computational thinking, data literacy, and basic programming skills. Generative design platforms and AI-assisted analytical tools require students to critically interpret outputs rather than passively apply them.

Research indicates that targeted training in scripting-based environments and parametric modelling strengthens students' ability to evaluate AI-generated results and apply them within architectural contexts, supporting both creative and analytical reasoning (Gates, 2023).

3.3 Interactive and Adaptive Learning Environments

AI-driven interactive technologies offer opportunities to enhance experiential learning in architectural education. Immersive tools such as Virtual Reality (VR) and Augmented Reality (AR) support spatial understanding and real-time design evaluation, while adaptive learning systems facilitate personalized learning pathways.

However, their educational effectiveness is closely linked to pedagogical alignment with course objectives and assessment strategies, rather than their mere availability as visualization tools (Komatina et al., 2024).

3.4 Technical Infrastructure and Digital Capacity

Sustainable AI integration requires adequate technical infrastructure, including access to high-performance computing resources, reliable digital platforms, and specialized design software. Data-intensive applications such as generative modelling and digital twins place significant demands on computational capacity.

Without appropriate infrastructure, AI adoption remains limited in scale and pedagogical impact, reducing its contribution to architectural engineering education (Bhurke, 2023; Matter and Gado, 2024).

3.5 Faculty Development and Professional Capacity

Faculty preparedness is a critical factor in the effective integration of AI into architectural curricula. Professional development initiatives that combine technical training with pedagogical guidance enable academic staff to integrate AI meaningfully into teaching and assessment practices.

Evidence from higher education research suggests that structured workshops and curriculum-oriented training significantly enhance instructors' confidence, competence, and willingness to adopt AI-supported educational approaches (Bentley et al., 2023).

3.6 Academic–Industry Partnerships

Collaboration between universities and industry plays a central role in supporting meaningful AI integration in architectural engineering education. Partnerships with technology providers and professional practice enable access to current AI tools and expose students to real-world applications, bridging the gap between academic learning and professional expectations.

Research in higher education highlights that such collaborations also support applied research and curriculum relevance when aligned with educational objectives rather than short-term technological trends (Zawacki-Richter et al., 2019).

3.7 Knowledge Exchange and Inter-Institutional Collaboration

Inter-university collaboration facilitates the exchange of pedagogical expertise and curricular models for AI integration. Academic networks and joint initiatives enable institutions to share best practices, reduce duplication of effort, and adapt successful approaches across different educational contexts.

Such knowledge exchange is particularly important in emerging fields where standardized curricular models are still evolving.

3.8 Data Governance and Management

The integration of AI in architectural education requires clear institutional policies governing data collection, storage, and use. Given the data-intensive nature of AI applications, effective data governance frameworks are essential to ensure privacy, security, and responsible use.

National and international guidelines emphasize that ethical data management is a foundational requirement for sustainable AI adoption in higher education (SDAIA, n.d.).

3.9 Financial and Implementation Sustainability

AI integration involves significant financial and organizational commitments related to infrastructure, software licensing, and staff development. Sustainable implementation

therefore depends on dedicated budgeting strategies and long-term planning rather than isolated pilot initiatives.

Industry partnerships and shared-resource models can mitigate financial constraints while supporting continuous technical maintenance and educational innovation (Zawacki-Richter et al., 2019).

3.10 Ethical Frameworks for AI Use

Ethical considerations represent a critical dimension of AI integration in education. Institutions must establish clear policies addressing data privacy, algorithmic bias, transparency, and intellectual property.

Embedding ethical literacy within architectural curricula ensures that students and educators critically engage with the societal implications of AI, rather than treating technology as value-neutral (Huang, 2023; UNESCO, 2019).

Addressing biases and limitations within generative models further strengthens the educational validity of AI-supported learning environments (Almaz et al., 2024).

3.11 Experimental Validation of AI-Supported Learning

Evaluating the educational impact of AI requires empirical testing within controlled learning contexts. Experimental studies examining AI-assisted design platforms demonstrate that AI can enhance creativity and design exploration when integrated with reflective pedagogical strategies.

Such testing provides evidence-based insights into how AI influences learning outcomes, rather than assuming educational benefit by default (Anber, 2024).

3.12 Performance Measurement and Learning Analytics

AI tools offer new opportunities for assessing student performance in architectural education through learning analytics and automated feedback systems.

When aligned with studio learning objectives, these tools support formative assessment, enable timely feedback, and assist educators in monitoring learning progression. However, their effectiveness depends on transparent assessment criteria and pedagogical oversight (Ceylan, 2021).

3.13 Continuous Evaluation and Curriculum Refinement

Ongoing analysis of student performance following AI integration is essential for identifying strengths, limitations, and areas requiring curricular adjustment.

Continuous evaluation supports evidence-based refinement of teaching strategies and ensures that AI adoption contributes meaningfully to learning quality rather than becoming a static technological intervention (Al-Mungdi and Al-Sudi, 2024).

4. INVESTIGATING THE INTEGRATION OF AI IN ARCHITECTURAL ENGINEERING CURRICULA ACROSS GLOBAL UNIVERSITIES

To contextualize the case study within international practice, a comparative review of selected architectural engineering and architecture programs was conducted. Universities were purposefully chosen to reflect diversity in institutional scale, geographic context, and pedagogical approaches to Artificial Intelligence (AI) integration. Rather than providing exhaustive institutional descriptions, the analysis focuses on how AI is positioned within curricula and the pedagogical logic underpinning its integration.

4.1 Advanced Computational Design Models

Leading research-intensive institutions demonstrate advanced integration of AI through data-driven design studios and computationally oriented coursework.

At universities such as the Massachusetts Institute of Technology (MIT), AI-related methods—including machine learning and computational analysis—are embedded within studio-based problem-solving environments, emphasizing experimentation, iteration, and performance-driven design rather than isolated technical instruction (MIT School of Architecture and Planning, n.d.).

4.2 Early Integration of Computational Thinking

In contrast, some institutions prioritize early exposure to computational and algorithmic thinking as a foundation for later AI applications.

Programs such as those at the National University of Singapore (NUS) introduce computational logic and parametric reasoning at early stages of architectural education, positioning AI-related skills as integral to design thinking rather than advanced specializations (National University of Singapore, n.d.).

4.3 Practice-Oriented and Scalable Approaches

Mid-sized and teaching-focused institutions illustrate how AI integration can be scaled within diverse educational contexts.

Courses emphasizing architectural intelligence and generative workflows demonstrate that practical AI applications can be incorporated without extensive infrastructural investment, provided that pedagogical objectives remain clearly defined (Izmir University of Economics, n.d.).

4.4 Regional and Policy-Aligned Models

In regional contexts, universities such as King Fahd University of Petroleum & Minerals (KFUPM) reflect alignment between AI education and national development agendas by incorporating foundational AI courses within architectural programs.

These models highlight the role of policy frameworks in shaping curricular priorities, particularly in regions undergoing rapid digital transformation (KFUPM, n.d.).

4.5 Comparative Insights

Across these cases, AI integration strategies vary from advanced studio-based experimentation to foundational computational literacy. The absence of a single dominant

model underscores the need for context-sensitive evaluation frameworks that enable institutions to assess readiness, identify gaps, and define realistic pathways for AI adoption.

These comparative insights informed the development of the evaluative framework proposed in this study, supporting its applicability across diverse educational settings.

5. RESULTS AND DISCUSSION

This section presents the findings of the study through an integrated results and discussion approach, in which empirical outcomes are interpreted alongside relevant literature and the conceptual framework guiding the analysis. Given the exploratory nature of the research and its focus on institutional readiness within a single architectural engineering program, integrating results with discussion enables a more nuanced understanding of how observed patterns relate to pedagogical, organizational, and infrastructural factors influencing Artificial Intelligence (AI) integration in education. This approach is consistent with established practices in engineering education research, where contextualized interpretation is essential for deriving meaningful educational implications.

5.1 Results and Discussion of the Students Survey

The student survey yielded 149 valid responses, representing approximately 33% of the total undergraduate student population in the Architectural Engineering Program. This response rate is adequate for identifying dominant trends related to students' perceptions of Artificial Intelligence (AI) integration, particularly within an exploratory, program-level case study. Consistent with methodological practices in engineering education research, the findings are interpreted contextually rather than as statistically generalizable outcomes.

Analysis of the respondents' academic level (Figure 1) indicates a clear concentration of participation among senior students. Fourth-year students constituted the largest proportion of respondents (49%), followed by second year (21.5%) and fifth-year students (19.5%), while participation from first- and third-year cohorts was minimal. This distribution suggests that awareness of, and interest in, AI integration increases as students' progress through the curriculum.

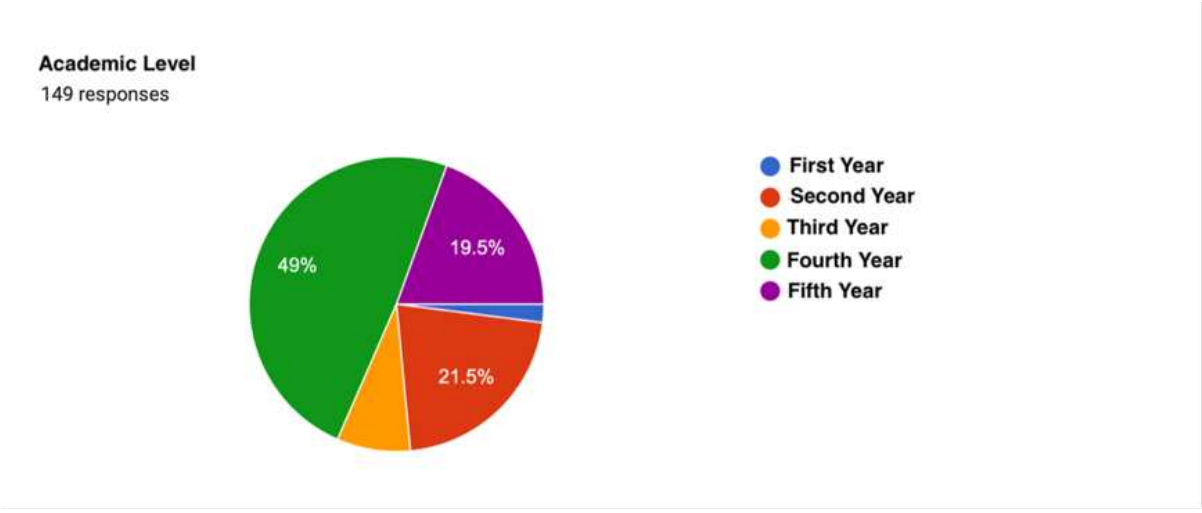


Figure.1 Academic level.

From an educational perspective, this pattern reflects the structure of the current program, where exposure to advanced digital tools and performance-driven design tasks is largely concentrated in the later years. Senior students are more likely to encounter complex design challenges, sustainability analysis, and professional expectations aligned with contemporary architectural practice, which heightens their recognition of AI's relevance. Similar findings have been reported in recent studies, where advanced-level students demonstrated stronger appreciation of AI's role in enhancing design thinking and professional preparedness (Kee et al., 2024; Tan and Luhrs, 2024). Conversely, the limited participation of early-year students highlights a lack of systematic early exposure to AI-related concepts. This finding directly addresses RQ2, indicating that student perceptions of AI value are shaped by curricular positioning rather than intrinsic technological interest alone. It also supports RQ3, as it reveals a structural barrier to AI integration: the absence of scaffolded learning pathways that introduce computational and AI-oriented thinking from the foundational stages of architectural education.

Overall, the student survey results reinforce the need for a curriculum-wide strategy that introduces AI concepts progressively across academic levels. Early engagement could foster more balanced awareness, reduce skill gaps between cohorts, and support coherent competency development throughout the program. These findings provide empirical grounding for the student-centered dimension of the proposed evaluative framework and underscore the importance of aligning AI integration with curriculum sequencing rather than limiting it to advanced stages.

Knowledge and Technical Tools

Analysis of students' responses regarding their familiarity and prior use of AI-related tools (Figure 2 and Table 1) reveals a pronounced disparity between awareness of design-oriented tools and more advanced data-driven or computational AI technologies.

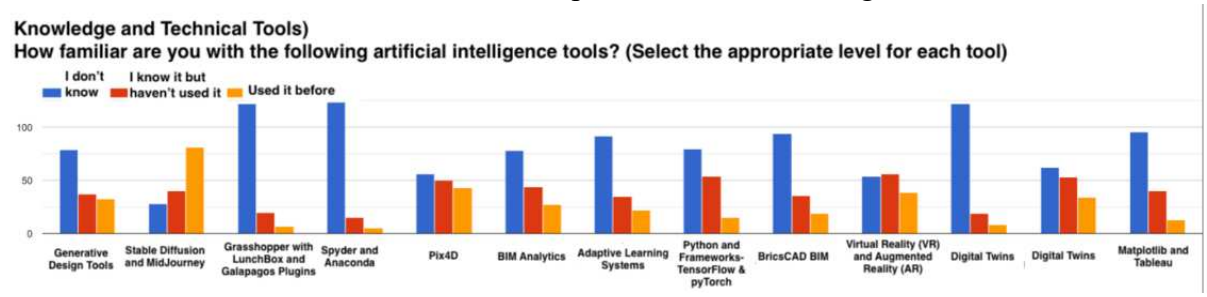


Figure 2. Knowledge and technical tools.

Tools closely aligned with existing architectural workflows—such as Grasshopper with parametric plugins and Virtual Reality/Augmented Reality (VR/AR)—demonstrate moderate levels of recognition. However, practical usage remains limited, indicating that exposure does not consistently translate into applied competence.

Table.1 Knowledge and technical tools

AI Tool	Don't	Know but Not	Used	Comment

	Know	Used	Before	
Generative Design Tools	65%	20%	15%	Low awareness and usage
Stable Diffusion & MidJourney	40%	35%	25%	Moderate awareness, limited usage
Grasshopper + Plugins	35%	45%	20%	Most known, low practical use
Spyder and Anaconda	85%	10%	5%	Very low awareness despite importance
Pix4D	55%	30%	15%	Limited awareness and usage
BIM Analytics	50%	30%	20%	Moderate awareness, needs practical training
Adaptive Learning Systems	60%	25%	15%	Weak integration despite importance
Python & TensorFlow/PyTorch	55%	30%	15%	Good awareness, needs hands-on practice
BricsCAD BIM	60%	25%	15%	Underused despite potential
VR & AR	50%	30%	20%	Reasonable awareness, expand use
Digital Twins	80%	15%	5%	Lowest familiarity, critical future tool
Matplotlib & Tableau	65%	25%	10%	Weak use of data visualization tools

In contrast, tools associated with programming, data analytics, and intelligent system modelling—such as Spyder and Anaconda, Digital Twins, and data visualization platforms—exhibit critically low levels of awareness and use. This pattern is particularly significant given the strategic importance of these tools for enabling machine learning workflows, performance monitoring, and evidence-based design decision-making. The findings suggest that students' familiarity is shaped less by the transformative potential of AI technologies and more by their visibility within existing curricula and studio practices. From an educational standpoint, this imbalance reflects a curriculum that privileges visual and form-generating technologies over computational reasoning and data literacy. Similar trends have been reported in architectural education literature, where students demonstrate greater comfort with generative and representational tools than with analytical or algorithmic systems, particularly in the absence of structured pedagogical support (Kee et al., 2024; Tan and Luhrs, 2024). These results directly address RQ2, indicating that student perceptions of AI are strongly influenced by curricular exposure rather than by independent technological exploration. They also respond to RQ3, as the uneven distribution of knowledge highlights institutional barriers related to curriculum design, skills scaffolding, and the lack of hands-on training in advanced AI tools. Without systematic integration and guided practice, AI remains perceived as a set of isolated technologies rather than a coherent design methodology.

Overall, the findings underscore the need for targeted curriculum interventions that bridge the gap between awareness and application. Embedding data-driven tools, programming environments, and intelligent system concepts within design studios and technical courses could enhance students' capacity to critically engage with AI outputs and support the development of holistic digital competencies. These insights provide empirical support for the

technical competency dimension of the proposed evaluative framework and reinforce the argument that effective AI integration requires both curricular alignment and practical skill development.

Students' perceptions of the importance of AI integration

The findings presented in Figure 3 reveal a strong consensus among students regarding the importance of integrating Artificial Intelligence (AI) technologies into the architectural engineering curriculum. A substantial majority of respondents (69.1%) rated AI integration as very important, while a further 21.5% considered it important. Collectively, more than 90% of participants expressed positive support for embedding AI within their educational experience, with only a marginal proportion expressing neutrality or opposition.

From an analytical perspective, these results directly address RQ2, indicating that students perceive AI not merely as an optional technological enhancement, but as a core component of contemporary architectural education. This perception aligns with recent studies emphasizing students' recognition of AI as a critical driver of design innovation, technical competence, and future employability in architecture and the built environment (Kee et al., 2024; Tan and Luhrs, 2024). Notably, the minimal level of skepticism (<10%) suggests that resistance to AI integration is unlikely to originate from the student body itself. Instead, these finding shifts attention toward institutional and curricular constraints, thereby informing RQ3. Similar conclusions have been reported in engineering and design education literature, where strong student support for AI adoption contrasts with slower institutional responses due to infrastructure limitations, curriculum rigidity, or faculty preparedness (Zawacki-Richter et al., 2019).

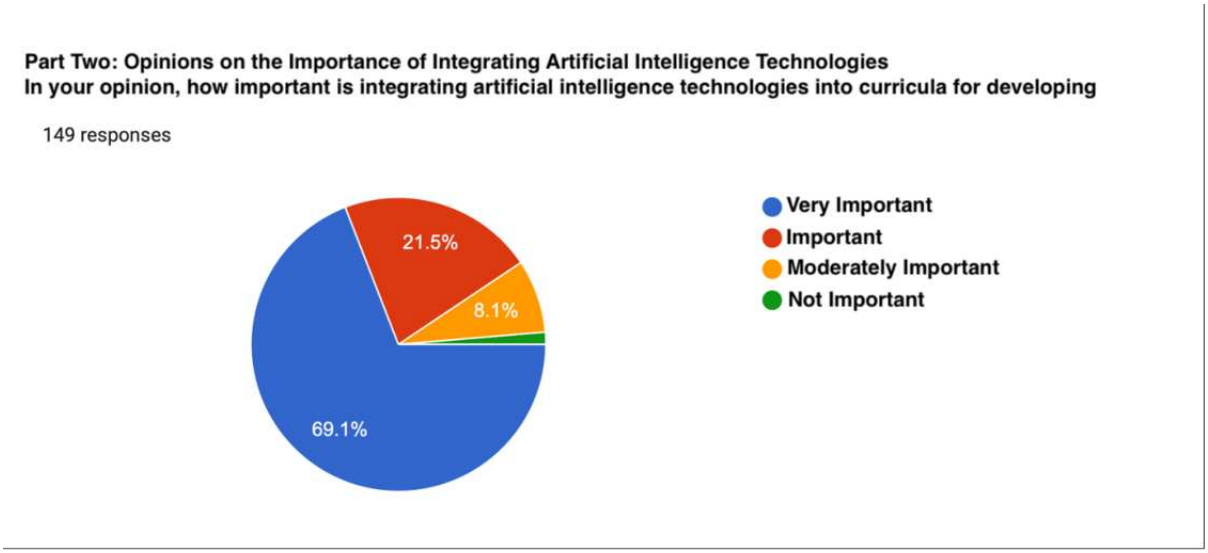


Figure 3. Students' opinions on the importance of integrating AI technologies in the curriculum

Furthermore, the high level of perceived importance complements the earlier findings on uneven tool familiarity (Section 6.3.2). While students strongly value AI integration, their limited exposure to advanced AI tools indicates a misalignment between curricular provision and learner expectations. This gap reinforces the argument that AI integration must move

beyond isolated digital tools toward a structured, curriculum-wide strategy that supports progressive competency development.

Overall, these results provide empirical justification for institutional-level reform and support the conceptual basis of the proposed evaluative framework. Student readiness and acceptance constitute a key enabling condition for AI integration, suggesting that future challenges lie primarily in curriculum design, pedagogical alignment, and organizational capacity rather than learner resistance.

Areas where AI can contribute to architectural education (Students' perspective)

The results presented in Figure 4 illustrate students' perceptions of the areas in which Artificial Intelligence (AI) can most effectively contribute to architectural engineering education. The findings indicate that students predominantly associate AI with design-centric and performance-oriented applications, rather than with pedagogical or learning-support functions.

Creative design emerged as the most frequently selected area, reflecting students' strong perception of AI as a tool for supporting generative thinking, idea exploration, and innovation in early design stages. This perception aligns with recent research highlighting the growing role of generative AI in enhancing architectural creativity and expanding the design solution space (Kee et al., 2024; Tan and Luhrs, 2024). Similarly, high levels of support for experimental design, performance simulation, BIM analytics, and data analysis indicate that students recognize AI's value in improving accuracy, environmental performance assessment, and evidence-based decision-making.

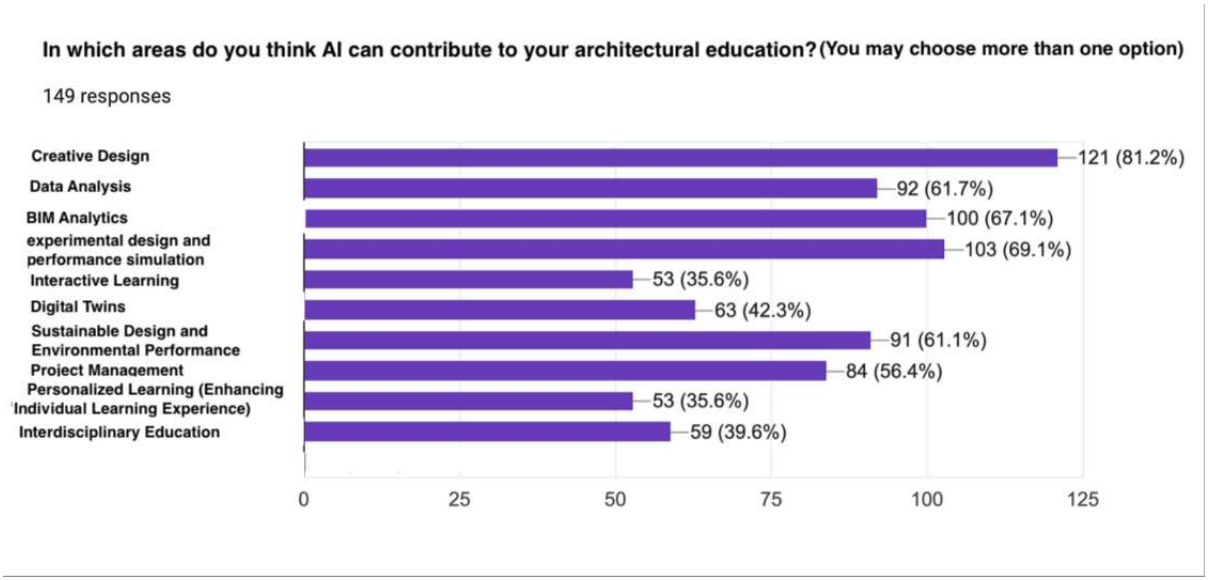


Figure 4. Areas where AI Can contribute to architectural education (Students' Perspective)

Notably, students also identified sustainable design, project management, and environmental performance as key areas for AI contribution. This suggests an awareness of AI's potential beyond form generation, extending into analytical and managerial domains that are increasingly critical in contemporary architectural practice. Such findings are consistent

with literature emphasizing AI's role in integrating sustainability metrics and performance evaluation within design workflows (Eastman et al., 2018; Adewale et al., 2024).

In contrast, comparatively lower responses were recorded for areas related to interactive and personalized learning, as well as interdisciplinary education. This pattern suggests limited student exposure to AI-enhanced educational methodologies, such as adaptive learning systems or personalized feedback mechanisms. From an analytical standpoint, this finding directly informs RQ2, indicating that students' understanding of AI remains primarily tool-oriented and practice-driven, rather than pedagogy-oriented.

These results also contribute to RQ3 by revealing an institutional gap: while students demonstrate clear expectations for AI to enhance design, analysis, and performance simulation, they appear less aware of AI's potential to transform learning processes themselves. This imbalance reinforces earlier findings on uneven AI exposure and suggests that current curricular structures emphasize AI as a technical aid rather than as a comprehensive educational strategy.

Overall, the findings indicate that students envision AI as a powerful enabler of creative and analytical competencies, but not yet as a driver of adaptive or personalized learning. This insight supports the need for curriculum strategies that broaden students' understanding of AI's educational role, integrating both design-oriented applications and AI-supported pedagogical innovations. These student perspectives provide empirical grounding for the learning and skills development dimensions of the proposed evaluative framework.

5.2 Results and Discussion of the Faculty Survey

The faculty survey received responses from 14 out of 15 academic staff members in the Architectural Engineering Program, corresponding to a participation rate of approximately 93%. Although the absolute number of respondents is limited, this high response rate provides near-complete coverage of the program's teaching staff and allows the findings to be interpreted as representative of prevailing faculty perspectives within this specific institutional context. As such, the results are treated as contextual evidence supporting the broader analysis rather than as statistically generalizable outcomes. Analysis of academic rank distribution (Figure 5) shows that most respondents are assistant professors, followed by associate professors and lecturers, with a small proportion of teaching assistants and no responses from full professors. This distribution indicates strong representation from mid-career faculty, who are typically most engaged in day-to-day teaching activities, studio coordination, and curriculum development. However, the absence of senior professors may limit insights related to long-term strategic planning and institutional governance of AI integration. This limitation reinforces the need to interpret faculty findings in conjunction with student data and institutional analysis.

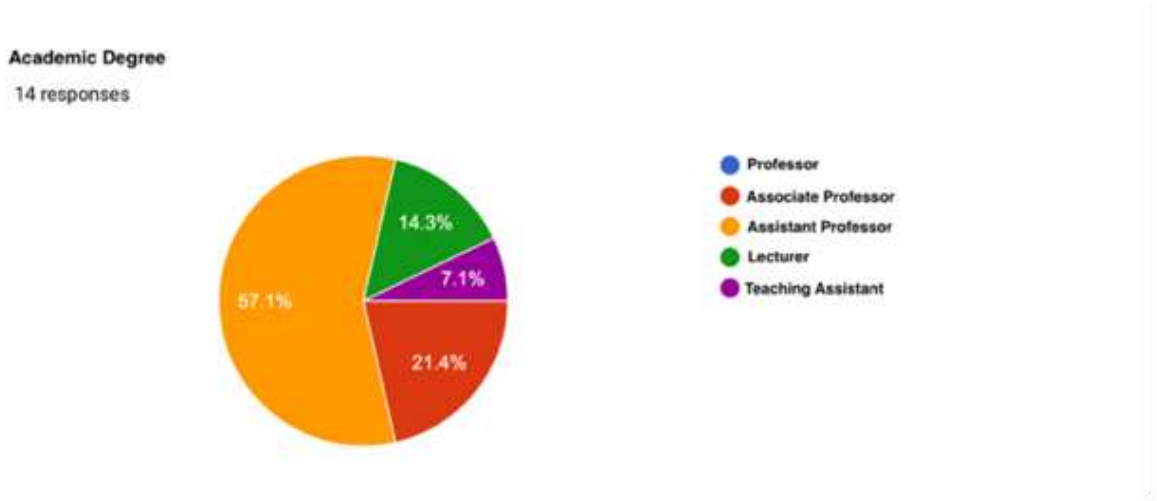


Figure 5. Academic Degree Distribution

Faculty members' self-reported levels of awareness and knowledge of Artificial Intelligence (AI) technologies used in architecture are presented in Figure 6. The results indicate that most respondents perceive themselves as having moderate to high familiarity with AI, suggesting a foundational level of conceptual readiness for AI integration within the curriculum. Nevertheless, only a small proportion reported very high levels of expertise, highlighting a gap between general awareness and advanced technical or pedagogical competence.

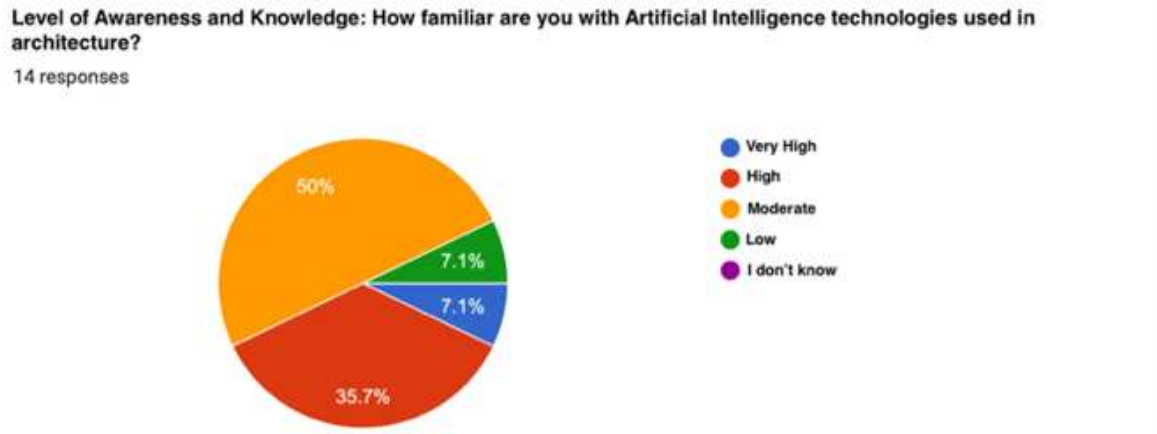


Figure 6. Level of Awareness and Knowledge

From an analytical perspective, these findings suggest that while faculty attitudes toward AI are broadly supportive, effective curricular integration may be constrained by limited depth of expertise. Similar patterns have been observed in engineering education research, where faculty demonstrate openness toward AI adoption but require structured professional

development to translate conceptual understanding into effective teaching practice (Zawacki-Richter et al., 2019).

In relation to RQ3, the faculty survey identifies academic capacity as both an enabling factor and a potential constraint in AI integration. Faculty awareness provides a necessary foundation for curriculum reform, yet the limited presence of advanced expertise underscores the importance of targeted training, pedagogical support, and institutional incentives. When interpreted alongside student survey findings, the faculty results further indicate that barriers to AI integration are primarily structural and organizational, rather than attitudinal.

Overall, the faculty survey functions as a supporting layer of evidence, complementing the more extensive student data. It confirms alignment between faculty openness and student expectations while emphasizing the need for systematic capacity-building strategies to ensure sustainable and meaningful integration of AI within architectural engineering education.

Knowledge and Technical Tools

Faculty members' familiarity with, and prior use of, AI-related technical tools are presented in Figure 7 and Table 2.

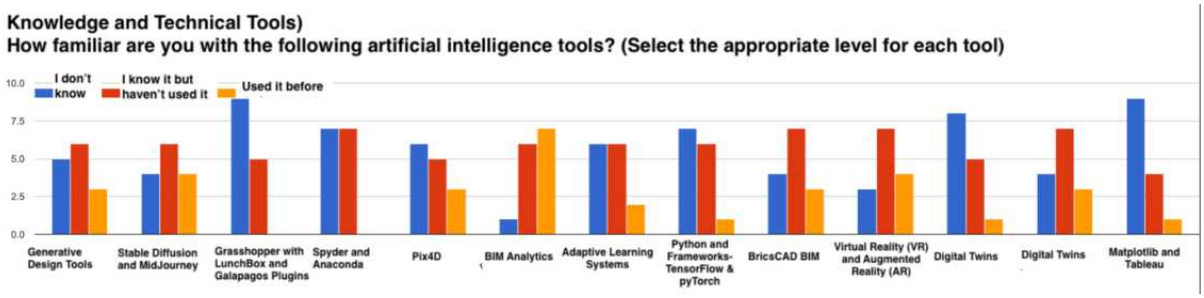


Figure 7. Knowledge technical tools

The results indicate uneven levels of awareness and application across different categories of tools. Technologies that are already embedded within architectural workflows—such as BIM analytics and Virtual Reality/Augmented Reality (VR/AR)—show relatively higher levels of familiarity and prior use. This suggests that faculty engagement with AI is currently mediated by tools that align closely with established teaching practices and studio-based activities.

Table 2. Knowledge technical tools

AI Tool	Don't Know	Know but Not Used	Used Before	Comment
Generative Design Tools	40 %	35 %	25 %	Moderate awareness and usage
Stable Diffusion & MidJourney	30 %	40 %	30 %	Good familiarity, some use
Grasshopper + Plugins	25 %	45 %	30 %	Most familiar, but low usage
Spyder and Anaconda	45 %	40 %	15 %	Low use despite importance
Pix4D	30 %	40 %	30 %	Moderate use, still needs support
BIM Analytics	25 %	35 %	40 %	Best known and applied tool
Adaptive Learning	30 %	40 %	30 %	Medium familiarity, more integration

Systems				needed
Python & TensorFlow/PyTorch	35 %	45 %	20 %	High awareness, limited practical use
BricsCAD BIM	35 %	40 %	25 %	Known but underused
VR & AR	25 %	35 %	40 %	Good use in immersive tools
Digital Twins	45 %	40 %	10 %	Low awareness of future-oriented tool
Matplotlib & Tableau	35 %	40 %	25 %	Moderate awareness, better than students

In contrast, tools associated with advanced computational workflows and data-driven intelligence—such as Digital Twins, Spyder and Anaconda, and programming-based AI frameworks—exhibit substantially lower levels of practical use despite their recognized relevance to emerging architectural practice. As shown in Figure 7, a significant proportion of respondents reported awareness without corresponding application, indicating a gap between conceptual understanding and pedagogical implementation. This pattern is reinforced by the distribution reported in Table 2, where several strategically important tools are identified as "known but underused." From an analytical perspective, these findings highlight some knowledge–practice gap at the faculty level. While conceptual familiarity with AI-related tools appears to be developing, limited hands-on experience constrains their integration into teaching and assessment. Similar challenges have been documented in engineering education research, where faculty readiness for AI integration is often characterized by general awareness coupled with insufficient technical depth and pedagogical confidence (Zawacki-Richter et al., 2019).

In relation to RQ3, the results suggest that faculty capacity constitutes both an enabling condition and a structural constraint. Existing familiarity with certain AI tools provides a foundation for curriculum enhancement; however, the limited application of advanced computational tools underscores the need for targeted professional development and institutional support. Without structured training and incentives, AI integration risks remaining confined to familiar technologies rather than expanding toward data-intensive and intelligence-driven design methodologies.

Overall, the faculty findings presented in Figure 7 and Table 2 complement the student survey results by confirming that uneven exposure to AI tools is not limited to learners alone. Instead, it reflects broader institutional patterns related to curriculum design, training provision, and infrastructure readiness. These insights further inform the technical capacity and faculty development dimensions of the proposed evaluative framework, reinforcing the need for coordinated strategies to bridge the gap between awareness and effective pedagogical use.

Perceived Areas of AI Contribution to Enhancing Student Education in Architecture

Faculty perceptions of the areas in which Artificial Intelligence (AI) can enhance student education are illustrated in Figure 8. The results indicate a strong alignment between faculty views and practice-oriented applications of AI, with emphasis placed on design performance, analytical accuracy, and decision-support functions rather than on pedagogical personalization.

As shown in Figure 8, BIM analytics received the highest level of support among faculty members, reflecting widespread recognition of AI's role in improving building modelling, performance evaluation, and evidence-based design decision-making. Similarly, high levels of agreement were observed for creative design, digital twins, and project management, suggesting that faculty perceive AI as a valuable enabler of innovation, real-time simulation, and workflow efficiency within architectural education. These findings are consistent with prior research highlighting AI's growing influence on performance-driven and systems-oriented design practices (Eastman et al., 2018).

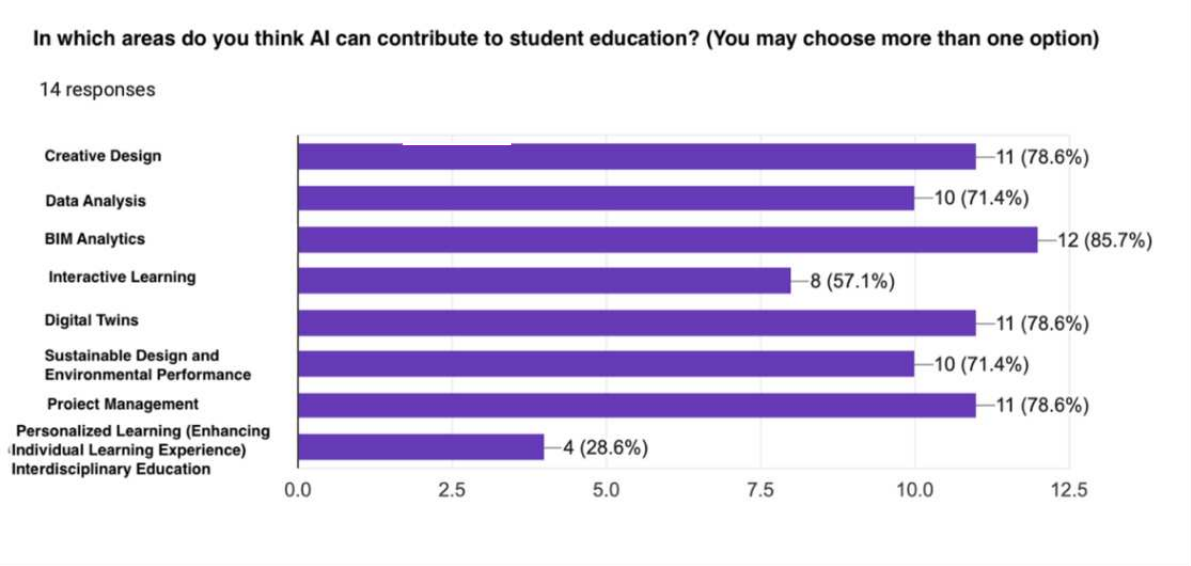


Figure 8. Areas of AI Contribution to Enhancing Student Education in Architecture

Faculty responses also indicate substantial support for AI applications in data analysis and sustainable design, demonstrating awareness of AI's potential to support environmental optimisation and data-informed architectural solutions. This orientation reinforces the view that faculty primarily associate AI with technical and analytical enhancement rather than with learning process transformation.

In contrast, lower levels of support were recorded for interactive and personalized learning applications. This pattern suggests limited familiarity with AI-driven educational systems that support adaptive learning, individualized feedback, or student-specific learning pathways. From an analytical standpoint, these finding complements student survey results and directly informs RQ3, indicating that institutional readiness challenges are not limited to infrastructure or curriculum design, but also extend to pedagogical conceptions of AI's educational role.

Overall, faculty members perceive AI as a strategic asset for enhancing design thinking, technical performance, and analytical competence in architectural education. However, the comparatively lower recognition of AI's pedagogical potential highlights the need for targeted faculty development initiatives that broaden understanding of AI beyond technical applications. These insights further inform the pedagogical and faculty capacity dimensions of the proposed evaluative framework, emphasizing the importance of aligning technological adoption with educational strategy rather than treating AI solely as a performance-enhancing tool.

Faculty perspectives on key AI tools supporting data analysis and creative design

Figure 9 illustrates faculty perceptions of the Artificial Intelligence (AI) tools considered most effective in supporting students' abilities to analyse data and develop innovative design solutions. The results show that Pix4D and BIM Analytics received the highest level of support (78.6%), reflecting strong faculty recognition of their role in performance-based analysis, accurate three-dimensional modelling, and data-informed design decision-making (Fig. 5). AI-driven architectural systems were also highly rated (71.4%), indicating their perceived value in early-stage design exploration and conceptual development.

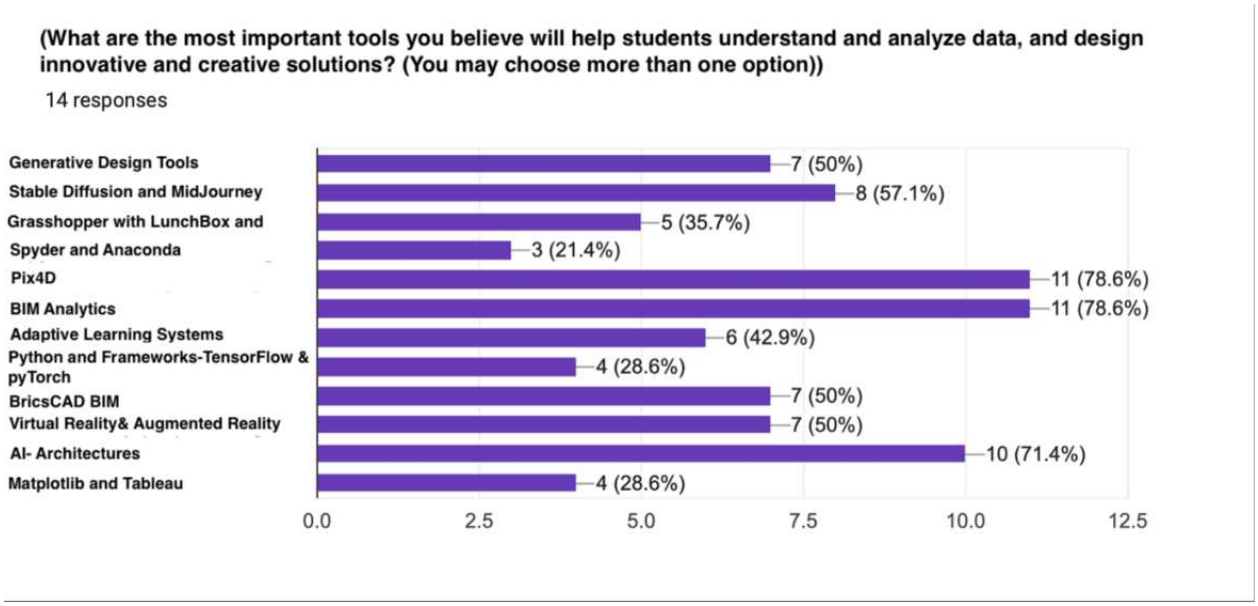


Figure 9. Faculty perspectives on which AI tools are most important in helping students a nalyze data and design innovative, creative solutions.

Tools related to generative design and immersive visualization—such as Stable Diffusion, MidJourney, Generative Design Tools, VR/AR, and BricsCAD BIM—received moderate to high levels of support (≥50%), suggesting broad faculty awareness of their contribution to creative exploration and visual communication. In contrast, programming-oriented and data analysis tools, including Spyder and Anaconda (21.4%) and Matplotlib and Tableau (28.6%), were among the least selected options, indicating limited familiarity or pedagogical integration of code-based analytical workflows. Similarly, Adaptive Learning Systems and Python-based AI frameworks (TensorFlow/PyTorch) received moderate support, reflecting growing awareness but constrained adoption within teaching practice (Fig. 9).

Overall, the findings indicate that faculty members currently prioritize AI tools that support visual modelling, simulation, and generative design, while advanced computational and programming-driven tools remain underutilized. This pattern suggests a need for curricular strategies that progressively integrate both visual and code-based AI tools, supported by targeted faculty training, to better align architectural education with data-driven and AI-integrated professional practice.

Key learning outcomes to be enhanced through AI integration

Faculty perceptions of the learning outcomes most likely to be enhanced through Artificial Intelligence (AI) integration are presented in Figure 10. The findings indicate strong consensus that AI has a significant role in supporting higher-order cognitive and design-related competencies within architectural engineering education.

As shown in Figure 10, enhancing creativity and design thinking, alongside developing analytical and problem-solving skills, emerged as the highest-rated learning outcomes. This reflects faculty confidence in AI's capacity to support critical thinking, exploratory design processes, and evidence-based decision-making. Such outcomes align closely with contemporary expectations of architectural education, where innovation and analytical reasoning are increasingly intertwined (Kee et al., 2024; Tan and Luhrs, 2024).

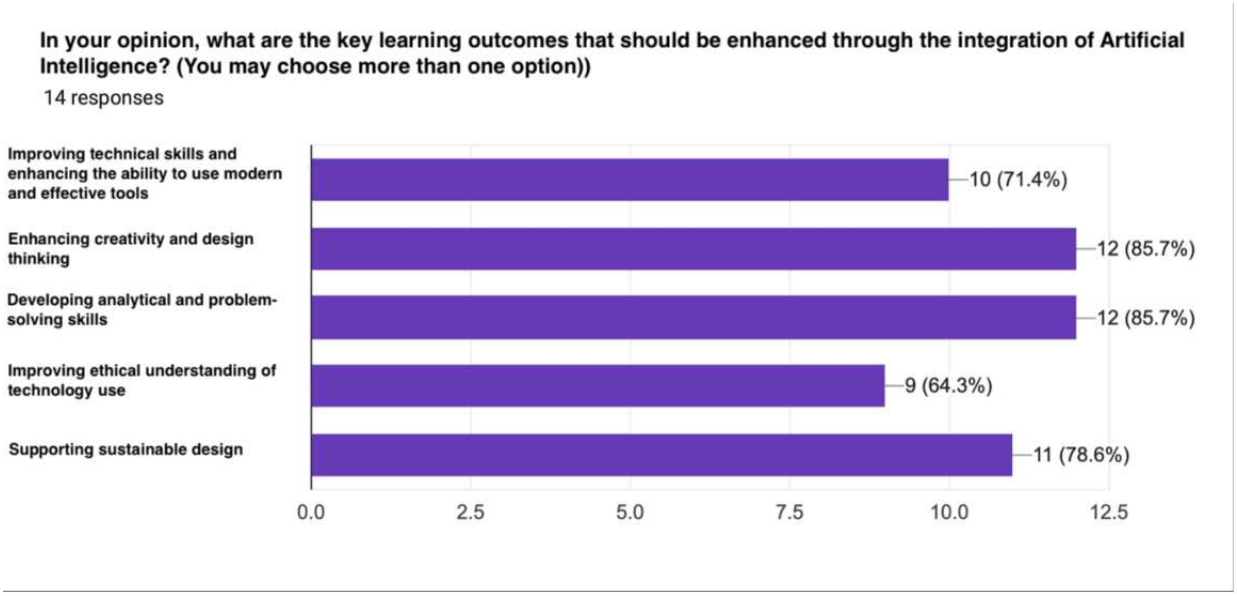


Figure 10. Key learning outcomes to be enhanced through AI Integration

Supporting sustainable design was also strongly endorsed, indicating awareness of AI's contribution to environmental performance analysis, energy optimisation, and sustainability-driven design strategies. This finding reinforces earlier results highlighting faculty emphasis on performance-oriented and data-informed applications of AI, rather than purely representational or visual functions.

Improving students' technical skills and their ability to use modern digital tools received substantial support, underscoring the perceived importance of hands-on engagement with AI-enabled design technologies. From an educational perspective, this suggests that faculty associate effective AI integration with experiential learning and applied competence rather than abstract conceptual exposure alone.

In contrast, ethical understanding of technology use received comparatively lower prioritisation. While still recognized as important, this result indicates that ethical and responsible AI use is not yet fully integrated into prevailing conceptions of learning outcomes within architectural engineering curricula. This finding directly informs RQ3, highlighting an institutional gap between technical adoption and ethical governance. Similar concerns have been raised in recent literature, emphasizing the need to embed ethical literacy alongside

technical competence to prepare students as responsible digital practitioners (UNESCO, 2019; Huang, 2023).

Overall, the results suggest that faculty primarily associate AI integration with enhancing creative, analytical, and technical capabilities, while ethical dimensions remain underemphasized. This imbalance highlights the need for curriculum strategies that explicitly integrate ethical reasoning, data responsibility, and critical reflection into AI-supported learning environments. These findings provide empirical support for the learning outcomes and ethics dimensions of the proposed evaluative framework and reinforce the argument that effective AI integration must address both competency development and responsible professional practice.

Key aspects to enhance for AI integration in the Architectural Engineering Program

Faculty perceptions of the key aspects requiring enhancement to support Artificial Intelligence (AI) integration in the Architectural Engineering Program are presented in Figure 11. The findings reveal a clear prioritization of pedagogical and human-capacity dimensions over purely technical or infrastructural considerations.

As shown in Figure 11, the highest level of agreement among faculty members was observed for incorporating interactive and adaptive learning technologies and providing professional training for faculty. This indicates a shared understanding that effective AI integration is not driven primarily by tool availability, but by educators' ability to meaningfully embed AI within teaching and assessment practices. This finding aligns with engineering education literature emphasizing faculty competence and pedagogical readiness as critical enablers of sustainable AI adoption (Zawacki-Richter et al., 2019; Bentley et al., 2023).

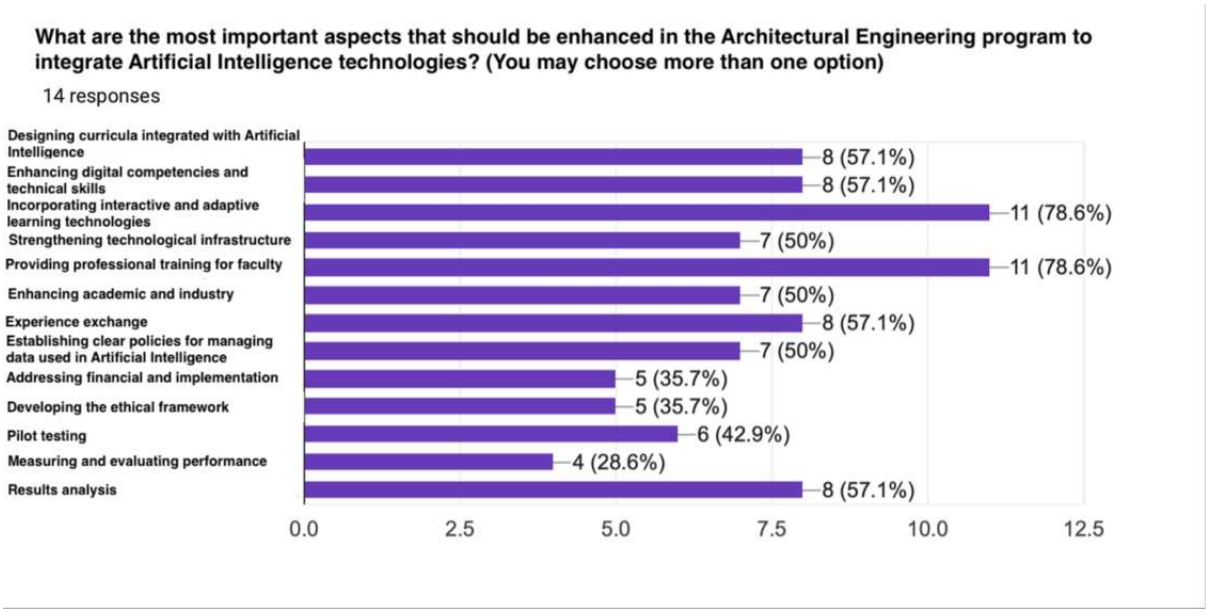


Figure 11. Key aspects to enhance for AI Integration in the Architectural Engineering Program

A second tier of priorities included designing AI-integrated curricula, enhancing students' digital and technical competencies, strengthening academic–industry partnerships, and conducting systematic results analysis. Together, these aspects reflect a curriculum-oriented

perspective that links AI integration to employability, professional relevance, and continuous quality improvement. From an analytical standpoint, these findings directly address RQ3, indicating that institutional barriers to AI integration are perceived less as resistance to change and more as challenges related to curriculum design, skills development, and alignment with external professional contexts.

In contrast, aspects related to governance and sustainability—such as strengthening technological infrastructure, establishing data management policies, developing ethical frameworks, and implementing pilot testing—received comparatively lower emphasis. While these elements remain essential for responsible and scalable AI adoption, their lower prioritization suggests that faculty members may underestimate the long-term importance of governance, ethics, and infrastructural readiness. This imbalance echoes concerns raised in recent studies, which caution that AI integration driven primarily by pedagogical enthusiasm without parallel attention to ethics, data governance, and institutional capacity risks becoming fragmented or unsustainable (UNESCO, 2019; Huang, 2023). From a framework-development perspective, these findings contribute directly to RQ5 by empirically illustrating how institutional readiness for AI integration is uneven across multiple dimensions. Faculty responses suggest that readiness is strongest in areas related to teaching practice and professional development, while structural and regulatory dimensions require further institutional attention. This pattern reinforces the need for a comprehensive evaluative framework that balances pedagogical innovation with governance, infrastructure, and ethical oversight, rather than prioritizing isolated aspects of AI adoption.

Overall, the results indicate that faculty members view interactive learning environments and professional development as foundational pillars for AI integration in architectural engineering education. However, the comparatively lower emphasis on policy development, ethical frameworks, infrastructure readiness, and pilot evaluation highlights critical gaps that must be addressed to ensure a balanced, effective, and future-oriented implementation strategy. These insights provide empirical grounding for the institutional and governance dimensions of the proposed evaluative framework and underscore the importance of aligning AI integration with long-term educational quality assurance rather than short-term technological enhancement.

The Importance of Professional Training for Faculty on AI Use in Teaching

The findings presented in Figure 12 demonstrate unanimous faculty agreement on the critical importance of professional training for the effective integration of Artificial Intelligence (AI) in teaching. All respondents (100%) rated professional training as either very important (64.3%) or important (35.7%), with no respondents indicating neutrality or opposition. This consensus highlights professional development as a central enabling condition for AI integration within architectural engineering education.

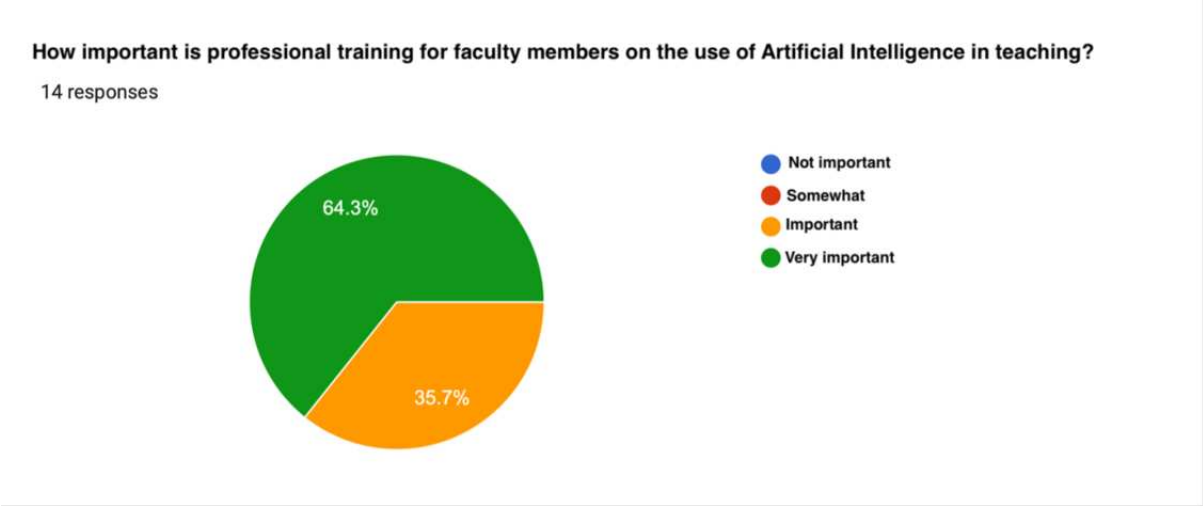


Figure 12. The Importance of Professional Training for Faculty on AI Use in Teaching

From an analytical perspective, these results directly address RQ3, identifying faculty capacity as a key institutional factor influencing AI adoption. While earlier findings indicated moderate levels of AI awareness among faculty, the strong emphasis on training reflects recognition of a gap between conceptual familiarity and pedagogically effective use. This distinction aligns with prior studies in engineering and higher education, which emphasize that AI integration depends not merely on tool availability, but on educators' confidence, pedagogical competence, and ability to align AI use with learning outcomes (Zawacki-Richter et al., 2019; Bentley et al., 2023).

The prominence of professional training also helps explain patterns observed in faculty tool preferences, where visually oriented and workflow-aligned tools were favoured over programming-based or data-intensive AI systems. Without structured training, faculty are more likely to rely on familiar technologies, limiting the depth and scope of AI integration. Similar trends have been reported in architectural education literature, where insufficient professional development constrains the adoption of advanced computational and data-driven methods despite their acknowledged relevance (Kee et al., 2024; Tan and Luhrs, 2024).

Importantly, the absence of dissenting responses suggests that resistance to AI integration does not stem from faculty attitudes, but rather from institutional support structures. These finding complements student survey results, which similarly indicate strong learner readiness for AI-enhanced education. Together, these results shift the focus of AI integration challenges away from cultural acceptance toward organizational capacity and staff development.

In relation to RQ5, the findings provide empirical justification for positioning faculty professional development as a core dimension within the proposed evaluative framework. Professional training emerges not as a supplementary activity, but as a foundational mechanism linking curriculum reform, pedagogical innovation, and sustainable AI adoption. Without ongoing, structured training initiatives, AI integration risks remaining superficial and uneven across courses and academic levels.

Overall, the results indicate that effective AI integration in architectural engineering education requires institutional investment in continuous faculty development that combines

technical skill-building with pedagogical guidance. Such an approach is essential to ensure that AI tools are not only adopted, but meaningfully embedded within teaching practices, assessment strategies, and curriculum design.

Main Challenges Hindering AI Integration in the Architectural Engineering Program

The faculty survey results (Figure 13) reveal that the primary challenges hindering the integration of Artificial Intelligence (AI) within the Architectural Engineering Program are predominantly institutional and infrastructural rather than conceptual or attitudinal in nature. Weak technological infrastructure emerged as the most frequently reported barrier (71.4%), indicating limitations related to computing capacity, software availability, and access to advanced AI-enabled platforms. This finding aligns with previous studies emphasizing that AI-driven design, simulation, and data-intensive workflows require robust digital infrastructure to function effectively within educational settings (Bhurke, 2023; Matter and Gado, 2024).

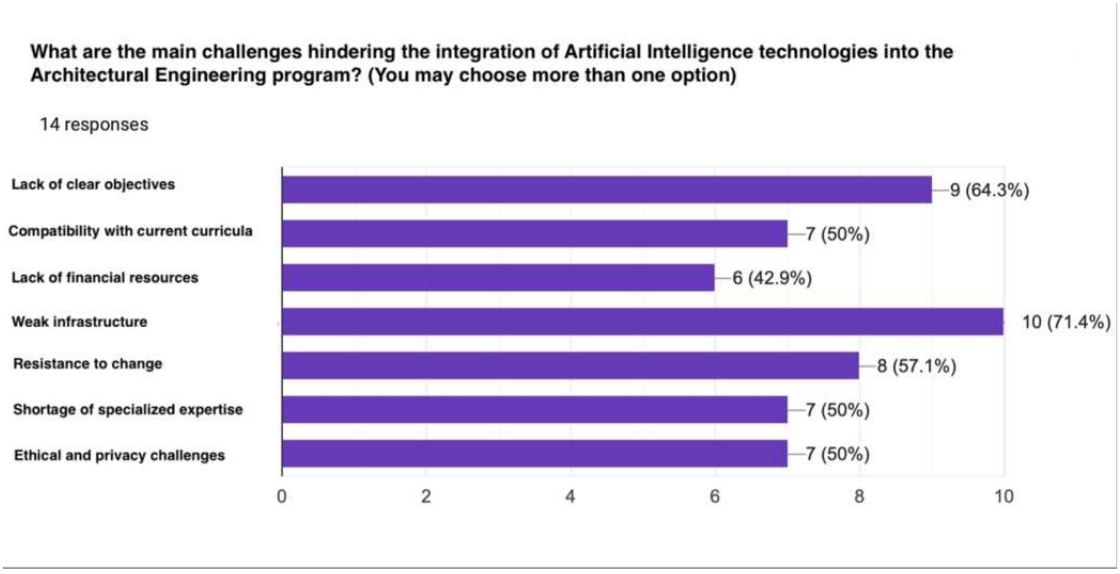


Figure 13. The Main Challenges Hindering AI Integration in the Architectural Engineering Program

Closely following infrastructure constraints, the lack of clear strategic objectives for AI integration (64.3%) was identified as a major challenge. This result suggests uncertainty at the program level regarding how AI should be positioned pedagogically—whether as a supporting analytical tool, a design methodology, or a broader educational paradigm. From a theoretical standpoint, this finding reinforces arguments in the literature that AI integration cannot succeed through isolated tool adoption alone but requires explicit curricular vision and alignment with learning outcomes (Zawacki-Richter et al., 2019). In relation to RQ3, this indicates that institutional ambiguity, rather than resistance to technology, constitutes a critical barrier to meaningful AI adoption.

Resistance to change (57.1%) also emerged as a significant concern, reflecting cultural and organizational inertia that may slow curricular transformation. However, when interpreted alongside earlier findings—particularly the strong faculty support for professional training, and students' overwhelming endorsement of AI integration, this resistance appears less

ideological and more structural. Similar patterns have been reported in engineering and design education, where hesitation often stems from uncertainty about implementation processes, workload implications, and institutional support rather than opposition to AI itself (Bentley et al., 2023).

Additional challenges, each selected by approximately half of respondents, included curriculum compatibility, shortage of specialized expertise, and ethical and privacy concerns. These factors collectively highlight the multifaceted nature of AI integration, spanning curriculum design, human capacity, and governance. Notably, ethical and privacy challenges were acknowledged but not prioritized as strongly as infrastructure or strategic clarity. This imbalance echoes concerns raised in recent literature warning that ethical governance is often underemphasized during early stages of AI adoption, despite its central importance for responsible and sustainable educational implementation (UNESCO, 2019; Huang, 2023).

Interestingly, lack of financial resources was perceived as a comparatively less critical barrier (42.9%). This suggests that financial constraints alone do not explain the slow pace of AI integration; rather, respondents perceive organizational readiness, planning, and capacity-building as more pressing concerns. These finding challenges assumptions that funding is the primary obstacle and instead points to the importance of strategic coordination and institutional leadership.

From a framework-development perspective, these findings directly inform RQ5, demonstrating that institutional readiness for AI integration is uneven across dimensions. While there is growing awareness and openness among faculty, weaknesses in infrastructure, strategic planning, and governance undermine the sustainability of AI adoption. These results empirically justify the inclusion of infrastructure readiness, strategic alignment, faculty capacity, and ethical governance as distinct yet interrelated dimensions within the proposed evaluative framework.

Overall, the findings indicate that successful AI integration in architectural engineering education requires more than technological enthusiasm. Addressing infrastructural deficits, articulating clear curricular objectives, reducing organizational uncertainty, and embedding ethical and governance considerations are essential to move AI integration from isolated experimentation toward a coherent, institutionally grounded educational transformation. These insights reinforce the argument that AI integration should be treated as a quality-driven institutional process rather than a purely technical upgrade.

5.3 Institutional Leadership and Strategic Readiness

The findings of this study are further illuminated by insights derived from institutional leadership, which reveal a cautious and incremental approach to AI integration within the Architectural Engineering program. While program leadership expresses a generally positive attitude toward the use of AI—primarily to enhance information delivery and selected teaching practices—there is limited evidence of a comprehensive strategic vision encompassing curriculum transformation, infrastructure investment, evaluation mechanisms, and long-term sustainability planning. This partial readiness helps explain several patterns observed in the empirical results, including the lack of dedicated AI courses, insufficient technical infrastructure, and the absence of clear performance indicators for assessing AI-related

learning outcomes. Similar challenges have been reported in higher education contexts where leadership support exists but is not yet translated into structured governance frameworks or actionable implementation roadmaps (Zawacki-Richter et al., 2019; Jin et al., 2024). The findings suggest that effective AI integration requires not only faculty enthusiasm and student demand, but also proactive institutional leadership capable of aligning strategic planning, resource allocation, professional development, and ethical governance. Without such alignment, AI risks remaining an isolated enhancement rather than a sustained pedagogical transformation within architectural engineering education.

6. PROPOSED AI-ARCHEDUQUAL EVALUATIVE FRAMEWORK

Building on the empirical findings and informed by the critical gaps identified in the literature, this study proposes the AI-ArchEDUQUAL framework (Artificial Intelligence in Architectural Education Quality) as a structured evaluative model for assessing institutional readiness for AI integration in architectural engineering education. Rather than presenting AI integration as a set of isolated technologies or tools, the framework conceptualizes readiness as a multi-dimensional educational quality construct encompassing pedagogical, organizational, technical, and ethical conditions.

The development of the framework directly responds to the research questions posed in this study. Specifically, findings related to curriculum structure and content (RQ1), stakeholder perceptions (RQ2), institutional barriers and enabling factors (RQ3), and international benchmarking insights (RQ4) collectively revealed the absence of a coherent mechanism for systematically evaluating AI readiness at the program level. Addressing this gap, the AI-ArchEDUQUAL framework provides an integrative lens through which AI integration can be assessed beyond descriptive accounts of tools or practices, thereby responding explicitly to RQ5. Consistent with prior research emphasizing the need for institutional and quality-oriented approaches to AI adoption in higher education (Zawacki-Richter et al., 2019; Jin et al., 2024), the framework is grounded in both empirical evidence from the case study and theoretical insights from architectural and engineering education literature. It is designed to support diagnostic evaluation, strategic planning, and comparative analysis across institutions operating in diverse educational contexts.

6.1 Dimensions of the AI-ArchEDUQUAL Framework

The proposed AI-ArchEDUQUAL framework conceptualizes institutional readiness for Artificial Intelligence (AI) integration in architectural engineering education as a multidimensional quality construct. The framework was derived through triangulation of empirical evidence from student and faculty surveys, insights from academic leadership, and comparative analysis of international curricula. Rather than treating AI adoption as a purely technological upgrade, the framework emphasizes the interdependence of pedagogical, organizational, technical, and ethical conditions required for sustainable integration. Six interrelated dimensions were identified, each corresponding to recurrent patterns observed in the empirical findings and supported by existing literature.

Curriculum Readiness

This dimension reflects the extent to which AI concepts and applications are coherently embedded within the curriculum and aligned with learning outcomes and professional practice. Empirical findings related to uneven student exposure and late-stage AI engagement (RQ1, RQ2) highlight the importance of curriculum sequencing and integration rather than isolated AI modules. Similar arguments are advanced in architectural education literature, which stresses the need for scaffolded curricular alignment to support AI-enabled design thinking (Kee et al., 2024; Tan and Luhrs, 2024).

Faculty Capacity

Faculty readiness encompasses technical competence, pedagogical confidence, and willingness to integrate AI into teaching and assessment. Survey results revealed moderate awareness but limited advanced expertise among faculty (RQ3), reinforcing evidence from engineering education research that professional development is a prerequisite for sustainable AI adoption (Zawacki-Richter et al., 2019; Bentley et al., 2023).

Technical Infrastructure

This dimension addresses the availability of hardware, software, and digital platforms necessary to support AI-driven learning environments. Findings related to infrastructure limitations (RQ3) align with literature emphasizing that data-intensive AI applications require robust computational capacity to achieve meaningful educational impact (Bhurke, 2023).

Industry and Academic Partnerships

Partnerships with professional practice and technology providers support curriculum relevance, applied learning, and access to emerging AI tools. International benchmarking (RQ4) demonstrated that successful AI integration often relies on external collaboration rather than internal resources alone, echoing broader higher education research on industry-engaged learning models (Zawacki-Richter et al., 2019).

Ethics and Policy Readiness

Ethical governance emerged as an underemphasized yet critical dimension. While acknowledged by participants, ethical considerations received lower prioritization compared to pedagogical and technical aspects (RQ3). This finding mirror concerns in the literature that AI adoption frequently precedes the establishment of robust ethical and data governance frameworks, despite their importance for responsible education (UNESCO, 2019; Huang, 2023).

Student Readiness and Awareness

Student readiness reflects levels of awareness, motivation, and perceived employability benefits associated with AI integration. Strong student support for AI adoption (RQ2), combined with uneven tool familiarity, indicates high receptiveness but limited structured exposure. This dimension aligns with recent studies emphasizing learner acceptance as a key enabler of educational innovation in AI-supported design education (Kee et al., 2024).

Each dimension can be operationalized through context-specific indicators (Table 4), allowing institutions to adapt the framework to their own curricular structures and strategic priorities.

6.2 Core dimensions of the AI-ArchEDUQUAL evaluative framework and illustrative institutional indicators

Based on the triangulation of empirical findings and insights from the literature, the AI-ArchEDUQUAL framework conceptualizes institutional readiness for AI integration as a multi-dimensional quality construct. Rather than functioning as a validated measurement scale, the framework is proposed as an evaluative structure that supports diagnostic assessment and strategic reflection at the program level. Table 3 presents the core dimensions of the framework alongside illustrative institutional indicators derived from the case study and international benchmarking.

Table 3. Core dimensions of the AI-ArchEDUQUAL evaluative framework and illustrative institutional indicators

No.	Framework Dimension	Conceptual Focus	Illustrative Institutional Indicators*
1	Curriculum Readiness	Degree to which AI concepts are coherently embedded within architectural engineering curricula and aligned with learning outcomes and professional practice	Presence of AI-related content within design studios and technical courses; integration of generative design, data-driven analysis, or performance simulation within curricular structure
2	Faculty Capacity	Academic staff preparedness to meaningfully integrate AI into teaching, assessment, and supervision	Availability of structured professional development; faculty confidence in using AI-supported tools; ability to guide AI-informed design and analytical projects
3	Technical Infrastructure	Institutional digital capacity to support AI-enabled learning environments	Access to adequate computing resources; availability of AI-compatible software platforms; support for data-intensive and simulation-based learning activities
4	Industry and Academic Partnerships	Extent of collaboration with external stakeholders to support applied AI learning and research	Engagement with professional practice; joint academic–industry initiatives; student exposure to real-world AI applications
5	Ethics and Policy Readiness	Institutional governance mechanisms ensuring responsible and transparent AI use	Existence of data governance policies; ethical guidelines for AI use in education; awareness of algorithmic bias and data privacy issues
6	Student Readiness and Awareness	Learner preparedness, motivation, and perceived value of AI integration	Student awareness of AI relevance to employability; confidence in using AI-supported tools; willingness to engage with AI-enhanced learning

The proposed dimensions are interrelated and non-hierarchical, reflecting the systemic nature of AI integration in architectural engineering education. While the framework does not claim statistical validation at this stage, it provides a theoretically informed and empirically grounded basis for future scale development, cross-institutional comparison, and longitudinal evaluation.

6.3. Value and Contribution of the Framework

The AI-ArchEDUQUAL framework does not claim statistical validation at this stage; rather, it is presented as an exploratory, empirically informed evaluative model. Its primary contribution lies in shifting the discourse on AI integration from tool-centric adoption toward institutional readiness and educational quality. In contrast to existing studies that focus on individual AI applications or isolated pedagogical experiments, this framework offers a holistic structure for diagnosing gaps, prioritizing interventions, and supporting strategic decision-making at the program level.

From a research perspective, the framework establishes a foundation for future empirical validation, scale development, and cross-institutional comparison. From a practical standpoint, it provides academic leaders and policymakers—particularly in regions undergoing rapid digital transformation—with a structured tool to align AI integration with curriculum design, faculty development, infrastructure planning, and ethical governance.

By explicitly grounding the framework in empirical findings and contemporary literature, this study addresses the conceptual and methodological concerns raised in prior reviews and contributes a context-sensitive, quality-oriented perspective to the evolving field of AI in architectural engineering education.

7. CONCLUSION

This study examined institutional readiness for integrating Artificial Intelligence (AI) into architectural engineering education through an in-depth case study of Taif University, supported by international benchmarking and stakeholder perspectives. The findings reveal a clear alignment between student and faculty recognition of AI's educational value and the demands of contemporary architectural practice yet also expose significant structural gaps that constrain meaningful implementation.

While awareness and acceptance of AI are relatively high, particularly among senior students and teaching staff, AI integration remains limited in scope and depth. Advanced applications such as data-driven analytics, programming-based environments, and digital twins are largely absent from formal curricular structures. These limitations are not primarily attitudinal, but institutional in nature, stemming from fragmented curriculum design, insufficient faculty training, constrained technical infrastructure, and the absence of a clear strategic framework guiding AI adoption.

In response to these challenges, the study proposed the AI-ArchEDUQUAL evaluative framework as a quality-oriented, multi-dimensional model for assessing institutional readiness. Rather than focusing on individual tools, the framework conceptualizes AI integration as an interconnected educational process encompassing curriculum design, faculty capacity,

infrastructure, partnerships, governance, and student preparedness. Although exploratory in nature, the framework provides a structured basis for diagnostic assessment and strategic planning, particularly within contexts undergoing rapid digital transformation.

Overall, the study contributes a context-sensitive perspective to the growing discourse on AI in architectural engineering education by shifting the focus from technological potential to institutional readiness and educational quality. The findings and proposed framework offer transferable insights for architectural programs seeking to integrate AI in a pedagogically meaningful, sustainable, and ethically responsible manner.

8. RECOMMENDATIONS

Effective integration of Artificial Intelligence in architectural engineering education requires a strategic and quality-oriented approach. AI concepts should be embedded progressively across curricula to ensure coherent skill development, supported by targeted faculty development that combines technical competence with pedagogical application. Investment in digital infrastructure must align with curricular objectives to enable data-intensive and simulation-based learning. Strengthening industry and academic partnerships can enhance applied learning and curriculum relevance, while clear ethical and governance frameworks are essential to ensure responsible AI use. Continuous evaluation mechanisms should be adopted to monitor impact and support ongoing curriculum improvement.

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AUTHOR CONTRIBUTIONS

The author solely conceptualized the study, designed the research methodology, conducted the data collection and analysis, developed the proposed framework, and drafted and revised the manuscript. The author approved the final version of the manuscript for submission.

AVAILABILITY OF DATA AND MATERIALS

- The datasets generated and analysed during the current study are publicly available in anonymized form for academic and research purposes.
- The student survey dataset, containing anonymized responses, is available at an open-access repository.
- The faculty survey dataset, including anonymized responses, is also publicly accessible.

- Contextual institutional insights obtained from academic leadership were recorded in anonymized form and are made available as a supplementary dataset.

The survey instruments were originally developed and administered in Arabic to ensure clarity and inclusivity for participants. All data analysis, visualizations, and reporting were conducted and presented in English in accordance with international academic publishing standards.

All datasets have been fully anonymized to protect participants' privacy and comply with institutional ethical requirements. Publicly available documents and reports referenced in this study are cited in the reference list and can be accessed through their respective publishers.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the author.

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