Education Insights

Article

Transforming Architectural Engineering Education in Today's Learning Environment: An Education-Centered Perspective with Architectural Engineering as Context

Caidong Chen [1,*]

[1] Hainan Vocational University of Science and Technology, Haikou, Hainan, China
* Correspondence: Xinyang He, Hainan Vocational University of Science and Technology, Haikou, Hainan, China

Abstract: Under the combined pressures of carbon neutrality commitments, rapid digitalization, and the broader agenda of engineering education reform, the architectural engineering sector is shifting from experience-driven production toward data-informed, intelligent, collaborative, and low-carbon delivery. In parallel, the educational environment is increasingly characterized by learner-centered design, outcomes-based education (OBE), project-based learning (PBL), hybrid and online modalities, and stronger industry-education integration. Despite ongoing reforms, architectural engineering programs often struggle with misalignment between curricula and industry needs, fragmented practice teaching, uneven faculty engineering and digital capabilities, and assessment systems that overemphasize final results while underweighting process evidence. These gaps can leave graduates underprepared for complex project contexts requiring cross-disciplinary coordination, digital construction workflows (e.g., BIM-enabled collaboration), risk governance, and sustainability-oriented decision-making. This paper proposes an integrated "Competence-Context-Assessment" model that links graduate competencies to authentic engineering contexts and evidence-based assessment. Based on this model, it outlines practical pathways including modular curriculum reconstruction, a longitudinal project spine across semesters, dual-mentor mechanisms with industry partners, the fusion of BIM/digital twin concepts with virtual simulation, the embedding of engineering ethics and safety culture into technical decisions, and multi-source evaluation through portfolios and rubrics. Finally, the paper discusses implementation challenges related to resources, data governance, standards, and educational leadership, offering actionable recommendations for universities and vocational institutions seeking future-ready talent development.

Keywords: architectural engineering education; new engineering education; industry-education integration; intelligent construction; OBE; project-based learning

Published: 25 December 2025

Copyright: © 2025 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Architectural engineering is a prototypical field of complex socio-technical practice in which technical systems, regulatory requirements, organizational processes, and human decision-making are tightly intertwined. Projects in this domain are governed by stringent codes and standards, require sustained coordination among multiple stakeholders, and involve high levels of responsibility related to safety, quality, and public interest. In addition, architectural engineering projects are typically constrained by limited timeframes, budgetary pressures, and demanding performance expectations, all of which place considerable cognitive, technical, and managerial demands on engineers throughout the project lifecycle [1].

For decades, educational approaches in architectural engineering have relied predominantly on lecture-based instruction, supplemented by episodic site visits or short-term practical training. These approaches have focused on ensuring that students acquire foundational knowledge in areas such as engineering drawing interpretation, structural principles, quantity take-off, construction technologies, and basic site management. While such methods remain valuable for establishing disciplinary literacy and technical fundamentals, they tend to emphasize linear knowledge transmission and compartmentalized learning. As a result, students may demonstrate proficiency in individual subjects while encountering difficulties when required to integrate knowledge across domains or apply it effectively to complex, ill-structured engineering problems that resemble real project conditions [2].

At the same time, the architectural engineering industry has undergone rapid and far-reaching transformation. The widespread adoption of Building Information Modeling, prefabrication and industrialized construction methods, digital coordination platforms, smart site management technologies, and whole-life-cycle perspectives has fundamentally reshaped how projects are organized and delivered. Contemporary practice increasingly relies on collaborative digital environments, information-rich models, and continuous coordination among design, construction, and operation stages. Consequently, entry-level engineers are expected not only to possess solid technical foundations, but also to communicate across disciplinary boundaries, interpret integrated project information, and contribute to coordinated decision-making processes within multidisciplinary teams.

In parallel with these industry developments, higher education systems have experienced significant shifts in curriculum design and educational objectives. Increasing emphasis is placed on outcomes-based education, competence development, and the alignment between learning objectives, instructional activities, and assessment methods. Within this framework, professional competence is understood as the ability to apply knowledge, skills, and judgment in authentic contexts rather than the mere accumulation of theoretical content. Learning is therefore increasingly framed as an active and situated process that involves problem analysis, solution formulation, evidence-based justification, and reflection on professional responsibility. Technology-enhanced learning environments and practice-oriented pedagogical approaches are viewed as important mechanisms for supporting these forms of deep and transferable learning.

Against this background, the central challenge for architectural engineering education is not simply whether to introduce new digital tools or add isolated courses related to emerging technologies [3]. Rather, it concerns the reconstruction of the overall educational logic that underpins curriculum structure and implementation. This includes clarifying which competencies are essential for contemporary architectural engineers, determining the contexts in which these competencies should be systematically developed, and designing assessment approaches capable of evaluating students' integrated performance in complex and realistic situations. Without such coherence, curricular reforms risk remaining fragmented and may fail to produce graduates who are adequately prepared for professional practice.

This paper adopts an education-centered perspective on architectural engineering education, using the engineering discipline as the contextual setting rather than the primary analytical focus. It examines the interaction between transformations in industry practice and corresponding shifts in educational approaches, with particular attention to structural mismatches between current curricula and professional demands. By identifying typical gaps in competence development, learning integration, and assessment design, the study proposes a coherent educational model and a set of actionable reform pathways aimed at enhancing the relevance, coherence, and effectiveness of architectural engineering education under contemporary conditions.

2. Coupling Between Educational Change and Industry Transformation

2.1. Shifts in the Contemporary Educational Environment

Several interrelated shifts are reshaping the contemporary educational environment, with direct implications for engineering education. First, there is a growing emphasis on competence development and learning outcomes. Educational programs are increasingly required to define explicit graduate attributes and to demonstrate, through structured assessment, that students are able to apply acquired knowledge and skills in complex and non-routine situations [4]. This shift reflects a move away from content coverage as the primary indicator of quality and toward demonstrable performance in realistic contexts.

Second, learning design is becoming more contextual, integrative, and project-oriented. Rather than presenting concepts as isolated topics within separate courses, educators are encouraged to embed theoretical knowledge within problem scenarios that resemble professional practice. Such designs emphasize iterative learning processes in which students analyze problems, propose solutions, test assumptions, and reflect on outcomes. Through repeated engagement with context-rich tasks, students are expected to develop not only technical understanding but also judgment, adaptability, and responsibility.

Third, education is becoming increasingly digital and data-informed. Hybrid teaching modes, virtual laboratories, simulation environments, and digital collaboration platforms extend learning beyond the physical classroom and enable more flexible forms of participation. At the same time, the use of learning analytics and digital traces makes aspects of the learning process more visible to both students and instructors. This visibility supports formative feedback, adaptive instruction, and evidence-based improvement of teaching practices.

For architectural engineering education, these shifts imply a fundamental rethinking of curriculum organization and instructional strategies. Learning activities should be structured around problem solving, collaboration, and decision-making under realistic constraints, rather than around the linear transmission of disciplinary content. Students are expected to engage with tasks that require the integration of technical, managerial, and contextual considerations. As a result, learning processes should generate tangible artifacts, such as digital models, construction plans, engineering calculations, risk registers, and reflective accounts, which can serve as concrete evidence of competence and provide a basis for meaningful assessment.

2.2. Emerging Requirements in Architectural Engineering Practice

In parallel with educational change, architectural engineering practice is undergoing profound transformation. These changes can be broadly characterized by the convergence of digitalization, industrialization, greening, and intensified collaboration. Together, these trends are redefining how projects are planned, executed, and managed across the entire lifecycle.

Digitalization has become a central feature of contemporary practice. It includes the widespread use of Building Information Modeling for coordination and visualization, the integration of schedule and cost information into unified management systems, and the application of data-supported approaches to quality control and safety management. Platform-based workflows increasingly support information sharing among participants, reducing fragmentation while simultaneously raising demands for digital literacy and data interpretation.

Industrialization represents another significant shift, marked by the growing adoption of prefabrication and component standardization. These approaches relocate substantial portions of work from on-site construction to factory-based production, followed by on-site assembly. As a result, traditional boundaries between design, manufacturing, and construction are becoming less distinct. Engineers are required to consider production constraints, logistics, and assembly sequences at much earlier stages of project development.

Greening has also emerged as a key requirement in architectural engineering practice. This trend encompasses the use of low-carbon materials, energy-efficient design strategies, and systematic consideration of environmental performance throughout the building lifecycle. Life-cycle assessment and carbon accounting are increasingly incorporated into decision-making processes, requiring engineers to balance technical feasibility, economic efficiency, and environmental impact in a transparent and defensible manner.

At the same time, collaboration among project participants has intensified. Delivery modes such as engineering-procurement-construction arrangements and whole-process consulting promote earlier involvement of multiple parties and closer coordination across phases. While these modes can improve efficiency and coherence, they also increase the importance of communication skills, contract awareness, and risk governance. Engineers are expected to engage constructively with diverse stakeholders and to contribute to shared decision-making processes under conditions of uncertainty.

Taken together, these transformations significantly expand the target competence profile of architectural engineering graduates. In addition to traditional technical knowledge, students are expected to develop systems thinking, cross-disciplinary communication abilities, and literacy in digital workflows. They must also learn to balance safety, quality, cost, schedule, and sustainability considerations in a reasoned and accountable manner. These emerging requirements underscore the need for closer alignment between educational design and contemporary industry practice, forming the basis for the coupling analyzed in this study.

3. Key Gaps in Current Architectural Engineering Education

Despite ongoing reform initiatives, a number of recurrent gaps continue to characterize architectural engineering education. These gaps limit the effectiveness of curriculum reform and hinder the alignment between educational outcomes and contemporary professional demands.

(1) Curriculum lag and structural fragmentation. In many programs, curriculum structures continue to follow traditional disciplinary boundaries, such as structural engineering, construction technology, project management, and engineering economics. While this organization supports systematic coverage of specialized knowledge, it often underrepresents the integrative logic through which real engineering projects are conceived and delivered. As a result, students may become proficient in individual methods or analytical techniques, yet experience difficulty synthesizing technical, managerial, and contextual information into a coherent decision-making process when confronted with complex project scenarios.

(2) Limited authenticity and continuity in practice-oriented teaching. Practical components within the curriculum are, in some cases, dominated by demonstration-oriented activities, such as site observation and descriptive reporting, which provide limited opportunities for active problem solving. In other cases, practical tasks are weakly connected to explicit course outcomes and lack a clear progression from introductory experiences to more advanced and integrative competencies. The absence of continuity across practice activities can prevent students from accumulating and transferring experience in a systematic manner.

(3) Uneven faculty capacity in engineering practice and digital workflows. Rapid technological development in the architectural engineering industry makes it challenging for faculty members who lack sustained industry engagement to keep teaching content, tools, and case materials up to date. At the same time, industry professionals who participate in teaching activities may possess strong practical expertise but have limited experience with instructional design, student guidance, and learning assessment. This

imbalance can reduce the overall effectiveness of teaching and limit students' exposure to well-integrated theory-practice connections.

(4) Assessment systems that undervalue learning processes. In many cases, assessment relies heavily on written examinations or single final submissions. Such approaches tend to focus on outcomes while overlooking the learning processes that lead to those outcomes. Consequently, it becomes difficult to evaluate how students analyzed problems, how teams organized collaboration, how alternative solutions were considered, and whether decisions were supported by appropriate evidence. This limitation reduces the formative value of assessment and weakens its role in supporting competence development.

(5) Insufficient integration of ethics, safety culture, and sustainability reasoning. Although themes related to professional ethics, safety awareness, and sustainable development are often included in curricula, they are sometimes treated as supplementary topics rather than as fundamental constraints shaping technical choices. When these considerations are not systematically embedded into design, construction, and management tasks, students may fail to internalize their importance in real engineering decision-making. As a result, ethical judgment, safety responsibility, and sustainability reasoning remain peripheral rather than integral components of professional competence.

Collectively, these gaps reveal that challenges in architectural engineering education are not limited to individual courses or teaching methods, but are rooted in deeper issues of curriculum structure, pedagogical coherence, faculty development, and assessment design. Addressing these gaps requires a coordinated approach that aligns learning objectives, instructional strategies, and evaluation mechanisms with the complex realities of contemporary architectural engineering practice.

4. An Integrated "Competence-Context-Assessment" Model

To bridge the above gaps, this paper proposes an integrated model that tightly links competencies, learning contexts, and assessment evidence. Competence refers to clearly articulated graduate attributes and proficiency levels, including technical capability, digital workflow literacy, collaboration, and professional responsibility. Context refers to authentic or high-fidelity engineering scenarios that require students to make trade-offs under constraints, such as design coordination, schedule compression, resource allocation, safety planning, contract interpretation, and low-carbon strategy selection. Assessment refers to the systematic collection of evidence-artifacts, logs, reviews, and reflections-evaluated with transparent criteria (rubrics) and complemented by multiple perspectives (teachers, peers, and industry mentors) The model treats learning as the progressive construction of an evidence chain: students should be able to demonstrate not only what they produced, but also why they made decisions and how they managed risks and constraints (Table 1).

Table 1. Examples of Competencies and Evidence in Authentic Contexts.

Target competency	Authentic context/task	Assessment evidence
BIM-enabled collaboration	Multi-discipline model coordination and clash resolution	Model versions, clash reports, coordination meeting minutes
Schedule-cost integration	Baseline planning and scenario-based schedule compression	Network schedule, resource plan, cost estimate, rationale memo
Safety and risk governance	High-risk operations planning (lifting, temporary works, excavation)	Risk register, method statement, controls map, simulation log

Low-carbon decision-making	Material and construction method comparison under carbon constraints	Carbon estimation sheet, assumptions, trade-off analysis
Professional communication	Design review or technical briefing with constraints and objections	Slide deck, Q&A transcript, peer/mentor feedback

5. Reform Pathways for Future-Ready Talent Development

5.1. Modular Curriculum Reconstruction: From Linear Subjects to a Competency Matrix

Rather than adding isolated "new technology" courses, programs can reconstruct curricula into a competency matrix that maps modules to graduate outcomes. A typical structure may include: (a) foundations-graphics and drawing reading, materials and structural fundamentals, surveying, and construction basics; (b) digital construction-BIM modeling, collaboration processes, engineering software literacy, and smart site concepts; (c) low-carbon construction-life-cycle thinking, green materials, and carbon-aware planning; (d) management and governance-contracts, procurement, cost control, quality and safety management, and risk governance; and (e) integrative practice-cross-course projects and capstones. The crucial point is to ensure coverage and progression: each competency should be introduced, reinforced, and mastered through sequenced learning experiences.

5.2. A Longitudinal Project Spine: Organizing Learning Around the Logic of Real Projects

A "project spine" can connect multiple semesters through one coherent project narrative. Students may start withdrawing interpretation and quantity take-off, then progress to BIM-based coordination and construction planning, and finally conduct integrated optimization involving time, cost, quality, safety, and carbon performance. Such longitudinal design supports iteration, helps students experience consequences of earlier decisions, and cultivates systems thinking. To maintain feasibility, teaching teams can use a mid-scale building case with de-identified data, updating complexity as students advance.

5.3. Dual-Mentor Mechanisms and Deep Industry-Education Integration

Effective industry-education integration depends on operational mechanisms rather than symbolic partnerships. A dual-mentor system can be adopted, where academic instructors lead learning design and assessment, while industry mentors contribute authentic workflows, standards, and cases. Joint task design is essential: enterprises can provide a curated library of typical problems (e.g., recurrent quality defects, safety planning challenges, change management, procurement constraints), and instructors can translate them into teachable tasks with rubrics. Stage-gate reviews-simulated design reviews, method statement briefings, and coordination meetings-can further enhance realism and accountability.

5.4. Digital Enablement: Integrating BIM, Digital Twin Concepts, and Virtual Simulation

Digital tools should serve competence development rather than becoming narrow software training. A layered design is recommended. At the tool layer, students learn BIM modeling, scheduling, and cost tools to support communication and planning. At the simulation layer, virtual environments can train high-risk operations and safety decision-making in repeatable, low-cost settings. At the analytics layer, learning evidence (model iterations, logs, peer feedback) can be used for formative assessment, enabling timely and personalized feedback. "Virtual-real integration" allows students to rehearse risk-heavy scenarios before entering live sites, improving both learning effectiveness and safety.

5.5. Embedding Ethics, Safety Culture, and Sustainability Into Technical Decisions

Because architectural engineering directly affects public safety and long-term environmental outcomes, ethics and responsibility should be integrated into technical decision-making. Instruction can follow a "case-code-decision" sequence: de-identified accident and failure cases help students recognize systemic causes; relevant regulations and mandatory clauses provide boundaries; and project tasks require students to justify decisions under constraints. For example, schedule compression exercises can explicitly require a safety risk assessment and mitigation plan; material substitution tasks can require code compliance checks and durability reasoning; low-carbon proposals can require transparent assumptions and boundary definitions.

5.6. Multi-Source Assessment: From Scores to an Evidence Chain

A multi-source assessment system can combine formative and summative evidence. Formative evidence includes task breakdowns, data justification, risk registers, meeting minutes, and reflective journals. Summative evidence includes final models, construction organization plans, cost-schedule integrated deliverables, and oral defenses. Peer review and industry mentor feedback complement teacher evaluation, improving authenticity and fairness. Rubrics make expectations explicit across dimensions such as problem framing, feasibility, evidence quality, risk control, sustainability reasoning, and teamwork.

6. Implementation Challenges and Governance Recommendations

Moving from concept to practice requires governance and resource strategies.

Resource constraints are common, especially for simulation platforms and project libraries. A phased approach is advisable: start with one or two flagship courses and a reusable project case, then scale across the curriculum. Shared platforms and open standards can reduce duplication and prevent "tool islands".

Data governance and compliance are critical in industry collaboration. Programs should adopt a data classification mechanism (public, teaching-only, restricted) and use parameterized or de-identified cases when full project datasets cannot be shared. Clear agreements on intellectual property, access rights, and usage scope protect both schools and partners.

Faculty development is another bottleneck. Programs can support faculty internships in industry, co-teaching arrangements, and professional learning communities that focus on OBE design, PBL facilitation, rubric development, and portfolio-based assessment. Finally, quality assurance should align with the competence model: periodic curriculum mapping, stakeholder reviews, and evidence audits can ensure that reforms remain coherent and effective.

7. Conclusion

Contemporary educational change-characterized by competence orientation, contextual learning, and digital enablement-intersects with industry transformation toward intelligent, collaborative, and low-carbon construction. Architectural engineering education must therefore transition from a knowledge-transmission paradigm to a competence-generation paradigm. This paper proposed an integrated "Competence-Context-Assessment" model and derived actionable reform pathways: modular curriculum reconstruction, a longitudinal project spine, dual-mentor mechanisms with industry partners, digital integration through BIM and simulation, and multi-source assessment built around evidence chains. Future work can deepen this approach through differentiated strategies for research universities, application-oriented institutions, and vocational colleges, and through the development of shared case repositories and competency benchmarks.

References

1. N. V. Kasyanov, "The evolution of architectural morphogenesis at the beginning of XXI century in the context of scientific advances," *Procedia Engineering*, vol. 153, pp. 266-270, 2016. doi: 10.1016/j.proeng.2016.08.113
2. X. Pan, "Implementation of an adaptive rule-based, object-oriented expert system in architectural programming: an experiment in human-computer collaboration," *California Polytechnic State University*, 1999.
3. L. Stam, F. Ostuzzi, and A. Heylighen, "Open design: An actual topic in architectural education," *International Journal of Technology and Design Education*, vol. 32, no. 1, pp. 667-693, 2022.
4. G. Salvaneschi, C. Ghezzi, and M. Pradella, "Context-oriented programming: A software engineering perspective," *Journal of Systems and Software*, vol. 85, no. 8, pp. 1801-1817, 2012. doi: 10.1016/j.jss.2012.03.024

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of the publisher and/or the editor(s). The publisher and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.