Education Insights

Article

BIM Tec Research on Teaching Reform Driven by BIM Technology Integrating Theory and Practice in Civil Engineering

Zihan Wang [1,*]

[1] Hainan Vocational University of Science and Technology, Hainan, 571126, China
* Correspondence: Zihan Wang, Hainan Vocational University of Science and Technology, Hainan, 571126, China

Abstract: With the accelerating digital transformation of the construction industry, Building Information Modeling (BIM) has become a core technological driver in civil engineering, yet its integration into university education remains constrained by gaps between theory and practice, fragmented curricula, and limited alignment with the national 1+X Certificate System. Focusing on BIM teaching in civil engineering programs, this study aligns industry job requirements with the 1+X pilot framework to analyze current instructional challenges and propose a distinctive "Post-Class-Competition-Certificate-Innovation-Research" six-in-one reform model. Implementation pathways are designed across four dimensions-curriculum system reconstruction, training platform enhancement, university-enterprise collaborative education, and assessment optimization-to bridge the divide between theoretical learning and practical application. By leveraging BIM to build a coherent, practice-oriented teaching ecosystem, the study aims to cultivate interdisciplinary talent capable of meeting the digital competencies demanded by the modern construction industry, offering a valuable reference for BIM-oriented educational reform under the paradigm of emerging engineering education.

Keywords: BIM technology; civil engineering; teaching reform; 1+X Certificate System; integration of theory and practice

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1. Introduction

1.1. Background of Digital Transformation in the Construction Industry

The construction industry, as an essential component of the national economy, is experiencing a rapid shift toward digitalization, intelligence, and refined project management. In this broader transformation, BIM technology has become one of the most influential tools for integrating multidisciplinary information, optimizing engineering workflows, and improving coordination across design, construction, and operational stages. With increasing adoption by large engineering enterprises, BIM has demonstrated significant advantages in visualization, simulation, cost control, and lifecycle management, contributing to improved efficiency and enhanced project quality [1].

Despite the accelerating application of BIM in engineering practice, the industry still faces a pronounced shortage of skilled professionals. As BIM-related workflows become more standardized and deeply embedded across project phases, the demand for engineers proficient in data integration, model operation, and cross-disciplinary collaboration continues to grow. Current estimates suggest that the talent gap remains substantial, creating a persistent mismatch between industry needs and the availability of trained university graduates. This structural shortage highlights the urgency of cultivating students with both theoretical understanding and operational competence in BIM workflows.

To address this situation, universities must not only update their technical courses but also rethink pedagogical strategies that support deeper integration of digital competencies. Civil engineering programs need to adapt teaching objectives, curriculum structures, and practical modules to ensure that students develop industry-relevant skills. Without such adjustments, the gap between academic education and practical engineering needs will continue to widen, limiting students' competitiveness in the evolving job market.

1.2. Challenges in Current BIM Teaching within Civil Engineering Programs

Although many universities have introduced BIM-related courses, traditional teaching frameworks in civil engineering still place a greater emphasis on theoretical instruction, often isolated from real-world engineering scenarios. Students frequently learn the conceptual principles of BIM but lack opportunities to engage with authentic project cases or perform operations based on industry-standard workflows. As a result, their understanding remains fragmented, and they struggle to transform theoretical knowledge into practical ability. This mismatch leads to graduates who may understand BIM concepts but cannot effectively operate tools, interpret model data, or collaborate within multidisciplinary teams [2].

Another challenge lies in the fragmentation of course content. Because BIM intersects with architecture, structural engineering, geotechnical engineering, project management, and other fields, many universities distribute BIM-related knowledge across multiple courses without establishing a coherent and progressive learning pathway. This disjointed structure weakens the systematicity of knowledge acquisition and increases the difficulty of cultivating holistic BIM capabilities. Furthermore, practical training platforms in some institutions remain outdated or underutilized, reducing students' exposure to industry-equivalent software environments.

Additionally, the alignment between university teaching and the national 1+X Certificate System requires further strengthening. The 1+X system emphasizes competency-based training, standardized skill assessments, and application-oriented learning outcomes. However, some current BIM courses have not fully integrated the competency standards embedded in the certificate system, resulting in insufficient preparation for students seeking certification. Therefore, enhancing the synergy between course modules, practical tasks, and certification requirements is essential for improving teaching effectiveness and supporting students' future development.

1.3. Reform Orientation Based on the Integration of Theory and Practice

In response to the above challenges, this study adopts the goal of enhancing the integration of theory and practice as the core of BIM teaching reform. Guided by the concept of forming a continuous learning-to-application pathway, the proposed approach incorporates the "Post-Class-Competition-Certificate-Innovation-Research" model as a central organizing framework. This integrated model aims to connect professional positions, classroom learning, skills competitions, certificate training, innovation projects, and research activities into a unified teaching system. Such integration helps students progressively develop BIM competencies across multiple dimensions and achieve readiness for industry demands.

At the same time, the reform framework emphasizes the importance of aligning curriculum design with competency standards and practical workflows. By combining industry post requirements with the structure of the 1+X Certificate System, the proposed teaching plan restructures course content, enhances practical modules, and promotes collaboration with enterprise partners. This approach ensures that students not only master software tools but also understand complete engineering workflows, enabling them to participate in modeling, simulation, and collaborative tasks that mirror real project environments.

Through the systematic design presented in this section, the reform aims to break the long-standing separation between classroom teaching and engineering practice. By embedding BIM technology into a coherent and practice-oriented education pathway, universities can cultivate civil engineering graduates with stronger digital literacy, comprehensive application skills, and the ability to contribute effectively to the digital transformation of the construction industry. The overall goal is to provide a practical and operable framework for universities seeking to update their BIM teaching strategies under the background of emerging engineering education [3].

2. Current Status of BIM Teaching in Civil Engineering Major

At present, universities offering civil engineering programs have gradually incorporated Building Information Modeling (BIM) into their curricula. However, despite the steady advancement of BIM education, significant challenges remain in achieving effective integration between theoretical instruction and practical application. These challenges can be summarized across the following dimensions.

2.1" Emphasis on Theory while Neglecting Practice" in Teaching Content, Disconnected from Engineering Reality

Most universities still position "software operation" as the primary focus of BIM teaching. Courses such as *BIM Modeling Application* mainly introduce fundamental functions of commonly used software, including Revit and Navisworks, such as component modeling, view creation, and drawing export. While these elements are necessary, they are often presented in isolated modules that lack connection to full life-cycle engineering scenarios.

For example, in the Civil Engineering Construction Technology course, BIM-based construction simulation is often demonstrated through static PPT slides rather than through hands-on projects. Students are rarely guided to conduct pipeline collision detection, model-based schedule optimization, or scenario-based construction sequencing. Similarly, in cost-related courses, BIM quantity takeoff remains confined to simplified virtual cases and does not reflect the actual requirements of bill-of-quantities preparation, dynamic cost adjustment, or engineering change management in real projects.

This fragmented instructional model-characterized by theoretical explanation on one hand and isolated software demonstrations on the other-results in students being able to complete only basic modeling tasks. They remain unable to integrate BIM with essential civil engineering competencies such as engineering drawing interpretation, construction organization, or process control. Consequently, many students find themselves unable to transform theoretical learning into actionable engineering solutions when confronted with real project environments.

2.2. Loose Connection Between Curriculum System and 1+X Certificate System, Insufficient Post Adaptability

Since 2019, the implementation of the "1+X Certificate System" has aimed to enhance the practical skills of college students by supplementing academic degrees with vocational competency certificates. Certificates related to BIM-such as "BIM Modeler" and "BIM Engineer"-have gradually become important credentials in the job market for civil engineering students.

However, survey results from multiple universities indicate that a large proportion of institutions have not systematically embedded the competency requirements of the 1+X certificate system into their existing curriculum structures. On the one hand, the comprehensive BIM application capabilities required for certificate assessments-such as model review, 4D construction simulation, quantity takeoff, and operation-and-maintenance information integration-are not aligned with the predominantly “basic modeling” focus of current courses. As a result, students often need to participate in additional training programs outside the university, leading to unnecessary duplication of learning between academic courses and certificate-oriented training.

On the other hand, the existing curriculum structure is not sufficiently aligned with industry demand. Positions such as construction engineers require proficiency in “BIM + 4D schedule management” while cost engineers need to master “BIM + 5D cost analysis”. However, most universities have not decomposed BIM teaching modules according to job-related skill requirements. This disconnection causes students to experience a considerable learning gap when transitioning into employment, requiring extensive enterprise-level retraining to meet practical demands [4].

2.3. Teaching Reform Framework for the Integration of BIM Theory and Practice Under the “Post-Class-Competition-Certificate-Innovation-Research” Six-in-One Education Model

To address the above issues, a comprehensive teaching reform framework-namely the “Post-Class-Competition-Certificate-Innovation-Research” six-in-one model-is proposed. This framework, as shown in Table 1, takes industry post requirements as the guiding foundation, uses curriculum reconstruction as the core, and incorporates competitions, certificates, innovation activities, and research engagement as extended supports. The aim is to build a coordinated system that integrates learning, practice, assessment, and innovation, thereby enhancing students' professional competencies and improving the effectiveness of BIM education.

Table 1. Core Links and Implementation Paths of BIM Teaching Reform.

Core Links	Core Objectives	Specific Implementation Paths	Key Achievements
Post: Aligning with Industry Posts	Ensure consistency between teaching content and industry needs	Investigate enterprises such as China State Construction Engineering Corporation and China Railway Group Limited, and sort out BIM competency requirements for core posts including construction workers and cost engineers.	Form a “post competency-BIM skills-course knowledge points” mapping table.
Class: Reconstructing Curriculum System	Lay a solid foundation for the integration of “learning and doing”	Build a three-level BIM curriculum system of “foundation-core-practice”, breaking the separation between theoretical and practical courses.	Integrate theoretical knowledge into practical modules to realize “learning by doing and doing by learning”.
Competition: Promoting Learning Through Competitions	Strengthen the ability to solve complex engineering problems	Integrate content from national BIM skill competitions into teaching, and drive learning through competition tasks.	Improve students' practical BIM application capabilities in real scenarios.
Certificate: Integrating Courses with Certificates	Standardize integration standards and avoid duplicate learning	Integrate assessment standards of “1+X” certificates (e.g., BIM Modeler) into curriculum content.	Realize effective connection between “curriculum content-certificate training-post capabilities”.

Innovation: Expanding Application Scenarios	Promote the transformation of theoretical innovation into practical achievements	Carry out innovation and entrepreneurship projects based on BIM technology (e.g., prefabricated building optimization, intelligent operation and maintenance platform development).	Cultivate students' innovative thinking and entrepreneurial capabilities, and expand BIM application scenarios.
Research: Feeding Back Teaching	Enhance integration depth and realize a closed loop	Decompose teachers' BIM research projects into student practical topics and guide students to participate in the research process.	Form a closed loop of "theory-practice-research" and improve teaching depth with cutting-edge research.

3. Implementation Paths of Teaching Reform for the Integration of BIM Theory and Practice

3.1. Reconstructing the "Three-Level Progressive" BIM Curriculum System to Achieve In-Class Integration of Theory and Practice

Under the guidance of the "Post-Class-Competition-Certificate-Innovation-Research" education model, the BIM curriculum is organized into three progressive layers-foundation, core, and practice-forming a continuous development path that integrates theoretical understanding and practical skills. The dual-line approach of "theory + practice" is embedded across all layers to cultivate students' professional competence systematically.

Foundation Layer (Freshmen and Sophomores): This initial stage emphasizes foundational knowledge acquisition and conceptual enlightenment. Courses such as Introduction to BIM and Engineering Drawing and BIM Fundamentals provide students with a thorough understanding of projection principles, structural representation, and geometric modeling. In practical sessions, students employ Revit to model fundamental structural components including beams, columns, slabs, and walls. By combining 2D engineering drawing principles with 3D digital modeling, students develop spatial cognition and foundational modeling skills. The curriculum aligns with the primary level of the 1+X BIM certificate, enabling students to gradually internalize modeling standards, nomenclature conventions, and component classification, while also fostering awareness of collaborative workflows in team projects.

Core Layer (Juniors): The core stage targets professional competence enhancement through advanced theoretical instruction and specialized applications. Courses such as *BIM Structural Design* and *BIM Construction Management* encourage students to apply foundational knowledge to complex, discipline-specific tasks. In structural courses, students use PKPM-BIM to carry out a full structural workflow, from load calculation, reinforcement detailing, to structural model verification. In construction management courses, students utilize Navisworks to conduct 4D construction simulation, schedule optimization, and resource allocation for realistic projects, adhering to intermediate-level 1+X BIM certificate standards. This stage also emphasizes interdisciplinary collaboration, requiring students to work in teams to simulate project coordination, identify potential design conflicts, and optimize construction sequences. By integrating theoretical learning with scenario-based problem solving, students consolidate knowledge while developing practical judgment and project management skills.

Practice Layer (Seniors): The practice layer focuses on comprehensive application, interdisciplinary integration, and innovation-oriented learning. Courses such as *BIM Full-Life-Cycle Application* and *BIM Graduation Design* engage students with university-enterprise cooperative projects, enabling them to complete full-process BIM applications encompassing design, construction, cost estimation, and facility operation management. Students are organized into groups to simulate real project teams, adopting roles such as structural engineer, cost analyst, and project manager. Graduation projects are often aligned with advanced BIM certification or national competitions, providing platforms for integrating course learning, certification preparation, competitive tasks, and innovative project execution. This layer cultivates students' problem-solving ability, innovation, teamwork, and readiness for professional practice, ensuring they are equipped to handle real-world engineering challenges effectively [5].

3.2. Building a "Virtual-Physical Integrated" Training Platform to Establish a Carrier for Theory-Practice Integration

To bridge the gap between theoretical knowledge and practical application, a trinity-based BIM training platform combining virtual simulation, physical training, and enterprise projects is developed.

The **virtual simulation platform** leverages the university's experimental centers and integrates BIM with VR/AR technologies to create immersive, full-life-cycle engineering scenarios. Students can visualize complex construction sequences, conduct virtual walkthroughs, and engage in collaborative project simulations. The platform enables task-specific operations such as collision detection, quantity takeoff, and schedule simulation, allowing students to experiment with design alternatives and analyze project feasibility in a risk-free environment. Collaborative tools on the platform support real-time team interaction, role assignment, and progress tracking, strengthening project coordination skills and enhancing understanding of construction management principles.

The **physical training base** is established through university-enterprise collaboration and is equipped with BIM workstations, model assembly zones, and process demonstration areas. After completing virtual simulations, students can perform hands-on assembly of components, verify virtual designs, and adjust parameters based on observed performance. Enterprise engineers provide on-site guidance, offering insights into real-world construction constraints, workflow optimization, and problem-solving techniques. This iterative process allows students to validate theoretical models, refine practical skills, and build confidence in applying BIM methodologies to tangible projects.

The **enterprise project library** compiles real project cases and complete data sets from cooperative enterprises. Students assume the role of enterprise engineers, executing comprehensive tasks including model creation, 4D construction simulation, cost estimation, and resource management. Enterprise professionals evaluate the outcomes against industry standards, providing detailed feedback on model accuracy, process rationality, and project viability. This immersive approach ensures students' competencies are closely aligned with industry requirements and post-specific demands, thereby facilitating a smooth transition from academic learning to professional practice.

3.3. Deepening the University-Enterprise Collaborative Education Mechanism to Inject Integration Power

To address the persistent, disconnect between university instruction and industry needs, a comprehensive university-enterprise collaboration mechanism is implemented, spanning teacher engagement, curriculum development, and student evaluation.

Teacher Engagement: Faculty members participate directly in enterprise BIM projects to gain first-hand experience of current industry practices. Simultaneously, enterprise engineers are appointed as industrial professors to co-teach specialized courses. This dual-qualified teaching team ensures that students are exposed to the latest BIM technologies, industry workflows, and practical problem-solving strategies. Regular joint workshops and on-site project mentoring sessions further enhance knowledge transfer, enabling students to integrate theoretical learning with hands-on applications.

Curriculum Development: A joint curriculum committee, comprising university educators and enterprise experts, oversees the continuous alignment of course content with national standards and industry trends. The committee evaluates emerging BIM tools, construction methods, and regulatory requirements, and incorporates them into course syllabi. Courses are designed with practical scenarios, case studies, and project-based tasks to ensure that students acquire both the theoretical depth and practical versatility needed for professional engineering roles.

Evaluation Mechanism: Enterprise professionals actively participate in student assessments, providing evaluations that mirror real-world performance criteria. Assessment dimensions include model precision, construction feasibility, cost optimization, innovation, and teamwork. Feedback from industry experts informs iterative adjustments in teaching methods and curriculum design, creating a closed-loop system that enhances both instructional quality and student readiness for professional posts.

3.4. Optimizing a Multi-Dimensional Assessment System to Quantify the Integration of Theory and Practice

Traditional assessments focusing solely on final modeling projects are insufficient to capture students' holistic capabilities. A multi-dimensional evaluation framework is therefore proposed, integrating process assessment, phase assessment, and comprehensive assessment, while encompassing all aspects of the Post-Class-Competition-Certificate-Innovation-Research framework.

Process Assessment (40%): This component emphasizes ongoing learning and skill development. Students are evaluated on engagement in class discussions, completion of practice tasks, participation in collaborative projects, and application of knowledge in problem-solving scenarios. Assessment tools include training logs, online learning records, reflective reports, and peer evaluations, capturing both individual and group performance throughout the learning process.

Phase Assessment (30%): Phase assessments focus on competency development aligned with certifications and competition-based tasks. Students complete project simulations and practical assignments each semester, reflecting the requirements of intermediate-level 1+X BIM certificates or national BIM competitions. For example, students may conduct 4D construction simulation within a limited timeframe or solve complex engineering coordination problems. Evaluations are jointly conducted by university instructors and enterprise professionals, combining technical accuracy, efficiency, and innovation.

Comprehensive Assessment (30%): This component evaluates students' integrated capabilities through graduation projects or innovation-based initiatives. Assessment dimensions include structural design, construction sequencing, cost control, and application of advanced BIM technologies. Achievements such as obtaining advanced BIM certifications, winning competition awards, or successfully implementing innovative solutions in projects serve as bonus criteria, providing a holistic measure of students' proficiency and the effectiveness of theory-practice integration.

4. Discussion

The implementation of the "Post-Class-Competition-Certificate-Innovation-Research" six-in-one teaching reform framework has demonstrated significant potential in bridging the gap between theoretical instruction and practical engineering skills in civil engineering education. By systematically integrating curriculum reconstruction, immersive virtual-physical training platforms, university-enterprise collaboration, and multi-dimensional assessments, students are provided with a learning environment that closely mirrors real-world engineering scenarios. This approach not only enhances students' technical competencies in BIM modeling, 4D construction simulation, and 5D cost management but also cultivates essential soft skills such as teamwork, problem-solving, and project coordination.

However, several challenges have emerged during implementation. First, the complexity of coordinating multi-layered curricula and enterprise participation requires robust administrative and organizational mechanisms. Universities must balance academic objectives with the practical needs of partner enterprises, ensuring that projects and tasks remain pedagogically valuable while meeting real industry standards. Second, the reliance on advanced technologies, such as VR/AR and collaborative BIM platforms, necessitates substantial investment in hardware, software, and maintenance, which may limit scalability in smaller institutions or vocational colleges. Third, while multi-dimensional assessment provides a more comprehensive evaluation of student competencies, it also increases the workload for instructors and enterprise mentors, and requires consistent standards to ensure fairness and objectivity across diverse projects and teams.

Despite these challenges, the teaching reform framework offers several advantages. The integration of competitions and certifications directly motivates students to apply theoretical knowledge in competitive and goal-oriented contexts, fostering higher engagement and innovation. University-enterprise collaboration ensures that students' learning outcomes are aligned with industry requirements, facilitating smoother transitions into professional roles. Additionally, immersive training platforms enhance experiential learning, enabling students to anticipate and solve real construction problems before entering the field.

Looking forward, the sustainability and scalability of this reform depend on continuous improvement in three areas. First, universities should establish structured feedback loops to iteratively refine course content, project design, and assessment methods based on student performance and industry trends. Second, technology adoption should be complemented with instructor training programs to maximize effective utilization of BIM, VR/AR, and digital collaboration tools. Third, expansion of the framework beyond traditional four-year universities, extending to junior colleges and vocational programs, can help cultivate a broader base of technically proficient civil engineering professionals. By addressing these considerations, the teaching reform framework can evolve into a robust model for integrating theory and practice, contributing to the development of a digitally competent and industry-ready civil engineering workforce.

5. Conclusion

BIM technology serves as an effective “technical bridge” for integrating theoretical knowledge with practical skills in civil engineering education. The six-in-one teaching reform framework of “Post-Class-Competition-Certificate-Innovation-Research” proposed in this study successfully addresses the key disconnection issues present in traditional curricula by aligning course content with professional post requirements, reconstructing a progressive curriculum system, establishing comprehensive training platforms, strengthening university-enterprise collaboration, and optimizing multi-dimensional assessment mechanisms. Through this integrated approach, students are better prepared to apply BIM methodologies to real-world engineering projects, enhancing both their technical competencies and problem-solving capabilities.

Looking ahead, several directions are critical for the sustained development of BIM-based teaching reforms. First, it is essential to further strengthen the long-term mechanism of university-enterprise collaboration by establishing structured incentive policies for enterprise participation in teaching and research activities. Second, teaching content must be continuously updated to keep pace with technological advancements, including the integration of BIM with emerging technologies such as digital twin simulations, artificial intelligence, and smart construction management systems. Third, the scope of reform should be broadened to include junior colleges, vocational programs, and other tertiary education institutions, thereby cultivating a wider base of digitally competent and practice-oriented civil engineering professionals.

By addressing these aspects, the proposed framework not only promotes the integration of theory and practice at the undergraduate level but also contributes to the long-term development of a skilled workforce capable of meeting the evolving demands of the construction industry. Ultimately, this reform model provides a systematic pathway for enhancing the digital literacy, practical skills, and innovative capabilities of civil engineering graduates, offering sustained support for the high-quality and technology-driven advancement of construction practices.

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