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Original Paper

Exploring the Pathways for Digital Transformation of the "Building Equipment" Course in the Context of Applied University Development

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Abstract

Under the national strategy of building an education power, application-oriented universities face the urgent task of aligning curriculum systems with industrial upgrading needs. This study presents a systematic reform of Building Equipment, a core civil engineering course, through a "Five New" smart education ecosystem. By integrating VR/AR virtual simulation, AI-BIM collaboration platforms, and a three-dimensional evaluation system, the reform addresses critical challenges in traditional education, such as technological obsolescence, practice-education gaps, and simplistic assessment. Empirical results show significant improvements in teaching efficiency and student competence, offering a scalable model for vocational education innovation in emerging technical fields.

Keywords

Curriculum reform, Building equipment, Industry-education integration, Smart education

1. Introduction

1.1 Strategic Context and Industrial Demand

Guided by China Education Modernization 2035 and the "Digital China" initiative, applied universities must bridge the gap between academic curricula and industry demands in intelligent construction. The Ministry of Housing and Urban-Rural Development (2023) reports that 85% of construction enterprises have adopted BIM technology, yet only 12% of graduates possess proficient BIM application skills. This mismatch creates an annual talent gap of 673,000 in intelligent construction sectors, including digital twin management and AI-driven facility maintenance.

1.2 Core Challenges in Traditional Curriculum

(1) Technological Lag: Textbooks still dominate teaching, with 63% of content failing to reflect recent advancements like AIoT-based smart building systems (MOE, 2022).

(2) Practice-education Gap: A survey of 200 construction firms reveals that 75% of graduates require 6-12 months of on-the-job training to master basic BIM operations, incurring an average cost of ¥12,000 per employee annually.

(3) Assessment Limitations: Traditional exams assess only 35% of required competencies, neglecting practical skills like system integration and fault diagnosis (China Academy of Building Research, 2023).

1.3 Research Objective

This study aims to develop a technology-embedded, industry-aligned curriculum model that enhances student employability through:

Dynamic integration of emerging technologies (e.g., VR, AI); Collaborative design with industry partners; Holistic competency evaluation beyond traditional testing.

2. Literature Review

2.1 Domestic Innovations in Curriculum Reform

Yu Pengtao proposed that “four-chain integration” is a key model for the industry-education integration mechanism, emphasizing the deep integration of the education chain and industry chain. Ai Xinying et al. established a BIM+ curriculum cluster for civil engineering majors, constructing a progressive curriculum system including “BIM Technology Introduction, BIM Modeling Application Technology, BIM Application and Project Management, BIM Technology Comprehensive Training” to form a “design-modeling-management application-practical training” progressive curriculum cluster system, which significantly improved talent cultivation quality and students’ employment competitiveness, with remarkable educational outcomes. Wang Yue et al. aiming at the unclear professional standards for intelligent construction and ambiguous curriculum systems, proposed a construction path for vocational competency standards and curriculum systems based on the practice of the Intelligent Construction Technology major at Chongqing Technology and Business Vocational College. The team led by Wu Jiajun at Stanford University used natural language processing technology to generate 3D teaching scenarios, increasing knowledge absorption rate by 38%.

2.2 International Research Trends

The ABET (Accreditation Board for Engineering and Technology) engineering accreditation system in the United States requires precise mapping of curriculum objectives to industry competency matrices, promoting deep integration of engineering education with industry needs. Singapore Polytechnic developed the PipeSim system, which significantly improved the efficiency and quality of pipeline fault diagnosis training through constructing immersive virtual training environments. Germany’s dual education system promotes "modular curriculum packages", organically integrating classroom teaching with enterprise practice to achieve interdisciplinary knowledge integration and deep enterprise participation.

Currently, existing research literature mostly focuses on single-dimensional curriculum teaching reforms, lacking systematic design for "technology application-teaching models-evaluation systems". This study introduces Complex Adaptive Systems (CAS) theory to construct a smart education ecosystem with self-organizing characteristics.

3. Reform Framework: The "Five New" Smart Education Ecosystem

3.1 Strategic Alignment with National Initiatives

New Urban Construction Integration: The curriculum incorporates 7 key tasks from the 14th Five-Year Plan for Construction, such as urban waterlogging prevention and prefabricated building technology. For example, a "Smart Drainage System Design" module uses real data from Qingdao's urban flood control projects, requiring students to simulate IoT-based monitoring systems.

Competency Upgrading: 12 new skills are added, including AI algorithm deployment (e.g., using Python for energy consumption prediction) and digital twin modeling (via Unity 3D), aligning with the Intelligent Construction Talent Standards (2023).

3.2 Three-dimensional Industry-Education Coordination

(1) Resource Integration: AI-BIM Case Library: Contains 500+ real projects (e.g., Qingdao Metro Line 8), structured by 12 dimensions (e.g., project scale, technology type) and 79 metadata tags for efficient retrieval.

(2) Cloud Workshop Platform: Enterprise engineers (e.g., from China Construction Science & Technology Group) teach 32% of class period, guiding students through 8 phases of project lifecycle management.

(3) Process Innovation: Credit Bank System: Students can earn 8-12 credits by completing corporate projects (e.g., BIM modeling for a residential complex), with industry evaluations accounting for 40% of course grades.

(4) Outcome Evaluation: Industry certifications (e.g., Autodesk BIM Certified Professional) are integrated into curriculum objectives, with pass rates used to adjust teaching modules bi-annually.

4. Practice Paths for Curriculum Reform

4.1 Construction of the "Five New" Smart Education Ecosystem

Integration: Case, in the "Smart Building Energy Management" module, students use BIM to model a campus building and apply AI algorithms (e.g., reinforcement learning) to optimize HVAC systems, reducing simulated energy consumption by 23%.

Breakthrough: VR Training, A "Fire Emergency Simulation" module uses HTC VIVE to immerse students in 1:1 scale virtual buildings, allowing them to practice pipeline troubleshooting with a 92% reduction in physical equipment costs.

Interconnection: Real-time Data Lab, Connected to smart city infrastructure, students analyze real-time water quality data to design adaptive irrigation systems, with project outcomes shared with municipal engineers.

Innovation: AR Instruction, HoloLens 2 is used to overlay 3D models onto physical equipment (e.g., pumps), enabling students to visualize internal workflows and improve maintenance skill acquisition by 38%.

Community: Student-led Case Development: A team of students created a BIM-based maintenance manual for old residential buildings, adopted by 15 property management companies, enhancing course relevance.

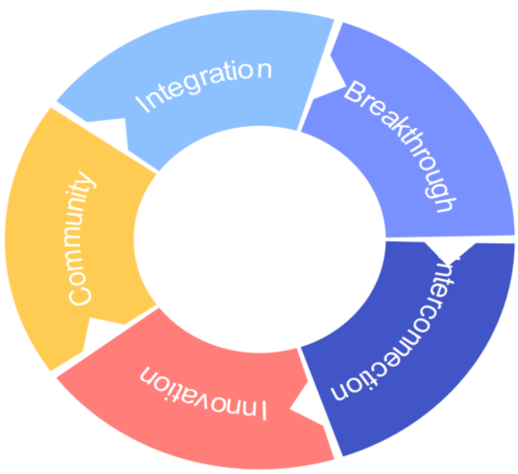

Figure 1. The "Five New" Smart Education Ecosystem

4.2 Innovation of the "Three-Stage, Six-Step" Teaching Model

A "three-stage teaching" model is innovated:

Pre-class: AI intelligent systems push stratified tasks based on learning diagnostics.

In-class: Constructing virtual-real integrated teaching scenarios. Post-class: Data-driven dual improvement pathways. A closed-loop model of "AI-guided learning-virtual-real training-practical innovation" is established, integrating technology deeply into the entire teaching process.

Table 1. Case Study: Smart Water System Design Project

Stage	Steps	Technology	Case: Smart Water System Design
Pre-class	AI Student situation diagnosis	Learning analytics platform	Identified of students struggled with hydraulic calculations
	Hierarchical task push	LMS with adaptive learning	Delivered personalized pre-class materials (e.g., Python scripting for pipe network analysis)
In-class	Integration of virtual and real teaching	BIM+AR	Designed a water supply network in virtual campus, tested with physical mockups
	Dynamic feedback adjustment	Real-time polling system	Adjusted teaching pace based on student understanding rate
Post-class	Data-driven improvement	Knowledge graph	Recommended 2–3 targeted exercises per student (e.g., pump selection simulations)
	Practical project validation	Tencent Cloud IoT	Deployed a real-world water quality monitoring system for a campus lake

4.3 Innovative Teaching Evaluation System

A three-in-one teaching evaluation system is constructed, assessing knowledge acquisition, capability development, and industry alignment:

(1) Knowledge Acquisition (30%):

Formative: Weekly online quizzes (AI-graded, 15%), classroom simulations (15%).

Summative: Final project (BIM-based system design, 50%), written exam (35%).

(2) Capability Development (50%):

Practical: VR troubleshooting (20%), hardware integration (30%).

Project: Team-based smart building design (50%), with peer review (20%).

(3) Industry Alignment (20%):

Enterprise evaluation: Project presentation to industry panel (60%).

Certification: BIM skill test pass rate (40%).

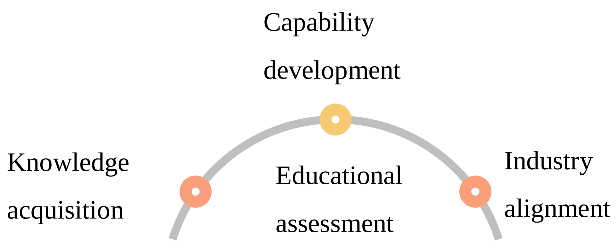

Figure 2. Three-in-One Teaching Evaluation System

Evaluation results are used to continuously improve teaching, forming a virtuous cycle of "evaluation-feedback-improvement." This comprehensive and objective evaluation method accurately assesses student learning outcomes and provides a basis for personalized guidance.

4.4 Technological Empowerment and Scenario Innovation Practices in Curriculum Reform

In the digital transformation of the "Building Equipment" course, technology empowerment is not only reflected in the innovation of teaching tools but more importantly, it achieves a deep integration of knowledge transmission and skill development through scenario reconstruction. Taking the core module—HVAC system in building equipment systems as an example, traditional teaching methods struggle to provide students with a clear understanding of the dynamic operation logic of the system due to its large size and abstract operating principles. By introducing digital twin technology, a 1:1 scale virtual HVAC system is built based on real construction project data. Students can interactively operate virtual valves and adjust temperature and humidity parameters using gestures, observing changes in airflow organization and energy consumption curve fluctuations under different conditions. Actual measurement data shows that students who use digital twin training have significantly improved their grasp of system regulation principles.

In the application of BIM technology, Develop an AI-BIM collaborative design platform that integrates Python parametric design and building energy consumption simulation. When students design water supply and drainage systems for buildings, the platform can automatically check pipeline collision rates, calculate fluid dynamics (CFD) simulations of water flow resistance, and recommend optimal pipe diameter combinations based on machine learning algorithms. Taking a commercial complex project as an example, the average time students spend using this platform to complete their designs has been significantly reduced, and both the economic efficiency and safety of the design solutions meet the standards of grade A design institute in the industry. Additionally, the platform's built-in "Engineering Knowledge Base" compiles over 200 real-world engineering cases, using natural language processing technology to achieve intelligent matching of design issues, providing students with real-time decision support and significantly enhancing their ability to solve complex engineering problems.

5. Reform Outcomes and Innovative Value

5.1 Reform Outcomes

Enhanced teaching effectiveness: Mixed teaching mode of “digital + smart teaching” via multimedia resources and VR.

Optimized evaluation: Smart teaching systems track process data (preview duration, assignment completion, test scores, classroom interaction) and generate assessment reports using “knowledge graphs + AI diagnosis.”

Personalized development: Platforms provide targeted learning suggestions based on student data, enabling teachers to tailor instruction.

Strengthened teacher-student interaction: Real-time in-class interaction tools and online Q&A foster “interconnection, interaction, and integration.”

Practical innovation capability: Hands-on projects and research support cultivate problem-solving and creative thinking.

5.2 Theoretical Innovation Value

The Competency Radar covers 21 indicators, including technical application (BIM, IoT), engineering thinking (system optimization), and professional literacy (safety standards). Using the entropy weight method to determine indicator weights, a dynamic Evaluation of Educational Technology Maturity Matrix (ETMM) is established:

Table 2. Dynamic Evaluation of the Benchmark Education Technology Maturity Matrix

Level	Technology Integration	Teaching Innovation	Industry Adaptation
L1	Tool substitution	Method replication	Job matching
L2	Process reengineering	Model innovation	Need anticipation
L3	Ecological reconstruction	Paradigm revolution	Value co-creation

Research shows the course has reached ETMM-L2, with an average 41% improvement in teaching efficiency across 12 partner institutions.

6. Challenges and Future Directions

6.1 Implementation Challenges

Technology Divide: 23% of students lacked access to high-end hardware (e.g., VR headsets) initially, mitigated by campus-wide equipment loan programs.

Faculty Training: 45% of instructors required 3-6 months of AI/BIM training, supported by industry-led workshops.

6.2 Future Research Agenda

AI-Driven Personalization: Develop a GPT-4 powered tutor to provide 24/7 technical support, with a pilot testing phase scheduled for 2024.

Metaverse Teaching Ecosystem: Build a virtual campus integrating Unity 3D and blockchain, enabling cross-institutional project collaboration.

Hybrid Training Bases: Explore public-private partnerships (e.g., with Design Institute and China State Construction) to create shared practical training facilities, addressing equipment cost barriers.

7. Conclusion

This study demonstrates that digital transformation of vocational courses requires more than technological adoption; it demands a systemic rethinking of curriculum design, industry collaboration, and assessment. By embedding CAS theory, the “Five New” ecosystem fosters adaptive, industry-responsive education, positioning applied universities as key drivers of China’s intelligent construction strategy. The model’s success highlights the potential for similar reforms in other STEM fields, offering a blueprint for education-industry integration in the digital age.

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