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Original Paper

Research on the Collaborative Education Model of Industry-Education Integration for Building Electrical and Intelligent Specialty under the Context of Smart Construction

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Abstract

Under the background of smart construction and emerging engineering education, this paper addresses issues such as insufficient integration of industry, academia, and research, as well as a single education model in the cultivation of building electrical and intelligent specialty talents. A collaborative education model based on "multi-dimensional integration" is explored, establishing an education framework characterized by "One Core, Two Lines, Three Entities, Four Aspects, and Five Advantages" (1+2+3+4+5). The paper also develops a "KAQ" (Knowledge, Ability, Quality) shared mechanism to optimize the curriculum system, practical teaching, and quality evaluation framework. Furthermore, this study illustrates innovative pathways for university-enterprise collaboration through the case of smart construction site simulation teaching. The findings provide theoretical and practical references for training high-quality, interdisciplinary talents aligned with industrial needs, thereby enhancing the quality of emerging engineering talent cultivation.

Keywords

Smart Construction, Building Electrical and Intelligent Specialty, Industry-Education Integration, Collaborative Education, Emerging Engineering, Smart Construction Site Simulation Teaching

1. Introduction

1.1 Background and Significance of Smart Construction in Emerging Engineering

The global construction industry is undergoing a transformative shift driven by the integration of advanced technologies such as Building Information Modeling (BIM), the Internet of Things (IoT), artificial intelligence (AI), and big data analytics. This transformation, often referred to as "smart construction," aims to improve efficiency, reduce costs, enhance safety, and enable sustainable building practices. In response, the education sector has increasingly recognized the need to align talent cultivation with the evolving demands of the construction industry.

Emerging engineering education (commonly termed "New Engineering") is a strategic initiative designed to produce interdisciplinary professionals who can adapt to rapid technological advancements. Smart construction, as a critical application domain of emerging engineering, requires professionals who are proficient in digital tools, capable of interdisciplinary collaboration, and equipped with innovative thinking. These professionals must not only understand the technical aspects of construction but also grasp the broader implications of digital transformation on project management, sustainability, and workforce dynamics.

Building electrical and intelligent specialty plays a vital role in smart construction. This field encompasses the integration of electrical systems, communication technologies, and intelligent controls within buildings to achieve automation, energy efficiency, and enhanced safety. As a cornerstone of smart construction, the demand for expertise in this area has grown exponentially. However, traditional education methods often fail to adequately prepare students for the interdisciplinary and practical challenges posed by smart construction.

1.2 Challenges in Talent Cultivation for Building Electrical and Intelligent Specialty

Despite the growing importance of smart construction, there remain significant challenges in talent cultivation for the building electrical and intelligent specialty. These challenges stem from the rapidly evolving technological landscape, the complexity of interdisciplinary integration, and the gap between academic training and industrial needs.

Firstly, traditional curricula in many educational institutions still focus on isolated technical knowledge rather than interdisciplinary and applied skills. For instance, students often receive training in electrical engineering or communication technologies without gaining hands-on experience in integrating these systems within smart buildings. This gap limits their ability to solve real-world problems and meet the expectations of employers.

Secondly, there is insufficient collaboration between universities and industries. Many academic programs operate in isolation from the construction sector, resulting in limited opportunities for students to participate in real-world projects or internships. This lack of industry engagement deprives students of the practical skills and knowledge required for smart construction roles.

Thirdly, the rapid pace of technological advancement poses a challenge for educators to keep their teaching methods and content up to date. Technologies such as IoT, cloud computing, and AI are becoming increasingly relevant in smart construction, but their integration into academic programs often lags behind industry adoption. This creates a skills gap where graduates are not adequately equipped to work with the latest tools and methodologies.

Finally, there is a lack of innovative teaching methods that leverage digital platforms and simulation-based tools. Traditional classroom lectures and textbook-based learning fail to capture the dynamic and interactive nature of smart construction. Without exposure to simulation platforms or project-based learning, students are unable to fully understand and apply complex concepts in practical contexts.

1.3 Research Objectives and Scope

The objective of this research is to develop a collaborative education model that addresses the challenges of talent cultivation in the building electrical and intelligent specialty under the context of smart construction. The study aims to design and implement an innovative framework for industry-education integration that aligns academic training with the demands of the construction industry.

Specifically, this research focuses on the following objectives:

(1) To analyze the current state of talent cultivation in the building electrical and intelligent specialty and identify key challenges.

(2) To propose a "1+2+3+4+5" collaborative education framework that integrates academic, industrial, and research resources for holistic talent development.

(3) To evaluate the effectiveness of simulation-based teaching platforms, such as smart construction site models, in enhancing students' practical skills and interdisciplinary understanding.

(4) To provide actionable recommendations for universities and industries to improve their collaboration in training high-quality professionals for smart construction.

The scope of this research includes both theoretical and practical components. Theoretically, it investigates the principles of collaborative education and its application to smart construction. Practically, it examines the implementation of simulation-based teaching methods and their impact on student outcomes. By combining these approaches, the study aims to contribute to the development of a sustainable and scalable model for talent cultivation in emerging engineering education.

2. Literature Review

2.1 Current State of Industry-Education Integration in Engineering Education

Industry-education integration has become a central theme in engineering education as academic institutions strive to align their training programs with the practical demands of industry. This integration aims to bridge the gap between theoretical knowledge and practical application by fostering partnerships between universities, industries, and research institutions.

In recent years, governments and educational organizations worldwide have issued policies to promote industry-education integration. For instance, China’s Education Modernization 2035 initiative emphasizes the need for “deep integration of production and education,” while the United States champions cooperative education programs, such as the ones pioneered by the University of Cincinnati, where students alternate between academic study and paid industry placements. In Europe, Germany’s dual education system remains a hallmark of industry-education collaboration, where apprenticeships and academic training are seamlessly integrated.

Despite these advancements, the implementation of such integration remains uneven. Many programs still face challenges, including insufficient communication between academia and industry, limited involvement of enterprises in curriculum development, and an inability to adapt quickly to technological advancements. The building electrical and intelligent specialty, in particular, suffers from a lack of tailored frameworks for integrating emerging technologies like Building Information Modeling (BIM), artificial intelligence (AI), and the Internet of Things (IoT) into academic training.

2.2 Models and Practices of Collaborative Education in Domestic and International Contexts

Collaborative education models vary widely across countries and institutions, reflecting differences in economic conditions, cultural contexts, and industry needs.

2.2.1 Domestic Practices

In China, the “school-enterprise cooperation” model has gained traction, particularly in applied and vocational universities. Institutions often sign agreements with enterprises to offer “order-based” training programs, where students follow a specialized curriculum tailored to a specific company’s needs. However, these programs often focus on technical skills and overlook the interdisciplinary and innovative competencies required for smart construction. Additionally, China’s “2011 Collaborative Innovation Plan” promotes the establishment of innovation centers where universities, research institutions, and industries work together on joint projects, but such centers are primarily research-focused and rarely address undergraduate training.

2.2.2 International Practices

Globally, several notable models exemplify successful industry-education collaboration:

(1) Cooperative Education (Co-op): Popularized in the United States, Co-op programs allow students to alternate between academic coursework and full-time employment in their field of study. For example, Northeastern University’s Co-op program integrates six-month industry placements into its engineering curricula, providing students with valuable hands-on experience.

(2) Dual Study Programs: In Germany, dual study programs combine classroom instruction with apprenticeships at partner companies. These programs are particularly effective in aligning academic knowledge with industry requirements and often lead to high employability rates.

(3) Triple Helix Model: Proposed by Etzkowitz and Leydesdorff, this model highlights the interaction between universities, industries, and governments. It emphasizes collaboration for innovation and workforce development, particularly in high-tech sectors.

While these models demonstrate the potential for industry-education integration, they are not without limitations. Many programs struggle to scale due to resource constraints, and some fail to adapt quickly to emerging industry trends, such as the digitization of construction processes.

2.3 Gaps and Limitations in Existing Approaches

Despite the progress made in collaborative education, several gaps and limitations hinder the effectiveness of current models in preparing students for the challenges of smart construction:

(1) Limited Interdisciplinary Focus: Most existing models prioritize technical skills within a single domain, such as electrical engineering or construction management. However, smart construction requires a fusion of skills across multiple disciplines, including IoT, AI, and sustainable design. Current programs often fail to provide students with the interdisciplinary training needed to meet these demands.

(2) Insufficient Industry Involvement in Curriculum Development: While many universities collaborate with industries, the depth of this collaboration is often superficial. Enterprises are rarely involved in designing curricula or defining learning outcomes, leading to a mismatch between academic training and industry needs.

(3) Underutilization of Digital Tools and Simulations: Although digital tools such as BIM and virtual reality (VR) are revolutionizing the construction industry, their adoption in academic training remains limited. Many institutions lack the resources or expertise to incorporate simulation-based teaching methods, which are crucial for preparing students to work in smart construction environments.

(4) Inadequate Metrics for Evaluating Collaborative Education: Existing programs often lack robust mechanisms for assessing the effectiveness of collaborative education. Metrics such as student employability, industry satisfaction, and learning outcomes are rarely tracked systematically, making it difficult to refine and improve these programs.

(5) Uneven Implementation Across Institutions: Collaborative education models are often implemented inconsistently across institutions. Elite universities with abundant resources tend to benefit the most, while smaller or less prestigious institutions struggle to establish meaningful partnerships with industries.

Addressing these gaps requires a reimagined approach to collaborative education, one that integrates interdisciplinary training, deepens industry engagement, leverages advanced digital tools, and incorporates robust evaluation mechanisms. This paper aims to fill these gaps by proposing a comprehensive framework for collaborative education in the building electrical and intelligent specialty under the context of smart construction.

3. Methodology

3.1 Framework of the Study: One Core, Two Lines, Three Entities, Four Aspects, Five Advantages

The proposed methodology is centered on a collaborative education framework tailored to meet the interdisciplinary and practical demands of smart construction. This framework, referred to as the "1+2+3+4+5" model, integrates academic, industrial, and research resources into a cohesive structure designed to cultivate high-quality professionals in the building electrical and intelligent specialty.

(1) One Core: The central focus of the framework is talent cultivation. The primary objective is to prepare students who are innovative, adaptable, and proficient in applying smart construction technologies. This talent-centric approach ensures that all elements of the framework align with the

goal of producing industry-ready graduates.

(2) Two Lines: The framework operates along two guiding principles: mutual benefit and resource sharing. The mutual benefit principle emphasizes the reciprocal value of collaboration, where universities gain practical insights and industries benefit from fresh perspectives and skilled talent. The resource-sharing principle focuses on optimizing the use of infrastructure, expertise, and technology across all stakeholders.

(3) Three Entities: The framework integrates three critical elements of talent cultivation:

① Knowledge (K): Foundational understanding of building electrical systems, intelligent technologies, and interdisciplinary principles.

② Ability (A): Practical skills such as problem-solving, system integration, and project management.

③ Quality (Q): Professional attributes, including teamwork, ethics, and lifelong learning.

(4) Four Aspects: The framework targets four key dimensions of education to create a holistic learning experience:

① Curriculum: Development of interdisciplinary and industry-relevant courses, such as IoT in construction, BIM applications, and smart building systems.

② Teaching Team: Formation of dual-role faculty teams comprising university instructors and industry experts.

③ Practical Training: Implementation of hands-on projects, internships, and simulations to bridge theory and practice.

④ Quality Assessment: Establishment of robust evaluation mechanisms to monitor and improve educational outcomes.

(5) Five Advantages: The framework leverages five distinct strengths to ensure comprehensive support for the education process:

① Universities: Provide theoretical knowledge and access to academic resources.

② Enterprises: Offer real-world challenges and opportunities for students to apply their skills.

③ Research Institutions: Introduce cutting-edge innovations and methodologies.

④ Government: Facilitate policy support and funding for collaborative initiatives.

⑤ Digital Platforms: Enable virtual learning, simulation, and remote collaboration.

This structured framework ensures an integrated and systematic approach to cultivating talent equipped to address the challenges of smart construction.

3.2 Data Collection and Analysis Methods

The study employs a mixed-methods approach to collect and analyze data, combining quantitative and qualitative techniques to ensure a comprehensive evaluation of the proposed framework.

(1) Quantitative Data Collection:

① Surveys and Questionnaires: Distributed to students, faculty, and industry professionals to assess the effectiveness of current teaching methods, identify gaps, and evaluate the implementation of the proposed framework.

② Learning Outcome Metrics: Pre- and post-intervention assessments are conducted to measure improvements in student knowledge, skills, and quality (KAQ). Key metrics include test scores, project performance, and internship evaluations.

(2) Qualitative Data Collection:

① Interviews and Focus Groups: Conducted with stakeholders such as university administrators, industry partners, and students to gather insights into the strengths, weaknesses, and areas for improvement in the collaborative education process.

② Case Studies: Detailed documentation of the implementation and outcomes of specific projects, such as smart construction site simulations.

(3) Data Analysis Methods:

① Statistical Analysis: Quantitative data is analyzed using descriptive and inferential statistics to identify trends and relationships.

② Content Analysis: Qualitative data from interviews and focus groups is coded and analyzed to extract recurring themes and insights.

③ Comparative Analysis: Outcomes from traditional education methods are compared with those achieved under the collaborative framework to evaluate its impact.

3.3 Case Selection: Smart Construction Site Simulation Teaching

The smart construction site simulation teaching platform serves as the central case study for this research. This platform is chosen for its ability to replicate real-world construction environments and integrate advanced technologies such as BIM, IoT, and virtual reality (VR). The simulation provides students with a controlled yet dynamic setting to apply theoretical knowledge, develop practical skills, and engage in interdisciplinary problem-solving.

(1) Platform Features:

④ Realistic Simulation: Virtual models of construction sites that include elements such as electrical systems, safety protocols, and project management workflows.

⑤ Interactivity: Hands-on tasks such as system integration, fault diagnosis, and performance optimization.

⑥ Collaboration Tools: Opportunities for students to work in teams, mimicking real-world project settings.

(2) Implementation Process:

① Preparation Phase: Development of simulation scenarios based on industry standards and expert input.

② Execution Phase: Students complete tasks within the virtual environment, guided by dual-role instructors from academia and industry.

③ Evaluation Phase: Outcomes are assessed through project deliverables, peer evaluations, and performance metrics.

(3) Benefits of Case Selection:

The smart construction site simulation teaching platform aligns with the "1+2+3+4+5" framework by addressing all aspects of knowledge, ability, and quality. It also provides a tangible demonstration of how digital tools can enhance education in the building electrical and intelligent specialty.

This case study provides both qualitative and quantitative evidence to validate the proposed collaborative education framework, ensuring its relevance and applicability to real-world challenges in smart construction.

4. Collaborative Education Model Design

4.1 Building the "1+2+3+4+5" Collaborative Education Framework

The "1+2+3+4+5" collaborative education framework is designed to address the challenges of talent cultivation in the building electrical and intelligent specialty under the context of smart construction. This framework systematically integrates academic, industrial, and research resources into a unified model, ensuring that students develop the knowledge, abilities, and qualities necessary for success in a rapidly evolving technological landscape.

The framework is structured around five key dimensions: one core, two guiding principles, three critical entities, four essential aspects, and five external advantages. These elements are interconnected to form a cohesive system that fosters interdisciplinary learning, practical application, and continuous improvement.

To visualize this framework, Figure 1 illustrates its hierarchical structure and dynamic relationships between the components:

(1) At the center of the framework is "Talent Cultivation", the core focus, which represents the ultimate objective of the education process. All other components are designed to support and enhance this goal.

(2) Surrounding the core are the two guiding principles: mutual benefit and resource sharing. These principles provide the foundation for collaboration among all stakeholders, ensuring that each party contributes meaningfully and benefits equitably.

(3) The three critical entities—Knowledge (K), Ability (A), and Quality (Q)—represent the fundamental attributes that students must develop. These entities serve as the pillars of the talent cultivation process, integrating theoretical learning, practical skills, and professional attributes.

(4) The four essential aspects—Curriculum, Teaching Team, Practical Training, and Quality Assessment—form the operational components of the framework. They ensure a holistic and structured approach to education, from curriculum design to evaluation of outcomes.

(5) Finally, the five external advantages—Universities, Enterprises, Research Institutions, Government, and Digital Platforms—provide the necessary resources, expertise, and support to implement and sustain the framework effectively.

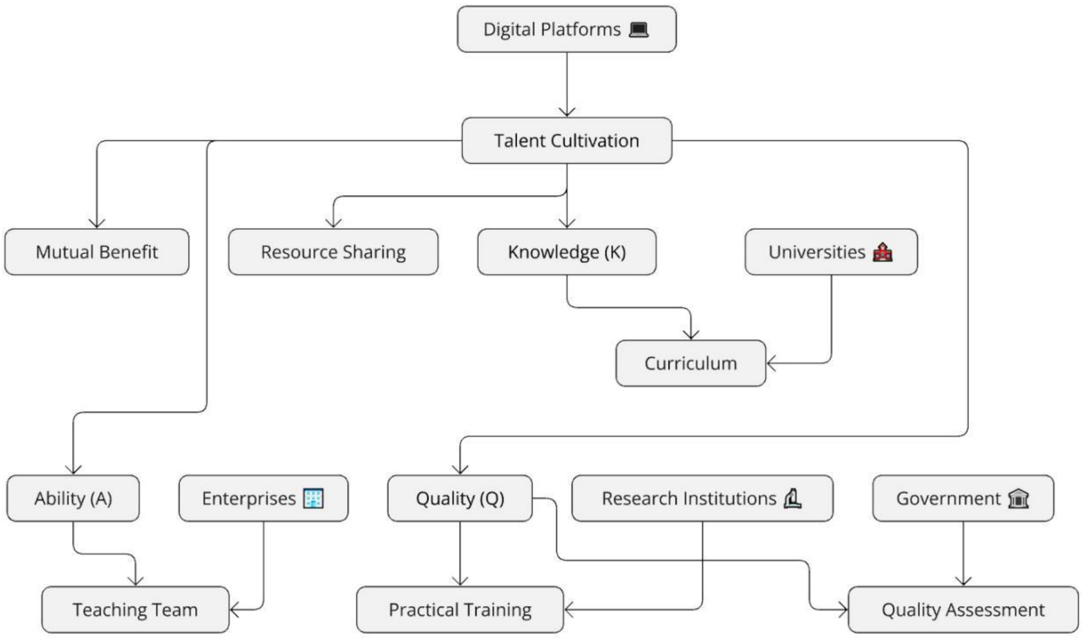

Figure 1. Structure of the "1+2+3+4+5" Collaborative Education Model

Figure 1 captures the interrelationships within the "1+2+3+4+5" framework. The concentric and radial layout demonstrates the hierarchy and flow of influence, where external advantages provide support to the four aspects, which, in turn, enhance the three entities. This interconnected system culminates in the core goal of talent cultivation.

By aligning these components, the framework ensures that students receive a comprehensive education that bridges the gap between academia and industry. The model is dynamic and adaptable, capable of incorporating advancements in technology, changes in industry demands, and feedback from stakeholders.

The next sections will delve deeper into the specific implementations of the collaborative education model, including curriculum design, teaching team development, and practical training mechanisms, all of which align with the framework illustrated in Figure 1.

4.2 Implementation of Collaborative Education Framework in Curriculum Reform

Curriculum reform is the cornerstone of implementing the "1+2+3+4+5" collaborative education framework. By aligning the curriculum with industry demands and integrating interdisciplinary and practical elements, the reform ensures that students in the building electrical and intelligent specialty are equipped with the knowledge, abilities, and qualities required for smart construction.

The implementation process is centered on the following strategies:

4.2.1 Aligning Curriculum Objectives with Industry Needs

The curriculum reform begins with a detailed analysis of industry trends and future skill requirements. Key focus areas include:

(1) Smart Construction Technologies: Integrating courses on Building Information Modeling (BIM), Internet of Things (IoT), Artificial Intelligence (AI), and sustainable building practices.

(2) Interdisciplinary Integration: Introducing modules that combine electrical systems, intelligent controls, and communication technologies within the context of smart buildings.

(3) Practical Skills Development: Emphasizing system design, integration, and troubleshooting through hands-on projects and real-world case studies.

To achieve this, the curriculum is designed collaboratively by academic experts and industry professionals, ensuring alignment with current and emerging demands in the construction sector.

4.2.2 Modular Structure of the Curriculum

The curriculum is organized into modular units to provide flexibility and encourage interdisciplinary learning. Each module focuses on a specific aspect of smart construction:

(1) Foundation Modules: Covering core knowledge such as electrical systems, control principles, and communication technologies.

(2) Application Modules: Focusing on the practical application of smart construction technologies, including system integration, project management, and safety protocols.

(3) Innovation Modules: Encouraging students to engage in research and development activities, such as designing intelligent building systems or optimizing energy efficiency.

This modular structure allows students to progress from foundational knowledge to advanced, application-oriented learning, ensuring a comprehensive educational experience.

4.2.3 Integration of Simulation-Based Learning

Simulation-based learning is a critical component of the reformed curriculum, providing students with a virtual environment to apply theoretical concepts and develop practical skills. Key features include:

(1) Smart Construction Site Simulations: Students engage in realistic scenarios that mimic the complexities of real-world construction projects.

(2) Interactive Problem-Solving Tasks: Challenges such as fault diagnosis, system optimization, and project coordination are embedded into the simulations.

(3) Assessment and Feedback: Performance is assessed through metrics such as task completion time, accuracy, and teamwork, with immediate feedback provided to enhance learning.

Simulation-based learning not only bridges the gap between theory and practice but also prepares students to work in dynamic and technology-driven environments.

4.2.4 Development of Interdisciplinary Courses

To foster a broader understanding of smart construction, the curriculum incorporates interdisciplinary courses that blend technical knowledge with soft skills. Examples include:

(1) BIM Applications and Data Analytics: Combining design and analytical skills to optimize construction processes.

(2) IoT in Building Systems: Teaching students how to integrate IoT devices into building management systems.

(3) Sustainable Smart Buildings: Exploring the intersection of green technologies and intelligent controls.

(4) Communication and Leadership in Engineering: Enhancing teamwork and project management capabilities.

These courses enable students to develop a holistic perspective, which is essential for addressing the complex challenges of smart construction.

4.2.5 Establishing a Continuous Feedback Mechanism

The reformed curriculum incorporates a continuous feedback mechanism to ensure its relevance and effectiveness. This mechanism involves:

(1) Stakeholder Input: Regular consultations with industry partners, alumni, and students to gather insights on curriculum strengths and areas for improvement.

(2) Performance Monitoring: Tracking student outcomes, such as internship evaluations, employment rates, and project success, to measure the impact of the curriculum.

(3) Iterative Updates: Periodically revising course content, teaching methods, and learning objectives based on feedback and technological advancements.

By fostering a culture of continuous improvement, the curriculum remains dynamic and adaptable to the evolving needs of smart construction.

4.2.6 Impact of Curriculum Reform

The implementation of the "1+2+3+4+5" collaborative education framework in curriculum reform has a transformative impact on the learning experience. Students gain:

(1) Enhanced Practical Skills: Through hands-on projects and simulations, students become adept at applying theoretical knowledge to real-world challenges.

(2) Interdisciplinary Expertise: By engaging with diverse courses and collaborative projects, students develop a comprehensive understanding of smart construction.

(3) Industry Readiness: The integration of industry insights ensures that graduates are well-prepared to meet employer expectations and excel in their careers.

This curriculum reform represents a significant step toward bridging the gap between academia and industry, fostering a new generation of professionals equipped to lead the future of smart construction.

5. Case Study: Smart Construction Site Simulation Teaching

5.1 Overview of the Simulation-Based Teaching Platform

The Smart Construction Site Simulation Teaching Platform is a cutting-edge educational tool designed to bridge the gap between theoretical learning and practical application in the building electrical and intelligent specialty. It provides students with a realistic, immersive environment where they can apply interdisciplinary concepts, develop technical skills, and engage in collaborative problem-solving.

The platform integrates advanced technologies such as Building Information Modeling (BIM), Internet of Things (IoT), and Virtual Reality (VR), creating a virtual construction site that mirrors real-world conditions. This digital environment is tailored to the demands of smart construction, enabling students to interact with complex systems and workflows in a controlled, risk-free setting.

5.1.1 Key Features of the Platform

5.1.1.1 Realistic Simulation of Construction Scenarios

The platform replicates various construction site elements, including building electrical systems, intelligent controls, communication networks, and safety protocols.

(1) Students can navigate through a virtual construction site, inspect system components, and interact with dynamic elements such as power distribution panels, IoT-enabled sensors, and automated control systems.

(2) Scenarios are designed to reflect real-world challenges, such as optimizing energy consumption, diagnosing system faults, and managing emergency situations.

5.1.1.2 Interdisciplinary Integration

The simulation incorporates multiple domains of knowledge, including:

(1) Electrical Engineering: Wiring, power distribution, and fault detection.

(2) Communication Technologies: Network setup, device connectivity, and data transmission.

(3) Smart Building Systems: Integration of IoT devices, HVAC systems, and security controls.

By engaging with these interconnected systems, students gain a holistic understanding of smart construction processes and the role of intelligent technologies in modern buildings.

5.1.1.3 Interactive and Hands-On Learning

The platform emphasizes active participation through interactive tasks and hands-on activities, such as:

(1) Designing and implementing a building’s electrical and intelligent systems.

(2) Performing troubleshooting and optimization tasks on simulated systems.

(3) Collaborating in teams to complete project-based challenges within the simulation.

These activities foster critical thinking, problem-solving, and teamwork, which are essential skills for smart construction professionals.

5.1.1.4 Performance Assessment and Feedback

The platform includes an integrated assessment system that evaluates student performance in real time. Metrics such as task completion time, accuracy, efficiency, and teamwork are tracked and recorded.

(1) Immediate feedback is provided, allowing students to identify areas for improvement and refine their skills.

(2) Detailed performance reports help instructors monitor progress and tailor their teaching strategies to address individual and group needs.

5.1.1.5 Scalability and Accessibility

The simulation platform is designed to be scalable and accessible, making it suitable for diverse educational contexts:

(1) Scalable Implementation: It can accommodate various class sizes and adapt to different levels of complexity, from introductory to advanced courses.

(2) Remote Access: Students can access the platform from any location, enabling hybrid and distance learning opportunities.

5.1.2 Technical Architecture of the Platform

The Smart Construction Site Simulation Teaching Platform is built on a robust technical architecture that ensures high performance, reliability, and scalability:

(1) BIM Integration: The platform uses BIM models to provide accurate, data-rich visualizations of construction elements, allowing students to interact with digital twins of real-world systems.

(2) IoT and Sensor Integration: Virtual IoT devices mimic real-world sensors and actuators, enabling students to configure and monitor smart building components.

(3) Cloud-Based Infrastructure: A cloud-based backend supports real-time data processing and ensures that multiple users can access the platform simultaneously without performance degradation.

(4) VR Compatibility: The platform supports VR headsets, providing students with an immersive experience that enhances spatial understanding and engagement.

5.1.3 Educational Objectives of the Platform

The primary goal of the Smart Construction Site Simulation Teaching Platform is to prepare students for the complexities of smart construction through experiential learning. Its educational objectives include:

(1) Developing Practical Skills: Allowing students to practice technical tasks, such as system installation, integration, and troubleshooting, in a simulated environment.

(2) Enhancing Interdisciplinary Knowledge: Teaching students to navigate the intersections of electrical engineering, communication technologies, and intelligent building systems.

(3) Fostering Problem-Solving Abilities: Encouraging students to analyze complex scenarios, identify solutions, and implement them effectively.

(4) Building Teamwork and Communication Skills: Promoting collaboration through group projects and team-based challenges within the simulation.

The Smart Construction Site Simulation Teaching Platform exemplifies the principles of the "1+2+3+4+5" framework, particularly in its emphasis on practical training, interdisciplinary integration, and digital innovation. Its implementation has demonstrated significant improvements in student engagement, skill development, and readiness for industry challenges. The next sections will discuss the platform's implementation process, key features, and its impact on educational outcomes.

5.2 Implementation Process and Key Features

The implementation of the Smart Construction Site Simulation Platform is structured into three key phases: Preparation, Execution, and Evaluation and Feedback. These phases ensure a systematic approach to simulation-based teaching, providing students with an immersive and effective learning experience. The workflow of this process is detailed in Figure 2, which outlines the sequential steps and core activities involved.

Figure 2 illustrates the workflow of the Smart Construction Site Simulation Platform, emphasizing its step-by-step process and the integration of advanced technologies to create a realistic learning environment. The workflow is divided into three interconnected phases:

5.2.1 Preparation Phase

(1) Define Learning Objectives: Collaborate with academic and industry experts to identify critical skills and knowledge areas, such as BIM applications, IoT integration, and system troubleshooting.

(2) Develop Simulation Scenarios: Create realistic virtual models of construction sites, including electrical systems, IoT-enabled devices, and intelligent building controls.

(3) Configure Platform Infrastructure: Set up the platform using BIM models, cloud-based systems, and VR compatibility to ensure smooth operation and scalability.

5.2.2 Execution Phase

(1) Onboarding and Training: Provide students with tutorials, user guides, and orientation sessions to familiarize them with the platform's interface and tools.

(2) Scenario-Based Learning: Assign students specific tasks within the simulation, such as optimizing energy consumption, diagnosing system faults, or designing smart building systems.

(3) Collaborative Problem Solving: Facilitate teamwork by assigning group projects that require students to manage virtual construction workflows and solve complex problems together.

5.2.3 Evaluation and Feedback Phase

(1) Performance Assessment: Use integrated metrics such as task completion time, accuracy, and efficiency to evaluate individual and group performance.

(2) Feedback and Iteration: Provide immediate feedback through the platform’s system, allowing students to identify areas for improvement and repeat tasks as needed.

(3) Generate Learning Reports: Compile comprehensive reports on student performance, providing insights for both instructors and students to refine learning outcomes.

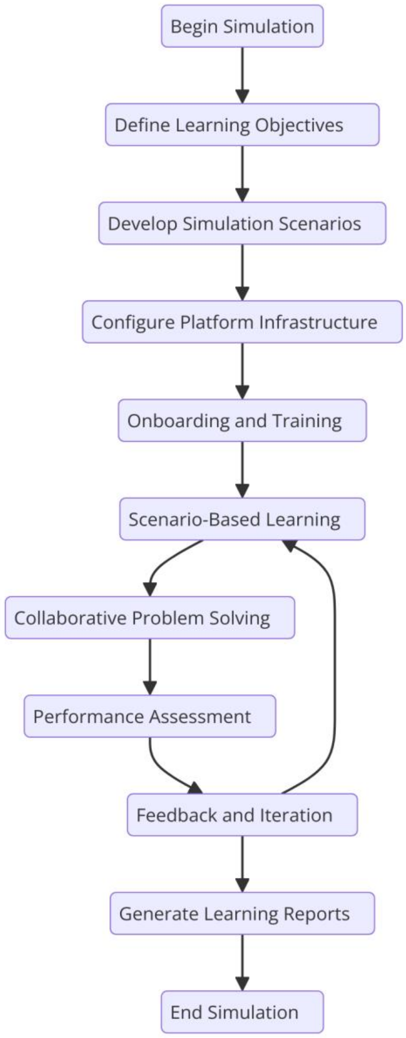

Figure 2. Workflow of the Smart Construction Site Simulation Platform

The workflow depicted in Figure 2 highlights the seamless integration of technology, pedagogy, and industry collaboration within the Smart Construction Site Simulation Platform. The process begins with clearly defined learning objectives, ensuring that all subsequent activities align with the desired educational outcomes. The execution phase immerses students in realistic and interactive scenarios, fostering practical skills and interdisciplinary knowledge. Finally, the evaluation and feedback phase ensures continuous improvement by providing actionable insights and opportunities for iterative learning.

5.2.4 Key Features of the Implementation Process

(1) Customizable Scenarios: The platform allows instructors to design simulation scenarios tailored to specific learning objectives. For example, students may be tasked with configuring IoT-enabled devices for energy management or designing a building's electrical system to meet safety and sustainability standards.

(2) Dynamic and Interactive Environment: Students interact with virtual models that mimic real-world conditions, such as troubleshooting electrical systems or monitoring IoT sensors. The dynamic nature of the simulation ensures that students are exposed to a wide range of scenarios, preparing them for the complexities of smart construction.

(3) Integrated Collaboration Tools: The platform facilitates teamwork through shared virtual workspaces, where students can collaborate on projects, share insights, and divide responsibilities. This feature simulates real-world construction team dynamics and promotes communication and leadership skills.

(4) Real-Time Feedback and Iterative Learning: The platform provides immediate feedback on student performance, enabling learners to identify mistakes, understand the underlying concepts, and retry tasks for better outcomes. This iterative process enhances retention and skill mastery.

(5) Scalability and Accessibility: The cloud-based infrastructure ensures that the platform can support diverse class sizes and remote learning, making it accessible to students regardless of location. This scalability is particularly beneficial in expanding the reach of advanced construction education.

By following this implementation process, the Smart Construction Site Simulation Platform effectively bridges the gap between theoretical education and practical application, fostering the development of industry-ready professionals in the building electrical and intelligent specialty. The subsequent sections will analyze the outcomes of this implementation and its impact on student learning.

5.3 Analysis of Practical Outcomes

The Smart Construction Site Simulation Teaching Platform was implemented to assess its effectiveness in enhancing students' technical, interdisciplinary, and soft skills. The analysis of its practical outcomes is based on pre- and post-simulation assessments, which measured student performance across various learning outcomes.

The results of this evaluation, presented in Table 1, highlight significant improvements in students' proficiency across multiple domains.

Table 1 provides a detailed comparison of students' proficiency levels before and after engaging with the simulation platform. The metrics include technical skills such as understanding BIM tools and IoT integration, practical abilities like troubleshooting electrical systems, and broader competencies such as teamwork, interdisciplinary integration, and long-term knowledge retention. Each learning outcome is accompanied by its assessment method, ensuring a comprehensive evaluation of the platform's impact.

Table 1. Learning Outcomes Comparison Before and After Simulation-Based Teaching

Learning Outcome	Pre-Simulation (% of students proficient)	Post-Simulation (% of students proficient)	Improvement (%)	Assessment Method
Understanding of BIM tools	45%	90%	45%	Quiz on BIM fundamentals and application scenarios
IoT integration in smart buildings	30%	85%	55%	Hands-on project on IoT-enabled systems
Electrical system troubleshooting	40%	88%	48%	Simulation-based fault diagnosis task
Collaboration and teamwork skills	50%	92%	42%	Peer evaluation and group task performance
Energy efficiency optimization	35%	80%	45%	Case study analysis and system optimization exercise
Overall problem-solving capabilities	38%	87%	49%	Complex scenario challenge with multi-disciplinary focus
Familiarity with smart construction workflows	28%	84%	56%	Workflow simulation assessment
Safety management in construction sites	32%	81%	49%	Safety protocol simulation task
Integration of interdisciplinary knowledge	25%	86%	61%	Capstone project evaluation
Knowledge retention after six months	40%	78%	38%	Follow-up quiz and project review

5.3.1 Significant Improvements in Technical Skills

(1) The most notable improvement was observed in IoT integration in smart buildings, where student proficiency increased by 55%. This result underscores the platform's ability to bridge the gap between theoretical concepts and their application in smart construction environments.

(2) Similarly, understanding of BIM tools saw a 45% improvement, demonstrating the platform's effectiveness in providing hands-on experience with industry-standard software.

5.3.2 Development of Interdisciplinary Competencies

(1) The integration of multiple domains was a key focus of the platform. Students' ability to apply interdisciplinary knowledge improved by 61%, reflecting the platform's success in fostering a comprehensive understanding of smart construction workflows.

(1) The improvement in energy efficiency optimization (+45%) highlights the platform's emphasis on sustainability, a critical aspect of modern construction projects.

5.3.3 Enhanced Soft Skills

(1) Collaboration and teamwork skills improved by 42%, as students participated in group projects that simulated real-world team dynamics. The use of shared virtual workspaces and collaborative tasks played a significant role in this outcome.

(2) Problem-solving capabilities, a crucial skill for tackling complex construction challenges, increased by 49%, indicating that students gained confidence and competence in handling real-world scenarios.

5.3.4 Improved Retention and Practical Application

(1) Long-term retention of knowledge, as measured six months after the simulation, showed a 38% increase. This indicates that the platform not only supports immediate learning but also promotes sustained understanding of key concepts.

(2) Students' familiarity with smart construction workflows improved by 56%, demonstrating their ability to navigate and manage integrated processes effectively.

5.3.5 Practical Impact on Safety Awareness

The safety management outcome, which improved by 49%, highlights the platform's role in instilling safety-conscious practices among students. Through virtual simulations of emergency scenarios, students gained valuable experience in identifying and mitigating risks on construction sites.

5.3.6 Discussion of Results

The improvements observed across all learning outcomes indicate the platform's comprehensive effectiveness in preparing students for smart construction challenges. The ability to simulate real-world conditions, combined with immediate feedback and iterative learning opportunities, creates an environment that bridges the gap between academia and industry.

Furthermore, the platform's interdisciplinary approach equips students with the skills to integrate technologies such as BIM, IoT, and energy management systems, aligning their training with industry demands. The enhancements in teamwork, problem-solving, and safety awareness further demonstrate the platform's holistic impact, preparing students not only as technically proficient professionals but also as effective collaborators and leaders.

5.3.7 Implications for Broader Implementation

The findings suggest that simulation-based teaching platforms can serve as a model for other educational institutions aiming to improve their engineering curricula. By adopting such platforms, universities can ensure that their graduates are equipped with the technical and soft skills necessary to excel in a rapidly evolving industry. Moreover, the scalability and accessibility of the platform make it a viable solution for both on-campus and remote learning contexts.

The next section will explore the broader implications of these results, including recommendations for expanding the use of the simulation platform and potential areas for future research.

6. Results and Discussion

6.1 Evaluation of the Collaborative Education Model

The "1+2+3+4+5" collaborative education model was evaluated based on its implementation in the Smart Construction Site Simulation Teaching Platform. The results demonstrate the model's effectiveness in achieving its intended objectives.

6.1.1 Alignment with Industry Needs

The curriculum reforms under the collaborative model successfully incorporated industry-relevant skills, including BIM applications, IoT integration, and energy optimization. The active involvement of industry partners ensured that the courses remained aligned with current technological advancements and workforce requirements.

6.1.2 Interdisciplinary Integration

By combining knowledge, ability, and quality (KAQ), the model promoted an interdisciplinary approach, as evidenced by a 61% improvement in students' ability to integrate concepts from electrical engineering, communication technologies, and intelligent building systems. This outcome highlights the model's capacity to break down traditional academic silos.

6.1.3 Effectiveness of Practical Training

The incorporation of simulation-based learning within the practical training aspect of the framework yielded significant gains in technical skills, problem-solving capabilities, and safety awareness. Students reported increased confidence in applying theoretical knowledge to complex real-world scenarios, demonstrating the model's success in bridging the gap between theory and practice.

6.1.4 Sustainability of the Framework

The collaborative education model's reliance on digital platforms and resource sharing ensured scalability and sustainability. By leveraging cloud-based simulation tools, the model can be implemented across diverse educational contexts, including remote learning environments.

6.1.5 Evaluation Mechanisms

The inclusion of continuous feedback loops and performance assessments facilitated iterative learning and improvement. Stakeholder input from students, instructors, and industry partners provided actionable insights to refine the teaching approach.

6.2 Contributions to Talent Development in Building Electrical and Intelligent Specialty

The implementation of the collaborative education model has made significant contributions to talent development in the building electrical and intelligent specialty.

6.2.1 Enhanced Technical Proficiency

The platform effectively developed critical technical skills, such as designing intelligent building systems and diagnosing faults in electrical systems. With proficiency improvements of up to 55% in areas like IoT integration, graduates are now better equipped to meet the demands of smart construction projects.

6.2.2 Fostering Interdisciplinary Expertise

The model emphasized the integration of multiple domains, ensuring students gained a comprehensive understanding of interconnected systems. For example, energy efficiency optimization and BIM tools were integrated into a unified learning process, preparing students for roles requiring both technical and strategic thinking.

6.2.3 Development of Soft Skills

Beyond technical capabilities, the model prioritized soft skills such as collaboration, communication, and leadership. Group projects within the simulation environment allowed students to develop teamwork skills, as evidenced by a 42% improvement in collaboration metrics. These attributes are critical for success in multidisciplinary teams.

6.2.4 Alignment with Sustainable Construction Goals

By incorporating courses on energy optimization and green building technologies, the model supports the broader industry shift toward sustainable construction practices. Students are now prepared to contribute to environmentally conscious projects that align with global sustainability objectives.

6.2.5 Increased Employability

The combination of technical and interdisciplinary training has significantly enhanced student employability. Industry feedback indicated that graduates trained under this model possess a competitive edge in the job market, particularly in roles requiring expertise in smart construction technologies.

6.3 Challenges and Recommendations for Future Applications

While the collaborative education model demonstrated considerable success, several challenges were identified during its implementation. Addressing these challenges will further enhance its effectiveness and scalability.

6.3.1 Challenges Identified

(1) Resource Constraints: The development and maintenance of simulation platforms require substantial financial and technical resources. Smaller institutions may struggle to implement similar systems without external support.

(2) Faculty Training: Instructors need specialized training to effectively use advanced simulation tools and integrate interdisciplinary content into their teaching.

(3) Industry Engagement: Maintaining active participation from industry partners can be challenging, particularly in rapidly changing technological environments.

(4) Scalability for Large Cohorts: While the platform supports scalability, large class sizes may dilute the quality of hands-on experiences and personalized feedback.

(5) Adaptability to Technological Changes: The rapid evolution of construction technologies requires continuous updates to simulation content and teaching materials.

6.3.2 Recommendations for Future Applications

(1) Increased Funding and Partnerships: Institutions should seek funding from government grants and private organizations to support the development and expansion of simulation platforms. Collaborative partnerships with industry leaders can also provide access to cutting-edge tools and expertise.

(2) Faculty Development Programs: Comprehensive training programs should be established to equip instructors with the skills needed to use simulation tools and facilitate interdisciplinary learning.

(3) Enhanced Industry Collaboration: Institutions should formalize long-term partnerships with industry stakeholders through agreements that outline shared responsibilities and mutual benefits. Regular advisory board meetings can ensure curricula remain aligned with industry needs.

(4) Optimized Student-Platform Ratios: To maintain the quality of hands-on experiences, institutions should ensure an appropriate student-to-platform ratio by investing in additional simulation licenses or hardware.

(5) Modular and Updatable Content: Simulation platforms should adopt modular designs that allow for easy updates, ensuring the content remains relevant as technologies evolve.

6.3.3 Potential for Broader Implementation

The success of the collaborative education model in this case study suggests that it can be adapted to other engineering disciplines and educational contexts. Future research should explore its applicability in fields such as civil engineering, mechanical engineering, and renewable energy technologies. Additionally, pilot programs in diverse geographic and institutional settings can provide insights into its scalability and adaptability.

By addressing these challenges and implementing the recommended solutions, the collaborative education model can continue to play a transformative role in engineering education. Its success in the building electrical and intelligent specialty serves as a blueprint for the development of innovative, industry-aligned training programs that prepare students to lead in the era of smart construction.

7. Conclusion and Future Work

7.1 Summary of Key Findings

This study explored the development and implementation of a collaborative education model for the building electrical and intelligent specialty under the context of smart construction. The research focused on addressing the challenges of talent cultivation through a structured "1+2+3+4+5" framework, supported by practical applications via the Smart Construction Site Simulation Teaching Platform. The key findings are as follows:

(1) Effectiveness of the Collaborative Model: The proposed model effectively integrated academic, industrial, and research resources, demonstrating significant improvements in students' technical proficiency, interdisciplinary knowledge, and practical skills. The results showed substantial increases in learning outcomes, including a 61% improvement in interdisciplinary integration and a 55% enhancement in IoT-related competencies.

(2) Enhanced Student Readiness for Industry: The collaborative education approach bridged the gap between academic training and industry demands, equipping students with both technical and soft skills necessary for smart construction projects. Improvements in problem-solving (+49%) and teamwork (+42%) underscore the model’s ability to foster holistic development.

(3) Role of Simulation-Based Learning: The simulation platform played a critical role in translating theoretical knowledge into practical application. It provided students with immersive and hands-on experiences, preparing them for real-world challenges in a controlled, risk-free environment.

(4) Scalability and Sustainability: The use of digital tools and resource-sharing principles ensured the framework’s scalability and adaptability. Institutions can leverage the findings of this study to implement similar models in other engineering disciplines.

7.2 Implications for Industry-Education Integration Practices

The findings of this study have significant implications for the broader field of industry-education integration:

(1) Strengthening University-Industry Collaboration: The study highlights the importance of active and sustained collaboration between universities and industry partners. By involving industry experts in curriculum design and teaching, educational institutions can ensure their programs remain relevant to evolving market needs.

(2) Advancing Simulation-Based Education: The success of the Smart Construction Site Simulation Platform underscores the potential of technology-driven teaching methods. Simulation platforms enable students to gain practical experience in complex, interdisciplinary environments, bridging the gap between theory and practice.

(3) Promoting Interdisciplinary Learning: The integration of multiple domains—such as BIM, IoT, and energy optimization—within the curriculum reflects the growing need for interdisciplinary expertise in smart construction. This approach can serve as a model for other fields that require cross-disciplinary collaboration.

(4) Fostering Lifelong Learning: By emphasizing continuous feedback, performance assessment, and iterative improvement, the framework encourages a culture of lifelong learning, preparing students to adapt to future advancements in technology and industry practices.

(5) Policy Implications: Policymakers should consider supporting the adoption of collaborative education models through funding initiatives and regulatory frameworks that incentivize university-industry partnerships.

7.3 Directions for Further Research

While this study provides a robust foundation for collaborative education in the building electrical and intelligent specialty, several areas warrant further exploration:

(1) Expanding to Other Disciplines: Future research should investigate the applicability of the "1+2+3+4+5" framework in other engineering and technical fields, such as civil engineering, mechanical engineering, and renewable energy technologies. Comparative studies can help identify discipline-specific adaptations and common success factors.

(2) Longitudinal Impact Analysis: This study focused on immediate and short-term outcomes of the collaborative education model. Long-term studies are needed to evaluate the sustained impact on graduates' career trajectories, industry performance, and adaptability to technological advancements.

(3) Economic Feasibility and Scalability: While the framework demonstrated success in the case study, research is needed to assess its economic feasibility and scalability, particularly for smaller institutions with limited resources. Studies should explore cost-effective methods for implementing simulation platforms and fostering industry collaboration.

(4) Innovations in Digital Learning Tools: As technology evolves, new digital tools such as augmented reality (AR) and artificial intelligence (AI) can be integrated into simulation platforms to enhance learning experiences. Research should explore the pedagogical implications and technical requirements of such innovations.

(5) Diversity and Accessibility: Ensuring equitable access to collaborative education models is critical. Future research should address how these frameworks can be adapted to diverse student populations, including those in underserved regions or remote learning environments.

(6) Policy and Institutional Support: Further studies should examine the role of institutional leadership and government policies in facilitating the implementation of collaborative education models. Research on funding mechanisms, incentives for industry participation, and frameworks for public-private partnerships would provide valuable insights.

By addressing these areas, future research can build on the findings of this study to advance the adoption and refinement of collaborative education models. These efforts will not only enhance engineering education but also ensure that graduates are well-prepared to contribute to the rapidly evolving landscape of smart construction and beyond.

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