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Original Paper

Research on Interdisciplinary Integration and Construction of the Smart Construction Professional Curriculum Cluster

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Abstract

As the core direction of digital and intelligent transformation in the construction industry, smart construction places heightened demands on the interdisciplinary integration of professional curriculum systems. Centered on the development of a smart construction curriculum cluster, this research explores innovations in the curriculum system within a multi-disciplinary context. Utilizing BIM-VR platforms, robotics engineering, intelligent equipment, and AI technologies as core supports, it facilitates the deep integration of disciplines such as civil engineering, computer science, and automation control. The study proposes curriculum innovation strategies based on the OBE and CDIO models, along with a modular curriculum framework, constructing a four-tiered curriculum cluster (Foundation-Core-Integration-Practice). Practical teaching is enhanced through industry-academia collaboration and the integration of production, education, and research. For curriculum cluster optimization, the study develops a smart construction competency matrix and a sustainable development framework, introducing a dynamic evaluation mechanism to improve the adaptability of the curriculum system and the quality of talent cultivation. The findings provide theoretical support for the reform of smart construction education, promote the development of smart construction programs in higher education institutions, and contribute to the high-quality development of the construction industry.

Keywords

Smart Construction, Interdisciplinary Integration, Curriculum Cluster Development, BIM-VR, Artificial Intelligence

As an important direction for the digital transformation of the construction industry, smart construction is driving the deep integration of construction industrialization, informatization, and intelligence. In recent years, national and local governments have successively introduced policies to support the development of the smart construction industry. As a pilot city, Qingdao has accumulated extensive experience in BIM technology, intelligent construction, and smart sites. However, the smart construction discipline still faces challenges such as difficulties in interdisciplinary integration, an incomplete curriculum system, insufficient practical teaching resources, and lagging industry-academia collaboration, which constrain the quality of talent cultivation. Therefore, constructing a scientific and rational smart construction curriculum system and promoting interdisciplinary integration and innovation in practical teaching have become urgent issues to address. This study focuses on the development of a smart construction curriculum cluster, analyzes industry trends, identifies key skill requirements, and proposes a comprehensive framework based on OBE, CDIO, and modular curriculum concepts, covering core courses such as smart construction technology, project management, data analysis, automation, and robotics. Simultaneously, the study emphasizes the importance of practical teaching, suggesting the use of innovative teaching methods such as BIM-VR, intelligent equipment, and AI technology, combined with laboratory practice, project-driven learning, and industry-academia collaboration to enhance students' hands-on operational skills. Furthermore, the study explores mechanisms for curriculum cluster evaluation and optimization to ensure the synchronization of teaching content with industry needs. Ultimately, the research aims to establish a sustainable smart construction curriculum system that provides theoretical support and practical guidance for talent cultivation in higher education institutions, facilitating the digital transformation of the construction industry.

1. Development of the Smart Construction Discipline and Teaching Innovation

1.1 Overview of Smart Construction Discipline Development and Policy Orientation

In recent years, national and local governments have placed great emphasis on the development of smart construction. Departments such as the Ministry of Housing and Urban-Rural Development and the Ministry of Education have successively introduced policies to promote the digital, industrial, and intelligent transformation of the construction industry. For example, the "14th Five-Year Plan for Construction Industry Development" highlights smart construction as a key lever for enhancing the industry's core competitiveness and calls for accelerated integration and application of technologies such as BIM, artificial intelligence, and the Internet of Things. At the local level, Qingdao, as one of the first national pilot cities for smart construction, has released a series of guidance documents explicitly outlining goals for developing the smart construction industry and cultivating talent in this field. Against this backdrop, smart construction programs in higher education institutions should closely align with policy demands, optimize curriculum design, promote interdisciplinary integration, and cultivate talent equipped with new technology application skills, innovative capabilities, and engineering practical abilities to meet the industry’s urgent need for interdisciplinary professionals.

1.2 Interdisciplinary Integration in Smart Construction Curricula

Interdisciplinary integration is the core of the smart construction curriculum system, involving multiple fields such as civil engineering, computer science, automation control, and artificial intelligence. Currently, domestic smart construction curriculum systems in higher education institutions mainly follow three models: first, expanding smart construction direction courses based on civil engineering programs; second, strengthening construction industry application courses based on computer science or intelligent manufacturing programs; and third, establishing independent smart construction disciplines to form a complete interdisciplinary training system. To achieve interdisciplinary integration, the smart construction curriculum cluster should adopt a four-tier structure of “Foundation + Core + Integration + Practice,” maintaining the rigor of traditional engineering courses while enhancing the teaching of new technologies such as information technology, intelligent construction, and digital twins. By integrating multidisciplinary resources and optimizing teaching models, the smart construction curriculum system can effectively improve students’ comprehensive abilities and provide high-quality talent support for the intelligent development of the construction industry (Crawford, A., & Stephan, A., 2021, p. 103942).

1.3 Interdisciplinary Curriculum Innovation

Interdisciplinary curriculum innovation in the smart construction discipline is primarily reflected in areas such as BIM-VR platforms, robotics engineering, intelligent equipment, and AI technology applications. Courses on BIM-VR platforms enhance students’ understanding of Building Information Modeling and improve their capabilities in visual management through 3D modeling and virtual reality technologies. Robotics engineering courses cover automated construction, intelligent inspection, drone surveying, and other content, cultivating students’ ability to apply intelligent construction technologies. Courses on intelligent equipment focus on technologies such as smart site management, structural health monitoring, and IoT sensors, enhancing students’ skills in intelligent building management. Courses on computer technology and AI applications integrate machine learning, computer vision, big data analytics, and other topics to explore the use of AI in construction scheduling, quality inspection, and safety management. Through these curriculum innovations, the smart construction discipline can cultivate interdisciplinary talent capable of meeting the future demands of the construction industry.

1.3.1 BIM-VR Platform

BIM (Building Information Modeling) technology is a core supporting technology for smart construction, and the introduction of VR (Virtual Reality) technology further enhances the visualization of architectural design, construction management, and operation and maintenance processes. The development of BIM-VR platform courses aims to cultivate students’ capabilities in data modeling, virtual simulation, and intelligent analysis throughout the entire building lifecycle. Course content includes fundamental BIM modeling and optimization, BIM applications in construction management, VR immersive experience technology, and integrated BIM-VR applications. Students will learn software such as Revit, Navisworks, and Unreal Engine, and simulate engineering cases through virtual construction environments to improve their construction planning and safety management skills. The course adopts a teaching model of "theoretical instruction + software practice + case studies + simulation training," combined with the application scenarios of BIM-VR technology, enabling students to intuitively understand complex engineering problems and enhance their practical engineering abilities. Through the application of the BIM-VR platform, students can master digital building technologies, providing technical support for the innovative development of the future smart construction industry.

1.3.2 Robotics Engineering

The application of robotics engineering in the field of smart construction is gradually deepening, offering new approaches for automation and intelligence in construction. This course covers the fundamental theories, programming control, construction applications, and intelligent monitoring of construction robotics technology. Students will learn about cutting-edge technologies such as bricklaying robots, concrete 3D printing, and drone inspection, and master skills in ROS (Robot Operating System), Python programming, and intelligent sensor applications. The course employs a model of "theoretical teaching + experimental training + engineering case analysis," combined with construction robotics simulation platforms and real engineering cases, to enhance students' hands-on skills and understanding of intelligent construction. Upon completion, students will possess the ability to apply construction robotics, enabling them to utilize smart construction equipment in future engineering practice, thereby improving construction quality and efficiency, and cultivating interdisciplinary talent with a cross-disciplinary background for the industry's development.

1.3.3 Intelligent Equipment

The application of intelligent equipment in smart construction spans automated construction, intelligent monitoring, and smart site management. This course primarily introduces key technologies such as construction intelligent sensors, automated construction machinery, and intelligent monitoring systems, aiming to equip students with the skills to operate and apply smart construction equipment. Course content includes intelligent monitoring devices (e.g., IoT sensors, laser scanners), automated construction equipment (e.g., unmanned construction machinery, intelligent tower cranes), and smart site management systems (e.g., BIM+GIS integrated platforms). Through a model of "classroom teaching + equipment operation + case studies + field training," students will learn how to use intelligent equipment to enhance the safety, precision, and automation level of construction. The design of this course helps cultivate students' comprehensive application abilities in intelligent construction and operation management, providing technical support for the digital upgrade of the smart construction industry.

1.3.4 Computer Technology and AI Applications

The application of artificial intelligence and computer technology in smart construction is becoming increasingly widespread, driving the construction industry towards greater intelligence and data-driven practices. This course mainly covers AI intelligent recognition, computer vision, big data analysis, and intelligent scheduling optimization technologies, aiming to develop students' ability to apply AI in the construction industry. Course content includes construction data analysis and big data technology, machine learning and computer vision, intelligent scheduling algorithms, and integrated BIM+AI applications. Students will learn technologies such as Python, TensorFlow, and OpenCV, and master the application of AI in construction schedule optimization, quality inspection, and automated monitoring. The course adopts a model of "programming practice + case analysis + industry application practice," encouraging students to engage in algorithm development based on smart construction cases, thereby improving their data analysis and intelligent optimization capabilities and fostering innovative technical talent for the future smart construction industry (Sacks, R., Girolami, M., & Brilakis, I., 2020, p. 100011).

2. Interdisciplinary Smart Construction Curriculum Cluster Development

2.1 Curriculum System Innovation Directions: OBE, CDIO, and Modular Curriculum

In developing the smart construction curriculum cluster, innovating the curriculum system is key to enhancing the quality of talent cultivation. Adopting Outcome-Based Education (OBE), the CDIO engineering education model, and a modular curriculum structure can effectively meet the rapidly evolving demands of smart construction and strengthen the development of students' comprehensive abilities. The OBE model focuses on student learning outcomes and competency development. By establishing clear learning objectives and evaluation systems, it ensures close alignment between curriculum content and industry needs, guaranteeing that students acquire knowledge and skills directly relevant to engineering practice. The CDIO model emphasizes cultivating students' engineering practical ability and innovation skills, highlighting the four stages of "Conceive, Design, Implement, Operate" to enhance their project management and problem-solving capabilities. The modular curriculum system involves the scientific division and integration of knowledge in the smart construction field, creating distinct modules at different levels—such as foundational, core, integrated, and practical courses. This ensures students progressively enhance their skills and deepen their understanding and application abilities in smart construction at different stages. By integrating these three educational concepts, the smart construction curriculum system achieves both systematic structure and flexibility. It ensures students possess the necessary theoretical foundation, technical skills, and innovative awareness, preparing them to become interdisciplinary and innovative professionals for the industry.

2.2 Curriculum Cluster Development Strategy: Four-Tier Structure (Foundational-Core-Integrated-Practical)

The development strategy for the smart construction curriculum cluster should follow a four-tier structural model consisting of "Foundational Courses, Core Courses, Integrated Courses, and Practical Courses." This ensures the curriculum content covers the entire spectrum from fundamental knowledge to practical application, fostering students' comprehensive abilities. The Foundational Courses tier primarily covers traditional fundamentals of civil engineering and architecture, such as《Structural Mechanics》, 《Architectural Drawing》, and 《Civil Engineering Materials》, providing students with a solid disciplinary base. The Core Courses tier focuses on the key technologies of smart construction, including Building Information Modeling (BIM), intelligent construction techniques, robotics applications, and the integrated use of AI in construction. These courses ensure students develop professional technical competencies in smart construction and cultivate their ability to devise solutions for complex engineering projects. The Integrated Courses tier involves interdisciplinary technological integration, such as combining BIM with VR, or integrating robotics engineering with intelligent construction equipment. This promotes knowledge transfer and cross-application across multiple disciplines, enhancing students' innovation capabilities and engineering application skills. The Practical Courses tier employs project-driven learning and industry-academia collaboration to immerse students in real engineering environments. Through practical training in areas like project design, construction management, and intelligent technology application, this tier ensures students can effectively translate theoretical knowledge into practical engineering competence. Through this four-tiered curriculum design, students can progressively master the knowledge and skills required for smart construction, enhance their overall quality, and meet the industry's demand for interdisciplinary talent. The development strategy for the four-tier structure of the smart construction curriculum cluster is illustrated in Figure 1 below.

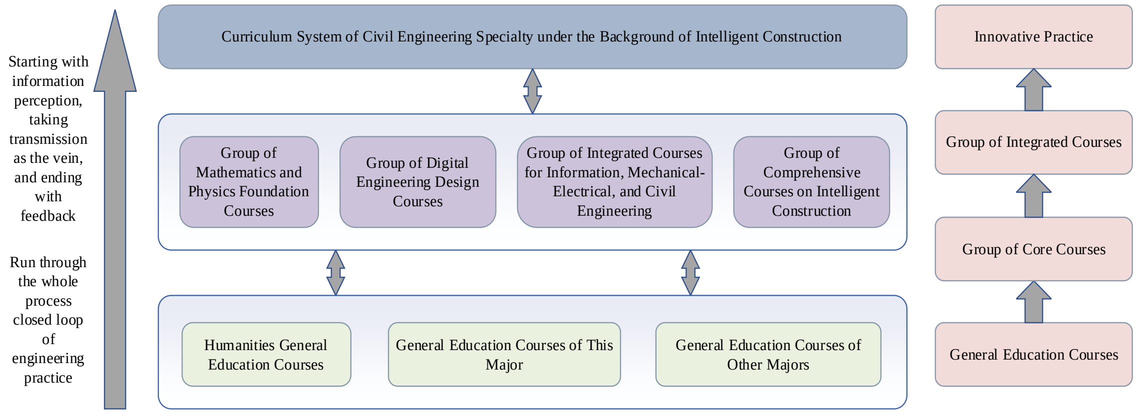

Figure 1. Construction Strategy for the Four-Tier Structure of the Intelligent Construction Professional Course Group

2.3 Curriculum Cluster Optimization and Competency Matrix Development

The optimization of curriculum clusters and the development of competency matrices are pivotal measures for enhancing the teaching quality in smart construction programs. Through rational curriculum optimization and well-designed competency matrices, academic programs can better align with industry needs, ensuring students comprehensively develop their technical capabilities, innovative thinking, and practical skills during their learning process. Curriculum optimization requires timely updates and adjustments to course content in response to the rapid advancement of smart construction technologies and evolving market demands. This includes strengthening instruction on emerging technologies such as BIM, VR, and artificial intelligence, optimizing the overall course structure, and incorporating interdisciplinary curriculum modules. Simultaneously, curriculum design should avoid single-discipline teaching models, instead fostering forward-looking, practical, and innovative course content through cross-disciplinary collaboration. The competency matrix development involves establishing clear correlations between specific courses and targeted competencies based on the educational objectives of the smart construction program. This process defines precise capability indicators that each course should achieve. The competency matrix enables scientific assessment of students' learning progress and knowledge acquisition while providing data-driven support for curriculum adjustment and refinement. This approach not only facilitates progressive competency development throughout different learning stages but also ensures graduates possess the comprehensive capabilities required by the smart construction industry, thereby meeting the construction sector's demand for interdisciplinary and innovative professionals.

2.4 Integration of Industry, Education, and Research: Industry-Academia Collaboration and Practical Teaching Base Development

The integration of industry, education, and research constitutes a crucial component in the development of the smart construction curriculum cluster. Through industry-academia collaboration and the establishment of practical teaching bases, classroom learning can be closely aligned with actual engineering requirements, thereby enhancing students' practical abilities and innovative capacities. Industry-academia collaboration provides students with diverse practical platforms, enabling their participation in real engineering projects where they learn to translate theoretical knowledge into operational skills. By partnering with leading construction enterprises and smart construction technology companies, academic institutions can stay abreast of the latest industry developments and technological needs, ensuring the forward-looking nature and practical relevance of the curriculum. Furthermore, such collaboration facilitates talent development and technological research cooperation between enterprises and universities, creating more employment opportunities and career development pathways for students. The development of practical teaching bases—including smart construction laboratories and intelligent construction site simulation centers—provides students with realistic and highly interactive learning environments. Through these industry-academia jointly built bases, students can engage in practical activities such as real engineering data analysis, construction simulation, and intelligent equipment operation, thereby cultivating their problem-solving skills and innovative thinking in engineering contexts. This integration not only enhances students' professional competencies but also fosters a virtuous cycle between smart construction education and industry development, cultivating high-quality talent to support the digital and intelligent transformation of the construction industry.

3. Curriculum Cluster Evaluation and Sustainable Development Framework

3.1 Continuous Optimization Framework for Curriculum Cluster Development (Smart Construction Talent Training Model)

The continuous optimization framework for the smart construction curriculum cluster should be dynamically adjusted based on technological advancements and evolving industry demands to ensure close alignment between teaching content and practical applications. First, course materials must be regularly updated to incorporate emerging technologies and market needs in smart construction, particularly in areas such as BIM, artificial intelligence, and the Internet of Things. Second, teaching methodologies should shift from traditional lecture-based approaches to student-centered, practice-oriented models, emphasizing project-driven learning and problem-solving to enhance students' innovative thinking and practical skills. Additionally, the optimization framework should integrate a dynamic feedback mechanism, systematically gathering input from students, enterprises, and industry stakeholders to inform data-driven adjustments to curriculum design and content. This approach ensures the curriculum cluster remains technologically current while fostering students' professional competence and lifelong learning capabilities, ultimately cultivating highly skilled, interdisciplinary talent for the smart construction industry. The continuous optimization framework for the smart construction curriculum cluster is illustrated in Figure 2 below.

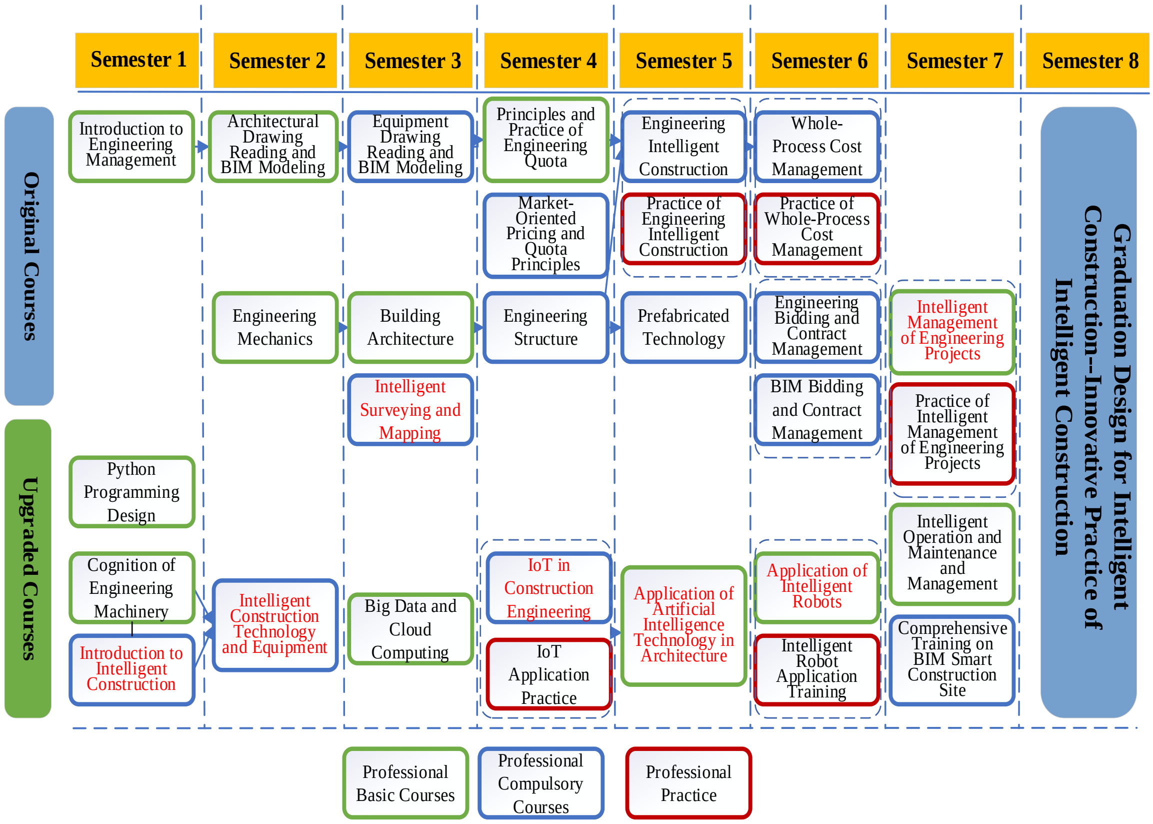

Figure 2. Framework of Interdisciplinary Curriculum Group Construction System

3.2 Curriculum Cluster Evaluation System and Improvement Mechanism

The optimization of the curriculum cluster requires guidance from an effective evaluation system to enhance teaching quality. The evaluation framework should encompass four key dimensions: student assessments, faculty feedback, industry needs, and technological trends. Student evaluations should not only reflect knowledge acquisition but also assess practical skills, teamwork, and innovative capabilities. Faculty feedback should focus on the innovativeness of course design and the effectiveness of teaching methods. Industry input helps evaluate students' performance in real-world work environments, ensuring the curriculum remains aligned with sector demands. Meanwhile, regular industry surveys keep the curriculum adaptive to future technological developments. Based on these multidimensional insights, an improvement mechanism enables timely adjustments to course content and teaching methodologies, enhancing the integration and practicality of the curriculum system. This process ensures that graduates possess sufficient engineering competence and technological innovation skills to meet the growing talent demands of the smart construction industry.

3.3 Future Prospects (AI + Smart Construction Education, Smart Construction, and Metaverse-Based Teaching)

Looking ahead, smart construction education will deeply integrate with cutting-edge technologies, particularly artificial intelligence (AI), smart construction, and the metaverse. The incorporation of AI into smart construction education will advance teaching in areas such as data analysis, construction optimization, and quality control in architectural engineering, cultivating students' intelligent thinking and technical application skills. The adoption of smart construction technologies will accelerate the automation and intellectualization of site management, leading to an increased emphasis in the curriculum on the practical application of IoT, smart sensors, and big data analytics in construction processes. Metaverse-based teaching, utilizing virtual reality (VR) and augmented reality (AR) technologies, will offer immersive learning experiences, allowing students to engage in design, construction, and management practices within virtual environments. This will strengthen their spatial awareness and engineering application abilities. The introduction of these emerging technologies will break the of traditional teaching approaches, providing students with more flexible and innovative learning experiences. Such advancements will further promote the integration of smart construction education and industry development, supplying highly skilled talent to support the intelligent transformation of the future construction industry (Zhou, Y., Zhang, J., & Li, H., 2022, p. 04022001).

4. Conclusion

This study has focused on the interdisciplinary integration and development of a curriculum cluster for the smart construction major. It proposes a curriculum system design based on OBE, CDIO, and a modular course structure, while optimizing course content and a competency matrix in line with industry demands. By strengthening the instruction of core technologies such as BIM, robotics engineering, intelligent equipment, and artificial intelligence, a systematic yet flexible curriculum cluster has been constructed, aiming to cultivate interdisciplinary talent with innovative capabilities and comprehensive practical skills. The research demonstrates that the innovation and integration of interdisciplinary courses can effectively enhance students' comprehensive abilities. Furthermore, the combination of industry, academia, and research provides a practical platform for curriculum implementation, enhancing its applicability and forward-looking nature. With the rapid development of the smart construction industry, future educational models will increasingly integrate cutting-edge technologies such as artificial intelligence, smart construction, and the metaverse, driving the continuous optimization and upgrading of the curriculum system. The development of the smart construction curriculum cluster not only provides high-quality talent support for the industry but also offers theoretical and practical guidance for the reform of higher education. It contributes to the intelligent and digital transformation of the construction industry, supporting its high-quality development.

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