Research on the Construction of Informatisation Laboratories and the Innovation of Experimental Teaching – Taking the Digital Construction and Building Industrialisation Smart Laboratory as an Example

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Abstract. In the context of the accelerating digital transformation of the construction industry, the establishment of an informatised laboratory has emerged as a pivotal strategy for enhancing the quality of laboratory instruction. This study employs the Digital Construction and Building Industrialisation Smart Laboratory of a specific university as a case study, exploring a laboratory construction model that integrates advanced technologies such as digital twins (DT), the Internet of Things (IoT), intelligent construction robots, virtual simulation, VR and AR. The integration of a prefabricated construction engineering practical system, an IoT training platform and an intelligent construction robot training platform has resulted in the construction of an immersive experimental teaching system that combines the virtual and the real, as well as a multi-modal teaching system that integrates learning, training, testing, competition and evaluation. Research findings indicate that the informatised laboratory, characterised by real-time 3D synchronisation, immersive teaching methods and an intelligent assessment system, has enhanced students' average practical and theoretical grades. These results offer a replicable framework for the reform of experimental teaching in construction engineering colleges and universities, providing a theoretical foundation for the innovation of interdisciplinary laboratory construction and the integration of industry and education.

Keywords: Informatisation laboratory, Experimental teaching, Digital twin, Intelligent construction, Educational innovation

1   Introduction

The global construction industry is undergoing a paradigm shift toward industrialization and smart sustainability, catalyzed by China's "14th Five-Year Plan for Energy Conservation and Green Building Development" (Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2022). While emerging technologies like BIM and prefabricated construction have elevated industry digitalization to 37% globally (Smith et al., 2023)[1] , China's architectural education system struggles

to bridge the talent gap (Zhang et al., 2023)[2]. Outdated laboratory infrastructure persists, with only 32% of Chinese architecture institutions deploying virtual simulation equipment (China Institute of Education Sciences, 2023), resulting in a critical mismatch between graduate competencies and industry demands (Zhang & Wang, 2022)[3].

This transformation necessitates educational innovation through smart laboratory ecosystems. International precedents demonstrate the efficacy of digital integration: IoT-enabled platforms improve laboratory utilization by 40% (Müller, 2021)[4], while VR-enhanced training reduces operational errors by 25% (Tanaka & Yamamoto, 2023)[5]. The Technical University of Munich's BIM-robotics integration model exemplifies how immersive environments can increase student engagement by 40% while reducing training costs by 30%. Recent studies further confirm that IoT-teaching scenario integration optimizes resource allocation through intelligent feedback mechanisms.

The present study is anchored in a project to establish a digital construction and intelligent laboratory for industrialised construction at a certain university. Digital technology forms the core of the study, which explores the practical path of building an information-based laboratory through school-enterprise collaboration, technological integration and teaching reconstruction. The aim is to provide a solution that can be referenced by similar institutions.

2   Content of the Construction of the Informatisation Laboratory

The core task of the informatisation laboratory is to enhance the quality and efficiency of experimental teaching through the utilisation of contemporary technology. The Digital Construction and Building Industrialisation Smart Laboratory employs a prefabricated construction engineering practical system, integrating virtual simulation technology and digital twin technology to formulate a comprehensive and interactive teaching platform.

2.1   Experimental Equipment and Platform Construction

The project has been developed around the core concept of 'integration of virtual and physical, school-enterprise collaboration, and data-driven'. The construction of a laboratory system with four modules has been undertaken, and the prefabricated construction engineering practice system integrates DT and AR technology to simulate the entire prefabricated construction process. The Internet of Things training platform uses a sensor network to monitor environmental data in real time and supports the development of smart construction scenarios. The intelligent construction robot training platform is equipped with a 6-axis collaborative robot to simulate processes such as steel bar binding and concrete pouring. The intelligent engineering construction management platform relies on BIM technology to manage the entire project lifecycle. The project focuses on the configuration of the following equipment, as shown in Table 1. Through these systems, students can not only better understand theoretical knowledge, but also

practically operate these technologies, improving their engineering and technical capabilities.

Table 1. List of core laboratory equipment.

Equipment name	Function description	Technical features
Modular construction engineering practical system	An interactive platform for virtual and physical operations covering the complete construction process	Shanghai Vqisoft Infomation Co., Ltd.
Intelligent construction robot training platform	Process simulation of steel bar binding, concrete pouring, etc.	Robot control, PLC programming, intelligent construction simulation
Internet of things training platform	Intelligent environmental monitoring, intelligent construction site monitoring, intelligent control of construction machinery	Wireless sensors, radio frequency equipment, cloud platform integration
Intelligent construction management platform	Intelligent project management, full process management, full data restoration, full scenario simulation	Cloud platform integration

2.2 Analysis of Student Learning and Clear Teaching Objectives

In the domain of construction education, conventional experimental teaching methods frequently fall short in providing adequate opportunities for practical engagement. The establishment of an informatisation laboratory has been instrumental in addressing this deficit. The Digital Construction and Building Industrialisation Intelligence Laboratory has been designed to present a novel teaching model that integrates virtual and physical components, enabling students to replicate the entire construction process of a building through virtual simulation technology and obtain real-time feedback. This innovative approach is expected to enhance the efficacy of the learning process. Conventional teaching methods are predominantly characterised by a unidirectional transmission of knowledge, whereas the innovative system employs a 'three-stage progressive' model, as illustrated in Table 2.

Table 2. Comparison of experimental teaching systems.

Indicator	Traditional model	Informatisation model
Teaching content	Static theoretical explanation	Dynamic virtual-real interaction
Practice carrier	Physical model	Virtual-real fusion system
Feedback mechanism	Delayed manual scoring	Real-time data-driven assessment
Student participation	Passive acceptance	Active exploration

3 Innovation in the Laboratory Teaching System

3.1 Teaching System Innovation

The notion of information-based experimental teaching cannot be considered a mere renewal of equipment; rather, it encompasses the utilisation of virtual simulation, digital construction, and analogous methodologies. Consequently, students are no longer confined to conventional laboratory equipment; rather, they are empowered to engage with an integrated virtual training platform for learning. This model ensures that students operate in a safe environment and enables them to perform in a variety of complex situations through virtual reality technology. The subsequent table 3 provides a comparison between virtual practical training and traditional practical training.

Table 3. Comparison of virtual practical training and traditional practical training.

Contents	Virtual Hands-on Training	Traditional Hands-on Training / On-site Hands-on Training
Learning Costs	Low (low investment, unlimited student capacity)	High (high investment, limited capacity)
Security	Safe, high degree of control	Dangerous, uncontrollable factors exist
On-site environment	Unaffected by various factors such as weather, can complete all the construction process learning in a short period of time	Easily affected by seasons, construction progress, site management, etc.
Learning efficiency	High	Low
Knowledge coverage	Wide	Narrow (limited by site site, narrow knowledge coverage, long construction period, unable to see the whole process)
Knowledge update	Fast (can be timely updated in accordance with national or local norms, and cutting-edge scientific research)	Slow (related to the actual situation of each place, some places are backward in construction technology)
Green	Low carbon	High Carbon
Educational equity	Absolute fairness (uniform standards and uniform assessment)	Comparatively fair (different venues, programmes, difficult to achieve uniform standards and assessment)
Learning Difficulty	Easy (can refine and repeat the operation, amplify some construction scenes that are difficult to represent)	Difficult (some construction processes are difficult to reflect in the field situation)
Characteristic Cultivation	Easy (can focus on the training of related specialities according to students' interests, employment needs, etc.)	Difficult (construction process is irreversible, limited internship sites, difficult to arrange learning according to individual student's personality and needs)

A comparison of data sets reveals that virtual practical training has the capacity to overcome the limitations of equipment and space, while also simulating operations multiple times in a safe environment. This assists students in more effectively mastering the necessary skills. The laboratory has been constructed with the utilisation of digital twin and Internet of Things technology, resulting in the creation of a three-dimensional teaching space that encompasses 'physical operation - virtual mapping - real-time feedback'. The assembly building engineering combat system utilises a sensor network to collect position, attitude and assembly sequence data of the physical sand table components in real time, concurrently generating a high-precision 3D digital twin model. Students can observe the dynamic assembly process of the components in the virtual scene through the large visualisation screen during the physical operation, thereby enhancing their spatial cognition accuracy and reducing operating errors.

The experimental course employs a three-tier progressive structure, namely "basic skills - special ability - comprehensive application", which is adapted to the stage characteristics of students' ability development. In the basic stage, students acquire the principles of intelligent environmental monitoring and mechanical control through the Internet of Things training platform and complete standardised operation training. In the special stage, students utilise the intelligent construction robot training platform to simulate typical construction tasks, such as rebar binding and concrete pouring. They are required to correctly select the control method of the robot's various functions according to the requirements of different construction processes. In the comprehensive stage, the team completes the design from design to operation and maintenance, and the team completes the whole life cycle project practical training from design to operation and maintenance. This hierarchical teaching model has been shown to enhance students' comprehensive problem-solving skills and higher-order thinking abilities. Conventional experimental evaluation methods are subject to limitations, including delayed feedback and ambiguity in standards, which can impede effective learning. This study proposes the integration of big data analysis technology to provide real-time feedback on students' performance, thereby facilitating personalised learning.

3.2   Needs Analysis of the Information System

3.2.1 Optimise Innovative Teaching Mode. It is imperative to eschew the conventional, monotonous pedagogy of traditional teaching methods and instead, conceptualise an innovative educational paradigm that is underpinned by the assembly informationisation system, a multifaceted integration of virtual reality and parallel modes. The integration of virtual reality with parallel modes facilitates a comprehensive experience encompassing the assembly's entire lifecycle, from production to transportation to construction. This approach incorporates virtual practice, sand table displays, augmented reality (AR) learning, and other interactive components, thereby significantly enhancing student engagement and classroom participation. Consequently, students transition from a state of passive knowledge acceptance to one of active knowledge exploration.

3.2.2 Reduce the Cost and Risk of Practical Training. Problems often encountered in traditional assembly building practical training include the following: a wide area occupied by equipment, a large volume of apparatus, many hidden dangers in operation safety, and high costs of daily operation and maintenance. The assembly information system does not require large-scale physical equipment and sites, thereby effectively avoiding the risk of safety accidents caused by physical operation errors. It also significantly reduces the site rental, equipment purchase and maintenance costs required for practical training, creating favourable conditions for institutions to carry out efficient, safe and economical practical training teaching..

3.3   Design of the Information System

A concerted effort has been made to establish a comprehensive space that integrates teaching, practical training and display. The primary function of this space is to showcase the assembly concrete construction process and to facilitate students' understanding of structures and technologies. Students specialising in assembly concrete are able to gain intuitive, comprehensive and hands-on experience of the assembly construction process during construction practical training. The construction training programme is designed to restore the authenticity of assembly construction, establishing assembly concrete construction scenes that are based on and higher than the real, while leveraging resources to comprehensively demonstrate the assembly building construction process. This approach offers an effective means of integrating assembly building theory and practice, ensuring that students can enhance their professional competencies through construction practical training.

The integration of theoretical instruction and practical training is a pivotal approach to comprehensively enhancing higher vocational education and cultivating proficient practical technical talents. The establishment of an integrated and comprehensive teaching and practical training system via a virtual information platform ensures the fulfilment of talent training objectives, facilitating the successful transition of students into the workforce post-graduation, enabling them to thrive without the necessity of additional pre-service training or further education. The system architecture design concepts are illustrated in Figure 1.
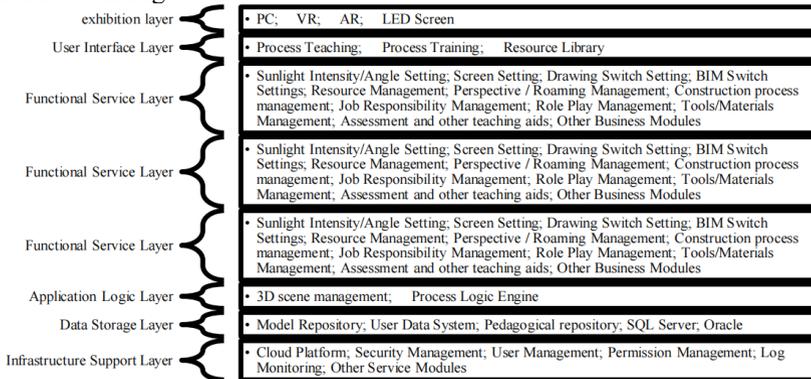

Fig. 1. System Functional Module Diagram.

3.4   Design of the Main Functional Modules of the Informatisation System

The utilisation of information technology, such as BIM and VR, facilitates a comprehensive understanding of the prefabrication, transportation, storage, lifting and cast-in-place structural construction of the primary components of the assembled building, including exterior wall panels, stacked panels, shear walls, stairs and other components. This comprehensive learning process is achieved through two modes of teaching and practical training, as illustrated in Figure 2.
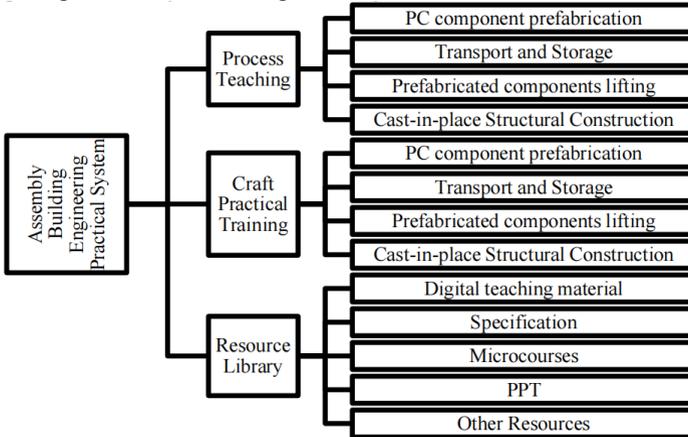
Fig. 2. System Functional Module Diagram.

3.5   Test results of the Information-based System

The findings of the evaluation, as evidenced by an analysis of students' performance and teachers' teaching feedback, demonstrate that: firstly, it has been demonstrated that there has been a marked increase in the level of interest among students in the assembly building course. Indeed, the majority of students have reported a significant increase in their interest in the course, with many commenting on the appeal of the practical training process. Secondly, there has been a substantial enhancement in the practical ability of students, as evidenced by a significant improvement in their performance in practical operations such as fabrication and installation of assembly building components. This has been accompanied by a notable increase in the operational proficiency and accuracy of students. Thirdly, the teaching effect has been significantly enhanced. Teachers are able to understand the students' learning process more comprehensively and adjust the teaching strategy in time, which significantly improves the quality of teaching and raises the students' overall performance by 15 points on average.

3.6   Conclusion of the Application of the Informatisation System

The implementation of an assembly building informatisation system has effectively addressed the challenges inherent in conventional construction education, particularly in

the domain of assembly building instruction. The integration of this system has been shown to enhance students' practical capabilities and engagement in the learning process. It has also been demonstrated to optimise the pedagogical approach, facilitate streamlined data management, and mitigate the economic and logistical risks associated with practical training. The system has yielded positive outcomes in preliminary trials and possesses considerable potential for dissemination and implementation. Going forward, the system will be further refined and its application expanded to provide more robust support for the training of assembly construction professionals.

4   Effectiveness of Laboratory Construction and Implementation

4.1   Improvement of Teaching Effectiveness

As illustrated in Table 4, a comparative analysis of the performance of students in Class of 2023 (traditional teaching) and Class of 2024 (IT teaching) is presented.

Table 4. Comparison of teaching effectiveness.

Indicators	Traditional teaching (2023 level data)	Informatised teaching (2024 level data)	Improvement
Theoretical achievement (average score)	72	87	15%
Students' practical grades (average score)	78	90	12%
Student satisfaction	85%	90%	5%
Student participation rate	100%	100%	/

The findings of the study demonstrate that, in comparison with conventional teaching methods, the integration of information technology in education has yielded notable enhancements in experiment participation rates, skill mastery, and theory conversion efficiency. Specifically, the mean score of students' practical grades increased from 78 to 90, and the mean score of theory grades increased from 72 to 87. This finding indicates that the novel teaching system, which integrates virtual and real, intelligent assessment and hierarchical practical training, effectively addresses the discrepancy between theory and practice in traditional teaching. Moreover, information-based teaching significantly enhances students' comprehensive abilities.

4.2   Transformation of Scientific Research Achievements

During the project construction cycle, the team members published 12 papers, applied for 8 patents and constructed 3 virtual simulation courses. In addition, the laboratory has provided technical consulting services for four local enterprises, and the assembly

building software system developed by the university-enterprise cooperation has been applied to three actual engineering projects.

5   Demonstration and Promotion Experience

Combination of real and virtual training, real-time three-dimensional synchronisation. Each constituent part of the assembled building engineering practical sand table is equipped with an IoT sensing module, and the system is capable of sensing the orientation, status, assembly position and sequence of the module in real time. Through the utilisation of a digital twin and a 3D posture adaptation algorithm, the system is able to achieve real-time synchronisation with the 3D simulation scene. Trainees are able to comprehend the correct and incorrect situations of their assembly building, all-round operation and related technical requirements in a timely, intuitive and comprehensive manner.

Education and Teaching Quality Improvement. The present project aims to enhance the quality of architectural education through two key initiatives: the renewal of educational equipment and the research into teaching reform. The integration of advanced equipment into the curriculum is expected to facilitate a paradigm shift in teaching methodologies, rendering them more intuitive and vivid. This, in turn, is anticipated to enhance students' comprehension of abstract theoretical construction knowledge. Concurrently, the deployment of cutting-edge equipment will provide educators with a more diverse array of resources and enhanced precision in practical teaching, thereby contributing to the development of students' practical abilities.

Enhanced application of scientific and technological innovation. The equipment renewal project will also promote the application of science and technology innovation in the field of architectural education. Through the introduction of cutting-edge technology and equipment, it is expected that students will be encouraged to engage in more innovative practices and cultivate the spirit and ability of innovation. At the same time, the application of new equipment will also promote the innovation of teaching content and methods and the modernisation of architectural education.

Optimisation of resource utilisation. The utilisation of new equipment is associated with enhanced energy efficiency and prolonged service life, thereby facilitating the optimisation of resource utilisation. The judicious application of equipment resources contributes to the reduction of energy wastage and environmental degradation, thereby facilitating the realisation of environmentally sustainable educational practices. Moreover, the incorporation of new equipment fosters resource sharing and collaboration, thereby enhancing the efficiency of resource utilisation.

Enhancement of Industry Influence. The implementation of this study will enhance the influence of construction education in the industry. By demonstrating advanced teaching equipment and innovative teaching methods, it can attract more industry attention and resource investment, and promote the sustainable development of architectural education. Simultaneously, students with high quality and innovation ability will be trained to deliver more excellent talents to the industry and enhance the overall competitiveness of the industry.

6   Conclusion

The construction of information technology laboratories is pivotal in promoting the quality of education. Through the integration of digital twin, Internet of Things and other technologies, an efficient and intelligent digital construction and construction industrialisation intelligent laboratory has been constructed, where students are able to learn on an efficient platform integrating virtual and reality, theory and practice, significantly enhancing their professional skills and innovation ability. The advent of new technologies will see the role of the IT laboratory evolve to encompass a wider range of disciplines, thereby promoting the intelligent and digitalisation process within the construction industry and cultivating a workforce with future development potential.It is imperative to explore the in-depth integration of AI and VR, expand interdisciplinary resource sharing, and nurture a more diverse talent pool for the construction industry.

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