# Research on Innovative Experimental Teaching Mode of Civil Engineering Materials for Digital and Intelligent Operation and Maintenance of Urban Infrastructure under the Background of Urban Renewal

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**Abstract: Traditional experimental teaching of civil engineering materials have limitations including lack of targeted teaching systems, disjointed competence cultivation, and imperfect collaborative mechanisms. Therefore, based on the OBE engineering education concept, this paper conducts systematic research on innovative experimental teaching mode of civil engineering materials. By reconstructing a three-stage and nine-module curriculum system covering the entire process of material performance data collection-operation and maintenance decision-making, designing an open experimental project system of basic verification-comprehensive application-innovative inquiry, constructing a scenario-based collaborative mechanism featuring co-construction of projects, co-training of teachers, and sharing of achievements, and establishing a multi-dimensional dynamic evaluation system integrating process result, competence literacy, and individual team, a four-in-one innovative teaching mode of curriculum experiment collaboration evaluation is formed. This mode effectively addresses the pain points of traditional teaching, realizing the transformation of teaching content from traditional mechanical testing to interdisciplinary integration, teaching mode from cramming-style to independent inquiry, and evaluation method from single summative evaluation to multi-dimensional process evaluation. It significantly improves students' cross field practical capabilities and engineering literacy in materials digital intelligence operation and maintenance.**

**Keywords: Urban Renewal; Digital and Intelligent Operation and Maintenance; Civil Engineering Materials; Experimental Teaching Reform; OBE**

## 1. Introduction

China's urbanization has entered a high-quality development stage [1-3]. The Ministry of Housing and Development's Guiding Opinions on Promoting the Coordinated Development of Intelligent Construction and Industrialized Construction points out the need to accelerate the leap of infrastructure operation and maintenance towards digital and intelligent [4-6]. The Ministry of Education's Guidelines for Emerging Engineering Education emphasizes interdisciplinary integration and cultivating innovative talents capable of solving complex engineering problems, pointing out the direction for engineering education reform [7-8]. The in-depth integration of new-generation information technology and civil engineering has driven the industry's transformation from experience driven to data driven [9-10]. Collecting structural stress, cracks and other data through IoT sensors and predicting material durability with AI algorithms have become the core technical paths of intelligent operation and maintenance [11-13].

However, current experimental teaching of civil engineering materials still has significant shortcomings: the teaching content is mainly focused on traditional mechanical performance testing, lagging behind the development of digital and intelligent technologies; the teaching mode adopts a cramming style method, with experimental scenarios disconnected from engineering practice, students lack data analysis and intelligent diagnosis capabilities [14-15]. Therefore, driven by multiple strategic backgrounds, the innovation and reform of the traditional experimental teaching mode of civil engineering materials have become an urgent and important task.

At the same time, current domestic and foreign research on the reform of experimental teaching of civil engineering materials has accumulated practical experience in information technology integration and science-education collaboration in China, and formed characteristic models in practice orientation, digital integration, and collaborative talent training abroad [16-17]. However, considering the dual backgrounds of urban renewal and digital and intelligent operation and maintenance, there are still three obvious deficiencies: (1) The teaching system lacks pertinence, and no experimental curriculum system of civil engineering materials that meets the needs of urban renewal and focuses on digital and intelligent operation and maintenance has been formed. Most existing reforms only stay at the level of single technology application or partial content optimization [18-19]. (2) There is a disconnect in competence cultivation. Neither domestic nor foreign research has systematically constructed competence cultivation logic of material science data technology algorithm application operation and maintenance decision-making [20]. (3) The collaborative mechanism is not perfect. Industry- university- research collaboration is mostly concentrated on single projects or technical cooperation, lacking a long-term teaching collaborative mechanism deeply bound to urban renewal scenarios, which is difficult to support the demand for interdisciplinary talent training.

Therefore, this research, based on the needs of the urban renewal strategy and the development trend of digital and intelligent operation and maintenance, and guided by the OBE engineering education concept, reconstructs the experimental teaching system of civil engineering materials. Its theoretical significance lies in establishing an interdisciplinary teaching framework integrating material science digital intelligence technology engineering operation and maintenance, enriching the theory of experimental teaching reform under the background of emerging engineering education; its practical significance lies in improving students' data thinking, algorithm application and engineering practice capabilities through the systematic innovation of curriculum content, teaching mode and evaluation system, transporting high-quality interdisciplinary talents for the field of digital and intelligent operation and maintenance of infrastructure, and supporting the implementation of the urban renewal strategy.

## 2. Innovative Design of Teaching Mode

### 2.1 Reconstruction of the Three-Stage and Nine-Module Curriculum System Driven by Digital Intelligence

The traditional experimental curriculum of civil engineering materials focuses on the testing of material, lacking systematisms, comprehensiveness and cutting-edge.

This research takes the cultivation of students' engineering practice capabilities as the core goal, and constructs an experimental curriculum system covering the entire process of material performance data collection operation and maintenance decision-making. According to the three stages of basic cognition digital intelligence integration operation and maintenance practice, the three-stage and nine-module curriculum system is reconstructed to realize the transformation from knowledge transmission to competence cultivation. The specific information of the three stages and nine modules is shown in Table 1.

The key points of the specific implementation process of the three stages are as follows:

Innovation in the material performance link of the basic cognition stage: On the basis of traditional experiments, new modules for testing the performance of intelligent materials such as self-healing concrete and smart cement are added, supplemented with engineering-oriented experimental content such as sulfate erosion resistance and durability, with the update rate of course content exceeding 80%. By comparing the mechanical properties and response mechanisms of traditional materials and intelligent materials, students' foundation in material science is consolidated.

Upgrade of the data collection link in the digital intelligence integration stage: Replacing traditional collection methods such as strain gauges, IoT wireless sensors and high-precision data collection terminals are introduced, and Python data analysis tool teaching is added simultaneously. Students are required to master skills such as sensor deployment, data transmission protocol parsing, and raw data preprocessing, realizing the capability leap from data acquisition to data governance.

Construction of the operation and maintenance decision-making link in the operation and maintenance practice stage: Deep learning models are introduced to guide students to establish models for material service life prediction, strength evolution and durability evaluation based on collected data.

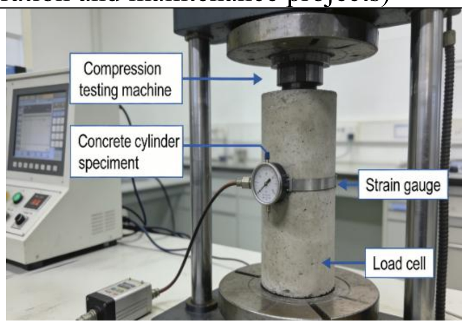
**Table 1. Digital Intelligence-Driven Three-Stage and Nine-Module Curriculum System of Civil Engineering Materials**

| Curriculum Stage | Core Goal | Included Modules |
|---|---|---|
| Basic Cognition Stage | Lay a solid foundation for material performance testing and digital intelligent tools | 1. Traditional Material Performance Testing Module (concrete compression/bending test, steel tensile test, etc.)<br>2. Basic Digital Intelligent Tools Module (Python/MATLAB basics, database operation)<br>3. Sensor Principle and Operation Module (sensor selection, calibration, use of data collection software) |
| Digital Intelligence Integration Stage | Build material-data correlation capabilities and master digital intelligent analysis technologies | 4. Material Performance Data Modeling Module (data fitting, parameter optimization)<br>5. AI Algorithm Application Module (practice of performance prediction algorithms, fault diagnosis algorithms)<br>6. Digital Intelligent Experimental Platform Operation Module (practical operation of BIM IoT based material monitoring platform) |
| Operation and Maintenance Practice Stage | Connect with urban renewal engineering scenarios and improve operation and maintenance decision-making capabilities | 7. Urban Renewal Scenario Simulation Module (simulation of material degradation in old buildings, analysis of operation and maintenance needs)<br>8. Digital Intelligent Operation and Maintenance Scheme Design Module (formulation of material maintenance strategies based on data)<br>9. Industry-University-Research Collaborative Project Module (participation in experimental design and analysis of actual enterprise operation and maintenance projects) |

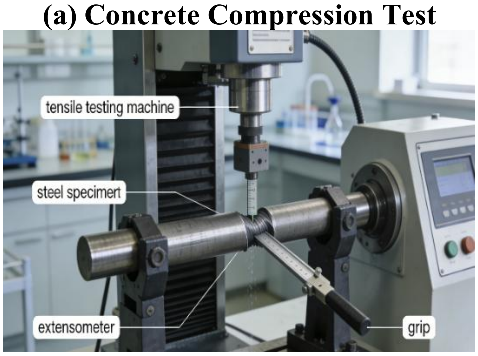
### 2.2 Design of Open Scenario-Based Experimental Projects Centered on Materials Digital Intelligence Capabilities

Guided by the actual needs of infrastructure operation and maintenance in urban renewal, a three-level experimental project system of basic verification comprehensive application innovative inquiry is designed to realize the in-depth connection between experimental teaching and engineering practice.

Basic Verification Experiments: Focus on cultivating basic capabilities of material performance data collection, such as Concrete Compression and Steel Tensile Strength Testing with Synchronous Data Collection by Strain Sensors (as shown in Figure 1). Students are required to complete the traditional compression test while collecting stress-strain data in real time through embedded strain sensors, compare and analyze the consistency between traditional testing and digital intelligent collection data, and understand the role of digital intelligent technology in improving experimental accuracy.



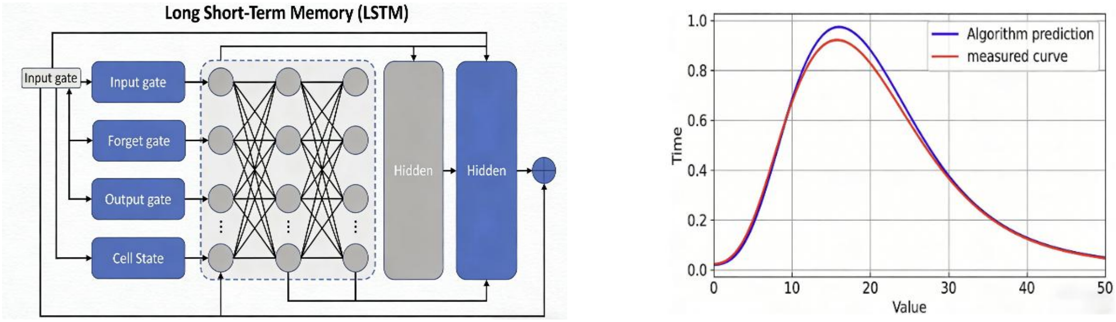

**(a) Concrete Compression Test**




**(b) Steel Tensile Test**

**Figure 1. Concrete Compression and Steel Tensile Strength Testing with Synchronous Data Collection by Strain Sensors**

Comprehensive Application Experiments: Focus on core capabilities of data modeling performance prediction, and design Concrete Carbonation Depth Prediction Experiment Based on LSTM Neural Network (as shown in Figure 2). Students need to obtain concrete carbonation data under different environmental parameters (temperature, humidity, $CO_2$ concentration) through accelerated carbonation experiments, build and train an LSTM model using Python for verification, and finally generate a carbonation depth prediction curve to provide data support for the durability operation and maintenance of infrastructure.




**(a) LSTM Algorithm Principle** **(b) Comparison of Accuracy between Predicted and Measured Curves**

**Figure 2. Concrete Carbonation Depth Prediction Experiment Based on LSTM Neural Network**

Innovative Inquiry Experiments: Oriented to operation and maintenance decision-making innovative design capabilities, open projects are designed in combination with urban renewal scenarios (as shown in Table 2), such as Degradation Diagnosis of Bearing Materials in Old Bridges and Optimization of Operation and Maintenance Schemes. Student teams need to investigate the actual operation status of bridges, formulate material degradation detection schemes (such as ultrasonic flaw detection combined with sensor monitoring), analyze data to identify bearing degradation risks, and finally propose an optimized operation and maintenance scheme integrating digital intelligent monitoring (such as adjustment of replacement cycle, preventive maintenance suggestions), and display the results through defense.

**Table 2. Open Projects Designed for Operation and Maintenance Decision-Making Innovative Design Capabilities**

| Number | Field | Name |
|---|---|---|
| 1 | Bridge Engineering | Degradation Diagnosis of Bearing Materials in Old Bridges and Optimization of Digital Intelligent Operation and Maintenance Schemes |
| 2 | Tunnel Engineering | Intelligent Monitoring of Lining Cracks in Urban Tunnels and Innovative Design of Structural Reinforcement |
| 3 | Road Engineering | Disease Identification of Asphalt Pavements on Main Roads in Old Urban Areas and Research on Preventive Maintenance Schemes |
| 4 | Structural Engineering | Durability Evaluation of Concrete Structures in Existing Buildings and Integration of Green Restoration Technologies |
| 5 | Bridge Engineering | Settlement Monitoring of Urban Interchange Bridge Piers and Development of Operation and Maintenance Decision Support Systems |
| 6 | Tunnel Engineering | Diagnosis of Water Seepage Diseases in Municipal Tunnels and Design of Treatment Schemes Integrating Sensors |
| 7 | Structural Engineering | Seismic Performance Evaluation and Innovative Reinforcement and Renovation Schemes of Masonry Structures in Old Communities |
| 8 | Road Engineering | Pavement Smoothness Detection of Urban Expressways and Research on Optimization of Maintenance Cycle Decision-Making |
| 9 | Bridge Engineering | Structural Health Monitoring of Large-Span Old Bridges and Innovative Design of Lightweight Reinforcement Technologies |
| 10 | Tunnel Engineering | Structural Health Diagnosis and Intelligent Operation and Maintenance Management Schemes of Urban Underground Comprehensive Pipe Corridors |

## 3. Design of Open Experimental Teaching Links and Industry-University-Research-Application Collaborative Mechanism

### 3.1 Innovation of Open Experimental Teaching Links

The traditional cramming-style experimental teaching mode restricts students' initiative and innovation. This research stimulates students' independent inquiry capabilities through a three-dimensional open design of time openness, content openness, and resource openness.

Time Openness: Relying on the laboratory information management platform, all-weather open experimental appointment is realized. Students can flexibly book experimental time according to their own learning progress and project needs, ensuring the continuity of digital intelligent experiments.

Content Openness: The project-driven problem-oriented mode is adopted in innovative inquiry experiments. Only the experimental goals and core requirements are clarified, and students are allowed to independently design experimental schemes (such as sensor selection, data collection frequency, and selection of analysis methods). Teachers only provide technical guidance and risk control.

Resource Openness: An online offline experimental resource sharing platform is constructed. The online platform provides digital intelligent experimental teaching videos (such as sensor installation tutorials, AI algorithm practical demonstrations), data sets (historical data of urban infrastructure material operation and maintenance), and toolkits (Python analysis code templates, BIM model libraries); the offline digital intelligent experimental center (equipped with BIM workstations, IoT sensing test platforms, and AI computing power servers) is open, and a "tutor studio" is set up, where on-campus teachers and enterprise engineers jointly provide one-on-one guidance.

### 3.2 Construction of Scenario-Based Industry-University-Research-Application

To address the problem of shallow and short-term traditional industry-university-research collaboration, a long-term collaborative mechanism of university-enterprise linkage is constructed in combination with the needs of urban renewal scenarios, realizing a closed loop of teaching practice employment. The collaborative subjects and division of responsibilities between the two parties are as follows:

University: Undertakes the core task of talent training, is responsible for curriculum system design and experimental teaching implementation, and conducts research on digital intelligent operation and maintenance technologies (such as new sensing materials and intelligent algorithm optimization) to transform scientific research achievements into experimental teaching content.

Enterprise: Provides engineering practice scenarios and technical support, such as arranging students to participate in actual infrastructure operation and maintenance projects (such as subway tunnel material monitoring and urban road maintenance), sending engineers to serve as enterprise tutors to participate in experimental project evaluation and teaching evaluation, and donating or leasing digital intelligent experimental equipment (such as portable structural health monitoring systems).

The specific implementation paths of collaboration between the two parties are as follows:

Co-construction of Projects: The two parties jointly establish an experimental project library for digital intelligent operation and maintenance of urban renewal infrastructure. Every year, 3-5 core experimental projects are determined according to the key tasks of urban renewal, which are undertaken by student teams through bidding. Enterprises provide project requirements and on-site conditions, and universities and research institutions provide technical guidance.

Co-training of Teachers: Implement a double-qualified teacher training plan. University teachers regularly participate in digital intelligent operation and maintenance project practice in enterprises (such as participating in the construction of smart pipeline network monitoring systems), and enterprise engineers participate in the design and teaching of experimental courses in universities. 2-3 industry university research collaborative teaching seminars are held every year to update teaching content and technical standards simultaneously.

Sharing of Achievements: Technical schemes (such as suggestions for optimizing material operation and maintenance) and research reports (such as analysis of material degradation laws of infrastructure in a certain area) formed by students in experimental projects can be applied to actual urban renewal projects after enterprise evaluation; universities transform engineering problems fed back by enterprises (such as operation and maintenance difficulties of new composite materials) into experimental teaching cases, realizing a virtuous cycle of practice teaching scientific research.

**Table 3. Multi-Dimensional Dynamic Evaluation Dimensions and Indicators**

| Evaluation | Core Evaluation Indicators | Evaluation Method | Proportion |
|---|---|---|---|
| Performance in the Experimental Process | 1. Experimental design | 1.Teacher observation<br>2.Internal evaluation<br>3.Experimental result | 30% |
| | 2.Proficiency in intelligent tools | | |
| | 3.Team contribution | | |
| Quality of Experimental Results | 1.Completeness and accuracy of experimental data | 1.Teacher review<br>2.Enterprise review<br>3.Result defense scoring | 40% |
| | 2.Depth of analysis report | | |
| | 3.Feasibility of operation and maintenance scheme | | |
| Digital and Intelligent Ability | 1.Data processing and modeling ability | 1. Practical assessment<br>2. Testing of tools<br>3.Evaluation of innovative | 20% |
| | 2.Problem diagnosis ability | | |
| | 3.Technical learning ability | | |
| Engineering Literacy | 1.Safety regulations | 1.Teacher evaluation<br>2.Feedback<br>3.Safety assessment | 10% |
| | 2.Sense of responsibility | | |
| | 3.Innovative thinking | | |

## 4. Construction of Multi-Dimensional Dynamic Evaluation System

Traditional experimental teaching evaluation focuses on experimental reports result accuracy, which is difficult to comprehensively measure students' digital intelligent capabilities and engineering literacy. Based on the OBE concept, this research constructs a multi-dimensional dynamic evaluation system integrating process result, competence literacy, and individual team, realizing the transformation of evaluation from simplification to diversification and from summative to process-oriented.

### 4.1 Design of Evaluation Dimensions and Indicators

The evaluation system includes four core dimensions, each with specific quantifiable evaluation indicators, realizing comprehensive evaluation through a combination of quantitative qualitative methods. The specific evaluation dimensions and indicator methods are shown in Table 3.

### 4.2 Implementation Process of Dynamic Evaluation

The specific process to realize the dynamism and informatization of evaluation is as follows:

1. Real-time collection of process data: Students upload experimental schemes, data records, code files, and phased reports to the management system during the experiment. Teachers and enterprise tutors real-time check the progress through the system, record students' operation performance and problem feedback, and generate process evaluation data.
2. Phased evaluation and feedback: Phased evaluations are carried out in the basic verification stage, comprehensive application stage, and innovative inquiry stage of the experimental project. Combined with process data and phased achievements, targeted improvement suggestions are provided for students (such as needing to optimize the parameters of the LSTM model to improve prediction accuracy and needing to strengthen the rationality of team task division) to help students adjust their learning strategies in a timely manner.
3. Summative comprehensive evaluation: After the completion of the experimental project, a comprehensive student evaluation report is generated by combining process evaluation data (30%), summative achievement scores (40%), digital intelligent capability test results (20%), and engineering literacy evaluation (10%). At the same time, students are invited to conduct self-evaluation and reflection, forming a closed loop of evaluation feedback improvement re-evaluation.

## 4.3 Application of Evaluation Results

The evaluation results are not only used for student performance assessment but also serve as the core basis for teaching optimization:

Student Level: According to the comprehensive evaluation report, personalized ability improvement plans are formulated for students (such as recommending students with weak digital intelligent capabilities" to participate in special training on AI algorithms; arranging more on-site enterprise practice for students with "insufficient engineering literacy).

Teaching Level: Analyze common problems in evaluation data (such as low pass rate of a certain experimental module and high difficulty in using a certain type of digital intelligent tool), and optimize curriculum content and teaching methods (such as adjusting experimental steps and increasing class hours for tool practical training); update the experimental project library and evaluation indicators according to changes in engineering needs fed back by enterprise tutors (such as the application of new material operation and maintenance technologies), ensuring that teaching keeps pace with industry development.

## 5. Conclusions

Based on the implementation of the urban renewal strategy and the industry transformation demand for "digital and intelligent" operation and maintenance of infrastructure, closely following the orientation of the Ministry of Education's emerging engineering education, and taking the OBE engineering education concept as the core, this paper conducts systematic research on the innovative teaching mode aiming at the pain points of traditional experimental teaching of civil engineering materials, such as outdated content, disconnection between learning and application, single evaluation, and disjointed competence cultivation. The core achievements and conclusions are as follows:

(1) A three-stage and nine-module curriculum system covering the entire process of material performance data collection operation and maintenance decision-making is constructed, realizing the transformation of teaching content from traditional mechanical performance testing to the interdisciplinary integration of material science digital intelligent technology engineering operation and maintenance. Through the stepped design of consolidating core foundations in the basic cognition stage, building technical connections in the digital intelligence integration stage, and connecting with engineering scenarios in the operation and maintenance practice stage, combined with the update of more than 80% of the curriculum content and the integration of cutting-edge technologies such as intelligent materials, IoT sensors, and AI algorithms, the defects of insufficient pertinence and lack of cutting-edge in traditional courses are effectively made up, laying a curriculum foundation for cross-field competence cultivation.

(2) A three-level open scenario-based experimental project system of basic verification comprehensive application innovative inquiry is designed. Combined with the three-dimensional open mechanism of time content resource and typical engineering scenarios of urban renewal (such as operation and maintenance of old bridges and diagnosis of tunnel diseases), the limitation of cramming-style teaching is broken. By independently designing experimental schemes, operating digital intelligent platforms, and solving real engineering problems, students realize the capability leap from data acquisition to model construction and then to operation and maintenance decision-making, addressing the problems of disconnection between learning and application and insufficient cultivation of digital intelligent capabilities.

(3) A scenario-based industry-university-research-application collaborative mechanism deeply bound to university-enterprise is established. Through the closed-loop design of co-construction of projects, co-training of teachers, and sharing of achievements, enterprise actual operation and maintenance projects and engineering technical difficulties are deeply integrated into the teaching process, replacing the traditional shallow and short-term collaborative mode. This mechanism not only provides real scenarios and advanced equipment support for teaching but also realizes the transformation of scientific research achievements into teaching content and the accurate connection of students' practical capabilities with industry needs, providing long-term support for interdisciplinary talent training.

(4) A multi-dimensional dynamic evaluation system integrating process result, competence

literacy, and individual team is constructed. Through the closed-loop operation of real-time process data collection, phased feedback, and summative comprehensive evaluation, the traditional single and summative evaluation mode is replaced. This system not only fully covers the core dimensions of students' experimental operation, digital intelligent capabilities, and engineering literacy but also realizes the teaching optimization cycle of evaluation feedback improvement, providing a scientific basis for improving teaching quality and cultivating personalized talents.

The theoretical value of this research lies in establishing an interdisciplinary experimental teaching framework of civil engineering materials, enriching the theoretical system of experimental teaching reform under the background of emerging engineering education; the practical value lies in effectively improving students' cross-field practical capabilities in materials digital intelligence operation and maintenance" through the systematic innovation of four modules: curriculum, experiment, collaboration, and evaluation, transporting high-quality interdisciplinary talents for the field of digital and intelligent operation and maintenance of infrastructure under urban renewal, and supporting industry transformation and national strategy implementation. Future research can further expand the experimental coverage of urban renewal scenarios, deepen the in-depth integration of digital intelligent technologies such as AI and BIM with experimental teaching, optimize the long-term operation mode of the industry-university-research-application collaborative mechanism, continuously improve the pertinence and effectiveness of teaching reform, and provide a more promotable practical paradigm for engineering education to adapt to the industry's digital transformation.

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