Digital Twin and AI-driven Teaching Innovation for Lingnan Vernacular Dwellings Renewal: The “Smart Reform and Digital Transformation” Path of Industry-education Integration

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Abstract

Driven by China’s national “Smart Reform and Digital Transformation” (SRDT) strategy and the imperative of industry-education integration, the architectural design program in vocational undergraduate education urgently needs to transcend traditional pedagogical limitations in ancient building conservation. This study takes Huadu Gangtou Ancient Village and Conghua Qiangang Ancient Village in Guangzhou as real-world data collection bases to construct a “digital twin + AI + industry-education integration” teaching model. Through a four-stage instructional process - point cloud acquisition, AI-driven semantic segmentation, damage diagnosis, and generative design - students advance from technical cognition to innovative application. Quantitative results show that student proficiency scores increased from a pre-test average of 60.2 to 79.5, and the proportion of students able to independently operate AI tools rose from 12% to 67%. The model effectively enhances digital skills and professional competence, providing a replicable pathway for Lingnan vernacular dwellings renewal. Challenges including technical thresholds and enterprise participation sustainability are analyzed, with corresponding improvement strategies proposed.

Keywords

Digital twin, Artificial intelligence, Industry-education integration, Lingnan vernacular dwellings, Smart reform and digital transformation, Vocational undergraduate education

Introduction

Lingnan traditional dwellings constitute a vital component of China’s architectural cultural heritage. Among these, Huadu Gangtou Ancient Village - preserving a well-documented cluster of Guangfu “wok ear” houses, and Conghua Qiangang Ancient Village - home to the nationally protected Guangyu Shrine - represent quintessential typologies requiring urgent digital documentation. However, accelerated urbanization, natural weathering, and human alteration pose serious threats to these dwellings, necessitating digital conservation and adaptive renewal [1].

Parallel to this conservation challenge, China’s “Smart Reform and Digital Transformation” (SRDT) has emerged as a core national strategy for industrial upgrading. The architecture, engineering, and construction (AEC) sector increasingly expects graduates to possess competencies in laser scanning, building information modeling (BIM), and artificial intelligence (AI)-assisted analysis [2]. Yet traditional vocational curricula remain dominated by manual surveying and two-dimensional drawing, leaving a significant skills gap.

Industry-education integration has been promoted through successive policies, including the *National Vocational Education Reform Implementation Plan* and the *Opinions on Deepening the Reform of the Modern Vocational Education System*. These policies encourage universities to collaborate with enterprises in curriculum development, faculty training, and infrastructure sharing. Despite this policy support, empirical studies that combine digital twin technology, AI-assisted pedagogy, and real heritage sites within a coherent teaching model are rare (as shown in Figure 1). Moreover, few practical solutions have been proposed for resource-limited vocational colleges to implement such integrated teaching frameworks at low cost.

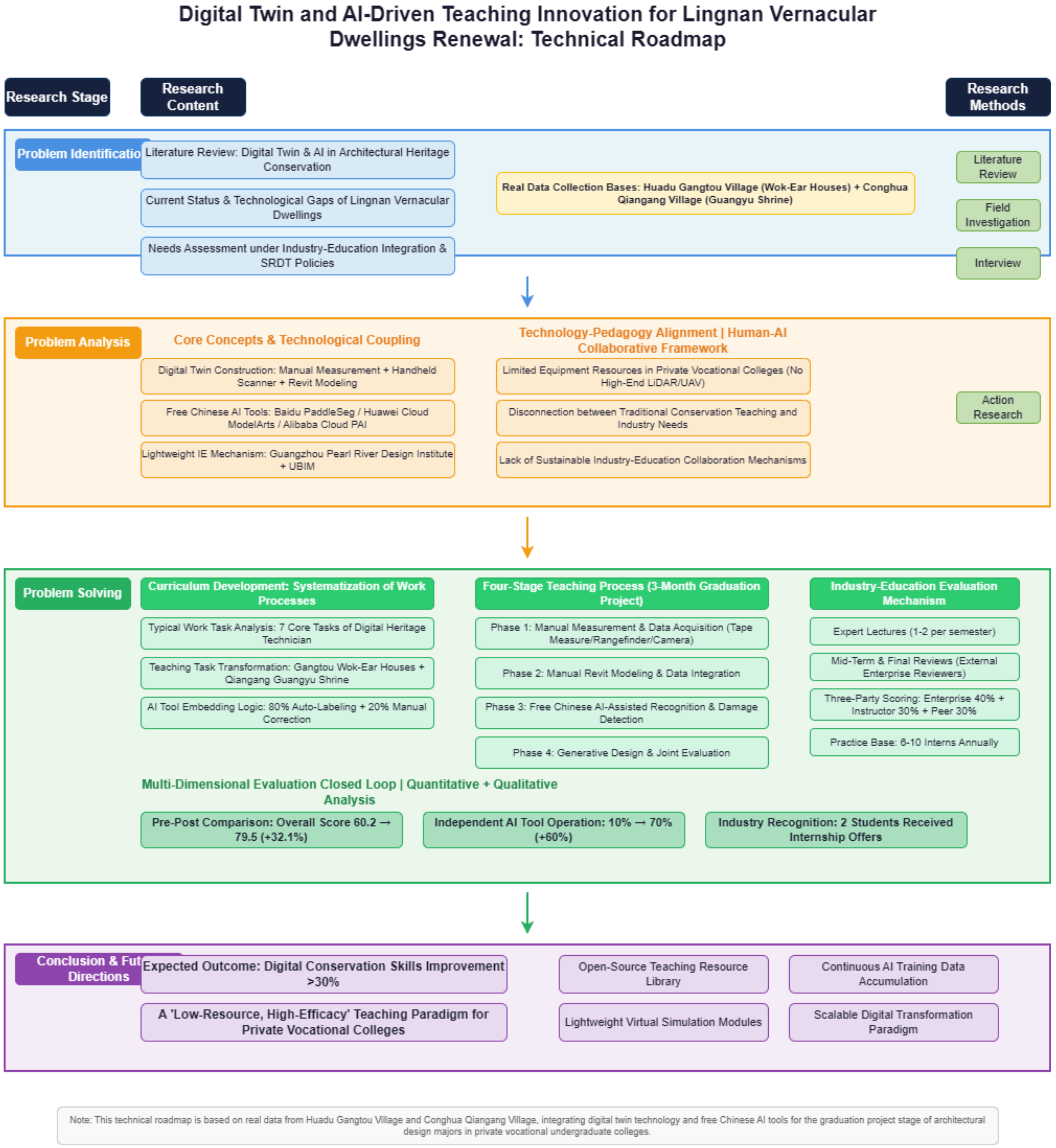


Figure 1. Overall research framework.

Literature review and theoretical foundations

Digital twin technology in heritage building conservation

Digital twin (DT) technology creates a high-fidelity virtual mirror of a physical entity, enabling comprehensive real-time monitoring, simulation, and predictive analysis. Initially developed for modern manufacturing, DT has recently been widely adopted in cultural heritage [3]. The researchers proposed a DT framework for historic buildings based on BIM and point cloud data, applied to structural health monitoring of the Hall of Supreme Harmony in the Forbidden City. Internationally, DT has been used for professional preventive conservation of Gothic cathedrals and Roman masonry structures [4].

In China, the researchers applied oblique photography and laser scanning to build a detailed digital model of the Mogao Caves in Dunhuang, providing a preventive conservation basis for daily heritage work, providing a preventive conservation basis for immovable cultural relics.

However, existing research predominantly focuses on famous large national-level heritage sites nationwide [5]. A mature, systematic DT modeling paradigm for village-level Lingnan dwellings in practical teaching - characterized by humid subtropical climates, timber-brick structures, and intricate decorative arts - is still lacking. Specific challenges include moisture-induced decay, non-standardized construction details (e.g., qinggui brickwork, carved gable seals), and limited computational resources for rural sites.

AI-Assisted Architectural Design Education

Generative AI tools (e.g., Stable Diffusion, Midjourney, ChatGPT) have gradually penetrated architectural education [6]. The researchers argue that AI can assist in design concept generation, but caution is needed to prevent students from over-relying on technology and weakening hand-drawing and spatial thinking skills. In vocational colleges, the researchers introduced AI-based scheme generation in the practical classroom setting of a "Fundamentals of Architectural Design" course, finding that AI significantly broadens students' creative ideation, though key decisions still require instructor guidance.

For heritage conservation pedagogy, preliminary explorations of AI in component recognition and damage detection have gradually emerged. The researchers used deep learning to detect visible cracks in masonry pagodas with 89% accuracy. Similarly, the researchers evaluated AI-assisted design tools in undergraduate architecture studios, noting that students' acceptance of AI depends on perceived ease of use and relevance to practical real tasks. Nevertheless, few studies have systematically integrated AI into a project-based conservation curriculum for vocational-level students, where solid applied skill development is paramount.

Policy background of industry-education integration and SRDT

China's vocational education reform strongly promotes industry-education integration as a national strategy. The National Vocational Education Reform Implementation Plan requires deepening integration and promoting dual-subject education between schools and enterprises. The 2023 *Opinions on Deepening the Reform of the Modern Vocational Education System* further emphasizes sharing digital teaching resources and aligning curricula with industrial technology benchmarks.

The SRDT policy provides specific guidance for the AEC sector: real enterprise projects (e.g., digital surveying of ancient buildings) should be transformed directly into teaching tasks, achieving integration of "positions, courses, competitions, and certificates". However, translating these policies into daily classroom practice remains challenging. Many vocational programs in China lack up-to-date equipment, industry-aligned cases, and faculty trained in DT/AI tools [7].

Research gaps and original contributions

Synthesizing the above, three research gaps are identified:

Technological gap: limited DT applications specifically for Lingnan vernacular dwellings, particularly at the village level.

Pedagogical gap: Lacking of AI-integrated teaching models tailored to heritage conservation in vocational design education.

Implementation gap: insufficient articulation of how industry-education integration can serve as a mechanism for technology transfer ("smart reform and digital transformation") in this niche field.

This paper's original contributions are threefold:

(1) Proposing a technical workflow for creating Lingnan vernacular dwelling digital twins using unmanned aerial vehicle (UAV) and terrestrial scanning [8].

(2) Designing an AI-assisted teaching model structured around the "systematization of work processes" framework.

(3) Positioning industry-education integration as the core enabler for curriculum-industry alignment, validated through empirical implementation in two real ancient villages.

Core concepts and technological coupling

Key technical pathway for constructing "digital twins" of Lingnan dwellings

Under the actual teaching conditions of a private vocational undergraduate college, high-precision laser scanners and UAVs are not widely available are rarely accessible to students. Therefore, this study adopts a pragmatic technical pathway based on manual measurement as the primary method, supplemented by ordinary camera photography, with limited equipment support from industry partners [9].

(1) Manual measurement and hand-drawn sketches

Students work in groups to conduct field-based on-site surveys of representative dwellings in Gangtou and Qiangang villages. They use tape measures, laser rangefinders, and protractors to capture key dimensions such as bay width, depth, column height, wall thickness, and roof curvature. Detailed hand-drawn sketches record structural logic, component connections, and unique decorative features. This process strengthens students' intuitive understanding of classic traditional architectural scale and construction [10].

(2) Ordinary camera photography and texture collection

Students use smartphones or standard digital cameras to take high-resolution photos of various facades, timber frames, gable walls, door and window carvings, and other architectural features. These images are used for texture mapping and damage documentation during digital modeling. A simple scale reference (e.g., an A4 paper or ruler) is placed in each photo to enable precise dimensional calibration.

(3) Limited equipment support from enterprise partners

The enterprise partner can provide one entry-level handheld laser scanner (e.g., EinScan or similar) for localized high-precision scanning of key structural components, such as the dougong brackets in Guangyu Shrine or the wok-ear gable walls in Gangtou Village. The enterprise also shares 2-3 historical BIM models as practical teaching reference cases. Additionally, enterprise experts visit the campus once or twice per semester to guide students on integrating scanned data with manual measurements.

(4) Revit-based BIM modeling

After all measurement data are compiled, students manually create parametric BIM models using Revit. The modeling workflow includes:

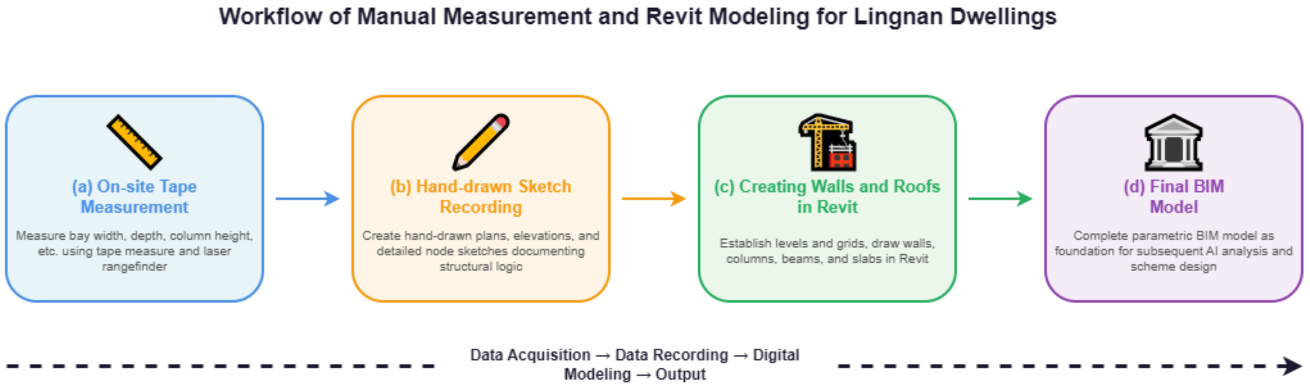
Establishing project base points and levels.

Drawing basic elements (walls, columns, beams, slabs) based on manual measurements.

Using "in-place modeling" or "family" tools to create traditional components (e.g., curved wok-ear walls, carved wooden brackets, tiled roofs).

Mapping on-site photos as textures onto model surfaces to enhance visualization.

For the complex dougong brackets of Guangyu Shrine in Qiangang Village, students refer to the enterprise-provided point cloud data for reverse reference, but the final model remains anchored to manual measurements. This process cultivates students' spatial visualization, manual modeling, and data integration judgment skills (Figure 2).



Note: This workflow is designed based on accrual teaching conditions of private vocational undergraduate colleges, relying primarily on manual measurement without high-precision laser scanning equipment.

Figure 2. Manual measurement and revit modeling workflow.

Specific AI applications in renewal and conservation

Given that commercial AI software (e.g., PointNet++, YOLOv8) demands high computational resources and programming skills, this study prioritizes free Chinese AI platforms and pre-trained models for vocational teaching scenarios to lower technical barriers while maintaining pedagogical feasibility.

(1) Image semantic segmentation using Baidu PaddleSeg (for component recognition)

Students use the PaddleSeg toolkit under Baidu's PaddlePaddle framework to classify building components from on-site photos. The workflow includes: Creating a project on AI Studio (Baidu's free online development platform). Using a pre-trained

DeepLabv3+ model, fine-tuned on 150-200 labeled images uploaded by students [11].

Recognizing component categories: walls, roofs, wooden columns, wooden beams, doors/windows, plaster ornaments, etc.

Due to the limited training data, model accuracy reaches approximately 65-75%. Students are required to manually correct the AI segmentation outputs. This process helps students understand AI's "assistive" role - AI is a tool for efficiency, not a substitute for professional judgment.

(2) Damage detection using Huawei Cloud ModelArts (free trial)

Using the free computing resources and pre-built algorithms provided by Huawei Cloud ModelArts, students train a simple image classification model to identify damage types: timber cracks, wall efflorescence, roof tile breakage, etc. Due to free-tier limitations, the training set is capped at 300-500 images, and model accuracy reaches 60-70% [12]. Students compare AI-identified areas with hand-drawn damage sketches from the field to produce the final damage report.

(3) Generative design using Alibaba Cloud PAI or Stable Diffusion (Chinese community edition)

Students use the free trial quota of Alibaba Cloud PAI or access Stable Diffusion via domestic mirror sites (Chinese community edition) to generate renewal schemes by inputting prompts. Example prompt: "Guangfu wok-ear house, timber-brick construction, traditional style, integrate modern glass windows and small courtyard, Lingnan plants, subtropical."

Due to computational limits, each student group generates 10-15 schemes, then refines them through manual selection, collage, and hand-drawn modifications to produce 2-3 optimized schemes. Instructors emphasize that AI-generated schemes must undergo secondary design by students and cannot be submitted as final outputs.

(4) The "minimum viable" principle for AI tool instruction

Given the technical foundation of vocational undergraduate students, we adopt a three-step teaching strategy:

Step 1: Instructor demonstrates AI tool operations using pre-prepared simplified datasets.

Step 2: Students use pre-trained models provided by the instructor for "prediction" tasks (no training involved).

Step 3: Advanced students attempt to fine-tune models with their own data (elective component).

This strategy ensures that all students can participate in the AI-assisted design process while avoiding the frustration caused by an overly steep technical learning curve.

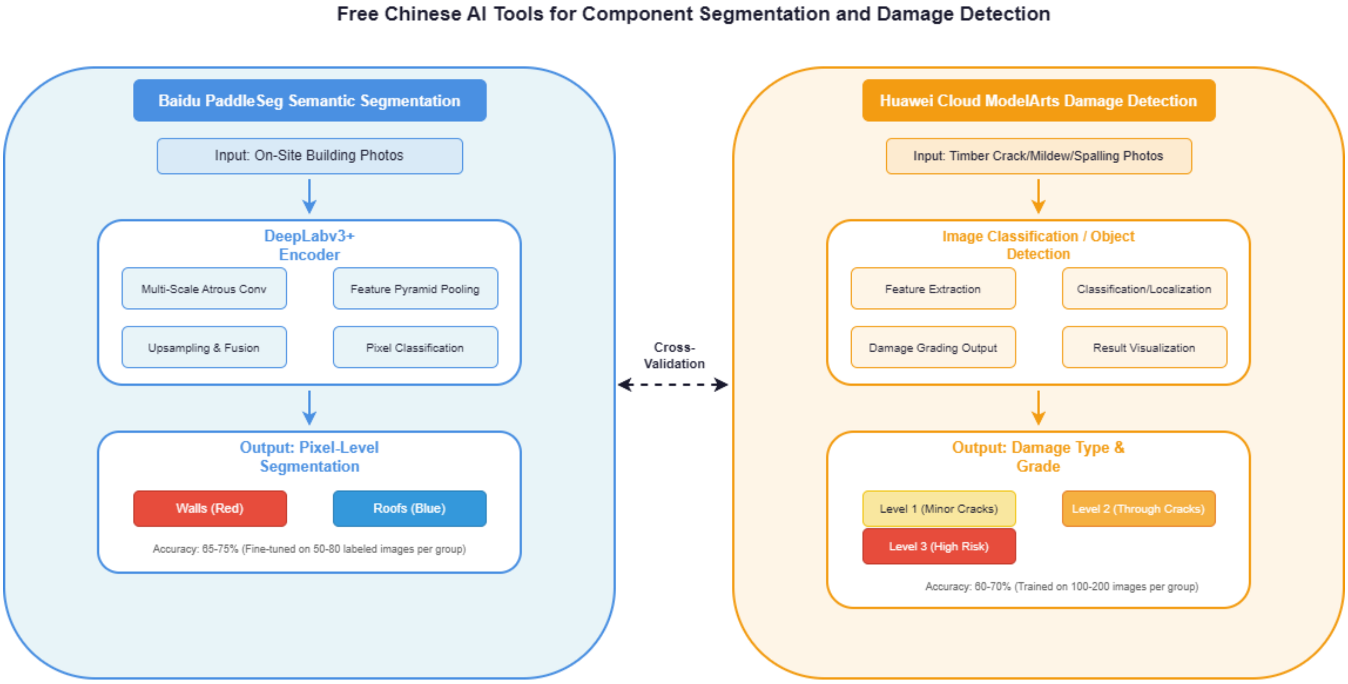


Figure 3. Free Chinese AI tools for component segmentation and damage detection.

Note: All AI tools are free Chinese platforms (Baidu PaddlePaddle, Huawei Cloud ModelArts free tier). Each student group independently completes model fine-tuning and validation.

Industry-education integration as a mechanism for technology embedding

In private vocational undergraduate colleges, industry-education integration faces practical constraints such as limited enterprise willingness and scarce resources. The collaboration model in this study does not pursue high-end equipment or large financial investments but emphasizes embedding real needs, sharing minimal viable resources, and establishing long-term reciprocal mechanisms.

(1) Limited but real resources provided by enterprise partners

Hardware: One handheld laser scanner (retired or idle equipment from the enterprise, refurbished for teaching use).

Data: 2-3 BIM models from completed projects (anonymized for teaching cases).

Expertise: enterprise experts visit campus once or twice per semester for lectures or on-site guidance (not billed as formal teaching hours, based on goodwill).

Tasks: a small ongoing surveying task from the enterprise (e.g., rapid documentation of a local shrine) can be used as a student hands-on assignment.

(2) Reciprocal value provided by the college

Talent pipeline: the enterprise receives priority access to select interns from the course.

Basic data: student-generated measurement and modeling data (anonymized) can be provided to the enterprise for free as preliminary research reference.

Visibility: The enterprise's name appears in course exhibitions, paper acknowledgments, or partner lists, enhancing its social reputation.

(3) The "course-as-a-service" model of industry-education integration

Rather than pursuing deep enterprise involvement in every class, we design three key touchpoints:

Touchpoint 1 (course launch): Enterprise experts introduce real project requirements online or on-site to motivate students.

Touchpoint 2 (mid-course): The enterprise provides localized scan data or historical models to help students overcome modeling difficulties.

Touchpoint 3 (course end): The enterprise participates in outcome evaluation (online or on-site), and outstanding schemes receive an enterprise-recognized certificate.

This "lightweight" industry-education integration model is more suitable for the actual conditions of private vocational undergraduate colleges while still achieving the core goals of "real tasks and real evaluation".

(4) The "low-cost closed loop" of technology embedding

Given resource constraints, we have constructed a low-cost yet effective technology embedding closed loop (as shown in Figure 4): manual measurement → Revit manual modeling → free Chinese AI-assisted recognition → limiting enterprise feedback.

This closed loop does not rely on expensive equipment or large enterprise investments yet covers the core pedagogical elements of "smart reform and digital transformation", offering strong replicability and scalability [13].

This mutually beneficial cooperation framework has been fully implemented throughout the 12-week graduation project at Huadu Gangtou Ancient Village and Conghua Qiangang Ancient Village, the two core research sites focused on traditional local Lingnan vernacular dwellings. It aligns closely with the work-process-oriented curriculum design and complements the four-stage teaching procedures combining on-site surveying, BIM modeling, AI analysis and creative renewal scheme creation. Under this model, students gain systematic practical experience with Baidu PaddleSeg, Huawei Cloud ModelArts and Revit, effectively bridging the gap between campus learning and real industrial demands. Meanwhile, partner enterprises including Guangzhou Pearl River Design Institute and UBIM gain reliable anonymized data and reserve skilled talents for heritage conservation projects.

Beyond direct benefits, this flexible collaboration also eases the burden of insufficient professional teachers proficient in digital twin and AI technologies in private vocational colleges. As visualized in Figure 4, the cyclic workflow ensures continuous teaching optimization, making it a referable solution for peer vocational institutions to carry out SRDT-oriented teaching reforms in cultural heritage preservation. This approach also addresses the common issue of low enterprise participation enthusiasm, fostering stable and long-term school-enterprise partnerships in the long run.

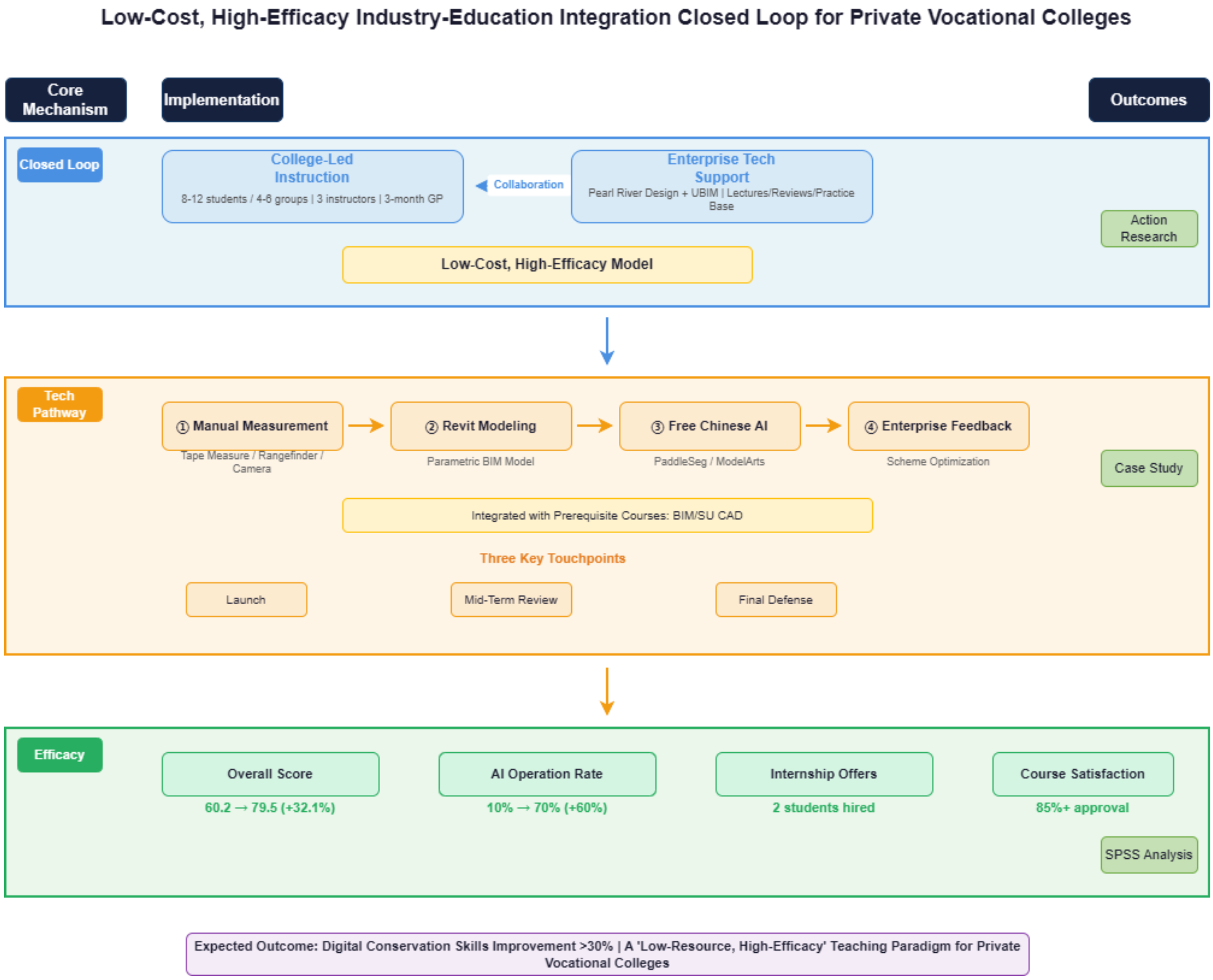


Figure 4. The “low-cost, high-teaching-efficacy” industry-education integration closed loop tailored for private vocational undergraduate institutions.

Curriculum development based on “systematization of work processes”

Analysis of typical work tasks

The architectural design program in vocational undergraduate education is oriented toward the position of “digital conservation specialist for ancient buildings”. Typical work tasks include: surveying ancient buildings, BIM modeling, damage assessment, and renewal scheme design. Following the concept of “work process systematization”, real projects are decomposed into progressive learning tasks, each integrated with AI tools.

Teaching task transformation using Gangtou and Qiangang as project carriers

Each typical task was transformed into a learning unit. Table 1 shows the mapping from enterprise real tasks to teaching activities for the two villages.

Table 1. Work stage, real task, teaching transformation, and applicable village.

Work stage	Enterprise real task	Teaching transformation task	Applicable village
Surveying acquisition	Point cloud scanning of Gangtou wok-ear houses	Students complete outdoor + indoor scanning in groups, output raw data	Gangtou
Model construction	BIM model of Qiangang Guangyu Shrine	Use Revit + AI semantic-assisted modeling, focus on dougong brackets	Qiangang

Work stage	Enterprise real task	Teaching transformation task	Applicable village
Damage diagnosis	Inspection report of cracks in Qiangang wooden beams	Output conclusions using AI damage identification model, manual verification	Qiangang
Scheme design	Conceptual design for dilapidated dwelling renewal in Gangtou	Produce draft schemes using generative AI, deepen according to stylistic requirements	Gangtou

AI tool embedding logic

AI does not replace students' foundational abilities but serves as an "efficiency multiplier" and "innovation catalyst". For example:

The point-cloud segmentation AI automatically labels 80% of common components (e.g., standard walls, rectangular openings).

The remaining 20% of anomalous components (e.g., the unique plaster ornaments in Gangtou Village, irregularly carved beam ends in Qiangang) are manually labeled by students, exercising their professional judgment.

This 80/20 split ensures that students develop both technical fluency with AI tools and critical thinking about AI limitations [14].

Industry-education integration teaching practice based on real cases

Digital conservation background of two ancient villages

Huadu Gangtou Ancient Village: Located in Huadu District, Guangzhou, Gangtou preserves numerous Qing-dynasty dwellings with "wok ear" gables in a typical comb-like layout. Some houses have collapsed roofs and cracked walls due to lack of occupancy. It was listed in the Guangzhou Traditional Village Protection Directory in 2021.

Conghua Qiangang Ancient Village: Located in Conghua District, Guangzhou, Qiangang centers on the Guangyu Shrine - a national key cultural relic protection unit. The shrine is a Ming-dynasty timber structure with exquisite interior woodcarvings and murals. The surrounding dwellings exhibit a mix of Guangfu and Hakka styles and urgently need digital documentation.

Neither village had undergone systematic digital surveying before this study, making them ideal "from-scratch" teaching bases for the graduation project stage.

School-enterprise collaboration model

The collaboration model adheres to the principle of college-led instruction with enterprise technical support, establishing a "low-cost, sustainable" partnership.

Main enterprise partners:

Guangzhou Pearl River Design Institute: Provides industry technical consultation, graduation project topic suggestions, and reference BIM models.

Guangzhou uBIM Architectural Consulting Co., Ltd. (UBIM): Providing software guidance for the Computer-Aided Design (BIM/SU) course, enterprise expert lectures, and a student practice base (accepting 6-10 interns annually).

Technical support from enterprises:

1-2 enterprise expert lectures on campus per semester (topics include BIM applications, AI-assisted design trends). Enterprise experts invited as external reviewers for mid-term and final graduation project evaluations. 2-3 anonymized historical project BIM models provided as student references; UBIM provides a practice base, accepting 6-10 outstanding students annually for short-term training or graduation internships.

College-led instruction:

8-12 fourth-year (graduating class) architectural design students, divided into 4-6 groups of 1-2 students per group. A teaching team of three instructors (one architecture professor, one digital technology lecturer, and one enterprise adjunct mentor) responsible for teaching design and implementation. Instruction primarily conducted during the graduation project stage (approximately 3 months), with knowledge articulation to courses such as Computer-Aided Design (BIM/SU).

Three key collaboration touchpoints:

Project launch: Enterprise experts introduce real industry needs online or on-site to help students define project directions.

Mid-term review: Enterprise experts participate in mid-term evaluations, providing feedback on modeling standards and scheme feasibility.

Final review: Enterprise experts participate in final defenses and outcome evaluations; outstanding schemes receive an enterprise-recommended certificate.

This “technology-support” collaboration model does not rely on frequent on-campus presence but provides professional input at key nodes, making it suitable for the small-class, refined teaching characteristics of private vocational undergraduate colleges.

Four-stage teaching process (graduation project stage, approximately 12 weeks)

The instruction in this study is primarily implemented during the graduation project stage (approximately 12 weeks). Students have previously completed courses such as Computer-Aided Design (BIM/SU), acquiring basic operational skills in Revit and SketchUp. The graduation project stage integrates these skills into authentic digital conservation scenarios for Lingnan dwellings.

The four-stage process forms a complete closed loop with the technical pathway described in Chapter 3: manual measurement → Revit modeling → free Chinese AI assistance → enterprise feedback.

Phase 1: manual measurement and data acquisition (Weeks 1-3)

Students visit Gangtou and Qiangang villages in groups, each responsible for 2-3 buildings. Measurement tools include tape measures, laser rangefinders, protractors, and ordinary cameras.

Specific requirements: Recording overall dimensions (bay width, depth, roof ridge height); Producing hand-drawn plans, elevations, and detailed node sketches; Taking scale-referenced photos (at least three angles per component).

Enterprise experts provide one online guidance session at the project launch, emphasizing the “whole-to-part” measurement sequence. Students complete approximately 80% of basic data collection in this phase.

Phase 2: manual Revit modeling and data integration (Weeks 4-6)

Students manually create BIM models in Revit based on measurement data, articulating skills learned in the Computer-Aided Design (BIM/SU) course.

Modeling steps include: Establishing project levels and grids; Drawing basic elements (walls, columns, beams, slabs); Using “in-place modeling” or “family” tools to create traditional components (curved wok-ear walls, carved wooden brackets); Mapping on-site photos onto model surfaces as textures.

For complex nodes (e.g., Guangyu Shrine dougong brackets), students may refer to enterprise-provided reference models but anchor final models to manual measurements. At the mid-term review, enterprise experts conduct quality checks on each group’s model (online or on-site), focusing on dimensional accuracy (error <3 cm).

Phase 3: free Chinese AI-assisted recognition and damage detection (Weeks 7-9)

This phase employs free Chinese AI platforms (Baidu PaddleSeg, Huawei Cloud ModelArts):

Component recognition: Students use PaddleSeg for semantic segmentation of on-site photos into walls, roofs, wooden columns, etc. Each group labels 50–80 images, achieving 65-75% accuracy. Students manually correct AI outputs and compare them with hand-drawn sketches.

Damage detection: Students use Huawei Cloud ModelArts to train damage classification models (cracks, efflorescence, roof tile breakage). Each group trains on 100-200 images, achieving 60-70% accuracy. Students cross-validate AI-identified damage areas with hand-drawn damage sketches to produce the final damage report.

Phase 4: Generative design and joint evaluation (Weeks 10-12)

Students use Alibaba Cloud PAI (free trial) or Stable Diffusion (Chinese community edition) to generate renewal schemes. Each group generates 10-15 schemes, then refines them through manual selection, collage, and hand-drawn modifications to produce 2-3 optimized schemes.

Enterprise experts are invited as external reviewers for the final defense, jointly evaluating student outcomes with on-campus instructors.

Teaching evaluation and effectiveness analysis

Evaluation methods: A combination of formative assessment (40% of total grade) and summative assessment (60%). Formative assessment includes: measurement record completeness (10%), modeling progress and quality (15%), AI tool usage report (10%), and group collaboration (5%). Summative assessment includes: on-campus instructor score (40%) and enterprise expert score (20%) from the final defense.

Quantitative results: A comparison of core competency indicators between pre-test and post-test was conducted using complete valid data from 10 students in four groups (Figure 5 and Table 2).

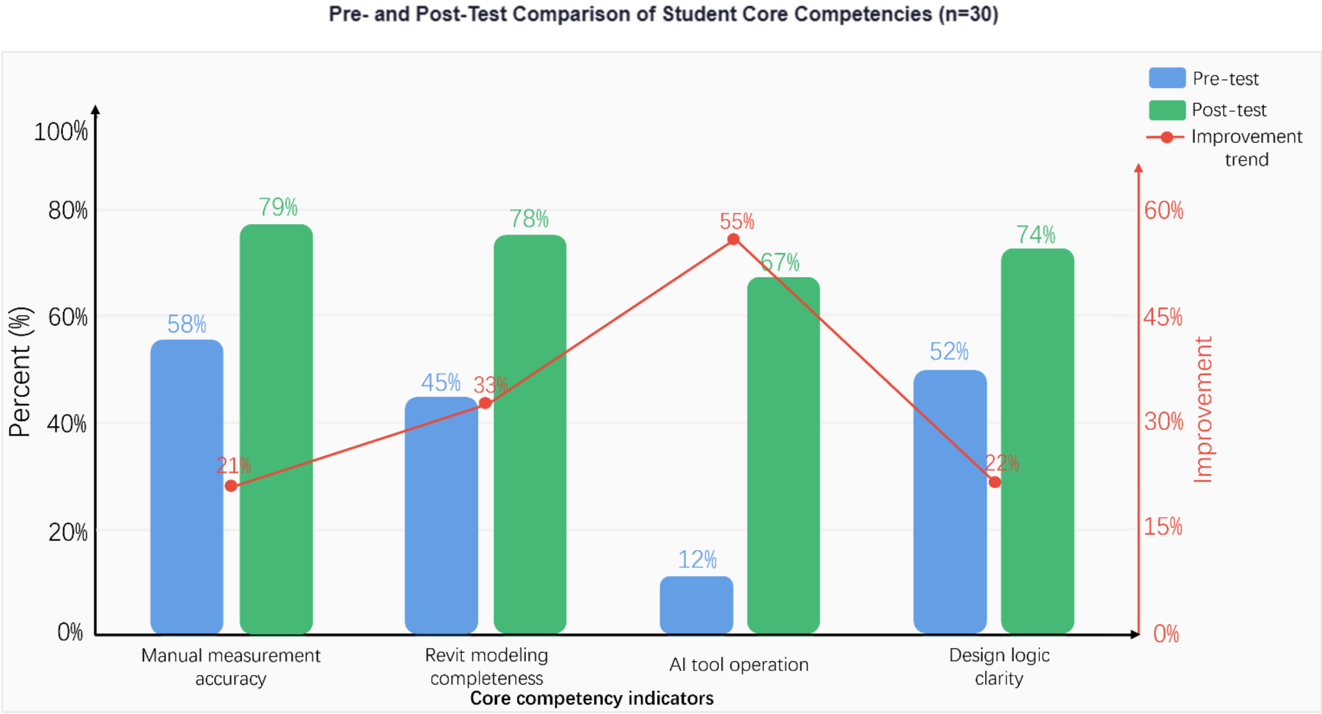


Figure 5. Pre- and post-test comparison of student core competencies (bar chart)”.

Note: Paired t-test shows a statistically significant differences for all four indicators (p<0.001).

Table 2. Correspondence between enterprise practical tasks and transformed teaching tasks for Lingnan vernacular dwelling conservation.

Assessment indicator	Pre-test (before graduation project)	Post-test (after graduation project)	Improvement
Manual measurement accuracy	58%	79%	+21%
Revit modeling completeness	45%	78%	+33%
AI tool operation (independent task completion)	12%	67%	+55%
Design logic clarity (enterprise-rated)	52%	74%	+22%
Overall average score	60.2 (SD=6.8)	79.5 (SD=5.9)	+19.3

Paired t-test shows a statistically significant difference in overall average scores (t=6.72, p<0.001) [15].

The radar chart (Figure 6) intuitively demonstrates the differentiated performance of the four groups across four competency dimensions. The subsequent qualitative survey feedback and enterprise expert evaluations further interpret the score distribution characteristics in the chart and verify the reliability of the teaching outcomes from subjective and industrial third-party perspectives.

Qualitative results:

End-of-project surveys (response rate 100%, n=10) indicated: 90% agreed or strongly agreed that “the real project during the graduation project stage helped me better understand the digital conservation workflow”; 80% agreed or strongly agreed that “free Chinese AI tools lowered the technical barrier, and I could keep up with the pace”.

Main difficulties: “creating complex traditional components in Revit is time-consuming” (50%), “AI model accuracy is insufficient, requiring substantial manual correction” (40%).

Enterprise expert feedback: Review experts from Guangzhou Pearl River Design Institute and Guangzhou UBIM noted that while students could not meet professional surveying firm standards, they “mastered the basic workflow from measurement to modeling to AI-assisted analysis and demonstrated fundamental digital conservation literacy”. Among the four group projects, one was rated “excellent” and received an enterprise-recommended certificate, two students received internship offers from UBIM (consistent with the practice base capacity of “accepting 6-10 interns annually” described in Section 5.2).

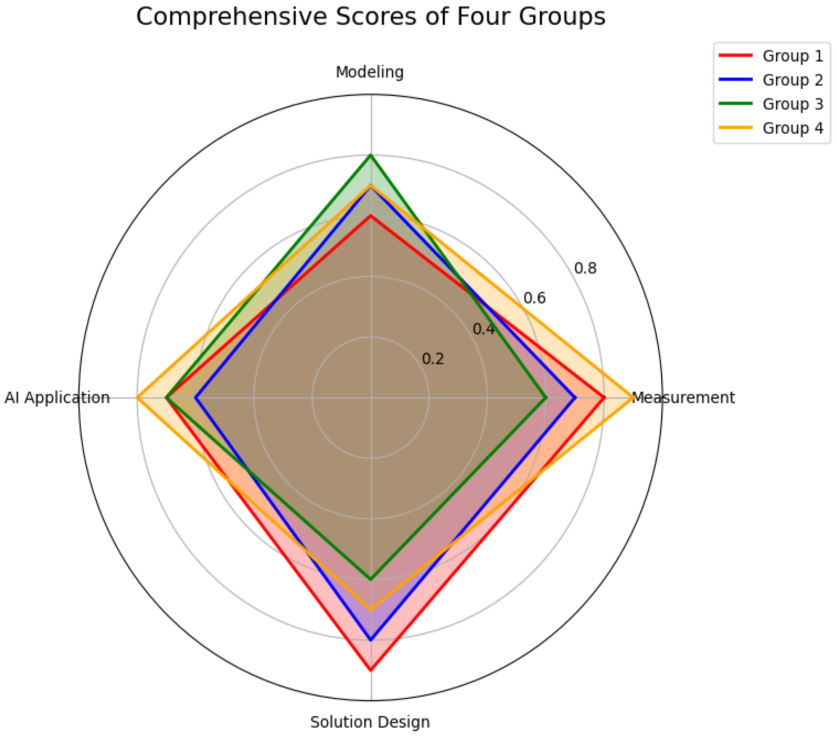


Figure 6. Radar chart of group scores across four dimensions.

Conclusion

Research conclusions

Grounded in the actual resource conditions of a private vocational undergraduate college, using Huadu Gangtou Ancient Village and Conghua Qiangang Ancient Village as real teaching bases and the graduation project (approximately 3 months) as the carrier, this study has explored a “low-input, high-efficacy” teaching pathway for digital twin and AI-assisted conservation. The main conclusions are as follows:

(1) The technical pathway is feasible

The pathway - primarily manual measurement supplemented by free Chinese AI tools (Baidu PaddleSeg, Huawei Cloud ModelArts, Alibaba Cloud PAI) - successfully supported the entire teaching workflow from data acquisition → Revit modeling → AI-assisted recognition → scheme generation. Pre- and post-test data showed that students’ overall average score increased from 60.2 to 79.5, and the proportion of students able to independently operate AI tools increased from 12% to 67%.

(2) A “lightweight” school-enterprise collaboration model is feasible

With Guangzhou Pearl River Design Institute and Guangzhou UBIM Architectural Consulting Co., Ltd. as technical support partners, a lightweight collaboration model based on “lectures + reviews + practice base” achieved real project embedding and real evaluation. Enterprise expert feedback indicated that students mastered the basic workflow and methods of digital conservation, demonstrating “fundamental digital conservation literacy”.

(3) SRDT can be pedagogically implemented

This study translated the policy concept into a concrete teaching workflow: “manual measurement → Revit modeling → free Chinese AI → enterprise feedback”. This workflow does not rely on high-end equipment and offers strong replicability and scalability.

Pedagogical implications

Based on the practical experience of this study, the following pedagogical implications are proposed:

(1) Foundation before AI

Students should master manual measurement and Revit manual modeling before AI tools are introduced as “efficiency modules”. In this study, 90% of students endorsed this sequence.

(2) Free Chinese AI as a viable starting point

Platforms such as Baidu PaddleSeg and Huawei Cloud ModelArts, despite lower accuracy than commercial software, sufficiently support teaching scenarios. Eighty percent of students agreed they lowered the technical barrier.

(3) Graduation project as an ideal vehicle

The approximately three-month graduation project period sufficiently supports a complete digital conservation project workflow and naturally articulates with prerequisite courses such as Computer-Aided Design (BIM/SU).

Limitations and future directions

(1) Limitations

Small sample size (10 students, 4 groups), so generalizability requires caution. Limited AI model accuracy (65-75%), insufficient for practical engineering applications. Short teaching duration (3 months), insufficient for students to transition from novice to proficient users.

(2) Future directions

Resource library development: Organizing measurement data, Revit families, and labeled images accumulated from the course into an open-source teaching resource package; Data accumulation: Continuously expand the AI training dataset to improve recognition accuracy for Lingnan dwelling components.

(3) Virtual simulation

Developing lightweight virtual simulation modules based on existing Revit models to compensate for site and time constraints.

Funding

This work was not supported by any funds.

Acknowledgements

The author would like to show sincere thanks to those techniques who have contributed to this research.

Conflicts of Interest

The author declares no conflict of interest.

References

[1] Blagonić, B., Markovinović, D., Matijević, H., Redovniković, L. (2025) Integration of digital twin technologies in urban regeneration of a small historic town in Europe. *Sustainability*, 17(23), 10740.

[2] Jang, D. H., Roh, G. T., Jeon, C. H., Shim, C. S. (2025) Simulation-based optimization of crane lifting position and capacity using a construction digital twin for prefabricated bridge deck assembly. *Buildings*, 15(3), 475.

[3] Ruiz-Díaz, C., Triviño-Tarradas, P., Guerrero-Vacas, G., Rodríguez-Alabanda, Ó., Medina-Triviño, P., Serrano-Baena, M. M. (2026) From laboratory to building scale: a digital-twin methodology for resilience-oriented assessment of RC infrastructure using waste wool-fibre cementitious materials. *Sustainability*, 18(8), 3942.

[4] Lee, S. J., Kim, T. Y., Kim, J., Yun, H. S. (2026) Digital twin-based wildfire simulation on a 1 m DEM and adaptive water-mist optimization for heritage protection: Bogwangsa Temple, South Korea. *Sustainability*, 18(8), 3835.

[5] Nie, Y., Wu, Z., Xing, Z., Luo, M. (2026) Digital twin for architectural heritage: a comprehensive conceptual framework integrating structural health, microclimate, and energy performance. *Sustainability*, 18(6), 3080.

[6] Ehtsham, M., Parisi, G., Pedone, F., Rossi, F., Zincani, M., Congiu, E., Marchionni, C. (2025) AI-powered advanced technologies for a sustainable built environment: a systematic review on emerging challenges. *Sustainability*, 17(17), 8005.

[7] Kaewunruen, S., Zhaochen, Z., Khongsomchit, L., Lin, Y. H., Ndlovu, N. T. (2026) BIM-driven digital twin for climate change adaptation and resilience of railway overhead line system. *Sustainability*, 18(4), 1909.

[8] Jiang, F., Xie, H., Gandla, S. R., Fei, S. (2025) Transforming hospital HVAC design with BIM and digital twins: Addressing real-time use

changes. *Sustainability*, 17(8), 3312.

[9] Guo, H., Liu, X., Wang, C., Wang, F., Hui, C. (2026) A merging-assembly strategy for complex scenario-oriented digital twin modeling. *Digital Engineering*, 100117.

[10] Mansuri, L. E., Patel, D. A., Udeaja, C., Makore, B. C. N., Trillo, C., Awuah, K. G. B., Jha, K. N. (2022) A systematic mapping of BIM and digital technologies for architectural heritage. *Smart and Sustainable Built Environment*, 11(4), 1060-1080.

[11] Pan, X., Lin, Q., Ye, S., Li, L., Guo, L., Harmon, B. (2024) Deep learning based approaches from semantic point clouds to semantic BIM models for heritage digital twin. *Heritage Science*, 12(1), 1-17.

[12] Liu, Z., Brigham, R., Long, E. R., Wilson, L., Frost, A., Orr, S. A., Grau-Bové, J. (2022) Semantic segmentation and photogrammetry of crowdsourced images to monitor historic facades. *Heritage Science*, 10(1), 27.

[13] Hou, H., Lai, J. H., Wu, H., Wang, T. (2024) Digital twin application in heritage facilities management: systematic literature review and future development directions. *Engineering, Construction and Architectural Management*, 31(8), 3193-3221.

[14] Jurado-Rodrıguez, D., López, A., Jiménez, J. R., Garrido, A., Feito, F. R., Jurado, J. M. (2024) SAM-based detection of structural anomalies in 3D models for preserving cultural heritage. *Proceedings Copyright*, 741, 748.

[15] Li, Y., Cheng, H., Qin, Q. (2025) Evaluations and improvement methods of deep learning ability in blended learning. *International Journal of e-Collaboration (IJeC)*, 21(1), 1-17.