Article

The Effectiveness of a Digital Twin Learning System in Assisting Engineering Education Courses: A Case of Landscape Architecture

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Abstract: In conventional engineering education, issues such as the discrepancy between virtual and real environments, rigid practical operations, lack of reflective support, and a disconnect between online and offline learning prevail. Digital twin technology, with its high fidelity and real-time interaction features, presents an innovative instructional aid for engineering education. This study developed a digital twin learning system to assist instructors in implementing project-based teaching models in landscaping technology courses. To assess the effectiveness of this system, a quasi-experiment was designed. Seventy students from a vocational high school majoring in landscaping technology in China were recruited as participants. These students were divided into two groups, each consisting of 35 students, with the same teaching pace. The experimental group utilized the system to supplement the instructor’s teaching of landscaping courses, while the control group received instruction through traditional methods. The experiment lasted for eight weeks, comprising a total of 16 classes. Ultimately, the results indicated that students in the experimental group significantly outperformed those in the control group in critical thinking, cognitive load, learning experience, and academic performance. Additionally, this research examined the acceptance of learners toward using the digital twin learning system and its influencing factors based on the Technology Acceptance Model, aiming to provide insights into enhancing engineering education courses teaching effectiveness and targeted technological development.

Keywords: digital twin; engineering education; digital pedagogy; project-based learning

1. Introduction

In the era of Industry 4.0, engineering education is experiencing a shift toward digitalization, with digital twin technology emerging as a crucial enabling tool [1]. This technology offers new perspectives for reforming innovative talent cultivation models. Human–machine collaboration and integration further promote the convergence of the physical and digital worlds in the future industrial sector, creating new trends and characteristics in the digital development of engineering education [2]. Currently, both China and developed countries are prioritizing digital education reform to help students adapt to digital environments and enhance core digital skills in engineering, thereby better preparing them for future challenges [3]. Digital twin technology has been widely applied in various fields, such as providing visualization management in industrial manufacturing workshops [4], supporting decision making in smart city management [5], and monitoring production processes in the construction industry [6]. Extensive research indicates that digital twins create realistic learning environments [7]; enhance interactivity and immediate feedback [8]; enable the synergy of virtual and real-world tasks [9]; and offer deep, data-driven insights [10]. These features significantly support the cultivation of engineering talents with practical skills and innovative capabilities. Researchers can leverage digital...
twin technology to enhance the skills-training process in engineering education, including applications in landscape architecture teaching.

Digital twin technology holds significant potential for landscape architecture education. One effective and straightforward method in landscape teaching is to create highly realistic design and construction scenarios in a virtual space, allowing students to operate within this environment and thus reducing the risks and costs associated with actual operations [11]. However, several challenges remain in the current practice of engineering education. These include the imbalance between virtual and real environments, leading to cognitive biases and reduced learning effectiveness [12]; the separation of virtual laboratories from practical sites, causing a disconnect in practical operations and inconsistent experiences [13]; existing learning systems failing to effectively support learners’ reflective abilities [14]; and the separation of online and offline environments, which diminishes learners’ interest [15]. These factors restrict students’ learning and skill development in educational settings. Digital twin technology can partially address these issues. As a transformative information technology, digital twin technology facilitates the interaction and integration of the physical and information worlds by leveraging new technologies such as 5G, AR/VR/XR, and the Internet of Things (IoT) [16]. This integration enables a multimodal and reciprocal relationship between real and virtual contexts, thereby achieving “virtual reflecting reality and controlling reality with virtuality” and providing data and decision-making support for transforming the physical world [8]. Consequently, the data collection, modeling analysis, and decision-making capabilities of digital twin technology are expected to yield positive outcomes when applied to landscape architecture education [17]. Current research on the application of digital twin technology in engineering education primarily uses literature reviews and case studies. These studies demonstrate how digital twin technology enhances teaching effectiveness and practical skills through specific engineering projects or teaching examples. For instance, Wahbeh et al. [18] conducted a case study in the construction industry, revealing that learners could interact with objects in the digital twin environment using wearable devices and immerse themselves in the learning environment as virtual avatars, thereby supporting ubiquitous, cross-regional, and real-time practical exploration. Onaji et al. [19], through a case study of a digital twin framework in smart manufacturing, found that learners could achieve consistent learning experiences and knowledge transfer between digital twin and physical learning environments, with learning behaviors in the digital twin being recorded and synchronized with their physical counterparts. However, these studies often focus on showcasing the potential and application scenarios of digital twin technology, lacking detailed descriptions of specific teaching models and the systematic evaluation of student learning outcomes during application. To address these gaps, this study employs empirical research methods, designing teaching models systematically and comprehensively assessing student learning outcomes to explore the application of digital twin technology in engineering education.

Meanwhile, engineering education generally adopts project-based learning (PBL) [20]. This teaching method encourages students to engage in group collaboration to solve complex and challenging problems from the real world or to complete tasks derived from real-world experiences that require deep thinking [21]. Through this process, students gradually acquire knowledge, develop transferable skills, cultivate thinking patterns, and gain practical abilities. Demir et al. [22] suggest that technology-supported PBL can significantly enhance students’ learning outcomes and engagement compared to traditional PBL methods. Morales et al. [23], through experimentation, confirmed that PBL integrated with virtual reality technology significantly improves students’ independent thinking and collaborative inquiry levels while also noticeably increasing teaching efficiency.

In summary, traditional engineering education faces several challenges that limit students’ learning and skill development, such as the imbalance between virtual and real environments, stagnant practical operations, lack of reflective support, and the disconnect between online and offline environments. Specifically, in the field of landscape architecture, there is an inability to fully simulate realistic design and construction environments, hin-
dering students from engaging in practical scenarios and project operations. This directly impacts learners’ educational outcomes and experiences. To address these issues, we developed a digital twin learning system to assist teachers in implementing a project-based teaching model in landscape architecture courses at a vocational high school in China. The system’s effectiveness was validated in terms of learning experience, motivation, innovative thinking, and critical thinking. Additionally, we examined students’ acceptance and the influencing factors of the digital twin learning system in similar engineering education courses. This research provides a solid foundation for the theoretical and practical application of digital twin technology in engineering education. It complements the practical application of digital twin technology in landscape architecture courses. This study aims to address the following three research questions:

- How is the digital twin learning system applied in project-based courses in landscape architecture?
- Can the digital twin learning system improve students’ academic performance, critical thinking, cognitive load, learning experience, and other variables?
- Do learners accept the digital twin learning system and influencing factors?

2. Literature Review

2.1. The Application of Digital Twin Technology in Education

The advent of the digital twin era has provided new directions for the transformation of educational methods [24]. Currently, digital twin technology is widely used in the field of engineering education, such as water conservancy engineering, smart city, smart agriculture, cultural heritage restoration, and mechanical manufacturing (refer to Figure 1). In terms of high realism, students can gain learning experiences and practical exploration consistent with physical learning environments through the synchronous operation of physical entities or digital twins in a digital twin learning environment [25]. This synchronous operation not only enhances students’ practical abilities but also deepens their understanding and application of knowledge [16]. However, current research mostly remains at the proof-of-concept and preliminary application stages, with the actual effects and broader promotion yet to be further validated [26]. In terms of strong interaction, students can use wearable devices to interact with objects in the digital twin space or engage in immersive exploration as virtual avatars in the digital twin learning environment [27]. This interaction mode provides significant support for ubiquitous, cross-regional learning activities and efficient group collaboration [28]. For example, students can perform simulated skill operations in the digital twin environment using virtual reality devices, thereby improving their practical skills [29]. Nevertheless, effectively integrating these technologies in practice to ensure students’ learning experiences and actual outcomes poses many challenges [30].

With the advancement of computer technology, the application of digital twin technology in education has gradually expanded. Current research primarily focuses on the construction of digital twin learning environments and teaching and learning support systems [31]. Using digital twin technology, various digital twin learning environments have been created, including digital twin intelligent learning spaces [32], digital twin platforms [33], and immersive architectural model twin environments [34]. The real-time interaction, symbiosis of virtual and real elements, and deep insights provided by digital twins offer learners an environment and resources that are observable, experiential, operable, verifiable, and developmental [15,35]. Furthermore, digital twin technology has enabled the development of cognitive digital twins [36], digital twin intelligent campuses [37], and digital-twin-assisted teaching systems [38]. These systems provide personalized learning strategies and teaching plans through real-time data analysis and feedback, demonstrating the potential of digital twin technology in enhancing teaching quality and efficiency [39]. For instance, a digital twin intelligent campus can monitor students’ learning behaviors and adjust teaching content and methods in real time to better meet students’ learning needs [32]. Although the theoretical exploration, technical development, and practical application of digital twin education have begun domestically and internationally, few
researchers have systematically summarized and analyzed the practical applications of digital twins [40]. Therefore, this study aims to design a teaching model for the application of digital twins to explore the effectiveness of digital twin learning systems in education. Through in-depth analysis and validation, it is expected to provide theoretical support and practical references for the widespread application of digital twin technology in education.

2.2. Digital Twin Technology in Landscape Architecture Technology Programs

2.2.1. Optimizing Synergy in Landscape Architecture

The application of digital twin technology is gradually reshaping teaching methods in landscape technology courses, providing new platforms and toolsets for plant landscape planning and design courses [41]. Traditional landscape design courses face numerous challenges, including inefficient communication, limited information sharing, difficulty in tracing and managing the design process, reliance on field surveys and craftsmanship, and constraints on interdisciplinary collaboration [42–44]. In contrast, integrating digital twin technology into landscape planning design courses can effectively promote multidimensional collaborative design [45]. Firstly, digital twin technology’s visualization and real-time assessment capabilities ensure that designers can update product design information in real time [46]. Although digital twin technology accelerates the design process and improves efficiency by sharing design files, models, and data in real time, its introduction may bring new challenges, such as reliance on technical tools, complexity in data processing, and requirements for team members’ technical proficiency [45]. Existing research highlights the advantages of digital twin technology in landscape planning, such as improved design quality and customer satisfaction. However, further exploration is needed to determine its effectiveness and applicability in practical applications [47]. For instance, Martinez-Gutierrez et al. [48] pointed out that digital twin technology can simulate design schemes more accurately and identify potential problems and risks promptly during project planning. Nevertheless, whether this technology is universally applicable to different types of landscape projects or adaptable to complex environmental conditions remains inadequately discussed. Lyu et al. [49] also emphasized that digital twin technology provides a more intuitive and interactive platform for design teams, enhancing collaboration and communication. However, the actual effectiveness and cost efficiency of this technology in various design scenarios require further investigation. Overall, digital twin technology shows immense potential in promoting sustainable landscape planning, reducing natural resource consumption, and protecting the ecological environment [50].
Therefore, this study not only needs to explore the application effects of digital twin technology in landscape architecture education but also consider its limitations in practical operations. Additionally, it should provide comprehensive theoretical support and practical references for future research.

2.2.2. Real-Time Monitoring of Plant-Growth Environment

Monitoring the growth environment of garden plants is crucial for ecosystem protection, biodiversity maintenance, and promoting sustainable ecological development [51]. Traditional methods of garden ecological monitoring typically rely on manual observation and periodic sampling, resulting in a low monitoring frequency and delayed data acquisition [52]. However, the advent of digital twin technology offers new solutions for garden ecological monitoring [53]. Digital-twin-based garden environment monitoring leverages advanced technologies such as sensing technology, network transmission technology, and artificial intelligence to map the real-world scenarios of plants and their growth environments into a virtual digital world [54]. By integrating multidimensional physical entity data and utilizing data mining, data analysis, and three-dimensional simulation technologies, it can present real-time environmental parameters, equipment status information, and plant-growth status [55]. This facilitates timely adjustments to environmental conditions, the control of equipment operation, and the regulation of plant-growth processes [56]. Furthermore, the application of digital twin technology involves not only real-time data monitoring but also the effective processing and analysis of sensor data [57]. For example, Wu et al. [11] demonstrated how digital twin technology could monitor temperature, humidity, and light intensity in a greenhouse environment, though their study faced errors in data processing that compromised its scientific validity. Ubina et al. [58] proposed an aquaculture-production control platform showcasing the application of digital twin technology in optimizing fish and plant resources. This platform monitored environmental indicators such as temperature, light, water flow, pH, and dissolved salts through sensor data, optimizing system resource management [59]. However, this technology was not applicable to complex environments. To comprehensively evaluate the practical effects of digital twin technology, future research should focus more on analyzing and experimenting with its economic feasibility, effectiveness, and adaptability in various garden environments.

2.2.3. Enhancing the Effectiveness of the Garden-Production Program

Optimizing garden-production schemes is crucial for improving product quality, reducing production costs, and enhancing competitiveness [60]. Traditional garden-production methods often rely on experience and manual operations, which result in issues such as process opacity and inefficient resource allocation [61]. The advent of digital twin technology introduces new methods and avenues for optimizing garden-production schemes [62]. By integrating advanced technologies such as big data analysis and artificial intelligence, digital twin technology enables the digitization and intelligent management of production processes [63]. Garden enterprises can create digital models of production processes for simulation analysis and optimization design. Design teams can use digital twin technology to simulate production processes, evaluate the effectiveness of different schemes, and optimize resource allocation to improve production efficiency [64]. Compared to traditional production methods, digital twin technology offers significant advantages including predictive capabilities, rapid response times, and cost effectiveness [65]. For example, Buonocore et al. [66] demonstrated the application of digital twin technology in tree planting, showing that it can improve tree survival rates, reduce costs, and enhance economic benefits. This innovative technology contributes to better orchard-production management, improving fruit quality and yield (refer to Figure 2). Moghadami et al. [67] developed the Ag Scan3D+ system, which uses 3D LiDAR and cameras to monitor each plant, thereby increasing production efficiency but also leading to high costs. Despite these advantages, the application of digital twin technology faces several challenges. First, the high costs of
technology and maintenance may deter some garden enterprises [68]. Second, the technical complexity of system deployment and operation requires specialized personnel, raising human resource demands [69]. Additionally, efficient data collection and analysis processes require robust network and computing resources [70]. Future optimization of garden-production schemes should focus on the interplay between cost, technical complexity, and efficiency [71]. When designing and applying digital twin technology, it is essential to balance technological investment with economic benefits to ensure its sustainability and widespread applicability. Through continuous optimization and innovation, digital twin technology holds promise for playing an increasingly important role in garden production, achieving higher production efficiency and product quality.

Figure 2. Application of digital twins in optimising landscape production solutions.

2.3. Integration of Project-Based Teaching and Digital Twin Technology

In recent years, project-based learning (PBL) has become an important direction for educational innovation, especially in the fields of engineering and technology education. Kilpatrick [72] defined project-based teaching as planned action occurring in a social environment, involving full-body and -mind engagement. Patzold (1985) summarized the three key points of project-based teaching in engineering education: centering around products with social application value, learners self-organize and manage, and integrating knowledge with skills. Comprehensive foreign theoretical research shows that project-based learning refers to learning from a typical occupational task as a case study, emphasizing the combination of theory and practice and leveraging student initiative. Students internalize theoretical knowledge through individual task practices and teamwork, enhancing problem-solving and collaboration skills [73]. In recent years, an increasing number of educational institutions have begun to explore the integration of project-based teaching with digital twin technology [74]. Project-based teaching emphasizes experiential learning, where students cultivate practical skills and knowledge by participating in real projects [75]. In the learning environment constructed by digital twin technology, high-speed information transmission technology ensures real-time model parameters, while VR and AR technologies enhance interactivity and engagement, promoting students’ independent exploration [76]. Learners can adjust parameters and remotely control physical twins using digital twin models, iteratively validate and optimize project proposals, and ultimately achieve optimal solutions to problems. In fields such as medicine, biology, and environmental science, digital twin technology provides a risk-free platform for experimentation and learning, enabling students to explore complex biological processes or environmental changes in simulated environments [77]. Digital twin technology shows great potential in providing customized learning experiences. It can adjust project difficulty and complexity based on students’ learning progress and needs, providing each student with a tailored learning path [23]. Madni A M et al. [27] demonstrated personalized project-teaching content and difficulty based on student interaction with digital twins, facilitating collaboration and communication among students and between students and teachers. In a shared virtual environment, students can collaborate to solve problems and share resources while teachers can monitor students’ progress in real time and provide immediate feedback. This interac-
tivity not only enhances students’ teamwork skills but also improves learning efficiency and participation.

Take the landscape architecture program as an example; with the acceleration of urbanization and the increasing awareness of ecological environment protection, the demand for professionals in the field of landscape architecture continues to grow [78]. However, traditional teaching methods in landscape education often focus on theoretical learning and lack integration with practical experience and modern technology, which are insufficient to meet the complexity and technical requirements of modern landscape projects [79]. The introduction of digital twin technology provides a new practical platform for landscape education, enabling students to engage in design experiments, simulate the interactive effects of ecosystems, and monitor plant growth in virtual environments, thus better understanding and addressing practical problems [80]. In the field of engineering education, especially in landscape architecture, the integration of project-based learning (PBL) and digital twin technology is gradually becoming an innovative teaching approach.

3. Research Methods

To address the limitations of case studies, this research employs a quasi-experimental design to compare the effectiveness of digital-twin-assisted teaching with traditional teaching methods by dividing participants into an experimental group and a control group. The specific research methods are as follows: First, this study developed a preliminary framework for a project-based-course teaching model based on digital twin technology and created a digital twin landscape learning system tailored to the actual needs of the course. The primary functions of this system include providing a virtual training environment, offering real-time feedback and guidance, delivering an immersive learning experience, and facilitating data-driven personalized learning paths. Second, using the “Courtyard Landscape Greening Project” from the “Plant Cultivation and Maintenance” course as an example, this study designed and developed a project-based teaching approach based on the digital twin landscape learning system. The effectiveness of the teaching was evaluated through a combination of surveys and interviews. Finally, based on the results of the data analysis, this study discusses the application effects of digital twin technology in landscape architecture education. The research is grounded in the UTAUT2 model and explores the factors influencing students’ intention to use similar digital twin learning systems (refer to Figure 3).

3.1. Experimental Design

3.1.1. Content of Experimental Design

To evaluate the effectiveness of the digital twin learning system in landscape architecture education, this study designed a quasi-experiment. Pretests indicated no significant differences between the experimental and control groups in terms of learning attitudes, motivation, and inclination toward innovative thinking. Students in the experimental group also underwent pretests on cognitive load and training on how to use the digital twin learning system. The intervention phase of the experiment lasted for 8 weeks, comprising a total of 16 sessions. During this period, different teaching methods were implemented for the two groups, with the experimental group learning through the digital twin learning system, while the control group received traditional landscape architecture teaching guidance. After the intervention, post-tests were conducted on both groups of students. The specific experimental process is illustrated in Figure 4.
Figure 3. The framework diagram of the specific experimental methodology of this study.

Figure 4. Experimental procedure.
Meanwhile, in order to gain a deeper understanding of university students’ intentions to use digital twin learning systems, this study investigates the relationships between relevant variables based on the UTAUT2 [81] model. The target population for this research consists of university students who have used digital twin learning systems [82]. The survey was conducted by randomly sampling students from various engineering disciplines (civil engineering, computer science, and architectural design) who have used similar digital twin learning systems. The questionnaire was distributed both by instructors who utilized digital twin learning systems in their teaching and through offline methods. The study aims to analyze the advantages and limitations of digital twin learning systems and propose recommendations for improvement.

3.1.2. UTAUT2 Model and the Assumptions

The UTAUT2 model is innovative in the study of technology acceptance, particularly in the field of e-learning technologies [83]. This paper adopts the UTAUT2 model as the basis to examine students’ intentions to use digital twin learning systems. Since students do not need to invest financial capital to use digital twin learning systems, the price value construct is excluded from the model. Additionally, to gain a better understanding of students’ intentions to use digital twin learning systems, this study investigates the relationships between relevant variables based on the UTAUT2 model. The definitions and assumptions of the factors are shown in Figure 5.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Define</th>
<th>Hypothetical (→ for positive impacts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance expectation</td>
<td>The extent to which learners believe that using smart teaching tools will help them improve their academic performance</td>
<td>H1 PE→BI</td>
</tr>
<tr>
<td>Effort expectation</td>
<td>Ease of use of smart teaching tools by learners</td>
<td>H2 EE→BI</td>
</tr>
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<td></td>
<td></td>
<td>H3 EE→PE</td>
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<td>H4 EE→HM</td>
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<tr>
<td>Social influence</td>
<td>The extent to which learners are influenced by others when using smart teaching tools</td>
<td>H5 SI→BI</td>
</tr>
<tr>
<td></td>
<td></td>
<td>H6 SI→PE</td>
</tr>
<tr>
<td>Enabling factor</td>
<td>The extent to which a person or technology exists to support the use of smart teaching tools by learners.</td>
<td>H7 EF→BI</td>
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<td></td>
<td></td>
<td>H8 EF→EE</td>
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<tr>
<td>Hedonic motive</td>
<td>The enjoyment learners get from using technology</td>
<td>H9 HM→BI</td>
</tr>
<tr>
<td></td>
<td></td>
<td>H10 HM→UH</td>
</tr>
<tr>
<td>Using habit</td>
<td>Habitual behaviors of learners using smart teaching tools</td>
<td>H11 UB→BI</td>
</tr>
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Figure 5. Factor definitions and assumptions for the UTAUT2 model.

Performance expectations were shown to have a strong relationship between intention to use a particular system most of the time, and this results in H1; the TAM model hypothesizes that perceived ease of use (equivalent to effort expectancy) influences perceived usefulness (equivalent to performance expectancy) in an information system. Perceived ease of use in the model affects people’s enjoyment of using smart tools [84], and this results in H2, H3, and H4; the environment in which a student lives can have an impact on his or her intention to use smart teaching tools, i.e., there is a causal relationship between social influence and intention to use [85]. When learners perceive stronger social influence, they will be more inclined to use smart teaching tools. Also, they will feel that smart teaching tools can improve their learning efficiency, and this results in H5 and H6; in the TAM model, perceived usefulness is determined by a combination of perceived ease of use and external variables, with perceived ease of use being determined by external variables. The contributing factors in this study are external variables [83], and this results in H7 and
H8; in this paper, habit of use is defined as the habitual behavior of university students in using smart teaching tools [86], and this results in H11. In summary, the research modeling diagram is as follows in Figure 6.

**Service discipline**

Civil Engineering  Machine Design  Environmental Protection  Construction Management

**Type of technology used**

Digital Twin  Virtual Reality  Online Apps  Web 2.0(WiKi)

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Figure 6. Research model diagram.

4. Content and Results of Research

4.1. Content of Research

4.1.1. Framework Construction of Project-Based Teaching Model Driven by Digital Twin Technology

Teaching models are developed under the guidance of theories of teaching and learning, utilizing learning environments, resources, and tools to establish stable relationships among various elements of teaching and learning activities, design the process of teaching and learning activities, and ultimately form stable teaching activity procedures or configurations. This article utilizes the basic principles of project-based teaching models, guided by embodied cognition theory and constructivist theory and driven by digital twin technology. The project-based teaching model primarily consists of project preparation, project implementation, and project summary. In the project-preparation phase, teachers need to gain an in-depth understanding of students’ learning needs, characteristics, and the set learning objectives. Through meticulous project scenario design and task subdivision, the completeness and feasibility of the project are ensured. At the same time, teachers need to adjust the difficulty and complexity of tasks according to students’ actual situations to promote their participation and learning motivation. Digital twinning technology plays a crucial role in this phase. By collecting student data and generating digital twin models, teachers can better understand students’ learning status and needs, providing effective guidance for project implementation. During the project-implementation phase, students transition from theoretical knowledge to practical skills. They need to collaboratively develop project plans in a team environment and solve practical problems through embodied experiences and collaborative exploration. Teachers’ role in this phase is to guide and instruct. By providing necessary resources and support, they help students overcome difficulties and achieve project goals. Meanwhile, digital twinning technology serves the function of monitoring and optimization, tracking students’ learning status in real time, and simulating their learning processes based on specific algorithms to provide personalized learning guidance and feedback. Finally, in the project-summary phase, students showcase their
achievements and receive evaluation and feedback from teachers and businesses. This not only assesses students’ learning outcomes but also reflects on and improves the teaching process. Digital twinning technology in this phase collects evaluation data and optimizes the teaching process based on feedback results, providing more personalized and effective teaching support. In summary, the project-based teaching mode combined with digital twinning technology can not only enhance students’ learning interest and engagement but also promote their practical skills and innovative thinking. Meanwhile, teachers can obtain more student feedback and data support through digital twinning technology, providing more scientific and effective means for optimizing the teaching process. The specific model design is illustrated in Figure 7.

Figure 7. Framework of project-based teaching model based on digital twin technology.

4.1.2. Development of a Digital Twin Garden-Learning System

Garden plant cultivation and maintenance (GPCM) is an important core course for landscape architecture majors. The course focuses on plants in cultivation and maintenance, on the one hand, by simulating real-world landscape design and maintenance projects in the digital twin environment, helping students to understand in depth how complex ecosystems affect the growth and health of landscape plants through the real-time monitoring and adjusting of ecological factors in the virtual model; this enables students to try out various landscape solutions under risk-free conditions, thus improving their practical skills. On the other hand, using the high flexibility and interactivity of the digital twin platform, students are taught how to analyze the data collected from the digital twin model in order to optimize the garden design and maintenance strategies, enhancing their ability to solve real-world problems and stimulating their design creativity and innovative thinking so that they can design both aesthetic and functional garden spaces. By means of VR immersive experience equipment, VR-supporting workstations, landscape-design virtual simulation systems, garden virtual simulation systems, landscape-design image-processing software, etc., we can realize the real, real-time, and virtual mapping of the garden landscape design and construction, and we can experience the virtual landscape construction, decision making, floriculture, maintenance, etc., so as to achieve virtual landscape scenario-based experiential teaching. In this paper, with reference to the five-dimensional model architecture of the digital twin [87], we propose the project-based learning platform as the system service platform and the six-dimensional model of the garden-learning system based on the digital twin, including the physical learning space (PLS), virtual learning space (VLS), cloud
services (CSs), digital data (DD), front-end display (FD), and connection (CN) (Equation (1)). The relationship between the dimensions is shown in Figure 8.

\[ M_{gpcm} = (PLS, VLS, CD, DD, FD, CN) \]  

Figure 8. Six-dimensional modeling of the digital twin garden-learning system.

The physical learning space (PLS) is the database for the implementation of project-based teaching, mainly integrating the functions of spatial and temporal basic data collection for plant cultivation and conservation design, multisource and multidimensional data fusion, and IoT sensing data reception, which are obtained through on-site surveys, base analysis, and IoT sensing. The physical teaching space also includes specialized cultivation areas and laboratories that are equipped with soil-testing equipment, water-quality-analysis instruments, greenhouse facilities, and various cultivation tools. Students can grow, observe, and manage different types of plants directly in these facilities. Through the use of sensors in these physical environments (e.g., soil moisture sensors, light intensity meters, temperature and humidity meters, etc.), students can collect data in real time about the growing conditions of their plants and synchronize these data to the digital twin platform for analysis and comparison.

Virtual learning spaces (VLS) serve as the foundational model for project-based learning, utilizing digital twinning technology to spatially model elements such as space, equipment, processes, and environments. Furthermore, three-dimensional modeling techniques enable the real-time monitoring and analysis of the spatial modeling information, complemented by 3D graphical visualization techniques for presentation and statistical analysis. The visualization interface offers real-time 3D visualization of environmental monitoring data in a novel manner, allowing users to immerse themselves in various states of crop-growth environments. It enables users to dynamically grasp the operational status and environmental parameter indicators of crop-growth-environment monitoring systems. Additionally, the digital layer sets alert thresholds for various environmental monitoring data, enabling intelligent adjustments to environmental elements when parameter indicators exceed preset thresholds.
Twin data are the basis for the operation of the digital twin garden-learning system, and DD mainly include the data in the physical teaching space (Dp), the data in the virtual teaching space (Dv), the data in the cloud service (Ds), and the learning data (Dl) (Equation (2)):

$$DD = (Dp, Dv, Ds, Dl)$$ (2)

Equation: Dp is mainly used to describe the physical elements that constitute the physical teaching space, such as the equipment, garden space, lighting, and other physical-element attribute data, as well as the dynamic process data that can reflect the operating state of the physical teaching space, the dynamic process data through the sensors, device interfaces, embedded acquisition cards, Internet of Things technology, etc.; Dv can represent the data related to the model of the physical teaching space (including the geometric model, physical model, behavioral model, rule model, etc.); Dv can represent the data related to the physics-teaching-space model (including the geometric model, physical model, behavioral model, rule model, etc.); Ds mainly includes models, algorithms, decision rules, database operations, etc., required for front-end display, as well as modal process data, human–computer interaction data, etc.; Dl includes expert knowledge, industry standards, commonly used algorithms, commonly used databases, commonly used API interfaces, and commonly used model-construction methods.

Cloud services serve as the computational core for educational implementation, responsible for processing data collected from physical and digital spaces, as well as sending instructional commands. The smart brain enables functions such as learning analytics, natural language processing, artificial intelligence, learning alerts, audio–visual processing, and image processing. It can analyze and process relevant data based on learners’ behavioral states and operational instructions, providing real-time intelligent feedback to assist learners in promptly refining their strategies. The smart brain offers services including learning monitoring, intelligent learning companions, smart tutors, and precise teaching, supporting autonomous learning and large-scale collaborative learning. With the support of the smart brain, data information throughout the entire learning cycle can be fully stored and utilized for the analysis of learning activities and prediction of learning behaviors, thereby providing robust support for improving learning performance and optimizing teaching strategies.

Connection processing is the transmission service carrier of project-based teaching, which provides support through a two-by-two two-way interaction, protocol transmission, feedback regulation, and dynamic simulation for the physical learning space, virtual learning space, cloud service, and front-end display (Equation (3)):

$$CN = (CN_{pv}, CN_{pc}, CN_{pd}, CN_{vc}, CN_{VF}, CN_{CD}, CN_{FD}, CN_{FC})$$ (3)

4.1.3. Course Flow Design

(1) Selection of projects

The selection and design of projects play a crucial role in the course’s project-based transformation. Projects should ideally originate from real-life scenarios in frontline enterprises as they are more aligned with practical work situations, providing authentic contexts that stimulate student engagement and facilitate knowledge transfer. This approach enhances students’ abilities to solve real-world problems and enables them to adapt more quickly to job roles after graduation. Project selection should aim for comprehensive coverage of the entire course curriculum. Taking the “Landscape Plant Cultivation and Maintenance” course as an example, a suitable project for in-class activities is the landscaping of a small courtyard, which is conducive to practical implementation in the training ground. Teachers will allocate a $4 \times 5$ m area on campus for each student group, replicating a real-life campus environment to determine the location and size of the courtyard. Working in groups, students will undertake the task of designing the courtyard landscaping, followed by the formulation of a landscaping plan and procurement planning for plant materials (with an emphasis on top-level procurement planning). Upon finalizing the plan,
students will proceed with the landscaping construction and ultimately be responsible for maintenance and survival.

(2) Teaching process design

1. Project preparation. Before formal teaching begins, teachers will decompose the project into multiple subprojects and interconnected tasks based on the principles of practical engineering education and integrated teaching content. Taking the courtyard landscape greening project training as an example, it can be divided into three subprojects: courtyard landscape design, courtyard greening construction, and courtyard greening plant-maintenance management. Additionally, each subproject is further subdivided into several tasks, each covering specific knowledge points and competency requirements. For instance, the courtyard landscape design subproject may include tasks such as plant selection and layout, soil improvement and fertilization management, and planting and transplanting techniques. The courtyard greening construction subproject may involve tasks like site preparation, procurement and use of greening materials, and supervision of the construction process. Lastly, the courtyard greening plant-maintenance management subproject could encompass tasks such as pest and disease control, water and fertilizer management, and application of maintenance techniques. Each task corresponds to specific teaching knowledge and practical skills, allowing students to comprehensively grasp relevant knowledge and skills in the field of plant cultivation and maintenance through completing these tasks, as shown in Figure 9 for reference.

<table>
<thead>
<tr>
<th>In-class project</th>
<th>Project 1: Courtyard landscaping project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subproject</td>
<td>1-1 Courtyard Landscape Design</td>
</tr>
<tr>
<td></td>
<td>1-2 Courtyard greening project construction</td>
</tr>
<tr>
<td></td>
<td>1-3 Garden greening plant maintenance and management</td>
</tr>
<tr>
<td>Knowledge Point</td>
<td>1. Garden plant cultivation technology</td>
</tr>
<tr>
<td></td>
<td>2. Garden plant seedling cultivation technology</td>
</tr>
<tr>
<td></td>
<td>1. Daily plant maintenance and management techniques</td>
</tr>
<tr>
<td></td>
<td>2. Plant shaping and pruning</td>
</tr>
<tr>
<td>Capacity</td>
<td>1. Selection and application of garden plants</td>
</tr>
<tr>
<td></td>
<td>2. Drawing and reading of greening construction drawings</td>
</tr>
<tr>
<td></td>
<td>1. Formulate a greening project construction plan</td>
</tr>
<tr>
<td></td>
<td>2. Organize the greening project construction</td>
</tr>
<tr>
<td></td>
<td>3. Adopt conventional measures to keep alive</td>
</tr>
<tr>
<td></td>
<td>1. Ability to formulate landscaping maintenance plans</td>
</tr>
<tr>
<td></td>
<td>2. Ability to trim and trim trees, shrubs, ground cover, and lawns, and manage soil, fertilizer, water, and pests and diseases</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>After-school program</th>
<th>Project 2: Greening and maintenance of the campus garden training field</th>
</tr>
</thead>
<tbody>
<tr>
<td>Progress</td>
<td>Site actual survey</td>
</tr>
<tr>
<td></td>
<td>Propose replanting opinions and maintenance plans</td>
</tr>
<tr>
<td></td>
<td>Construction organization design; Schedule</td>
</tr>
<tr>
<td></td>
<td>Replanting of trees and shrubs; Replanting of lawns and ground cover; Watering, fertilizing, pruning and other maintenance</td>
</tr>
<tr>
<td>Achievement</td>
<td>Map of existing condition</td>
</tr>
<tr>
<td></td>
<td>Construction drawing, maintenance plan</td>
</tr>
<tr>
<td></td>
<td>Construction organization design and schedule</td>
</tr>
<tr>
<td></td>
<td>Plant planting survival rate and maintenance feedback form</td>
</tr>
</tbody>
</table>

Figure 9. Project schedule for practical training in cultivation and maintenance of landscape plants.
Teachers create and publish prelearning tasks on the digital twin learning system, integrating core content from the plant cultivation and maintenance course. The aim is to assist students in self-learning before class, gaining a deeper understanding of the fundamental concepts and processes of plant cultivation and maintenance (Figure 10a). For example, regarding the courtyard landscape design subproject, students are required to read materials related to plant cultivation and maintenance, understanding the growth habits, suitable environments, and maintenance techniques of different plants. Additionally, students watch practical operation course videos on plant cultivation and maintenance on the Chinese University MOOC platform to gain preliminary insight into the course content. Furthermore, students need to complete online quizzes to assess their mastery of plant cultivation and maintenance knowledge. During the process of completing prelearning tasks, the digital twin learning system records students’ participation, exercise completion, and accuracy in real time. Teachers utilize these data, combined with the teaching objectives of the plant cultivation and maintenance course, to assess students’ learning progress through data mining and intelligent analysis techniques. By understanding students’ mastery of plant cultivation and maintenance, teachers can tailor teaching designs and guidance, providing personalized learning support to students. By integrating the content of the plant cultivation and maintenance course into prelearning tasks, students’ learning effectiveness and practical abilities can be enhanced more effectively, enabling them to gain a deeper understanding and application of the knowledge learned in class. The digital twin learning system automatically groups students with different learning situations and assigns subdivided tasks to suitable students. Finally, based on students’ prelearning results, the system automatically pushes teachers’ preuploaded learning resources of different difficulty levels and differentiated content. The digital twin learning system visualizes learners’ prelearning data (Figure 10b). With the visualization of data, teachers can diagnostically assess students’ prelearning effectiveness and mastery of knowledge points, providing a basis for classroom teaching design.

2. In-class project implementation and evaluation. In the depth of the project-based learning, students will delve into the growth and development patterns of landscaping plants and their adaptability to the environment. They will apply acquired knowledge to real design projects. Teachers will highlight the challenges in courtyard landscape design, such as the need to consider various factors like size, shape, light, and moisture, ensuring the rationality and feasibility of design plans. Students are required to demonstrate systematic thinking, analytical skills, and innovative thinking in proposing technical ideas and designing solutions. Through collaborative teamwork, they will collectively complete project tasks. Teachers will form study groups of four based on students’ individual circumstances to discuss and analyze project requirements and devise corresponding solutions collaboratively. Based on these solutions, group members will divide tasks and conduct on-site inspections in designated training areas on campus to select a practical courtyard site for design and practice. Each group of students will be allocated a $4 \times 5$ m area in the training area by the teacher, who will also determine the location and size of the courtyard. Students, working in groups, will choose a courtyard project based on the results of on-site inspections, such as renovating an old courtyard or creating a leisure garden. Based on on-site inspection results and theoretical knowledge, students will conduct virtual landscape design and plan optimization, including plant maintenance, landscape layout, and greening construction (Figure 11).
Figure 10. Digital twin learning system prelesson interface. (a) Students view teacher-created projects; (b) visualization of student precourse preparation data.
Taking the example of a student team designing a public landscape space, the team consists of four vocational high school students majoring in landscaping. Each student is responsible for designing one module of the public landscape space model (Figure 12). During the design process, each student can upload their design data to the digital twin platform at any time. The design data automatically generate a three-dimensional digital twin model for visualization. Consequently, as long as any student submits updated data, all students can instantly view the latest-generated landscape space model along with its detailed design parameters. They can even simulate its operation in different environments using the digital twin. Furthermore, every historical update state of the digital twin is meticulously recorded. Students can backtrack to any state in the design process and review the digital twin model parameters and performance at that state. The advantages and disadvantages of different design schemes can be easily discerned by comparing the parameters and performances of different versions of the digital twin, thus preventing conflicts in design philosophies among different designers. Additionally, comparing different versions of design schemes enriches students’ design knowledge and experience, continually enhancing their design capabilities. Digital twin technology significantly enhances communication and collaboration efficiency among students, facilitating real-time information sharing through online collaboration platforms, thereby improving design efficiency and quality. Moreover, the richness and flexibility of digital tools make it easier for students to express creativity and adjust solutions, thereby increasing the innovation and flexibility of design.
In the courtyard greening plant maintenance and management project, digital twin technology integrates the actual courtyard environment with digital models, enabling digital management and the simulation of plant-growth environments. Initially, students use the digital twin learning platform to practice courtyard landscape design. Subsequently, they select appropriate sensors and plants based on the project’s specific needs and the environmental conditions to be monitored. The system offers a wide range of sensors that measure various parameters, such as soil moisture, temperature, humidity, and light intensity. For sensor selection (Figure 13a), students can browse a library containing detailed specifications and usage scenarios. For instance, if a student is researching the impact of soil moisture on plant growth, they can choose soil moisture sensors with varying sensitivities and ranges. For plant selection (Figure 13b), the system provides a comprehensive database of plants, detailing their growth requirements, optimal environmental conditions, and potential challenges. Students can select suitable plants according to project goals and simulate their growth under different conditions. These sensors are connected to the digital twin system, allowing students to monitor plant-growth conditions and environmental factors in real time and receive immediate maintenance guidance and optimization suggestions. Throughout the process, students learn about plant-growth characteristics, pest and disease control, and fertilization and irrigation techniques and participate in actual maintenance work. Additionally, the digital twin technology offers teachers the ability to track students’ practical operations and learning progress in real time, enabling them to provide personalized guidance and support. By leveraging digital twin technology, students can evaluate and compare the feasibility of different design schemes, helping them consider and optimize plant-maintenance management strategies from various perspectives. Meanwhile, the system incorporates virtual reality (VR) technology, allowing students to immerse themselves in the plant-growth environment (Figure 14). With VR equipment, students can virtually “walk” through their designed landscapes, observing the plants’ responses to different environmental conditions in real time. This immersive experience helps students gain a deeper understanding of the plant’s lifecycle and the impact of various factors on their growth. VR technology also enhances the learning experience by providing a realistic and engaging way to visualize complex concepts.
In the courtyard greening construction project, students engage in practical greening engineering activities at the training site, integrating the knowledge acquired from the courses on plant cultivation and maintenance. They undertake tasks such as soil improvement, plant layout, and horticultural decoration based on design plans and seedling procurement plans while actively applying plant cultivation and maintenance techniques to ensure the healthy growth of courtyard plants and the realization of landscape effects. This practical activity, combined with the principles of plant cultivation and maintenance courses, provides students with an opportunity to translate theoretical knowledge into practical skills, deepening their understanding of plant-growth requirements and maintenance methods. The pivotal role of digital twin technology is evident in this process. Through digital twin systems, students can design and optimize courtyard greening schemes in a virtual environment, simulate different scenarios of plant growth, and engage in practical maintenance based on monitored environmental factors (Figure 15). Teachers can utilize digital twin systems to monitor students’ design and practical activities in real time, providing timely guidance and feedback. This practice-oriented teaching model, based on digital twin technology, effectively promotes the application of plant cultivation and maintenance knowledge and the development of practical skills among students.

Figure 13. Interaction in digital twin learning system; (a) students choose the right sensor; (b) choose the right plant.

Figure 14. Students use VR devices to experience the digital twin garden-learning system.
Furthermore, digital twin technology allows students to compare the merits of different design schemes and learn from their experiences. They can experiment with various maintenance strategies in the real environment, observe plant-growth responses, and adjust and optimize the plans based on experimental results (Figure 16). This experiential learning approach enables students to apply plant cultivation and maintenance techniques more proficiently in actual work scenarios, laying a solid foundation for their future career development.

3. Summarize and expand after class. First of all, the system generates a detailed learning data report based on students’ learning data and completed works and visualizes the students’ learning situation. Teachers use these data to reflect on and summarize the lessons and evaluate the effectiveness of the teaching methods and learning content. Based on these data, teachers update and improve teaching resources to ensure the relevance and usefulness of their teaching materials and cases. Students view system-generated individual learning reports to understand their performance in the three areas of knowledge, skills, and literacy in the course, while the system provides feedback on individual students’ learning, including personalized guidance and suggestions for improvement, based on which students reflect and summarize their learning, identify their strengths and areas for improvement, and consolidate and expand their knowledge of the course. Students then make necessary corrections and refinements to improve the quality of their project work. Based on the students’ overall performance and specific feedback, teachers make subsequent instructional decisions, including adjusting teaching strategies, adding more
classroom interactions, or modifying assessment methods to better suit students’ learning needs and enhance teaching effectiveness, as shown in Figure 17.

Figure 17. Project schedule for practical training in cultivation and maintenance of landscape plants.

4.2. Results of Research
4.2.1. Results of the Experiment

The researcher conducted independent sample t-tests using SPSS 22.0 software to analyze the measurement data, obtaining the means, standard deviations, and statistical results for both the experimental and control groups, as shown in Table 1. The results revealed that the experimental group outperformed the control group significantly in critical thinking, collaborative learning tendencies, cognitive load management, learning experience, and academic performance. Particularly, academic performance was notably superior in the experimental group. However, there were no significant differences between the two groups in terms of learning attitudes, motivation, and creative thinking tendencies.

(1) Cognitive Load

There was a significant difference in cognitive load between the experimental group and the control group, indicating that the digital twin system effectively reduces learners’ cognitive load. By breaking down the project into multiple specific tasks, students can preview and understand relevant knowledge points in the digital twin learning system, thus reducing the burden of understanding complex concepts during class. For example, the courtyard landscape design subproject includes tasks such as plant selection and layout, soil improvement, and fertilization management. Students can preview the specific operations and principles of these tasks through the digital twin system, enabling them to grasp this knowledge more quickly in class. Moreover, the digital twin learning system provides learners with a realistic, manipulable, and continuously exploratory learning environment, making abstract knowledge and pictorial descriptions more concrete. This reduces the cognitive load associated with understanding textual and visual content.

(2) Creative Thinking Tendency

There was no significant difference in the inclination toward creative thinking between the experimental and control groups. The main reason for the lack of significant difference
is that short-term experimental interventions may not fundamentally enhance learners’ creative thinking. The students interviewed reported that using the digital twin system for learning indeed generated new ideas during the learning process. However, the emergence of creative thinking remained limited, which may be related to their usual learning experiences.

(3) Learning Experience

There was a significant difference in learning experiences between the experimental group and the control group, with the digital twin system significantly enhancing students’ learning experiences. Students simulate real-life situations in the virtual environment, repeatedly practice, and engage in interactive communication, thereby increasing their sense of participation and practical skills. For example, in courtyard landscape design, students use the digital twin platform for virtual landscape design and plan optimization, making learning more interesting and engaging. In contrast, traditional learning modes based on text and images do not provide learners with these conditions and opportunities. As a result, students have less effective participation, fewer practice opportunities, and insufficient communication scenarios.

(4) Critical Thinking

There was a significant difference in critical thinking between the experimental group and the control group, indicating that the two groups exhibit notable differences in critical thinking under different teaching methods. The digital twin system, through real-time feedback and evaluation, helps students identify and correct errors promptly, fostering their critical thinking abilities. For example, during practical operations, students receive immediate feedback through the digital twin platform, allowing them to improve their plans and enhance their problem-analysis and -solving skills.

(5) Academic Performance

There was a significant difference in academic performance between the experimental group and the control group, indicating that the digital twin system has a notable positive effect on students’ academic achievement. Students in the digital twin system engage in virtual operations and field investigations, resulting in a higher performance in landscape effects from planting, transplant survival rates, and seedling emergence rates compared to the control group. However, the control group showed a lack of mastery in specific skills related to plant growth and maintenance.

Table 1. Statistical test results of learning effect of experimental group and control group.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creative thinking</td>
<td>Experimental</td>
<td>35</td>
<td>10.46</td>
<td>1.874</td>
<td>0.343</td>
<td>0.645</td>
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<tr>
<td></td>
<td>Control</td>
<td>35</td>
<td>10.23</td>
<td>1.133</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Critical thinking</td>
<td>Experimental</td>
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<td>21.66</td>
<td>3.245</td>
<td>2.142</td>
<td>0.034 *</td>
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<td></td>
<td>Control</td>
<td>35</td>
<td>19.78</td>
<td>3.649</td>
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</tr>
<tr>
<td>Cooperative learning</td>
<td>Experimental</td>
<td>35</td>
<td>12.52</td>
<td>1.763</td>
<td>2.146</td>
<td>0.029 *</td>
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<tr>
<td></td>
<td>Control</td>
<td>35</td>
<td>11.47</td>
<td>1.548</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cognitive load</td>
<td>Experimental</td>
<td>35</td>
<td>10.45</td>
<td>1.678</td>
<td>−2.435</td>
<td>0.012 *</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>35</td>
<td>11.34</td>
<td>1.694</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Learning experience</td>
<td>Experimental</td>
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<td>12.74</td>
<td>2.438</td>
<td>2.056</td>
<td>0.032 *</td>
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<tr>
<td></td>
<td>Control</td>
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<td>10.86</td>
<td>1.973</td>
<td></td>
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<tr>
<td>Learning motivation</td>
<td>Experimental</td>
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<td>11.56</td>
<td>2.134</td>
<td>1.237</td>
<td>0.178</td>
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<tr>
<td></td>
<td>Control</td>
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<td>10.98</td>
<td>2.087</td>
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<tr>
<td>Academic record</td>
<td>Experimental</td>
<td>35</td>
<td>89.65</td>
<td>11.34</td>
<td>3.762</td>
<td>0.000 ***</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>35</td>
<td>72.14</td>
<td>13.65</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* p < 0.05, *** p < 0.001.
4.2.2. Structural Equation Results

In order to test the proposed model and to analyze the proposed hypotheses, structural equation modeling was used for the analysis. The evaluation indicators of the measurement model are reliability and validity. Reliability was tested using Cronbach’s coefficient and combined reliability. Validity was tested by convergent validity. The results of the reliability and convergent validity tests are shown in Table 2.

The standardized loadings of the observed variables corresponding to the seven latent variables in this study’s model are all much larger than the suggested value of 0.5, and all of them reached the significant level, indicating that this scale has good convergence [88]; the combined reliability of the seven latent variables is larger than the suggested value of 0.7, indicating that the measurement model of this study has good internal consistency; and the average variance extracted from the seven latent variables is larger than the suggested value of 0.5 in six cases, and six of the seven latent variables have mean variance extractions greater than the suggested value of 0.5, and one is less than 0.5 but the deviation is not large, indicating that these seven latent variables obtained a higher degree of variance from the corresponding observed variables and that the measurement model has good convergence [89].

In this study, structural equation modeling was conducted through Amos 22.0 software to investigate the overall fit evaluation and hypothesis testing of the model. In this paper, some general indicators are used to analyze the fit of the samples, resulting in the following model fit indices: normed is 2.659 (<3 is excellent), RMSEA is 0.062 (<0.08 is excellent), and CFI is 0.986 (>0.9 is excellent). All other indicators meet the criteria that the model can be adapted. It shows that this structural model meets the criteria for measurement, and the indicators test well and fit well, and the results of the path test are shown in Table 3.

The regression coefficient of the hypothesized path is significant when the absolute value of the CR is >1.96 with \( p < 0.05 \). In accordance with this criterion, it can be seen from Table 3 that 2 out of 11 hypotheses are not valid. The test results of the model show that performance expectation has a significant positive effect on students’ intention to use the digital twin learning system, and effort expectation has a significant negative effect on the intention to use. This indicates that students believe that using the digital twin learning system helps them achieve their learning goals, motivates them to use the digital twin learning system, and increases their intention to use the digital twin learning system. Meanwhile, the higher the level of effort during the use of the digital twin learning system, the lower the intention to use the digital twin learning system, which indicates that the ease of use of the learning system itself is important. The students believed that among the factors affecting the use of the digital twin learning system among students, the enabling factor and the use habit factor reflected a significant positive influence. This indicates that the compatibility of the technology itself and the supporting role it plays as part of the application of the digital twin learning system, as well as the development of students’ habits of using the learning system, are essential. In addition to this, effort expectation has a significant positive effect on both hedonic motivation and performance expectation, which suggests that the ease of use of the learning system affects the students’ enjoyment of using the system and improves the students’ perception of the usefulness of the system. Hedonic motivation has a significant positive effect on usage habitus, which suggests that the enjoyment in using the digital twin learning system enhances students’ inertia in using the system. External factors such as enablers and social influences have a positive and significant effect on internal factors such as effort expectations and performance expectations, respectively, which confirms that external factors do have some positive effect on internal factors.
Table 2. Reliability and convergence validity.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Index</th>
<th>Standard Load</th>
<th>Cronbach’s Alpha</th>
<th>CR</th>
<th>AMOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance expectation</td>
<td>PE1</td>
<td>0.753</td>
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<tr>
<td></td>
<td>PE2</td>
<td>0.836</td>
<td>0.834</td>
<td>0.872</td>
<td>0.541</td>
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<tr>
<td></td>
<td>PE3</td>
<td>0.698</td>
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<tr>
<td></td>
<td>EE1</td>
<td>0.583</td>
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<tr>
<td>Effort expectation</td>
<td>EE2</td>
<td>0.694</td>
<td>0.712</td>
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<td>0.502</td>
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<td></td>
<td>EE3</td>
<td>0.732</td>
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<tr>
<td></td>
<td>SI1</td>
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<td>Social influence</td>
<td>SI2</td>
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<td></td>
<td>SI3</td>
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<td></td>
<td>EF1</td>
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<td></td>
<td>HM1</td>
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<td>Hedonic motive</td>
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<td></td>
<td>UH1</td>
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<tr>
<td>Using habit</td>
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<tr>
<td></td>
<td>UH3</td>
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</tr>
<tr>
<td></td>
<td>BI1</td>
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<tr>
<td>Behavior Intention</td>
<td>BI2</td>
<td>0.725</td>
<td>0.826</td>
<td>0.845</td>
<td>0.652</td>
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<tr>
<td></td>
<td>BI3</td>
<td>0.810</td>
<td></td>
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Table 3. Path check table.

<table>
<thead>
<tr>
<th>Hypothetical Path</th>
<th>Beta</th>
<th>SE</th>
<th>CR</th>
<th>p</th>
<th>Inspection Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>HM ← EE</td>
<td>0.865</td>
<td>0.143</td>
<td>9.354</td>
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<tr>
<td>PE ← EE</td>
<td>0.376</td>
<td>0.125</td>
<td>2.532</td>
<td>**</td>
<td>remarkable</td>
</tr>
<tr>
<td>UH1 ← HM</td>
<td>0.782</td>
<td>0.053</td>
<td>10.351</td>
<td>***</td>
<td>remarkable</td>
</tr>
<tr>
<td>EE ← EF</td>
<td>0.834</td>
<td>0.056</td>
<td>9.431</td>
<td>***</td>
<td>remarkable</td>
</tr>
<tr>
<td>PE ← SI</td>
<td>0.652</td>
<td>0.127</td>
<td>6.578</td>
<td>***</td>
<td>remarkable</td>
</tr>
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<td>0.145</td>
<td>2.347</td>
<td>*</td>
<td>remarkable</td>
</tr>
<tr>
<td>BI ← EE</td>
<td>−0.349</td>
<td>0.315</td>
<td>−2.237</td>
<td>*</td>
<td>remarkable</td>
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<tr>
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<td>0.167</td>
<td>0.645</td>
<td>0.512</td>
<td>unremarkable</td>
</tr>
<tr>
<td>BI ← EF</td>
<td>0.458</td>
<td>0.148</td>
<td>2.643</td>
<td>*</td>
<td>remarkable</td>
</tr>
<tr>
<td>BI ← HM</td>
<td>0.165</td>
<td>0.087</td>
<td>1.258</td>
<td>0.125</td>
<td>unremarkable</td>
</tr>
<tr>
<td>BI ← UH</td>
<td>0.574</td>
<td>0.056</td>
<td>8.033</td>
<td>***</td>
<td>remarkable</td>
</tr>
</tbody>
</table>

5. Discussion

5.1. Discussion of Findings

This study is based on the UTAUT2 model and adapted to the context of the digital twin learning system. It explores the impact of performance expectancy, effort expectancy, social influence, hedonic motivation, and usage habit on students’ intention to use the digital twin learning system as a teaching tool, as well as the relationships among these variables. According to Venkatesh et al.’s [85] unified theory of acceptance and use of technology (UTAUT) model, effort expectancy generally has a positive influence on usage intention. This finding fills a gap in existing research on the effectiveness of digital twin technology in education, emphasizing the potential of the technology to improve learning performance. However, research by Venkatesh and Davis [90] indicates that in highly autonomous learning environments, complex technology can decrease user intention. This study finds that effort expectancy has a significant negative impact on usage intention, which differs from the main conclusions of the UTAUT model. A possible explanation is that the complexity of the digital twin learning system makes students feel that significant effort is required, thus reducing their usage intention. In subsequent interviews, one
participant stated, “I prefer systems that are easy to operate. Previously, systems provided by teachers required considerable time and effort to understand the interface and functions, which was frustrating”. Another student remarked, “The system’s steps are relatively simple, and I could adapt to it quickly”. Additionally, the course instructor noted that the use of the “visual cockpit” helped her manage the class and understand students’ learning statuses in real time. This indicates that when designing learning systems, it is crucial to focus on user experience and ensure the system is easy to operate. This finding highlights the importance of designing learning systems that are easy to use and provides an empirical basis for future educational technology design.

Furthermore, Van der Heijden’s [91] research found that hedonic motivation plays a significant role in the use of information systems, especially in non-work environments. Hsu and Lin [92] also noted that perceived enjoyment significantly influences the intention to use social media. This study further reveals that hedonic motivation has a significant positive impact on usage habits. In subsequent interviews, teachers mentioned, “In the plant cultivation and maintenance course, we designed highly interactive virtual experiments and simulations that allowed students to perform practical operations in a virtual environment with great results”. Students also remarked, “My favorite part of the system is the interesting interactive experiments and simulations”. The research results indicate that the enjoyment students derive from using the digital twin learning system can enhance their usage habits. The interactivity of virtual experiments and simulated operations enhances students’ learning interest, demonstrating that designing engaging content within digital twin learning systems is an effective strategy for increasing usage intention. This study also found that social influence has a significant positive impact on both effort expectancy and performance expectancy, indicating that external environments and peer support play a positive role in students’ intention to use the system and their perceptions of it. This finding is consistent with the existing literature and highlights the importance of social environments and peer interactions in the application of educational technologies.

Finally, Thompson et al. [93] emphasized the impact of facilitating conditions, such as technical support, on technology usage. Limayem et al. [94] highlighted that usage habits are critical factors for the long-term use of technology. This study found that facilitating conditions have a significant positive impact on usage intention, which is consistent with existing research. Students mentioned, “Sometimes, when using the system, I encounter technical issues such as login difficulties or operational glitches. If I receive timely technical support, the problems are quickly resolved, and I don’t feel frustrated”. Similarly, teachers noted, “When students use the digital twin learning system, timely technical support greatly enhances their usage intention and learning experience”. Therefore, in the digital twin learning system, technical support and environmental compatibility are crucial for improving usage intention.

5.2. Research Innovativeness

Traditional studies on the application of digital twin technology in education primarily employ case study investigations [95–97], but they lack empirical validation. These studies often showcase the potential and application scenarios of the technology through individual cases, without systematic empirical data support and a lack of research on the use of digital twins in landscape architecture courses. This study, by utilizing empirical research methods, allows for a direct observation and measurement of students’ performance and feedback while using the digital twin learning system in real-world environments. This approach provides more practical and valuable conclusions, aiding in the validation of the actual effectiveness and applicability of digital twin technology in education. This systematic and comprehensive approach more accurately reflects the true context of use and provides a more comprehensive analytical framework.

Currently, there are few studies that explore the acceptance and influencing factors of digital twin learning systems [16]. Most existing research focuses on the application effects of the technology itself and lacks in-depth investigation into user acceptance and its
influencing factors. This study constructs a second-generation unified theory of acceptance and use of technology (UTAUT2) model with six dimensions to explore the intention to use digital twin learning systems in engineering education courses. The model considers factors such as performance expectancy, effort expectancy, social influence, facilitating conditions, hedonic motivation, and habit, which are crucial for understanding students' usage intentions. The research findings indicate that teachers can effectively guide students to enhance their utilization of digital twin learning systems. This has significant implications for improving teaching effectiveness and student learning experiences. Based on the findings of this study, teachers can adjust their instructional strategies to fully leverage the advantages of digital twin technology, thereby promoting students' learning and development.

In the future, digital twin technology will create an intelligent learning environment where the virtual and real worlds are seamlessly integrated. Learners will continuously learn, optimize, and progress alongside their digital twin avatars in a virtual world, ultimately achieving personalized development. Digital twin technology not only provides a dynamic learning platform but also offers real-time data feedback and interaction, helping learners to continuously improve and enhance their skills. Through systematic empirical research and innovative model construction, this study not only fills the gaps in existing research but also provides a solid theoretical and practical foundation for the future application of digital twin technology in education.

5.3. Shortcomings of the Study and Future Directions

(1) The digital twin learning system developed in this study still has deficiencies in providing an immersive experience. Students may not fully immerse themselves in the virtual environment, which could negatively affect their learning experience and outcomes. The lack of immersion in the current system may be due to technical limitations or design flaws. In the future, more advanced virtual reality (VR) and augmented reality (AR) technologies could be applied to enhance the system's immersion. System optimization based on user feedback, improving interactive design and operational processes, will make the system more seamless and intuitive for students.

(2) This study did not adequately consider that learning modes may vary by age group and gender, overlooking the different needs and responses of students of different genders and ages when using the digital twin learning system. Future research should examine the experiences and outcomes of individuals from various gender and age groups when using the digital twin learning system.

(3) The sample size of this study was relatively small, consisting of only 70 students from a single vocational high school. This limitation may affect the representativeness and generalizability of the findings. Future research should aim to expand the sample size to include more students from various disciplines and institutions to enhance the representativeness of the results. Conducting large-scale empirical studies will help verify the broad applicability of the system.

6. Conclusions

This study aims to develop a digital twin learning system for landscape architecture and propose a project-based teaching model driven by digital twin technology. Using the "Plant Cultivation and Maintenance" course as an example, we conducted a teaching experiment based on the digital twin system, yielding the following conclusions: (1) The system can create a blended virtual and real garden teaching environment for landscape architecture students. Through real-time data analysis, simulation and visualization technologies, and an interactive learning platform, the system enhances learner interaction and engagement in the garden-skills-learning process. Additionally, the system effectively addresses the challenge of providing timely, personalized feedback and evaluation in large-class and online teaching, demonstrating its usability and efficiency. (2) Experimental results indicate that using the digital twin learning system for teaching significantly improves learners'
critical thinking, creative thinking, cognitive load, learning experience, and academic performance. Future applications of digital twin education should extend the experimental duration to observe its impact on other aspects of student development. (3) This study also analyzed the acceptance and influencing factors of using the digital twin learning system in similar engineering education courses. The results confirm that students have a high intention to use the digital twin system. Researchers should enhance the system’s usability and interactive enjoyment to further increase student engagement. Additionally, factors such as usage habits and facilitating conditions have a significant positive impact on usage intention. Therefore, researchers should modularize and functionalize the digital twin learning system, improving the specialization level of services and increasing students’ awareness of information-based teaching. This will allow students to fully appreciate the learning advantages provided by the digital twin learning system.

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References
5. Adel, A. Unlocking the future: Fostering human–machine collaboration and driving intelligent automation through industry 5.0 in smart cities. *Smart Cities* 2023, 6, 2742–2782. [CrossRef]


42. Leng, J.; Wang, D.; Shen, W.; Li, X.; Liu, Q.; Chen, X. Digital twins-based smart manufacturing system design in Industry 4.0: A review. J. Manuf. Syst. 2021, 60, 119–137. [CrossRef]
49. Lyu, B.; Wang, Y. Immersive visualization of 3D subsurface ground model developed from sparse boreholes using virtual reality (VR). Undergr. Space 2024, 17, 188–206. [CrossRef]
50. Cai, K.; Huang, W.; Lin, G. Bridging landscape preference and landscape design: A study on the preference and optimal combination of landscape elements based on conjoint analysis. Urban For. Urban Green. 2022, 73, 127615. [CrossRef]
65. Slob, N.; Hurst, W. Digital twins and industry 4.0 technologies for agricultural greenhouses. Smart Cities 2022, 5, 1179–1192. [CrossRef]
70. Pathak, H.S.; Brown, P.; Best, T. A systematic literature review of the factors affecting the precision agriculture adoption process. **Precis. Agric.** 2019, 20, 1292–1316. [CrossRef]


78. Mersal, A. Sustainable urban futures: Environmental planning for sustainable urban development. **Procedia Environ. Sci.** 2016, 34, 49–61. [CrossRef]


83. Davis, F.D. Perceived usefulness, perceived ease of use, and user acceptance of information technology. **MIS Q.** 1989, 13, 319–340. [CrossRef]


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