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Integrating Emerging Technologies in Construction Graduate Education: An Experiential Learning Experience through a Collaborative Digital Twin Project

Mr. Qinghao Zeng, Georgia Institute of Technology

Mr. Zeng is a researcher in the field of Architecture, Engineering, and Construction (AEC). With a strong commitment to bridging the gap between academic theory and practical application, Mr. Zeng specializes in integrating advanced technologies such as Digital Twins (DT), Building Information Modeling (BIM), and 3D laser scanning into construction education.

Mr. Tran Duong Nguyen, Georgia Institute of Technology

Tran Duong Nguyen is a licensed architect and master planner with more than 12 years of experience in various project management stages. He has conducted research on Sustainable Design and Energy Efficiency, focusing on Building Information Modeling (BIM), Digital Twin (DT), and Modular Construction (MC). Tran is also working on developing performance certification techniques for green building rating systems and Life Cycle Assessments. He is an enthusiastic doctoral researcher with a Master of Science degree in Construction Management from Kennesaw State University and is continuing his academic career as a Ph.D. student in Building Construction at the Georgia Institute of Technology in the Fall of 2022. Tran is passionate about research and teaching and has published numerous papers addressing critical challenges in the construction industry. He aims to enhance sustainability by integrating emerging technologies.

Kamyar Fatemifar
Abdurrahman Baru
Leonardo Garcia
Jing Wen

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In the rapidly evolving Architecture Engineering Construction and Facility Management (AECFM) industry, bridging the gap between academic theory and practical application is essential for preparing students for professional practice. To address this challenge, this paper presents an innovative class project that enhances graduate students' understanding of advanced Digital Twin (DT) technologies. By offering a hands-on opportunity to create a DT model of a campus building, this effort focuses on developing critical skills necessary for professional success. Through the integration of experiential learning into the construction curriculum, students gained a deeper understanding of these technologies in a real-world context. Specifically, the project integrates various emerging technologies, including 3D laser scanning, point cloud generation, and Building Information Modeling (BIM), to give students a comprehensive, real-world context for applying theoretical concepts. Students could simulate building operations and maintenance processes using model-based data-driven platforms that support the Construction Operations Building Information Exchange (COBie) standard. The real-time monitoring of occupancy and space utilization further enhanced their understanding of operational efficiency in the built environment. The primary goal of this project was to foster technical proficiency, critical thinking, and problem-solving skills through four steps within the experiential learning experience: abstract conceptualization, active experiment, concrete experience, and reflective observation. With direct engagement with advanced tools, student reflections indicated a significant increase in confidence and motivation to apply these technologies in professional settings. This hands-on approach helped students navigate and understand complex construction processes, reinforcing the value of practical experience in developing industry-relevant competencies. This paper provides a guide for educators interested in incorporating experiential learning into their curricula. The project's success, driven by interdisciplinary collaboration with academic staff and industry partners, highlights the importance of teamwork and real-world problem-solving in preparing students for the challenges of modern AECFM practice. The research demonstrates how emerging technologies can support students' professional development by aligning education with industry needs. The findings from this project contribute to ongoing discussions about the future of construction education, advocating for the broader adoption of technology-driven, collaborative learning strategies. By bridging the gap between education and industry, this approach ensures that graduates are better prepared to thrive in a technology-centric professional environment.

1. Introduction

The Architecture Engineering Construction and Facility Management (AECFM) industry is changing rapidly driven by the advent of cutting-edge technologies such as Digital Twin (DT). DT originated in NASA's Apollo Program to support remote, real-time spacecraft simulations. They have since evolved into robust, data-driven virtual models, thanks in large part to Dr. Michael Grieves' 2003 conceptual framework in Product Lifecycle Management (PLM) [1], [2]. Beyond manufacturing, DTs are now integral to the AECFM industry, supporting real-time sensing, data visualization, and analytics [3], [13], [5]. The integration of various advanced technologies under the Industry 4.0 paradigm has made DT essential for modern AECFM applications [15], [16], [8].

DT technologies offer dynamical simulations and data-driven insights, enabling informed decision-making across various project phases, including design and planning, construction management, and facility operations. DT has revolutionized construction practices, leading to significant advancements in productivity, cost savings, and delay mitigation. According to McKinsey & Co., implanting cutting-edge construction technologies could raise productivity by 15% and reduce costs by 10% [9].

Despite these benefits, a significant gap persists for AECFM practitioners to adopt DT: technological complexity. Implementing DT requires integrating various advanced technologies, including Building Information Modeling (BIM), reality capturing technologies (e.g., laser scanning and point cloud processing technologies), and DT creation platforms, which can be a barrier for firms lacking in-house expertise [10]. In response, the graduate program at the XXX incorporated DT technologies into its curricula and implemented a collaborative and hands-on DT project, using the experiential learning framework. This initiative is designed to equip students with the skills needed to tackle emerging industry challenges, address the existing skills gap, and prepare future AECFM professionals to meet modern industry standards while adopting advanced technologies [11].

This paper aims to present the design and implementation of a collaborative, hands-on Digital Twin (DT) class project, evaluate its impact on graduate students' learning and competency development, and address the central research question: What is the measurable impact of experiential learning through the collaborative, hands-on DT project on students' confidence, motivation, and technical proficiency? By investigating this question, the study contributes to the identification of the added value of technology-enhanced graduate education and its role in better preparing students for professional challenges. Ultimately, this research seeks to ensure that pedagogies remain compatible with both academic requirements and evolving professional requirements, thereby enabling students to acquire the expertise necessary for success in the modern AECFM industry.

2. Review of Experiential Learning Framework in Construction Education

Kolb’s experiential learning cycle offers a structured framework for understanding how students obtain knowledge through direct hands-on experience. This cycle comprises four interrelated stages: Concrete Experience, Reflective Observation, Abstract conceptualization, and Active Experimentation (see Figure 1). This cycle could guide learners in systematically connecting theory to practice [12], [13]. In the construction education context, each stage encourages students to engage with real-world scenarios, reflect on their hand-on experiences, and develop insights which could be applied in subsequent projects or tasks. Such iterative engagement not only deepens comprehension of core concepts from the course but also refines students’ critical thinking and problem-solving capabilities.

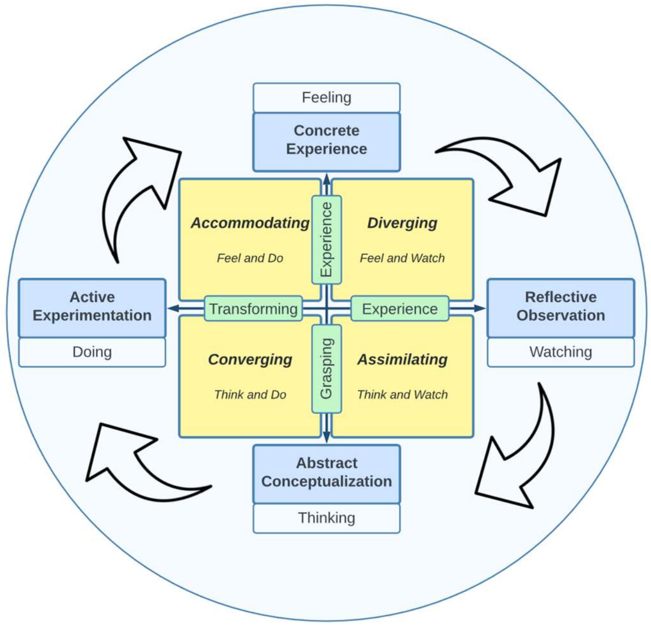

Figure 1. Kolb's experiential learning cycle [12], [13]

According to several research, hands-on projects serve as an essential mechanism for reinforcing theoretical knowledge in construction education. For example, Voutetaki and Thomoglou have implemented a hands-on workshop to explore the experiential learning method of structural engineering science at the university level [12]. The paper then assessed the positive effects on all grade architectural students' engagement in experiential learning, and based on the statistical analysis, over 80% of the students understand the concepts better and more than 75% of the students enjoy the 3D construction simulation experience. Additionally, Qu and Cheung explore the effect of e-learning training for construction mediation [14]. Nine parameters were under consideration regarding pedagogical principles for e-learning, *including intended learning outcomes (ILOs), content development (LCD), concrete experience (CE), reflective observation (RO), learning progress report (LPR), abstract conceptualization (AC), active experimentation (AE), learning assessment report (LAR), and learning interaction and student support (LISS)* [14]. As for research findings, LCD helps students better utilize the e-learning system and resources; the CE, RO, AC, AE, and LISS were found to boost students' involvement, interactions, and collaboration in learning and problem-solving skills; the LPR assisted with tracking students' feedback and learning progress; and LAR was used for evaluating students' learning outcomes.

Despite the growing interest in Digital Twin (DT) technologies within the Architecture Engineering Construction and Facility Management (AECFM) sector, limited empirical evidence regarding the effectiveness of technology integration into graduate-level construction curricula has been found. Existing studies often focus on isolated case studies of DT adoption [15], [16], [17], [18] or primarily emphasize technical feasibility [19], [20], with comparatively less attention given to systematically assessing their pedagogical impact. Furthermore, a critical need for evaluating students' learning outcomes in hands-on projects which utilize DT and emerging technologies exists. Addressing these research gaps is of great necessity for advancing construction education theory and ensuring that faculty, administrators, and industry stakeholders have well-substantiated, evidence-based strategies for implementing and assessing DT-focused experiential learning initiatives.

3. DT Class Project Design and Assessment Method

This section explains how the class project was designed by integrating the experiential learning framework and highlights the significant role of our industry partner, WireTwin, in the design and implementation of the Digital Twin (DT) class project. Additionally, the section provides a detailed explanation of the assessment process for the DT class project.

3.1 Implementation of Experiential Learning Framework

This class adopted an experiential learning approach to design the project and enhance students' learning outcomes. Such approaches are instrumental in building professional competency profiles by improving practical skills, modeling capabilities, and process simulation proficiency relevant to construction [21], [22]. Specifically, this Digital Twin (DT) class project focused on fostering problem-solving abilities and developing technical confidence through active participation and collaborative workflows.

The class project required students to utilize advanced technologies to create and maintain a DT of a campus facility. This workflow integrated BIM, reality capturing technologies (e.g., laser scanning and point cloud processing technologies), and a DT creation platform. Upon creating the DT, students performed several tasks in various building operation and maintenance scenarios to enhance their understanding of the DT's roles in improving operational efficiency within real-world contexts.

Table 1 outlines the design of the class project, structured within the experiential learning framework to ensure a successful hands-on learning experience. Through this framework, students were able to enhance their technical understanding, problem-solving skills, and critical thinking abilities effectively.

Table 1. Implementation Steps from Kolb's Experiential Learning Cycle

Steps	Specifications
Abstract Conceptualization	**Theoretical instruction on DT concepts and related technologies.** The course began with a series of lectures and readings on DT principles, BIM, point cloud generation, and data exchange standards such as COBie.
Active Experimentation	**Hands-on Laser Scanning, 360 Panorama Scanning, and BIM Modeling.** Students engaged in hands-on sessions with 3D laser scanning devices and point cloud processing software. Working in small teams, they collected onsite data from a designated campus library and then translated the scanned information into preliminary BIM models.
Concrete Experience	**Create a Digital Twin for a Campus Building.** To elevate the practical dimension, students collaborated to generate a functioning DT model of the campus building. Beyond geometric modeling, they integrated sensor data on occupancy, space utilization, and maintenance management adhering to COBie standards for structured information exchange.
Reflective Observation	**Debrief, Individual Reflections, and Group Discussions**. The final stage involved structured reflection activities in which students examined their initial assumptions and challenges faced. Debriefs were conducted through guided small-group discussions and reflective journaling.

3.2 Collaboration with Industry Partner: Use of WireTwin

Collaboration with industry partners was integral to the design and implementation of the class project. In particular, students worked closely with industry professionals from the DT platform, WireTwin, to gain firsthand knowledge and practical experience. This partnership allowed students to learn key processes, such as developing and uploading as-built BIM models, navigating the platform, interacting with the DT of the facility, linking the DT to facility sensors, and performing facility management and operational tasks using WireTwin.

Beyond providing technological support, industry representatives offered valuable feedback on students' interim and final deliverables, sharing expert perspectives on the strengths and weaknesses of the teams' approaches and technical competencies. By bridging the gap between academia and industry, the collaboration with WireTwin motivated students to develop and refine both professional and technical skills, including DT creation and maintenance, data management, and soft skills such as teamwork and project collaboration. This industry-academia partnership enhanced the learning experience by aligning classroom activities with real-world industry expectations.

3.3 Quantitative and Qualitative Assessment

To capture a comprehensive view of the project's impact on student learning, this study employed both qualitative and quantitative assessment data from two iterations of the same graduate-level construction course. One iteration was delivered without a final project component in the spring semester in 2023, while the other, including the newly introduced DT class project, was delivered in the spring semester in 2024.

Quantitative data were primarily collected through the institution's Course Instructor Opinion Survey (CIOS), which provides numerical ratings from students on course effectiveness, amount learned, and other key metrics. To compare these two datasets, descriptive statistics were first used to examine shifts in average ratings, standard deviations, and response distributions across key survey items. Subsequently, open-ended comments from both iterations were analyzed thematically, focusing on patterns related to course rigor, practical relevance, and engagement. This mixed-methods comparison enabled the research team to isolate the impact of the newly introduced DT class project from other instructional factors. Triangulating quantitative ratings with qualitative reflections provided a more nuanced understanding of how experiential, hands-on projects can enhance student motivation and better align conceptual learning with real-world professional demands.

4. Project Implementation Details

This section explains the implementation of the DT class project, where students were tasked with creating and maintaining a DT of a campus facility using the following workflow: selecting the facility for the DT, acquiring data through reality-capturing technologies, integrating BIM and COBie-compliant data, creating the DT using WireTwin, and enabling real-time data monitoring.

4.1 Building Selection and Data Acquisition

Students selected a campus library as the focus of their DT project. The selection was guided by two criteria: accessibility and the availability of some existing spatial data, such as floor plans, and images, as well as the presence of "OccuSpace" occupancy sensors and the facility manager's interest in the project. After selecting the facility, students performed the reality capturing tasks, including laser scanning (see Figure 2-a and Figure 2-b), 360-degree reality capturing and point cloud processing technologies (see Figure 3). Figure 2 outlines the initial workflow, which involved utilization of Faro laser scanning technology for automated point cloud generation and surveying. While these methods provided a foundational understanding of this technology, challenges such as misaligned reference points and outdated scanning tools compromised the quality of the generated point clouds.

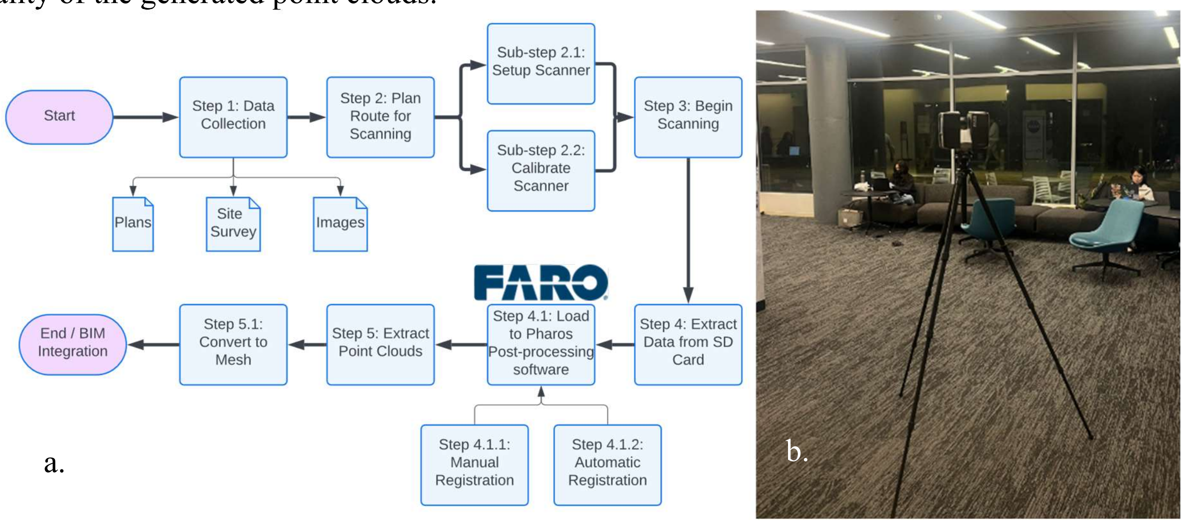

Figure 2. Reality capture process alternative 1 - laser scanning

To address these challenges, students transitioned to an alternative workflow, illustrated in Figure 3-a. This approach involved using the Insta 360 camera to capture 360-degree videos, followed by data processing with CUPIXVISTA to generate high-resolution 3D point clouds (see Figure 3-b). This workflow included steps such as setting up the routes for camera, recording 360 videos, transferring data, and leveraging automated point-cloud processing to generate an accurate point-cloud representation of the building. This transition significantly improved the quality and alignment of spatial and geometric data, enabling us to establish a robust foundation for subsequent BIM integration.

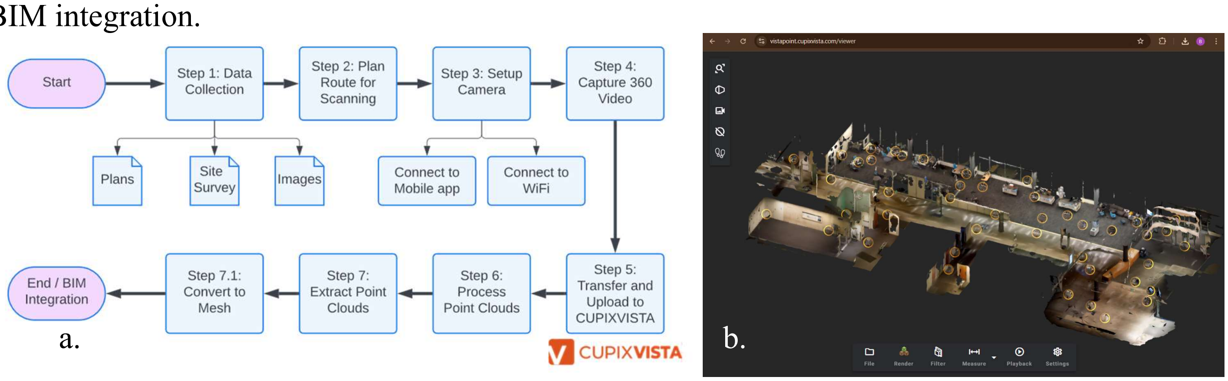

Figure 3. Reality capture process alternative 2 - Insta 360 camera and CUPIXVISTA

4.2 BIM Integration and COBie Compliance

Following data acquisition, the processed point clouds were imported into Autodesk Recap and subsequently into Revit to perform the modeling tasks in a BIM platform. The process, outlined in Figure 4, involved creating detailed building components, including walls, doors, floors, and furniture. These elements were assigned specific object-based variables with standard terminology and structure compliant with COBie, as required by the WireTwin platform which follows open BIM processes. The use of the COBie standard and of OmniClass classification for rooms, systems, and equipment as required by WireTwin, allowing students to enhance the model's functionality for facility management and real-time occupancy data reflection.

Challenges during this phase included discrepancies in data exchange between platforms, particularly scale and orientation issues when integrating point clouds generated by CUPIXVISTA with the Revit modeling environment. Figure 4 highlights how students resolved these issues by employing clash detection and iterative model adjustments to maintain consistency. Collaboration among team members, including effective communication and task allocation, was critical in overcoming these challenges. Additionally, feedback from library management and WireTwin associates guided refinements in the workflows, ensuring alignment with project goals and requirements.

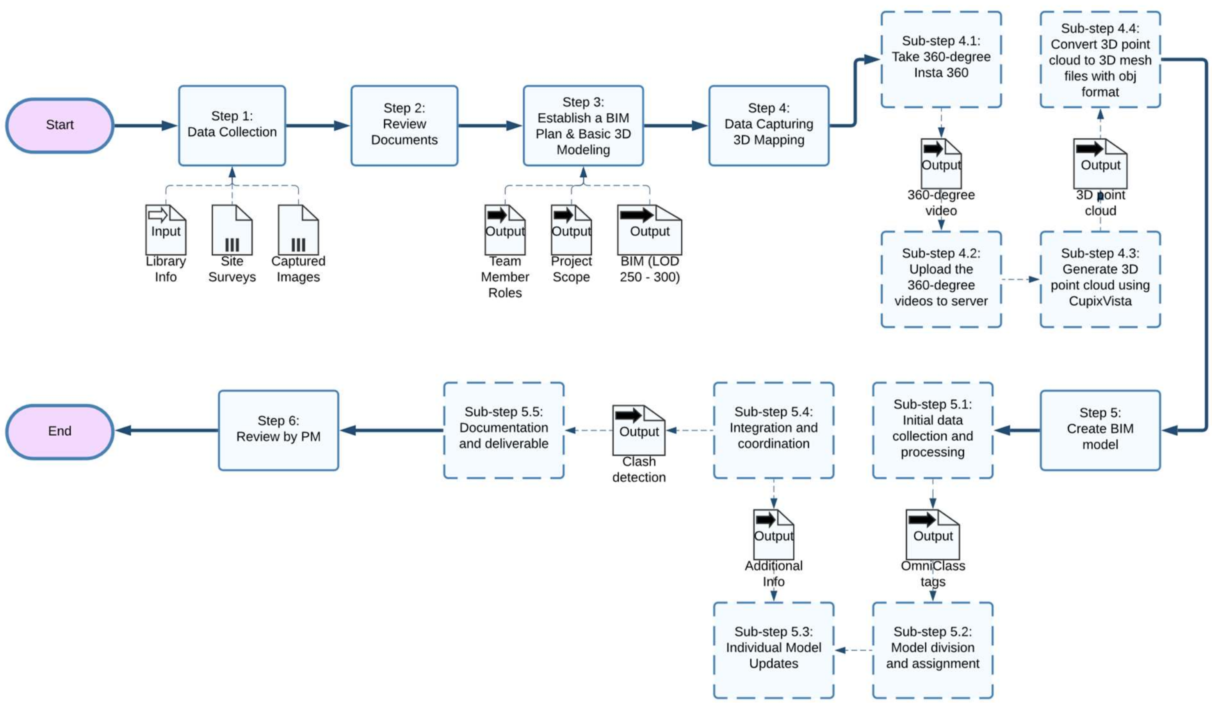

Figure 4. Building Information Model integration

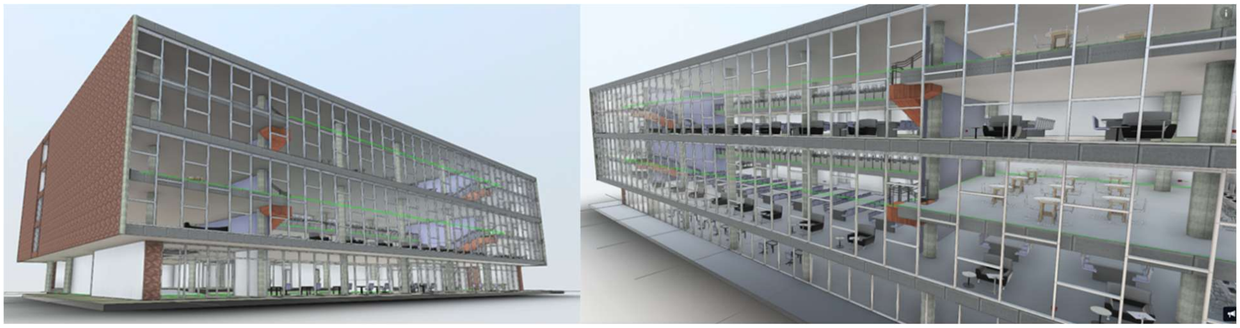

Figure 5. BIM model of the campus building

The finalized BIM model, with a Level of Detail (LOD) of 250-300, was uploaded to the Wiretwin platform (see Figure 5). This step ensured interoperability and positioned the model for further enhancements, such as real-time data integration.

4.3 Real-Time Data Monitoring

Real-time data integration was a key feature of the students' digital twin model. Using OccuSpace sensors, students captured data on occupancy and space utilization, as illustrated in Figure 6. These sensors were strategically placed based on insights from building management to ensure comprehensive coverage. The live data streams were linked to the BIM elements, creating a dynamic DT model capable of reflecting real-world conditions in near real-time.

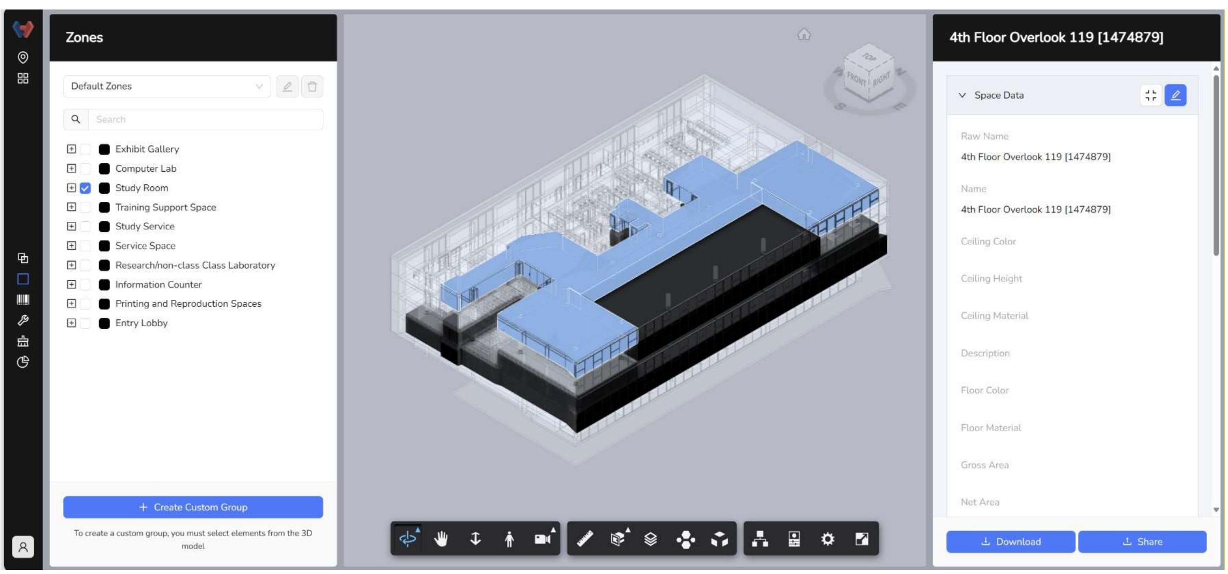

Figure 6. Digital Twin on WireTwin platform

Furthermore, students developed a profound understanding of the practical utilization of the DT on the WireTwin platform through pilot testing and implementation. They simulated maintenance task assignment and completion scenarios, which highlighted how a Digital Twin platform could optimize facility management and maintenance routines in comparison to current practices. By integrating predictive maintenance, operational optimization, and real-time 3D space utilization insights, the students' Digital Twin model demonstrated its potential as a valuable tool for facility management and strategic planning of the campus library.

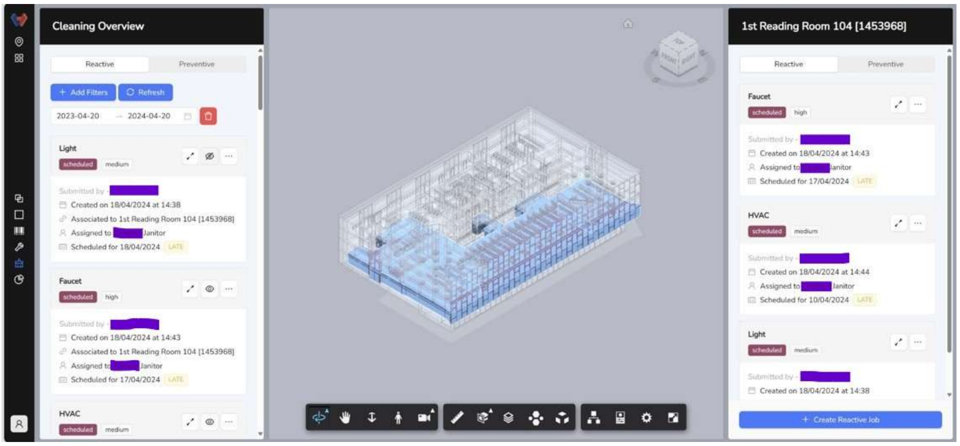

Figure 7. Task assignment on WireTwin platform

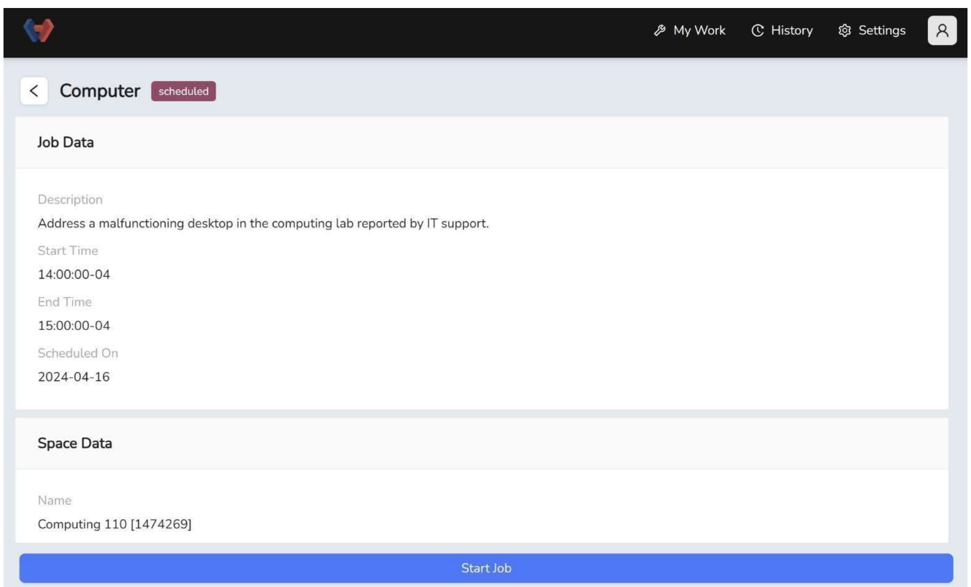

Figure 8. Task details including task description, time, and spatial information

5. Results and Discussion

This section explores and discusses the project's impact on student learning by analyzing qualitative and quantitative assessment results from 2023 and 2024.

5.1 Quantitative Results from Post-Project Surveys on Student Confidence, Motivation, and Technical Proficiency

In 2023, the course focused on the theoretical development of digital twins without offering hands-on activities. Four out of seven students (57%) completed the CIOS survey. In 2024, by contrast, a collaborative and hands-on DT project was introduced that required 3D scanning a real facility, interactive building modeling, and data integration, to which five out of six students (83%) responded.

The practical emphasis in 2024 is evident: average weekly study time doubled from four hours in 2023 to 8.6 hours, largely due to tasks such as laser scanning, BIM modeling, and sensor data integration. On a five-point scale, students in 2023 rated their perceived learning at about 3.5, reflecting a basic conceptual understanding but limited confidence in applying these concepts to real-world projects. The overall course rating was 3.75, indicating that, while students saw potential, they felt a practical component was lacking. In 2024, "Amount Learned" increased from 3.5 to 4.8. This improvement could be attributed to structural tutorials, timely feedback, and early introduction of hands-on experience like 3D scanning.

5.2 Qualitative Insights from Student Reflections

Student reflections on the DT class project provided deeper insights into how this experiential learning experience shaped both their technical and collaborative skills. While some students focused on the mechanics of digital twin development such as laser scanning, BIM modelling, and interface refinement, others highlighted user-centered design and interdisciplinary teamwork as critical for efficient project delivery. Three major themes were discovered in reflections:

- Practical Hands-on Experience: Students valued the opportunity to create an actual digital twin. Rather than simply memorizing concepts, they engaged in challenges like collecting and converting raw point-cloud data into usable 3D BIM models, which became key learning moments that reinforced their technical expertise.

- Collaboration and Teamwork: The project fostered a dynamic, team-based environment. Students frequently mentioned coordinating schedules, assigning tasks based on individual strengths, and maintaining clear communication. When they encountered issues, such as point-cloud alignment failures or digital twin errors, they worked together, drawing on interdisciplinary skill sets to find efficient solutions.

- Stakeholder Feedback: Brief interactions with the campus library's facility managers highlighted real-world operational and technical demands. While students initially proposed detailed BIM models with labelled rooms and COBie elements, the facility managers requested simpler features for broader usability. This feedback prompted students to balance advanced technological solutions with user-friendly design.

6. Conclusion

This study demonstrates how an experiential learning approach, integrating reality-capturing technologies, BIM, and a Digital Twin creation platform, can significantly enhance graduate students' technical competence, collaboration and communication skills, and professional readiness in construction education. By employing Kolb's experiential learning cycle and involving industry partners, higher engagement, increased study time, and measurable gains in student confidence were observed. Specifically, CIOS results indicate a significant increase in the "Amount Learned," from 3.5 in spring 2023 to 4.8 in spring 2024. This result aligns with Kolb's experiential learning cycle, where concrete experience and active experimentation lead to deeper conceptual understanding. By integrating Digital Twin projects into advanced construction courses, this study contributes to the body of knowledge by providing a practical model for bridging academic theory with Industry 4.0 demands. It illustrates how emerging technologies could boost professional readiness, aligning curricula more closely with AECFM industry expectations.

As for limitations, the small sample size constraints generalizability. Moreover, although Kolb's framework informed course design, no formal experiential learning metrics were used. Future work should expand this approach to multiple courses and institutions, incorporating direct assessments of experiential learning and exploring its long-term impact on graduates' professional competence.

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