

Integrating Digital Twins in Construction Education Through Hands-on Experiential Learning

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Abstract

This paper examines the value of including digital twin technology as a hands-on learning activity in a graduate-level building construction course. The methodology of teaching digital twins as a unit is presented, and the benefits of introducing this topic are examined within the framework of several learning objectives. The campus football stadium provided an opportunity for students to apply the digital twin skill to a real-life case. Feedback from the students was collected and is presented within the context of the intended goals.

Evaluation of the use of digital twins in this course found that the technique was highly valuable in providing a framework for students to understand the potential offered by various technologies in visualizing a facility throughout its lifecycle. Students more easily understood how each technology best fits and how several technologies could be used in concert with one another.

Keywords- Digital Twins; BIM; Asset Management; Facility Management; Preventative Maintenance; Digital Transformation

1 Background

This examination of the benefits that digital twin learning can offer in construction and facilities management education took place within a graduate level course, BC6005, which is offered each semester at The Georgia Institute of Technology. This course is intended to explore the Construction 4.0 framework and the various present and future technologies that contribute to this framework and can be applied in all stages of a facilities' life cycle. Construction 4.0 can be defined as the "organization of production processes based on

technology and devices autonomously communicating with each other along the value chain" [1].

Construction 4.0 relies heavily upon digital technologies and cyber-physical systems. Digital technologies include Building Information Modelling (BIM), Common Data Environment (CDE), unmanned aerial systems, cloud-based project management, Augmented Reality/Virtual Reality (AR/VR), artificial intelligence, cybersecurity, big data, and analytics, blockchain, and laser scanner.

Cyber-physical systems include robotics and automation, sensors, the Internet of Things, workers with wearable sensors, actuators, additive manufacturing, off site prefabricated construction, on-site construction, and equipment with sensors [2]. The course referred to in this report examines software and hardware tools and technologies such as virtual and augmented reality, laser scanning, drones, additive manufacturing, robotics, IoT, and others. The course introduces students to technologies they will use in various classes within the Building Construction curriculum at the Georgia Institute of Technology and industry. During the course, students work on hands-on tasks that provide the opportunity to develop practical skills with many of the technologies covered in the course.

The goal of the course is to provide a broad background and general knowledge through the following objectives, which are to be achieved by all students for successful completion of the course:

- Be able to describe the Construction 4.0 Framework and its importance for the construction industry.
- Understand and explain the various technologies introduced in the course and identify their use cases, including the concept, value, and application of creating digital twins and what technologies can be introduced and deployed on an ongoing basis, based on the use case
- Be able to identify the correct technology for

application to common construction issues.

- Functionally apply some of the technologies introduced in the class to practical situations found in construction environments.
- Work with stakeholders to identify specific needs in a real-life on-campus project.
- Confidently present the results of the application of a technology in solving a project need.

Digital twins are a digital replica of an actual physical asset. They integrate artificial intelligence, machine learning, and data analytics to produce simulation models that can be easily updated from multiple sources. In this manner, a digital twin represents the current condition of the asset [3]. The digital twin may be a physical instrument, social construct, biological system, or composite system. Building construction projects fall within this last category as a composite system, with both physical and social products [4]. Digital twins are comprised of a physical artifact, a digital counterpart, and that which connects these two [5]. This connection is made possible by the development of advanced sensing computer vision, the internet of things, and advanced analytics [6].

This paper explores the use of instruction of digital twin technology to enable students to better understand construction 4.0 and the technologies which enable it. This relates to both facility construction and facilities management. Using a digital twin to monitor a physical asset and analyze real-time parameters makes it possible to improve its operational efficiency. The Digital twin of a building can be used to improve its operation and maintenance efficiency by permitting facility managers to perform what-if analysis. This can be useful to enhance energy efficiency and improve users' comfort [7]. They can also be employed for such uses as life cycle and security planning. Such systems can enable facility operations and maintenance to improve operational efficiency from remote management and pre-planning asset maintenance and repair, such as illustrated in Figure 1. In this case an mechanical, electrical, and plumbing (MEP) room is shown with annotated physical assets connect to computerized maintenance management system (CMMS) and Internet of Things (IoT) sensors.



Figure 1. MEP room with annotated physical assets

Digital twin systems transform business by accelerating holistic understanding, optimal decision making, and effective action. They use real-time and historical data to represent past and predicted future states. Digital twins are motivated by outcomes, tailored to use cases, and powered by integration. They are built on data guided by domain knowledge and are implemented in IT/IoT systems [8].

A valuable collection of wide-angle visual data can be accomplished using Virtual Reality (VR) and Augmented Reality (AR) technology and 360 imaging. VR/AR is generally limited to an asset's design phase and special purpose build stages. This is attributable to the incapability of these technologies to feasibly document on-site progress in real-time [9]. For this reason, 360 imaging is a particularly valuable tool for developing digital twin models. This 360 imaging technology employs basic 360 cameras available at the consumer level. They permit rapid, low-cost visual data collection for current site conditions. Therefore, knowledge of 360 imaging techniques is critical to the understanding of digital twins for this industry sector.

2 Instructional Methodology

The digital twin assignment incorporated in the course included three parts. The first part included a series of three lectures delivered by guest speakers possessing extensive expertise in the digital twin domain. This part of the instructional assignment was conducted as an intensive one-week-long series of lectures and fieldwork. The lectures were conducted during regular class time, which is twice a week for 75 minutes each. The second part was performed by all students, working in groups of 2-3 students each. Here, the students focused only on 360 imaging as applied to digital twins. This promoted an understanding of what a digital twin is, and how they are created and employed on a job site. Upon completing this assignment, students undertook the third part which was a term project that included several technologies brought together by the digital twin framework.

2.1 Lectures

The initial instructional method included a series of 3 lectures. The purpose of the first lecture presented by guest Speakers Kelly Watt, CEO Visual Plan Inc., and Mark Schreiber, President of Safeguard Consulting, was to help students consider security design and safety implications through the building process. Most students had little to no experience with security considerations or what standards to consult. Design Twins were used as a tool to help engage subject matter experts early in the planning, design, and decision phases and throughout a project to provide oversight and ensure best outcomes. The example illustrated in Figure 2 illustrates the use of

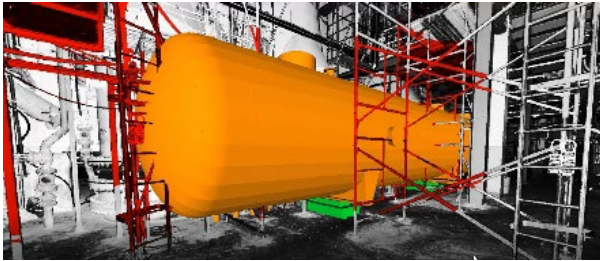


Figure 2. Point cloud and model of US nuclear plant

digital twins in design, planning and simulation to engineer a complex installation where room to navigate was less than one inch. Security was used as an example of an often-neglected process where early collaboration can drive value. Students were taught to think more broadly about facility lifecycle and all aspects and stakeholders pertaining to the site or facility rather than what is narrowly discussed in a project.

Key case examples from brownfield construction to existing facility improvement projects were presented. Comparing existing 2D Computer Aided Design (CAD) and Building Information Modeling (BIM) files to 360-degree panoramas through various project stages provided an effective means to communicate project information, and to identify issues, clashes, and change orders early. Case examples were used to illustrate the benefits of virtual collaboration, pre-planning, and involving subject matter experts early in projects and show where companies are increasing productivity, reducing re-work, and improving their bottom line.

The second lecture in the series was presented by guest speakers Kelly Watt and Amadeus Burger of Digital Plant Technology. Here students learned how digital twins are used post-commissioning for operational processes maintaining assets and facilities. Many of these processes are used together in a digital twin. Amadeus Burger spoke on specific projects creating and working with complex digital twins for nuclear energy and petrochemical plant maintenance. Students gained a clear understanding of the precision required for large equipment installs where lidar was instrumental. These applications drive clear differences between photogrammetry and lidar so students can better understand when to apply one technology over another.

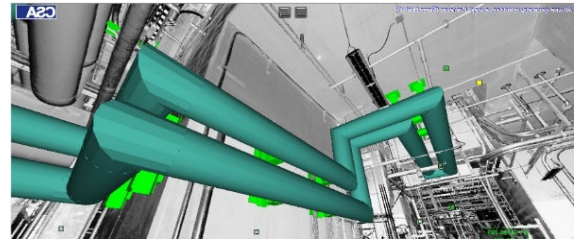


Figure 3. Point cloud/ piping model of a nuclear plant

Kelly Watt discussed methods that tie digital twins to computerized maintenance management systems, asset management, and real-time sensor and IoT devices. These integrations facilitate the ability of the digital twin asset to help produce precise operational efficiency. He presented case studies in nuclear energy and oil and gas production, such as is shown in Figure 3 where a digital model is used to facilitate quick identification of systems through a large and complex plant without the need to visit the site location. These studies illustrated how digital twins had been employed to reduce facility downtime and improve project turnover rates, thereby dramatically impacting project success and profitability. These examples taught students the strength and scenarios of selecting the appropriate technology based on the use case. The expected outcomes showed how digital twins gained unintended value when implemented.

Issues and scenarios impacting organizations from knowledge management, digital knowledge transfer, and employee turnover were presented as well as the challenges of managing operational change. This is where photogrammetry was presented as a game-changer in the speed of data collection, ease of use, and scalability. The benefits of digital representations and breaking data silos were demonstrated through case studies to offer significant gains for entire organizations.

A third lecture, presented by Kelly Watt, took place in small student teams conducted on-site at Bobby Dodd Stadium. Bobby Dodd is the football stadium and is located on the Georgia Institute of Technology campus. This session was given while seated in the stadium stands as shown in Figure 4. This was staged to give students a

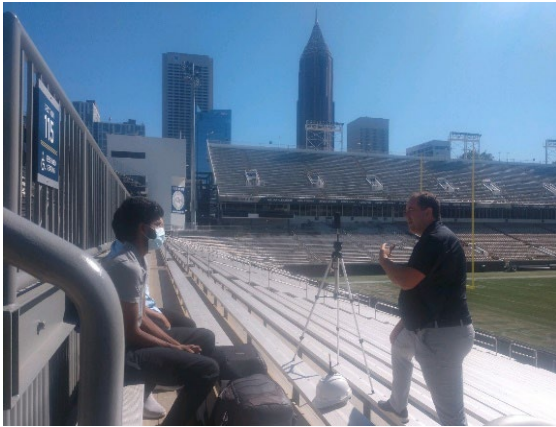


Figure 4. On-site lecture delivery method

feeling of being on a project site. The starting point for this lecture was a team discussion around the site capture approach, techniques, capture method (single panorama, cluster capture, video capture), and deployment methods (tripod, hardhat, pole, drone, 360Rover). Discussions included site preparation, staging, lighting, outdoor conditions like weather, prioritizing critical areas, and discussing what type of documentation is required for the scope of work, expected deliverables, and outcomes.

Also discussed were details concerning data collection using 360 imaging. This included level of data collection required, capture density, imaging within areas of repetitive architectural features, and capturing in difficult locations like ceiling spaces or small, constrained areas. Students were taught the differences in capturing data using lidar compared to photogrammetry, both from a technical approach and project deliverable perspective. The selection of appropriate technology considering specific applications was discussed at length.

The lecture also addressed lighting and capturing text in the field. Students learned how to approach data capture related to general site conditions, detailed site conditions, and asset documentation. Also discussed was scaling a project, taking a known measurement, placing an artifact in the space, or leveraging known object dimensions if accurate CAD/BIM are not available.

The lecture introduced how to use the native capture App and project settings. Students learned how to find their location in the 2D CAD and drop a marker pin at the start and completion of captured areas. Students were able to take this knowledge into their field capture and owner and stakeholder conversations in the term project phase.

2.2 Hands-on Field Data Collection

Following the lecture series, students worked in pairs and were assigned an area in the Bobby Dodd Stadium to capture. Each team applied what they learned on 360 imaging and judged how many panoramas to take and

where to capture them. They employed 360 cameras in conjunction with a field capture phone app to collect data (Figure 5). The camera was either mounted on a hardhat as depicted in Figure 6, or on a mobile robotic device. Each team was instructed on exact procedures to follow in data collection and monitored by the instructor. After completing the assigned capture area, each team reviewed their work and uploaded it for cloud processing. Students also learned how to identify assets, current nomenclature, tagging, and classification, as shown in Figure 7. Additional photography was taken to gather asset attribute details for the asset tagging project.



Figure 5. Digital Twin field capture app

The instructor then reviewed and provided feedback and points for improvement on the data capture exercise through a short video review and introduced the asset tagging assignment through a workflow document and video tutorial for the assignment.



Figure 6. Student collecting data



Figure 7. Asset tagging

Each student was next expected to tag ten assets, add attribute information and upload a photo of the asset nameplate with identification information. Figure 6 shows a stadium mechanical room 360 image on the right, floor plan in the centre and left display shows asset identified with attribute information collected and tagged by students on the left

The project delivery was an asset report from the Visual Plan software in PDF format used for review and grading. Some assets required online search for identification and to find operator manuals or other asset information. Students learned from this practical exercise the importance of organization asset information effectively. The instructor reviewed the tagging exercise and gauged student performance based on a designated rubric that determined the quality and completeness of the work done.

2.3 Term Project

Having gained an understanding of digital twins and essential field tools in creating these twins, students next had an opportunity to select from several of the other technologies introduced in the course to create a digital twin. These technologies included laser scanning and drone photogrammetry. Students also had the option of continuing with 360 imaging. Three teams selected 360 imaging, one team selected laser scanning, and one team selected drone photogrammetry as their technology tool.

The plan was to apply any one of these technology tools in a real-world setting. Bobby Dodd Stadium was used as the project setting. Students were requested to match the technology tool of their preference to a location in the stadium that was appropriate for the selected technology, based on their client's needs, in this case, the Georgia Institute of Technology facilities management department and campus police department. These departments are actual beneficiaries of this project and restricting the number of stakeholders that the students needed to consider helped facilitate this short project. The term project was divided into five parts;

1. Students selected team membership based on technology interest and available time for data collection and team meetings. Each team had from 4 to 6 members. The deliverable was notification to the instructor of team

membership and the technology tool selected.

2. Teams met during class with key stakeholders of the football stadium facility who included the campus Manager of Building Information Modeling/Virtual Design and Construction, Facilities Management, and the Lieutenant of the campus police department. Each student team obtained guidance from these stakeholders in developing a brief project scope that matched their technology tool to an appropriate physical setting which is of interest to the client. Students were instructed to keep their scope small enough to collect data in 1-2 site visits. The deliverable for this part of the project was the team minutes from this meeting and the brief project scope.

3. Data collection was conducted in 1-2 team visits to Bobby Dodd Stadium. Each visit was to be from 2-4 hours. The deliverable was a progress report of 1 page or less.

4. Data compilation and evaluation were then conducted appropriately for the technology tool employed. The deliverable was a progress report of one page or less.

5. Teams then presented their findings during the final class meeting of the semester. The stakeholder attended this presentation in the role of client beneficiary. A final team report was prepared and presented to the instructor at this time. These reports are to be combined with additional data collected on the stadium and presented to the University.

3 Student Feedback

Student feedback was solicited upon completion of the assignment to assess the effectiveness of meeting the learning objectives. This feedback was obtained by including a lesson learned question in the assignment and by posting a discussion board for voluntary feedback, including observations from the assignment. Seventeen comments were received on the discussion board, and 24 student comments received in response to the assignment lessons learned question. These comments were evaluated by the course instructor.

Consistent themes found in student feedback concerned the impact of digital twins on security and pre-incident planning for buildings, facilities, and operations, highlighting further opportunities for in-depth learning and application of effective building and construction pre-planning, documentation, and visualization to safety, security, and risk assessment. It was evident that each student experienced the curriculum differently. The learning outcomes inspired critical thinking on applying digital twin technology as a valuable methodology across various applications within their professional fields.

4 Findings

The use of digital twins provided a framework for understanding a range of technologies used in building construction. This framework proved valuable in a broad scope of learning objectives related to new technologies and relevant facility lifecycle applications.

Discussions with subject matter experts and guest lectures created a foundation for students to understand various visualization technologies and how they integrate to build digital twins to create long-term value during the construction process as well as throughout the building lifecycle post-commissioning: how the technology can be utilized beyond a single application across the organization, and how to set up facilities for success for operations, maintenance, security, and sustainability.

The introduction of 360 image capture was compared to 3D Lidar, SLAM, drone capture, and traditional survey to broaden the students' understanding of each technology and use case's differences. A key takeaway for students was to critically think through the scope of work, project requirements, site conditions, and existing project workflows to determine the best technology tool for the job and how various technologies work together to serve different purposes.

Knowing the stakeholders and their needs is key to approaching the project efficiently to meet the expected outcomes. The capture pre-planning helped students understand how the environment affects the data collection process, time to capture, and overall quality of data collected. Learning stakeholder requirements also helps the best approach to the project to meet desired business outcomes, whether the objective is project capture for construction, project oversight, asset management, or safety/security planning.

Inspecting existing asset tags on a campus facility, Bobby Dodd Stadium, allowed students the opportunity to apply earlier learning to an actual life project. This project incorporated asset characterization, attribution, and taxonomy. Students were presented with a real-world example of the challenges facilities managers face when asset information is incomplete or poorly organized by completing the asset tagging exercise. The term project allowed students to work together to combine technologies to solve a real-world problem. They gained exposure to a project cycle by working with a client to develop a project scope, complete it in a constrained period, and report results to their client. The University's knowledge that data collected would be used provided an opportunity to see firsthand why the technologies introduced in the course are essential within the industry. Finally, students were exposed to the importance of critical thinking to the effective implementation of the technologies introduced in the course.

The BC6005 course is comprised of a mix of students, many with several years of experience in

construction or facilities management and others entirely new to the field. This presented a challenge when covering digital twins within a short time period. Also, the class had an enrollment of 24 students. This made it impossible to provide access to camera and other equipment during the assigned class instructional period. Both students and instructors had to attend sessions outside of the class period. These additional sessions were offered throughout certain days.

5 Conclusions

The students' varied real-world experience, ranging from academic applications through to established professional careers, with specialties including civil engineering, construction, construction management, facilities management, architecture, and transportation, encouraged multiple perspectives and critical thinking on how digital twin technology represents a potentially valuable methodology across various applications within their professional fields.

The combination of lectures, discussions with subject matter experts, guided demonstration, and self-directed real-world application of various scanning techniques and 3D digital twin technology enhanced both the students' understanding of what constitutes digital twins and their ability to identify and assess which of the different visualization technologies can be optimized for each application workflow.

Through the guided hands-on capture project at the stadium, the students were able to engage with critical facilities and security stakeholders, learn how to identify overlapping project goals and outcomes, gain a crucial understanding of when and how to implement various imaging techniques, and how to process and present that data in an accessible, comprehensive deliverable to meet stakeholder needs.

Students effectively and functionally applied this learning through the term paper assignments, working directly with university personnel to identify specific needs in real-world applications on campus.

The real-world application of the course concepts underscored the accessibility and potential for adopting the technology into the construction industry and the process the students need to apply to integrate 3d digital twins into workflows effectively: identifying and understanding the scope of work, how to identify and mitigate potential issues, which technology is appropriate each application, and understanding project goals and outcomes across various stakeholders and their needs.

The benefits demonstrated by this instructional experience can be applied in the curriculum of building construction and facilities management programs at the university, and even community college level. It is expected that the incorporation of digital twin instruction into an institution's curriculum can be highly beneficial

for both graduate and undergraduate students. Students with knowledge of digital twin theory and methodology will have an enhanced ability to perform in the age of Construction 4.0. Such graduates will likely be in high demand as the construction industry further adapts to the digital environment. Further testing of the effectiveness of employing digital twin learning would be beneficial in an undergraduate course and at community colleges, as well as additional testing for graduate level education.

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