The Smart Campus as a Testing Ground for Smart Cities

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Abstract
As part of California Polytechnic State University (Cal Poly) Smart Campus Initiative, a multidisciplinary team of faculty from engineering and architecture colleges, are developing a digital twin of Cal Poly Campus that can represent and optimize the day to day college life and activities. In this paper, we have discussed the benefits, challenges, and opportunities of Cal Poly digital twin, and provide a set of recommendations for the application of Digital Twin in the higher education. A digital twin is a digital model, simulation and representation of a physical object. The application of this technology expands from built environment disciplines such as construction, and planning, to manufacturing and health care. The underlying concept of digital twin as a "dynamic software model of a physical thing or system" creates under-explored opportunities in various disciplines. The research team tested a model of digital twin by combining RFID and BIM technologies in order to integrate different type of real-time data, from environmental data to student movement, to create a useful tool for data driven decision making across campus units. This paper also discusses the benefits of students involvement in the process of developing campus digital twin through collaboration with companies such as Autodesk and Amazon Web Service (AWS). The presented pilot project results and discussions can be used for larger application at the other campuses and communities, while addressing a wide range of privacy, security, and ethical concerns.

Introduction

The global smart cities market is growing. From $99 billion in 2020 to almost $460 billion in 2027. This is a global movement for improving the quality of life and tackling some of the most challenging issues such as climate change, by using information and communication technology Universities have a critical role in growing implementation through training the workforce with cutting-edge skills and knowledge and conducting research and development. In addition, universities can play a bigger role, as a testing ground for innovation, and as a strategic asset in the smart city ecosystem. Students benefit from involvement in the process of developing a campus digital twin through collaboration with stakeholders including companies and an interdisciplinary campus community. Aside from their scientific merit, universities are the largest urban block owned by a single entity that can serve as a pilot site for several smart initiatives, including digital twins. A digital twin is a digital model, simulation and representation of a physical object.

Nowadays using digital communication including advance modulation techniques made the data transmission, data processing and digital representation much more efficient than before (Nhat. N.D, Malekmohammadi, A. 2015). Digital representations of real-world structures and environments can be extremely helpful in simulating and solving complex problems that involve these objects or spaces. Modern technology has made two-dimensional and three-dimensional digital representations of physical spaces widely accessible, and the most groundbreaking technological advancements are making entity simulation and tracking possible. Specifically, digital twins are enabling people and organizations to effectively approach problems through digital monitoring, analysis, and simulation. Public and private sectors understand the importance of digital twins, but they are unsure of how capable cities are to implement the technological system due to the perceived high initial costs and lack of current infrastructure. But

more than that, there is a lack of political will to invest in an avant-garde technology, when there are so few successful projects around the world that demonstrate the cost benefit potential. In such an environment where engineering and technology outpace policy and political will, university campuses can be the testing ground and demonstration site for Digital Twin technology.

As part of Cal Poly Smart Campus Initiative, we are working on a pilot project to create a digital twin for the campus beginning with one building area. This pilot project is a proof of concept for campus-wide digital twin to act as a model for data collection, analysis, and simulation. The immediate focus will be on minimizing the risk of infection by testing methods for monitoring students' movement on campus during the current pandemic. Its applications can get expanded to other aspects of campus life, such as campus security, energy consumption, space management, students' attendance patterns, and more.

Integrating the development of the digital twin with the learning mission of the university is the main goal of this project. The Digital twin platform is and will remain a work-in-progress. It is going to be a teaching and learning lab, where students and faculty experiment various applications and theories on the platform. Various classes across campus will be integrated with the development of digital twin and foster interdisciplinary projects. From construction management, electrical and computer engineering, computer science, to philosophy, and city planning, can play a role in the development of the digital twin, both in theory and practice. In this article, we provide a background information about digital twin technology and its application in higher education, and then we discuss our attempts in the development of the Digital Twin on campus, and the role of students in this process

Background

Students benefit from involvement in the process of developing a campus digital twin through collaboration with stakeholders including companies and an interdisciplinary campus community towards the outcome of an actual project. Planning, architecture, construction, and engineering education include core academic subjects such as statics, mechanics, planning, scheduling, estimating, methods and materials and focus on design and application. Lessons are usually delivered in individual classes utilizing a lecture format (Chinowskly, Brown, Szajnman, & Realph, 2006). But while the core courses are important, the knowledge conveyed in the core courses is insufficient to optimally perform construction operations towards completion of an actual project. Managerial, industry, business, professionalism, legal, contractual, technical, and people skills are required (Ahmed, Yaris, Farooqui, & Saqid, 2014). There are many ways to gain these skills in higher education. "The traditional segmented, topic-based approach to construction management curricula clearly has been successful at facilitating the attainment of specialized skills and concepts such as quantity surveying, estimating, or scheduling. However, the world does not always present problems that are topic specific and solved in a non-holistic manner" (Montoya, Kelting, and Hauck, 2009, p.66).

Learn by doing, hands on learning, experiential learning, active learning, service learning, project-based learning, and problem-based learning are variants on the schema of experience, observe, and reflect learning methodology, also called the theory of constructivism (Greenwood, Janke, Donegan and Schwab, 2017). This theory suggests that people are active learners building knowledge upon experiences and improving that knowledge through social interaction or groups (Frank, Lavy and Elata, 2003). Constructivist variants can in many instances be used interchangeably.

Learn by doing, understood as the teaching of the head and the hand, alludes to knowledge and skills acquisition through two processes, experiential learning and discovery learning. Experiential learning arises from self-reflective observations that accompany progressive iterations of hands-on-learning. Discovery learning arises from facilitative reflections that motivates students to discover new information by deduction and construction. Greenwood, et al. explain that learn by doing "…is an immersive, collaborative, process-oriented approach to the construction of knowledge and meaning-making that results in career-ready students prepared and committed to apply whole-system thinking to solve local and global problems" (2017, p. xvi).

Problem-based learning (PBL) is an alternative to traditional learning environments involving primarily lecture delivery (Yildririm, Baur, LaBoube, 2014). PBL features hands on learning with the goal of longer retention of the desired learning outcomes. PBL activities can demonstrate increased performance compared to a traditional classroom setting. Barlow states that soft skills typically not learned through passive learning are developed and honed through PBL (2011).

Spiral learning (SL) adds to the value of PBL by introducing concepts at various points. Veladat & Mohammadi list the goals of spiral learning as: "conceptualization, creativity, teamwork, individual work, to declare thoughts and achieve a hypothesis, to acquaint with terms, to apply images, knowledge, to interpret and criticize, learning, connect unfamiliar concepts with familiar ones, feeling trust, to extend information and the capability to maintain, pre-organizer, scientific thoughts" (2011, pp. 1118 – 1120). Built environment educators are tasked with developing students that can manage and lead an overall process, not just to excel at topic specific problems or isolated skills (Davis and Cline, 2009). The ideal way to teach these subjects and skills has evolved to PBL offering several pedagogical advantages for students where successful teamwork is required in the industry (Gunderson & Moore, 2008). As a consequence of combining PBL and SL student performance improved (Jamie, et al. 2016).

PBL can require more preparation time than lecturing often causing time related stress for instructors (Chinowsky, et al. 2006; Frank, et al. 2003). A further challenge of PBL is a lack of student knowledge prior to beginning the activity (Yildririm, Baur, LaBoube, 2014). Students in one PBL course often struggled to synthesize the individual subjects and skills from the topic specific courses into the integrated components of a complete construction related project (Benhart, Cabrel, Hummard, Metzinger, Morgan & Stanton, 2017). PBL often requires students to work in groups. Students working in a group can experience challenges such as: members dominating; members not contributing; pressure to accept differing ideas; and forceful conclusions (Gunderson & Moore, 2008). Some students struggle to solve vague, complex, real-world problems as they transition into industry. However, integrating these PBL classes across the curriculum gives students additional opportunities to solve these problems and reinforce the competencies required at graduation and on the job (Benhart, et al. 2017).

Students exhibit a preference for the way they learn and receive information (Kumar, Kumar, Smart, 2004). Frank, et al. found that students prefer passive learning that requires less effort on their part and are not familiar with an active learning environment such as PBL (2003).

However, Rokooei and Ford found that students and professionals perceive a studio-based curriculum as appropriate for construction management education (2019). Farrow, Liu, & Tatum found that students prefer learning activities that include experienced instructors, outside service projects, visualization, pictures and videos, field trips, discussions, student and group teaching (2011). Further, a recent study by Kolgraff, Kline and Kelting found that on a forced rank survey of fourteen different instructional delivery methods students preferred and perceived that the top two most effective methods were hands-on building and working in a team (2019). Through PBL and SL learning environments students feel that they learn and understand more (Gunderson & More, 2008). They also feel an advantage working with unknown individuals that are outside of their comfort zone. When real-world experiences were the project content in PBL, students were motivated to learn and work together more effectively towards their desired outcomes (Frank et al. 2003; Jaime et al. 2016; Maghiair, Sturges, Maurer, & Jackson, 2015). Students clearly benefit through involvement in the rich constructivist learning environment a real-world project with a specific purpose and a desired outcome provides (Cleary & Starzyk, 2020).

Digital Twin

There is no singular definition for "digital twin" due to the variations used by different industries (BIM, Laser Scan). However, most industries similarly define a digital twin as a dynamic virtual representation of a real-world object, process, or environment which can be updated with data from the real-world construct that is being represented (MIT Sloan). The real-world entity can be anything which exists concretely in the physical world. Digital twins differ from simpler digital mappings because of their ability to be updated from the real-world data. Also, digital twins differ from more basic simulation types as they can usually run real-time simulations for increased prediction accuracy, meaning that real data is input and real output data is observed, rather than simulations predicting without the ability to perceive real world results of their tests (Exor). This means that there is usually a data stream continuously updating the virtual model, or otherwise a way of incrementally and discretely uploading data to a digital platform which will update the model. Often, physical entities which are represented with a digital twin will have sensors on or around them which will have the ability to stream data to a digital twin representation. There is increasing conversation on establishing "digital twin" specific data standards or joining existing data standards such as 3d data – geometric, fast moving data – IoT standards to collate data input to increase efficiency. Further, this data stream can be analyzed in a predictive way to aid in decision making and simulate the results of that decision.

The importance of Digital Twin

High-speed advanced digital communication and cloud computing helped the researchers to develop many real-time monitoring systems (Oluwajobi, F., Nhat, D. and Malekmohammadi, A, 2018). e.g. Digital Twin. Digital twins are useful for monitoring systems of any size, and especially useful for tracking large or complex systems or objects which are difficult for humans to monitor effectively. This ultimately automates the process of watching for undesirable or notable states of the physical entity, and instead alerts humans when an event or condition of interest or concern arises. This often saves time, increases thoroughness of monitoring and safety. This data monitoring also provides opportunities for simulation of systems which humanity has been unable to consider in this way before. Digital twins serve as complex models

for the research of complex systems and entities by preserving resources, increasing safety and accuracy of simulations.

Application of Digital Twins

Digital Twins have great potential to optimize and visualize development as well as assist in the decision-making process for businesses and jurisdictions. Digital Twins do not belong to a singular industry or another. They rely on multiple systems to be successful. It requires an ecosystem to inhabit and gain data and make decisions. A recent large-scale application of digital twins in society is seen with the car and technology company Tesla (MIT Sloan). Each car Tesla produces has a unique digital twin, and this helps monitor the components of the vehicle. Sensors inside of the physical car send data to the digital twin which communicate the status of various components of the car. This is extremely useful in knowing how best to maintain the car, and it may speed up the process of repair, as users and mechanics will know the problem right away. The digital twin in Teslas also logs performance and usage information, which is useful in development for the company, and helps by delivering better iterations of the car in the future with things like increased safety and performance as well as greater energy efficiency.

While applications in automobiles are becoming more popular, applications in infrastructure systems for engineers are growing as well. There is a description of a digital twin of an oil rig which describes the progress in terms of production being the migration of data from being on a spreadsheet to being superimposed on a graphical three-dimensional CAD model (IOWorld Today). The transition of physical monitoring to digital twin monitoring has reportedly been a long time coming for the oil refinery industry.

The University of Melbourne developed an integrated system to help visualize various building envelopes. Users can adjust different development standards such as maximum height, setback, zoning overlays, etc. to help illustrate development impact. Communities and local officials can use similar visualization software like this to better understand the effects of development on a community. The University of Melbourne developed a spatial management system known as Space Man, which integrated university data (from the University chancellor office) into a dashboard system with four different hierarchies (Campus, Building, Floors, and Rooms) displaying building information (floor height, width, etc.). The application also includes indoor capturing of high-resolution images of inside the building for prospective users and includes measurement tools to measure the distance between two points. Space Man was described as a handy single stop tool and was utilized on the University's virtual opening day.

Digital Twins are still in their infancy and need larger buy in from policy makers and the public through a narrative change and use cases. Since data comes in various forms and defined differently by various industries, current technology lacks integration software to translate this data from various sources, which is an identified constraint to digital twin development. To build up a confidence in digital twins, universities and the business community need to document and build use cases to shift the narrative showing that digital twin campuses and cities yield dividends for stakeholders.

Recent Progress on Digital Twins

Digital twin abilities increase as computing power and network connection speeds increase. Because digital twins rely on the transfer of data, the faster this data transfer is, the

more powerful a digital twin system can become. With the onset of 5G networks, these systems will likely become even more useful, responsive, and accessible. The ever-growing "internet of things" technology, which just refers to networks of digitally connected physical devices, will also add to the progress of digital twinning (Garnsey). This is because with more devices being able to more easily share data and information, digital twin systems will be more powerful and complete. Greater connectivity means greater ability to utilize digital twins to monitor and simulate events in the real world.

The progress which has been building over time in the industry of digital twins is constantly allowing them to break into new markets and domains. This is because different domains have different requirements of speed, performance, and accuracy. As stated, the enhancement of 5G network infrastructure will likely be a huge step for digital twin abilities, because it will allow larger amounts of data to be transferred quicker over a network. With 5G coverage becoming more widespread over time, the speed of data transfer will be further increased, as speed and scale of coverage will allow data from far-away places to reach their remote destinations faster.

Paired with data transfer speed and coverage, data storage and backup on ever-growing cloud systems will allow digital twin systems to continue growing. There are more data warehouses than ever in the world, and most have very thoughtful disaster prevention systems in place to safeguard against data loss. These services have also become more and more affordable over time. This means that not only will digital twin maintainers be able to have their systems online streaming data to them, but that there will be reasonable ways to stream their data into logs that they can keep indefinitely with confidence.

Digital Twins in Higher Education

Both MIT and Stanford have statements on their websites about digital twin technology. Stanford university has applied digital twin technology to architecture, construction, and engineering in several projects to do what they describe as "improve value addition" to clients (Fischer, Agrawal). They describe "stream-lining" elements of the project that are necessary to increase value. Presumably this would mean that projects do need to be monitored over time by someone, but that by using digital twin technology, a machine is taking on more of this job and allowing humans to worry about the project development.

Meanwhile, the Copenhagen School of Marine Engineering and Technology Management is integrating digital twin content into their teaching curriculums as they believe they are the "reality of the industry" (Xcelgo). Students start by training the monitor of simpler systems such as a conveyor belt, and by the end of the course, they program a drill sequence which gives them valid real-world experience. Their digital twin program is reportedly very popular and expanding. Lecturers at the school encourage prospective learners to just get started, and they claim that the benefits that students will learn far outweigh the challenges they will face along the way.

Cal Poly Smart Campus as a testing ground for Smart Communities

This pilot project is the first phase of the Smart Campus initiative, and a proof of concept for campus-wide digital twin to act as a model for data collection, analysis, and simulation. The proposed digital twin is a virtual representation of a campus area, using real-time data to enable

understanding, managing and decision making across various units. The immediate focus is on evaluating technologies and systems to minimize the risk of COVID-19 infection by monitoring and managing the social distancing order on campus during the current pandemic. Its applications could expand to other aspects of campus life, such as campus security, energy consumption, space management, and students' attendance patterns.

In the first phase we teamed with the company VEC that tasked their two interns, also undergraduate students in the Construction Management major, to create a LIDAR point cloud capture of an existing campus building. The building chosen for the pilot project was the Construction Innovations Center at Cal Poly. The student interns then created a building information model (BIM) using Autodesk Revit from the imported point cloud data. Figure 1 shows a subset of the BIM of the Construction Innovations Center.
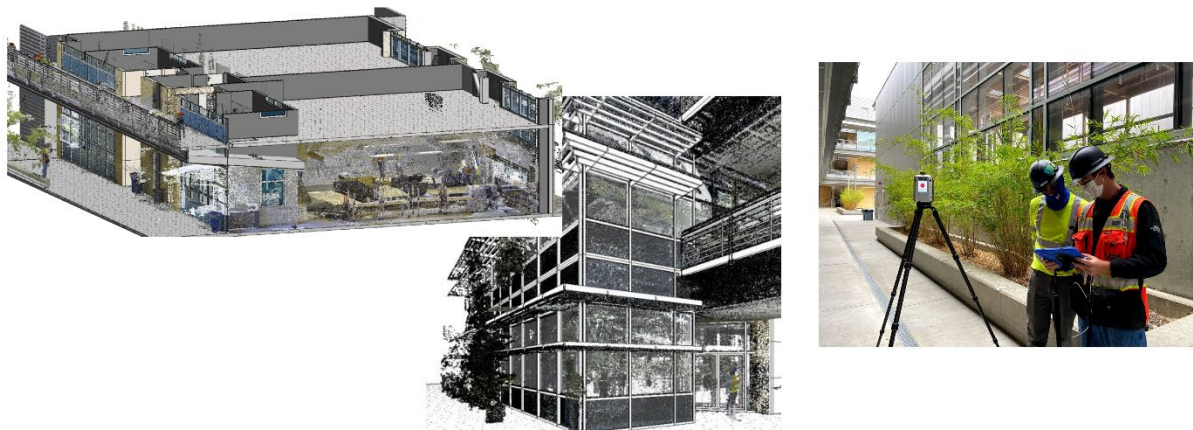

Figure 1: A subset of the BIM of the Construction Innovations Center

To monitor locations 32 RFID tags and 3 gateways were used to update location of entities on these models. The databases from the RFID system and the BIM of Construction Innovations Center were integrated on a web-based API platform called Autodesk Forge. The research team also created a software interface to display visual markers representing RFID tags in the 3D model in the Forge viewer.

In the immediate term, this could have applications to increase safety from the COVID-19 virus by monitoring classrooms for social density violations and contact tracing. This could also help measure the reality of testing different classroom maximum capacities, and the feasibility of keeping people 6 feet apart from one another.

RFID TAGS

The proposed system uses a Location Tracking System (LTS) RFID active tag with sensor capabilities that adds the ability for the tags to "talk" to each other rather than communicating through fixed RFID readers and antennas.

Using fixed Tags with known locations, we created fixed locations within Cal Poly campus, then we used mobile Tags issued to students that can be attached to student IDs to track their locations. Tag works seamlessly with an RFID asset tracking software solution that can dynamically display the location of Tags onto a map of our facility.

Our proposed system is an ad-hoc networked tag (self-generating mesh network) for RFID that requires very little infrastructure. The proposed active RFID tags offers a new way for tracking, monitoring and collecting data on campus. The tag-to-tag networking creates an ad hoc wireless network that is robust, reliable and reduces the amount of infrastructure needed for deployment.

Each tag connects to other tags to form a dynamic network of tags that can pass messages, such as location and sensor data, amongst each other. This technology allows for complete real-time monitoring with very little infrastructure requirements.

Tags operate as a Location Tracking System (LTS). Fixed Position tags are associated to a location. Each Asset tag dynamically calculates which Fixed tag it is closest to in order to determine its location. When an Asset tag is moved, its position is automatically updated and passed down the line until it reaches a system which is running to monitor network activity.

Our tags also provide its own API (Application Programming Interface) for interfacing with the network. Our software utilizes this API to provide complete support for tags. The tag Command Center, which is a module of our software, allows you to run every tag command possible. In addition, the tag Command Center also provides a map screen which will show the location of every tag within the campus.

The RFID tags use RSSI signal strength values to convey distance data to the gateways (O. Mohamed, J. Wang, and A. D. B., 2011). Signal strength degrades over distance, so if multiple gateways are picking up a signal from a single tag, the gateway that receives the strongest signal will most likely be the gateway closest to the tag. The way our system is designed to be used is: one gateway is placed in each room, preferably in the center (often mounted to the ceiling). That way, when the system detects which gateway is closest to a specific tag, it knows that the tag in question is in the room corresponding to that gateway.

System's Distance Measurement Accuracy

A test was carried out to measures the accuracy of the tag RSSI signals with respect to distance. Gateway was placed on the ground outside to a long hallway and recorded the observed signal strength of a single tag placed at various distances from the gateway.

This was considered as a "best case scenario' as there was nothing in between the tag and the gateway that could disrupt the signal, such as a wall. While there is a general trend of distance -> smaller signal strength, there is a margin of error in the accuracy of the measurements.
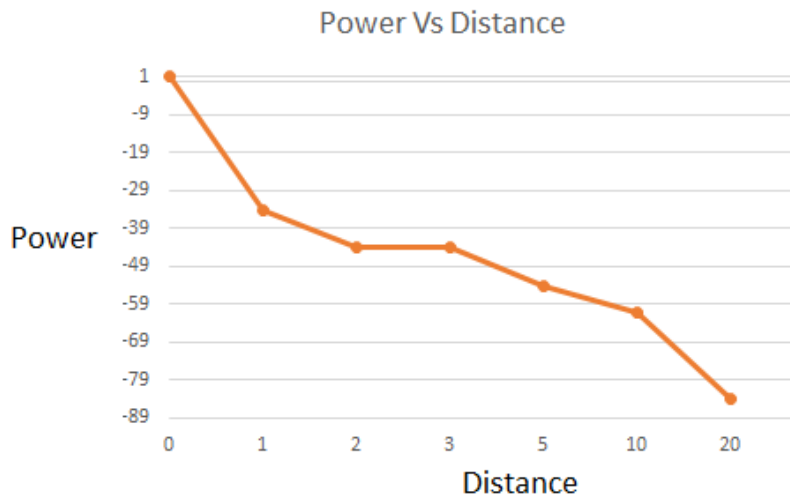
Figure 2: Signal Strength vs. Distance (gateway to tag)

Retrieving Location Data via API

Retrieving location data from RFID data management system for use in other programs/applications e.g. Autodesk 3D Model was done using an API and a Python script. Using this script and an API the data related to each individual tag and their corresponding locations can be selected and sent to another applications.

Data Privacy and Consent

When the development of digital twin systems involves personal data information, there are significant ethical considerations which must be made including privacy and security. There are different ways to care for these concerns, such as limiting the amount of data measured and tracked. Also, individuals and groups having their data collected must be fully informed of the processes and ramifications around this, and they should need to have their explicit consent delivered before they are monitored, or their data is collected. Furthermore, once data is collected, there must be processes in place to protect it, such as anonymity and digital data security protocols. These are issues which should be addressed in the development of digital twin systems involving human subjects.

Student Involvement

The curriculum of the construction management program at [university] is integrated. The program defines this integrated curriculum as a method of combining all of the core academic subjects into a single course under an overarching theme, such as residential construction, commercial construction, or civil construction. Construction management majors must take seven practice-specific integrated lab courses, each includes technical foundational information, estimating, scheduling, methods, material and a PBL component. Taken in sequence, these courses form an SL framework. Students in the program are encouraged to complete internships with industry companies to gain professional experience during the summer between academic years. For this project the student interns completed their work for VEC, in partnership with the university to gain experience and knowledge and apply it to a real world project scenario. The

students created a video recorded presentation to share the outcome of the project as well as reflect on their experience.

The authors reviewed the student's recorded presentation and identified constructivist learning indicators of experiential learning, discovery learning, PBL, and SL. The students indicated several experiential learning outcomes gained through working with an interdisciplinary team of stakeholders including to use of technical tools and software in Virtual Design and Construction, that learning through courses has to be relearned prior to application on the project, and due to the pandemic working restrictions, the students expressed gaining experience working with a team at a distance using communication tools such as shared files and Zoom video conferencing. Instances of discovery learning were identified as the students communicated that planning is necessary for successful execution, when the initial plan didn't work to have a backup or try something else, there is no quick way to gain experience other than doing the work, lessons learned from previous experience can be communicated to inexperienced associates to improve outcomes, and that more time invested doesn't necessarily lead to more outputs produced. The students also communicated that working on a real problem created better understanding of the required competencies, an indication of problem-based learning. The students further communicated that working as a member of a team helps improve individual skills previously introduced, an indication of spiral learning. Including students in the building of a digital twin platform and in data gathering clearly produced knowledge growth and applicable skills for the students involved in the project. Although these rich learning outcomes were experienced by a limited number of students, this process can be included in course work to reach a larger population of students.

Conclusion

This interdisciplinary project tested a digital twin model by integrating theories and technologies from BIM, sensing, and software engineering including applications that can be employed and adopted in campus planning. The outcomes of this project would help universities make informed decision and develop a safer campus environment.

Since data and information is packaged differently to various industries (different industries have different terms for the ultimately same product), we need to develop use cases that make information easily digestible to the general public. Digital Twin should be marketed as an access to data to inform decisions. The road map to creating a digital twin platform in the built environment should be streamlined and simplified for the specific purpose for wide adoption. Wide adoption should further increase availability and access to appropriate data streams increasing the usefulness of the digital twin. Simplicity of creation and wider access to data should lead the wider creation of digital twins to the creation of smart campuses and smart cities.

The RFID technology utilized in this test were clearly useful in tracking typically stationary assets in a location that can be tracked through a digital twin. This could be specifically useful for facilities professionals in tracking furniture, fixtures, and equipment. The RFID technology for tracking proximity or location of people for monitoring in the digital twin is clearly possible. However further investigation is necessary to determine proximity accuracy and the appropriate incremental real time tracking accuracy. Digital twin is clearly a tool platform that can be utilized to visualize data for analysis as demonstrated through the use of the RFID test.

Additional technologies should be tested in the digital twin platform to determine the best applications and sensors to achieve the desired outcome for appropriate decision making. In this pilot project, we found that one of the challenges for Digital Twin is the multi-source data sets and different data source standard specification. Therefore, utilizing a wider standard/open standard that can assist and integrate that data would be helpful. Future research should focus on integration of data from multiple sources in multiple formats for display on a standardized monitoring platform. Including students in the building of a digital twin platform and in data gathering clearly produced knowledge growth and applicable skills from the students involved in the project. Although these rich learning outcomes were experienced by a limited number of students, this process can be included in course work to reach a larger population of students.

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