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Implication of Developing Digital Twins to Improve Students' Learning Experiences

Dr. Mohammad Heidarinejad, Illinois Institute of Technology

Mohammad Heidarinejad, Ph.D. is an Assistant Professor in the Department of Civil, Architectural, and Environmental Engineering at Illinois Institute of Technology in Chicago, IL. Mohammad received his Ph.D. in Mechanical Engineering and his M.Sc. in Architectural Engineering, both from Pennsylvania State University. Previously he was a research assistant professor and research associate in the Mechanical Engineering Department at the University of Maryland College Park. Mohammad is recipient of several prestigious awards, including the ASHRAE New Investigator Award as well as IBPSA-USA Emerging Technology Award in support of his early career research. Mohammad is a registered professional engineer (PE). Mohammad teaches several courses such as Instrumentation and Measurements in Building Science, Energy Conservation in Building Design, HVAC Systems Design, and Control of Building Environmental Systems. Mohammad is also the Co-Director of The Built Environment Research Group (BERG) at Illinois Institute of Technology where he leads research in the areas of building energy and environmental systems, building automation systems, computational fluid dynamics, and indoor air quality. He is also a university wide award, named Michael J. Graff Award for Innovation in Teaching, at IIT for his novel teaching.

Prof. Ankit Srivastava, Illinois Institute of Technology

Prof. Srivastava is an Associate Professor in the department of Mechanical, Materials, and Aerospace Engineering. His expertise is in the general area of mechanics with specific interests in wave propagation, homogenization, metamaterials, and data driven modeling. His pedagogical interests lie in utilizing emerging technology to provide modern and relevant learning experiences to students.

Implication of Developing Digital Twins to Improve Students' Learning Experiences

Mohammad Heidarinejad[1] and Ankit Srivastava[2]

[1] *Department of Civil, Architectural, and Environmental Engineering, Illinois Institute of Technology, Chicago, IL 60616, USA*

[2] *Department of Mechanical, Materials, and Aerospace Engineering, Illinois Institute of Technology, Chicago, IL 60616, USA*

Abstract

This paper focuses on demonstrating how course modules could be developed via digital twins to improve students' learning experiences. The authors have taught a course named "creating digital twins of the IIT campus" two times in fall 2021 and spring 2022 and have leveraged inexpensive resources as well as open access and open-source tools to engage students in the process. The course started with utilizing iPads equipped with low-cost Lidar sensors to create the digital twins of campus. Students from different disciplines, ranging from architecture, engineering, computer science and engineering deployed different software packages, including but not limited to AutoDesk ReCap, AutoDesk Revit, Blender, Cloud Compare, Rhino, and Open3D package in Python to construct points cloud data in a 3D map space for campus buildings. Students created, collected, and combined the 3D data which will form the foundational layer of the digital twin. Then, they demonstrated the implications of these scans to: (i) create an entire scan of a new building on campus and develop building drawings (e.g., AutoCAD) and models (i.e., Revit); (ii) develop a game to utilize the scans; (iii) conduct asset management of the campus resources enabling to visualize the rooms, space information, and additional layers of information such as schedule of classes or inventory of furniture; (iv) utilize the scans to infer knowledge from the domain; and (v) demonstrate the use of the scanned data for the virtual reality (VR) for visualization, game development, other applications using Oculus headsets. This active learning process was under instructors' supervision, and they continuously provided guidance on how to work through the steps of problem-solving from the perspective of different disciplines. Students worked as teams to also identify stakeholders that would benefit from potential solutions. We also utilized a novel dissemination process and asked students to create YouTube videos. Overall, this paper is an ongoing effort to expand these active teaching usecases and include them in other courses, especially Architectural Engineering courses, in the near future to enable students to benefit from these functionalities in a digital twins domain.

Introduction

As we observed in the past three years, the COVID-19 pandemic has greatly influenced the ability of faculty and instructors to teach, and students to learn, using conventional approaches [1–3]. A sudden adaptation of teaching and learning from home during COVID-19 has especially impacted those courses that require hands-on learning activities, which suggests that our current curriculum designs for these types of courses may not be able to deliver the intended learning outcomes effectively [4]. It is reasonably expected that many institutions and students will face limitations in attending conventional classroom settings in the foreseeable future. One pedagogical shift to address this limitation is to leverage innovative technologies that to date have been utilized primarily only for research projects. Using Digital twins is an innovative technology that utilizes digital representations of physical objects and processes such as buildings and their systems, has the potential to transform remote learning by providing simulated hands-on experiences that are similar to those used in in-person settings.

A digital twin is a virtual representation of a real-world physical system or product (a physical twin) that serves as the indistinguishable digital counterpart of it for practical purposes, such as system simulation, integration, testing, monitoring, and maintenance [5]. Utilizing digital twins has been employed in previous ASEE efforts as highlighted in a few studies [6,7]. This paper summarizes our methods and learning outcomes for engaging students in building different teaching solutions that could assist in teaching students.

Methods

The course used for this demonstration is a unique course at the Illinois Institute of Technology (IIT) named The Inter-Professional Projects Program (IPRO) that all undergraduate students from different disciplines need to take six credit hours to finish their undergraduate degree [8]. IPRO is a unique feature of IIT curriculum, which usually comprise diverse teams, leading to creative ideas and better solutions to sustainability problems [9,10]. The pilot was conducted in fall 2021 and spring 2022 and the name of the course was IPRO 497: Creating Digital Twins of IIT campus [11]. The first semester was focused on the exploration of different resources to use inexpensive and open source and open access tools.

As Figure 1 shows the students lead testing the inexpensive iPads for scanning and capturing points cloud. A point cloud is a set of data points in space which these points may represent a 3D shape or object. The second spring in spring 2022 was focused on testing different educational applications. The entire idea for these IPROs was on developing digital twins of the IIT campus. Students utilized iPads equipped with low-cost Lidar sensors to create the digital twins of the campus. Students from different disciplines, ranging from architecture, engineering, computer science and engineering were part of this cohort for deployment. In addition, different software packages, including but not limited to AutoDesk ReCap, AutoDesk Revit, Blender, Cloud Compare, Rhino, and Open3D package in Python were used to construct points cloud data in a 3D map space for campus buildings. This IPRO was focused on creating, collecting, and combining the 3D data which will form the foundational layer of the digital twin to create the reality capture. Students started with testing different iPad applications, including but not limited to SiteScape, Forge, Scaniverse, and Polycam as each software tool had different capabilities in terms of the output formats (e.g., e57, ply). Students's experiences in using SiteScape is summarized here [12]. Students cleaned and merged the scans in order to create a clean digital twin of each building. After that in order to engage students in an active learning, the instructors provided insights to students about the direction of the class and worked with them to advance this experiential learning into different directions.

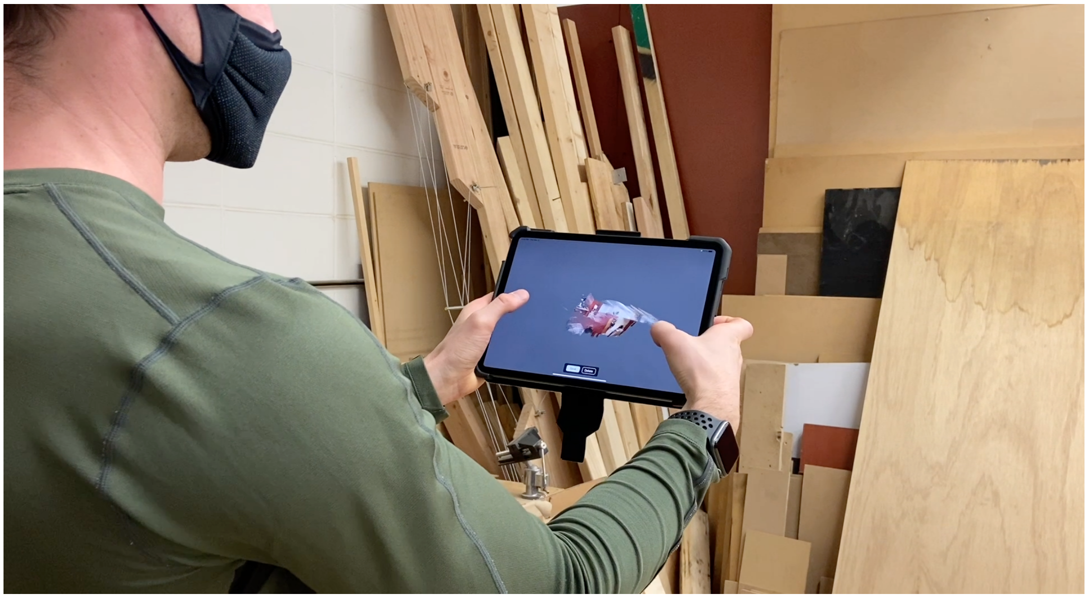

Figure 1. A student testing an inexpensive iPad for taking Lidar scans.

The hypotheses for the applications tested were:

1. Taking Lidar scans using different iPad apps and importing the points cloud data of the campus buildings in digital twins for further demonstration in other hypotheses.
2. Leveraging existing mechanical and architectural drawings of campus buildings in addition to the digital twins to develop Building Information Models (BIMs) for buildings or developing new architectural BIM for the activities in other courses.
3. Extending the BIM model to infer knowledge about the mechanical systems such as the air distribution systems and piping systems.
4. Creating an entire scan of a new building on campus that could be used in Architectural Engineering courses and other courses at IIT.
5. Demonstrate the use of the scanned data for the virtual reality (VR) for visualization, game development, other applications utilizing reality headsets (e.g., Oculus or Hololenses) to walk through different aspects of the digital twins for engineering applications such as inspecting the mechanical systems.

Throughout the whole process, the instructors provided guidance on how to work through the steps of problem-solving from the perspective of different disciplines. Students formed a team of five to six students and tackled these hypotheses to identify solutions. The group formation had the following requirements:

- Each group had five to six students, entailing different disciplines.
- Each student was responsible for working on the deliverables course project individually and as a team.
- Each student had a separate grade for individual and group parts of the project submissions.
- There were regular weekly presentations in addition to the final group project submission and presentation.
- Each group was required to present their report at the end of the semester during the final exam time.

Finally, the results and outcomes We also utilized a novel dissemination process and asked students to create YouTube videos as documented here:

https://www.youtube.com/channel/UCJ64bvoqH0GeADpEy3GZX8Q/videos

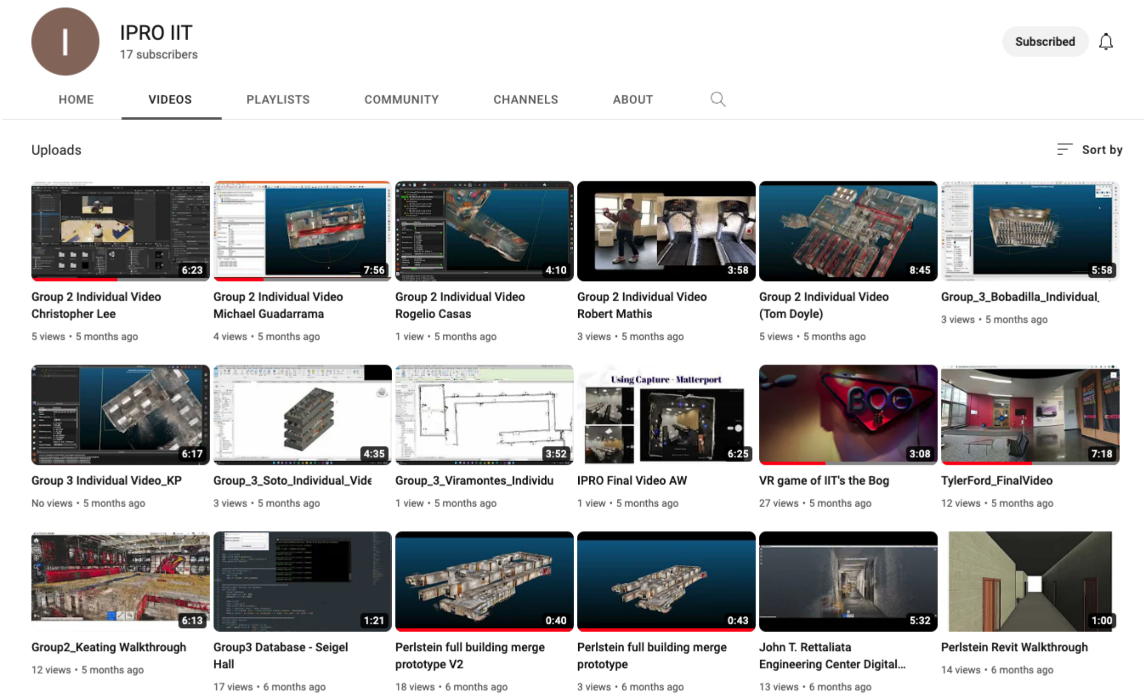

Figure 2. An overview of the IPRO YouTube videos.

Results

To ensure the given tasks are manageable, the tasks were divided into starting from individual small object scans, building a room with a neighboring corridor, and then extending further to include the entire floor and building. Figure 3 shows an example of scans for small objects that were created as an early task for students to build their competency. In Figure 3(a), a student captures the Man on a Bench artwork sculpture at the IIT campus [13] and in Figure 3(b) and Figure (c) they capture an object in their daily interactions.

(a) *(b)* *(c)*

Figure 3. Scans of small objects.

Figure 4 shows the scan of the room that was created to show how the scans could create a small office area. This task required taking at least more than one scan and students had to learn how to take scan segments, merge the scans, and visualize the scans.

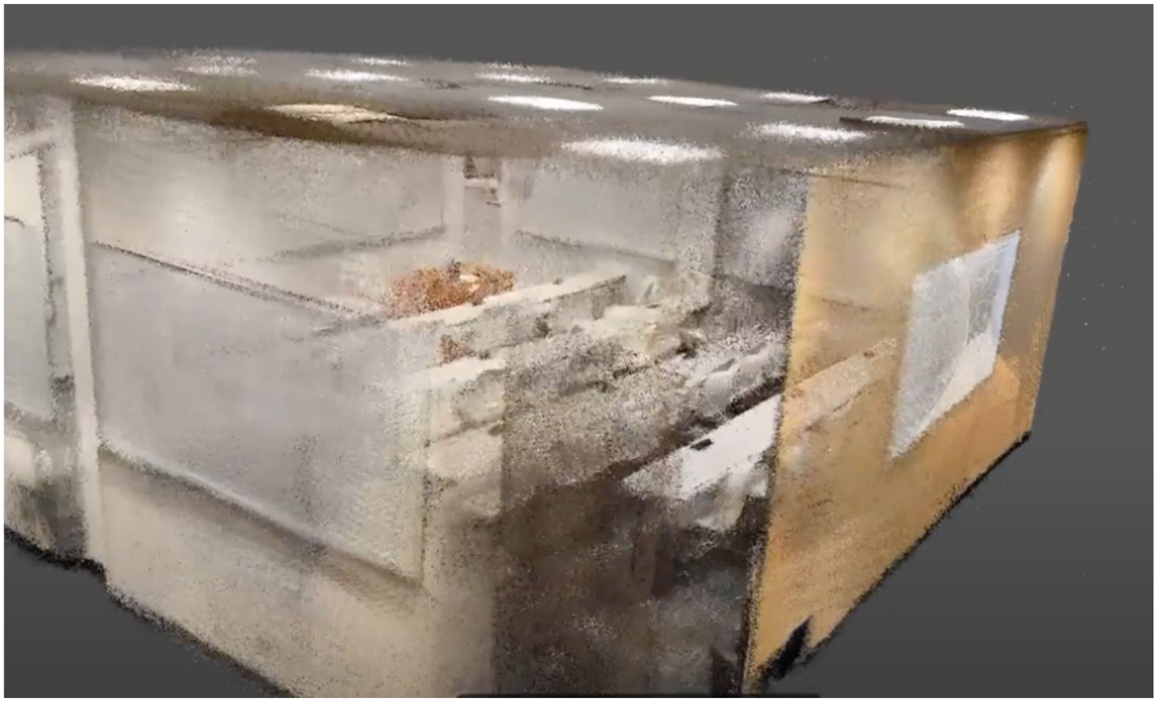

Figure 4. Scan of classroom as the second task for students.

Then, in the next steps, students aimed at building the entire building and creating walkthrough models. As Figure 5 to Figure 7 show, students were able to create the entire building and demonstrate the results in points cloud software tools.

Figure 5. Walking through the building and corridor as the points cloud are noticeable.

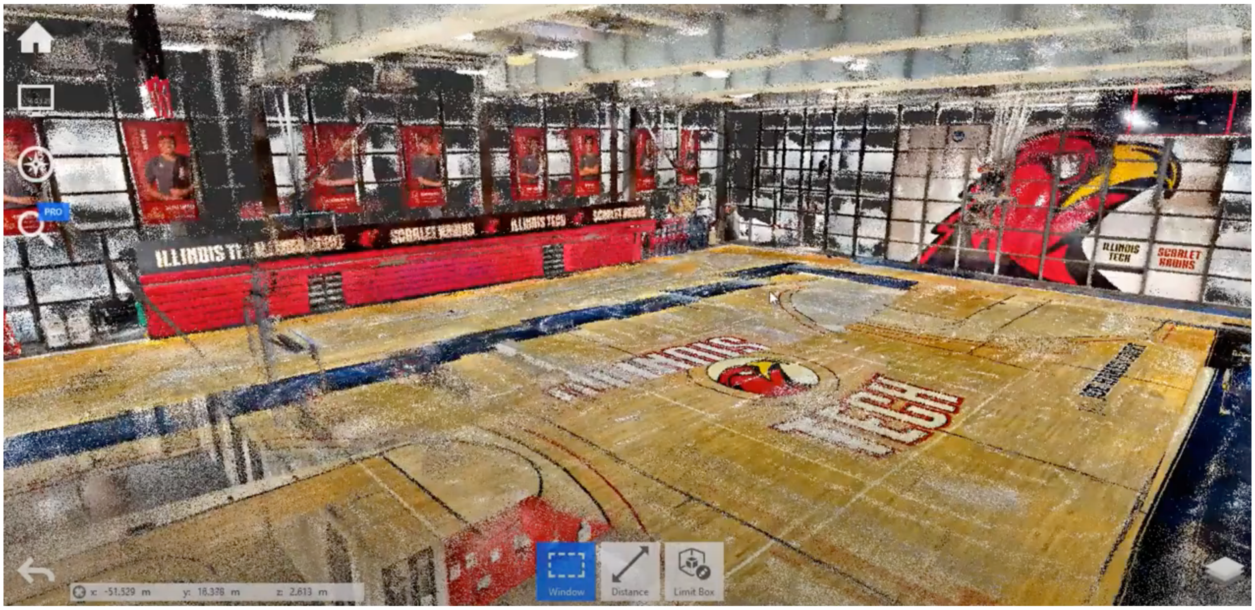

Figure 6. Demonstration of the gym facility as the points cloud are noticeable.

Figure 7. Demonstration of the entire building in CloudCompare software tool.

It is important to note that the above models required taking several scans (i.e., 75 scans and 80 million points in Figure 6) and even the completed models such as the one in Figure 7 required downsizing the scans and points from +500 million points to 195 million points. The students were very skillful towards the end of each semester, and they were able to take multiple scans effectively, downsize the number of points easily, and merge the scans quickly in order to use the scans for the next steps of the course deliverable.

Finally, students were ready to utilize all the efforts to create the BIM Architectural model for the building. As Figure 8 illustrates, all the scans were converted to a Revit model. The hope is to utilize this model for different courses in Architectural Engineering courses at IIT, such as the CAE 464/517: HVAC Systems Design and CAE 461: Fire Protection and Plumbing to add the mechanical, electrical, and plumbing (MEP) model. It is important to note that these campus buildings are old, and no digital AutoCAD or Revit models exist for them.

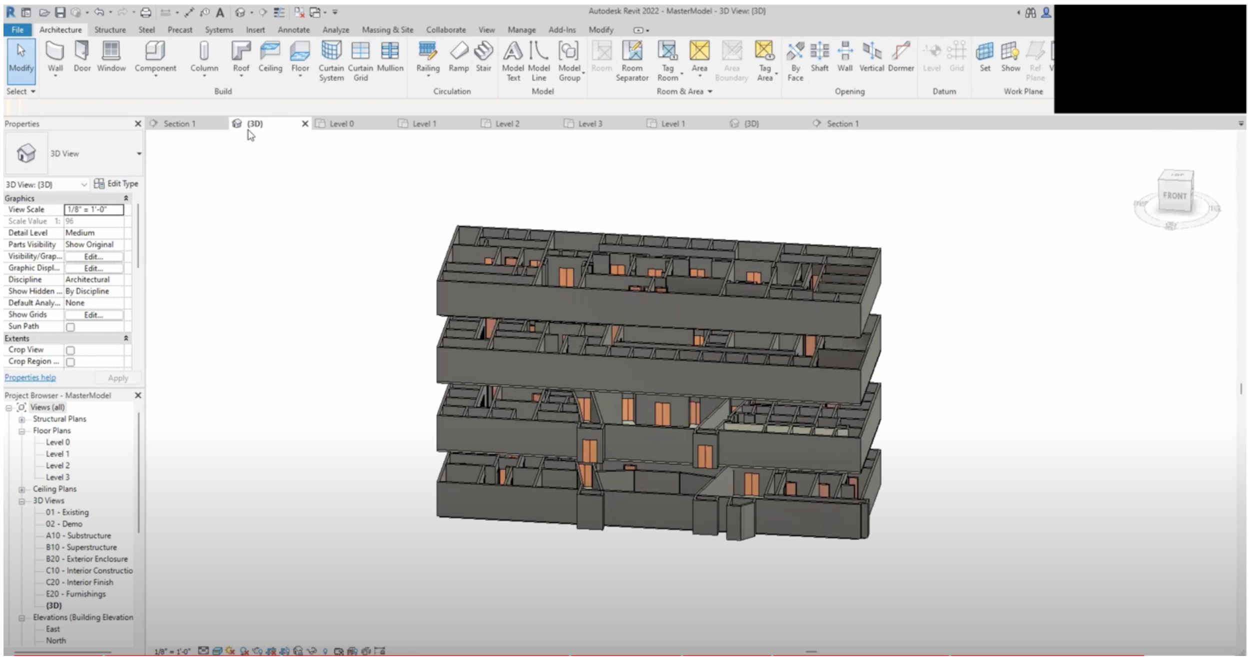

Figure 8. Architectural Revit model of the building.

The last step towards creating the digital twins and additional resources were to demonstrate how VR games and creating tools could be utilized. This step enabled students to develop a VR as an immersive capability to utilize the scans and the reality capture points for an interactive teaching environment. Figure 9 depicts an example of a VR game that was created from the Lidar scans and the game was built in Unreal and Unity software. As students pointed out "the team use various new tools and techniques we have not encountered before" which was a unique learning opportunity for them in addition to preparing games. The process was to utilize the lidar reality capture scans and points of the real-world environments, to importing the scans into CloudCompare and Blender to edit and prepare them, to uploading them into the Unreal and Unity engines to use as a game setting. They created digital scans of the BOG, a popular gathering space for students with an eight-lane bowling alley and created a VR game. The results demonstrated how mini games in VR could be used for future usage in the proposed courses to show the building mechanical systems (e.g., air handling units, boilers, chillers) and train a workforce who knows the building systems in an immersive environment.

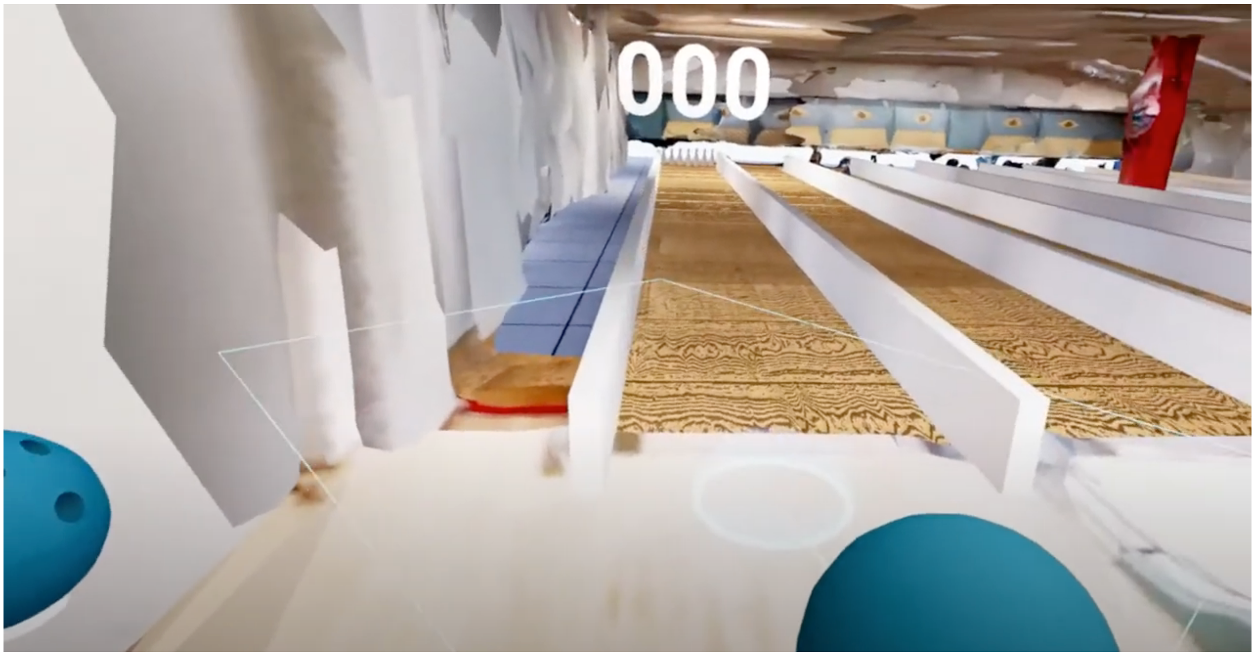

Figure 9. VR game developed from the scans.

Figure 10 shows how students created a virtual tour of the inside of a campus building using the Lapentor tool. Students used scans, took photos to represent the rooms and added information points to each room. The next layer of information was to add the class schedules. This would give a great sense for undergraduates not familiar with the building a great chance to familiarize themselves.

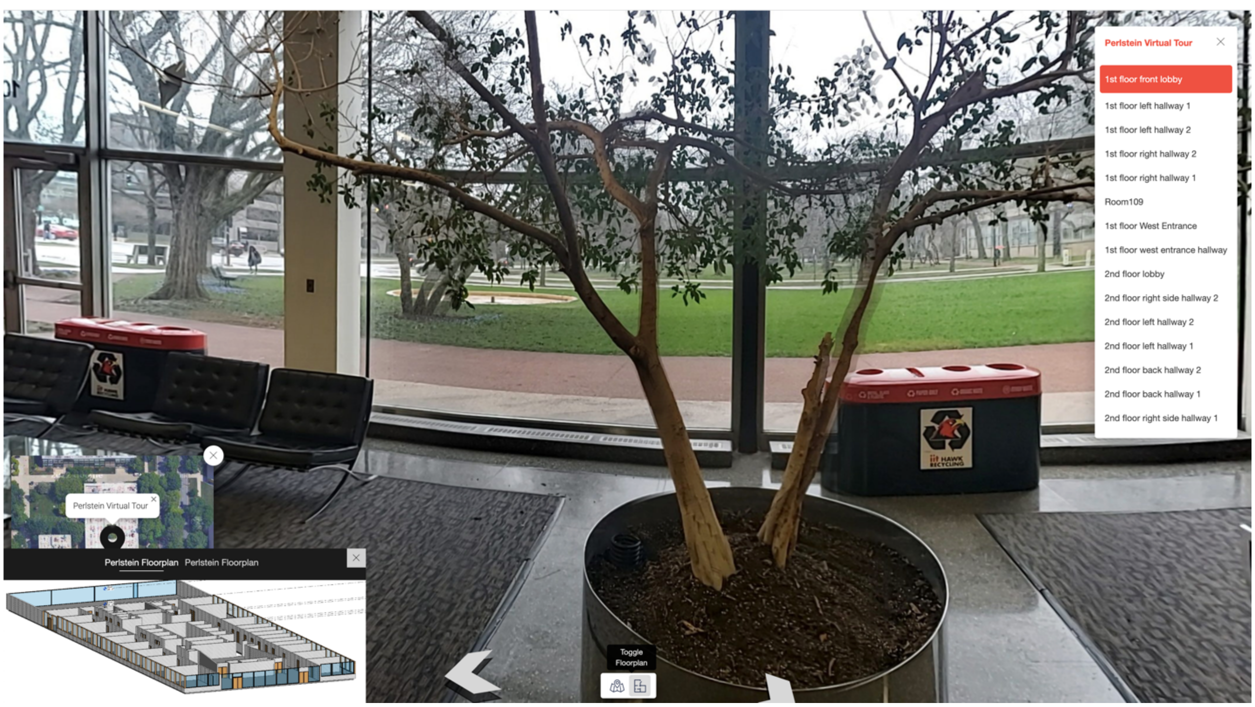

Figure 10. Asset management tool created from the scans.

The proposed digital twins' models will translate all the physical domains, including geometry, spaces, building systems (i.e., mechanical, shades, lighting) into one main data model that bridges physical and digital worlds, allowing demonstration novel teaching solutions to students. This work is in progress and the aim is to incorporate these use cases and their functionality in existing MEP courses to benefit from digital twins and create a new teaching environment in addition to traditional hands-on teaching. More than 50 students participated in the two semesters and engaged in active learning.

Conclusion

The results of this demonstration indicated digital twins are an effective tool to assist with developing teaching resources. This course design enabled students to form multi-disciplinary teams to build the resources. The results of this yearlong effort show the potential of digital twins to develop best practices in using digital twins for synchronous remote teaching to facilitate undergraduate students' tangible learning of a variety of topics under a range of real and scripted scenarios. The course engaged undergraduate students enrolled in the selected courses to train a cohort of students who are familiar with the concept of digital twins and prepared the next generation of the workforce who are trained with the idea of digital twins. In addition, this course and the results will be integrated into undergraduate programs to introduce students to research that is aligned with workforce development or graduate school preparation. Overall, this paper discussed the process on how digital twins can be applied to a variety of disciples and aid in student learning.

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References

[1] C. Carrillo, M.A. Flores, COVID-19 and teacher education: a literature review of online teaching and learning practices, European Journal of Teacher Education. 43 (2020) 466–487. https://doi.org/10.1080/02619768.2020.1821184.

[2] M.F. Wyne, S. Akhtar, M.A. Rahman, Impact of COVID-19 on Faculty Teaching and Student Learning, in: ASEE Conferences, Virtual Conference, 2021. https://peer.asee.org/37278.

[3] B. Karimi, M. Yazdanpour, P. Lewis, COVID-19 Effects on Higher Education: A Case Study, in: ASEE Conferences, Virtual Conference, 2021. https://doi.org/10.18260/1-2--36857.

[4] R. Sengupta, A.E. Sparkling, Incorporating Virtual Reality in Construction Management Education, in: ASEE Conferences, Virtual Conference, 2021. https://peer.asee.org/37324.

[5] M.A. Austin, P. Delgoshaei, M. Coelho, M. Heidarinejad, Architecting Smart City Digital Twins: A Combined Semantic Model and Machine Learning Approach, Journal of Management in Engineering. 36 (2020).
[6] A.M. Madni, D. Erwin, A. Madni, Exploiting Digital Twin Technology to Teach Engineering Fundamentals and Afford Real-World Learning Opportunities, in: ASEE Conferences, Tampa, Florida, 2019. https://doi.org/10.18260/1-2--32800.
[7] Zhenhua Wu, Work in Progress: Enable Digital Thread and Digital Twin Learning Environment for Cybermanufacturing Education, in: ASEE Conferences, Tampa, Florida, 2019. https://doi.org/10.18260/1-2--33611.
[8] IIT, Interprofessional Projects (IPRO) Program, (2023). https://ipro.iit.edu/.
[9] H. Arastoopour, M. Shahidehpour, J. Clair, IIT Campus as a Sustainability Living Laboratory for Education and Research for Students, in: ASEE Conferences, San Antonio, Texas, 2012. https://doi.org/10.18260/1-2--21471.
[10] N. Depaola, P.R. Anderson, R. Cammino, B. Haferkamp, L. Shunia, E.M. Brey, J. Mohammadi, F. Teymour, Experiential Learning Opportunities Exploring the Impact of Engineering Solutions – A Collaborative GenEd-Engineering Effort, in: ASEE Conferences, Seattle, Washington, 2015. https://doi.org/10.18260/p.24058.
[11] M. Heidarinejad, A. Srivastava, IIT Digital Twins IPRO, (2022). https://ipro.iit.edu/course/497-307-iit-digital-twin/.
[12] G. Corke, SiteScape massively expands iPad / iPhone LiDAR scan area, (2022). https://aecmag.com/reality-capture-modelling/sitescape-massively-expands-ipad-iphone-lidar-scan-area/.
[13] Chicago Park District, Man on a Bench | Artwork, (2023). https://www.chicagoparkdistrict.com/parks-facilities/man-bench-artwork.