INVIGORATING AEC EDUCATION USING MINECRAFT: A CASE OF LIDAR SURVEYING AND VIRTUAL LEARNING

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Abstract

The AEC industry is undergoing a digital transformation, which is leading to partially blended learning modes in collaborative and interactive learning environments. However, online meeting software has been found to have limited capacity when it comes to teaching and learning complex geometries and systems in AEC courses. To address this issue, this study conducted a collective case study on the use of Minecraft's game engine to enhance the teaching and learning (T&L) of university-level AEC courses, including 3D-LiDAR surveying, as-built 3D modeling, analytics and simulation, and underground structures. The study results suggest that a programmable and interactive world, though having some limitations, can still benefit students' learning. The analysis shows that gamified environments like Minecraft are particularly encouraged for the T&L of emerging digitalization technologies. To further improve future research, we recommend that computational quantity and material analytics be included, along with an open library for exchanging neutralized T&L materials.

Introduction

The rapid advancement of information and communication technologies (ICTs) has provoked a digital transformation in the architecture, engineering, and construction (AEC) practices and operations (Jacobsson et al., 2017; Xue et al., 2020). New digitalization tools and technologies, such as Building and City Information Modeling (BIM/CIM) and Geographic Information Systems (GIS), naturally embrace the prosperity and development in the AEC industry (Singh, 2014). As AEC companies increasingly adopt digitization, they require a new labor force capable of collaborating and communicating with ICTs (An et al., 2021). Due to the increasing demands of semantically-rich models and smart construction, Light Detection and Ranging (LiDAR) has become a significant trend in 3D surveying, serving as an important means of capturing 3D geometric information with millimeter accuracy (Xue et al., 2020). Meanwhile, higher education has encouraged AEC students to acquire skills and knowledge of emerging technology to meet the new competence expectations from industry partners (Haldorai et al., 2021). Therefore, today's AEC education is facing more opportunities, where not only traditional face-to-face or lecture-style teaching works, but blended learning modes also play a significant role in collaborative and interactive learning environments.

Online teaching and learning (T&L) has no 'one-size-fits-all' formulae (Sweet et al., 2022). AEC courses are no exception. The way we emotionally and cognitively experience our built environment is on the cusp of a technical revolution as well as a change in how humans experience physical space (Wang et al., 2020). The increasing mixing of virtual and physical environments, both physically and perceptually, is one of the specific effects on pedagogy (del Carmen Ramírez-Rueda et al., 2021). This has implications for how we study and teach architecture and construction, in particular, a subject that is closely tied to how we see, interpret, and learn about spaces and buildings (Olowa et al., 2022). Although online meeting software, such as Zoom, has made it easier to establish communication networks, online courses must be carefully designed with consideration of how students and educators perceive the purpose and value of interactions (Mielikäinen, 2022; Haldorai et al., 2021). The passive one-way mode of knowledge dissemination is limited in mobilizing all students, particularly in AEC courses involving complex geometries and systems. Thus, 3D or interactive T&L content is demanded to improve virtual T&L for AEC courses.

Figure 1: University virtual events hosted in 3D block campuses (UC Berkeley, 2020; Meisenzahl, 2020)

Minecraft is a multiplayer cross-platform sandbox video game that often replicates a virtual world from the real world (Microsoft, 2022). With over 140 million monthly active players (ActivePlayer, 2022), Minecraft is one of the world's most popular games. In Minecraft, a player has a first-person avatar in a voxel-based environment consisting of cubic blocks (Microsoft, 2022). Players can co-create fanciful structures from a variety of materials, interact with other players, and accept quests. Minecraft satisfies an important principle of effective learning (Callaghan, 2016) while having a connection to reality (see Figure 1). Due to the heavy planning and assembly of 3D shapes, which recruits greater levels of spatial skills, Minecraft could also serve as a valuable tool for supporting and developing spatial reasoning skills (Baek et al., 2020). Minecraft Education Edition (MCEE) is a specialized version for educational settings (Kuhn, 2018). In comparison, MCEE focuses on educational purposes such as code training, flood simulation, and 3D view shedding (Hébert & Jenson, 2020).

For T&L of emerging AEC technologies, Minecraft can also serve as a technique-aided solution for intuitive learning from the learner's perspective (Andersen & Rustad, 2022). AEC education is changing, with its focus shifting from the traditional theory-based curriculum to technology-mediated learning, such as architectural BIM designing (Chegu et al., 2016), 3D GIS surveying (del Carmen Ramírez-Rueda et al., 2021), and LiDAR sensing (Wu et al., 2021). In such learning, the initial and fundamental step is to understand and master the professional tools, such as Revit for building modeling (Xue & Lu, 2020a), ArcGIS for urban analytics (Li et al., 2023), and CloudCompare for point cloud editing (Wu et al., 2021). However, processing massive data is never easy for a qualified expert, which can leave students with an obscure understanding of knowledge. Moreover, the advanced computer environment is indispensable for running such professional AEC software, and the little engagement of students may lead to less attraction. As a result, adopting Minecraft, mixed reality, and mobile visualization methods in AEC education is reported to improve students' spatial perceptions, redefine construction information delivery, and enhance T&L activities for AEC education (Raes et al., 2020; Baek et al., 2020).

For better understanding of how AEC students use Minecraft as an educational tool when working in groups to learn a subject-specific skill, the research objectives of this study are:

(i) To enrich students' learning experiences in complex and non-intuitive technologies.
(ii) To help educators on 3D interactive T&L contents, and
(iii) To promote learners' collaboration and multidisciplinary teamwork.

By achieving the research objectives and analyzing research outcomes, we expect to have insights for enabling MCEE for AEC courses, such as general tips for using MCEE as an educational tool for AEC-specific T&L and implications for the responses of AEC education to the post-pandemic era.

The primary contribution of this study is the utilization of Minecraft with Python coding for T&L of complex 3D objects and systems in AEC education. The findings provide insights and additional knowledge regarding 3D LiDAR surveying and as-built modeling. For AEC educators, the presented approach helps realize spatial visualization and interaction, proactive co-creation, and vibrant gamification as part of a learning design.

Methodology

This study utilizes a mixed-method approach to enhance the pedagogical approach to AEC education. Figure 2 displays the conceptual research design of this study. First, a T&L case is selected, and the participants are identified. Next, two emerging technologies, 3D LiDAR surveying and virtual learning, are designed using Minecraft Education Edition (MCEE Ver. 1.14.70) to meet the T&L objectives of the target case. Based on the participants' feedback, this study presents the Minecraft-assisted T&L designs and analysis for additional AEC education scenarios and the post-pandemic era.

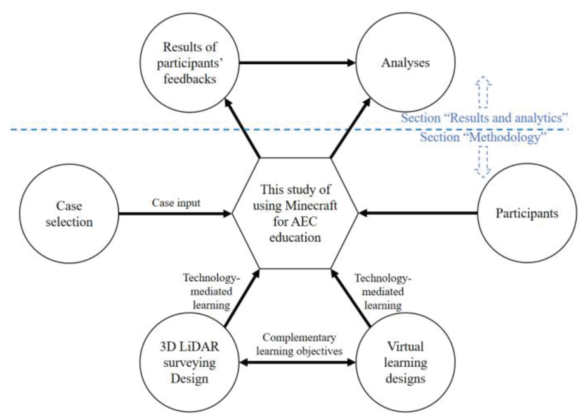

Figure 2: Conceptual research design of this study

Case selection

The case study course, RECO7613: Information Technology in Design and Construction, was offered by the Department of Real Estate and Construction at The University of Hong Kong (HKU). The course aims to teach students novel information technology (IT) approaches in design, construction, and operational contexts. It incorporates hands-on practices and case studies to demonstrate and analyze IT approaches for current construction processes and long-term innovation purposes. RECO7613 is a core course for the Master of Science in Integrated Project Delivery and is also available as an optional credit-bearing course for students from other departments. The collective case study investigated the use of Minecraft Education Edition in teaching and learning activities focused on LiDAR surveying and virtual learning for RECO7613.

Participants

A total of 20 taught-postgraduate students from the university participated in this research study. Most students had a background in AEC, while the rest had non-AEC majors such as Accounting and Human Resource Management. Similarly, most students had experience working in the local AEC industry. Students were initially grouped with a prioritized diversity of backgrounds. This case course also utilized a modular teaching approach. Participants were exposed to the presented study through theoretical learning content, group-based classroom tutorials, after-class group discussions, and a written assignment with general and open-ended questions. Finally, participant feedback was collected from the assignments for summary and analysis. It should be noted that all students and teachers at HKU have free licenses for MCEE for educational purposes.

T&L designs

3D LiDAR surveying

The new T&L designs for the case course included LiDAR surveying and Minecraft-based virtual learning. For LiDAR surveying, the first step involved 3D scanning. In the selected case, the target scan area was the Sun Yat-Sen (SYS) Steps at the Main Campus of HKU, as highlighted in Figure 3(a). The Paracosm PX-80, a handheld mobile LiDAR device, was utilized. The device can capture 360° LiDAR data at an accuracy of ±2-3 cm, with 300,000 points per second, and at ranges up to 80 m. The device includes a scanning app on an iPad mini that mounts on the handle for easy control and visual feedback on progress. A detailed hands-on guide for using the PX-80 was distributed to students, as shown in Figure 3(b).

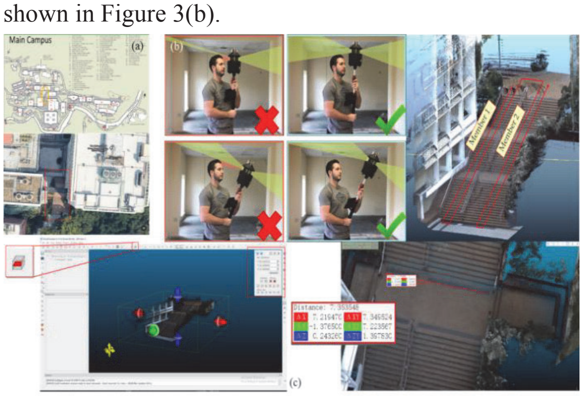

Figure 3: 3D LiDAR surveying for Minecraft. (a) the surveying area; (b) scanning instructions; (c) 3D measurement using LiDAR points

The next step involves editing and measuring the 3D point cloud using professional software called CloudCompare (Ver. 1.12). Students can preview the 3D scan of SYS Steps in CloudCompare, as shown in Figure 3(c). A cutting/slicing panel is used for parametric adjustment, 3D arrows for interactive adjustment, and temporary trim saving. In addition, 3D measuring tools, including points, segments, angles, and areas, were utilized in the experimental case.

Virtual learning: As-built 3D modeling

Three scenarios were created to cover different T&L topics: as-built 3D modeling, virtual campus co-creation, and understanding underground structures. In the first scenario, students were instructed to plan a gamified surveying project called "Anyone-Can-Build" for laypersons. As-built 3D modeling can be a slow and tedious task (Xue et al., 2019), so the T&L goal was to ensure that students understood how to utilize the surveyed LiDAR data in a group-based coursework. Specifically, there were three tasks to complete:

- Task 1: To reconstruct a 1:1 as-built model of the surveyed SYS Steps;
- Task 2: To test selfie function on the Minecraft SYS Steps; and
- Task 3: To try design, decoration, and renovation for SYS Steps in Minecraft.

In Task 1, a new "Flat" world is created in "Creative" mode in MCEE. The dimensions of the target areas are then identified, as shown in Figure 4(a). To replicate the three flight paths, students can open Microsoft MakeCode in Minecraft and copy the reference Python code into it, as shown in Figure 4(b). Students are encouraged to change the parameters according to the comments and click the big green "run" button to load the Python scripts. By doing so, they can pave the ground and construct approximate SYS Steps with Python codes, as shown in Figure 4(c,d). Students can also use parametric codes in Python to reconstruct SYS Steps, as the steps have repetitive geometries.

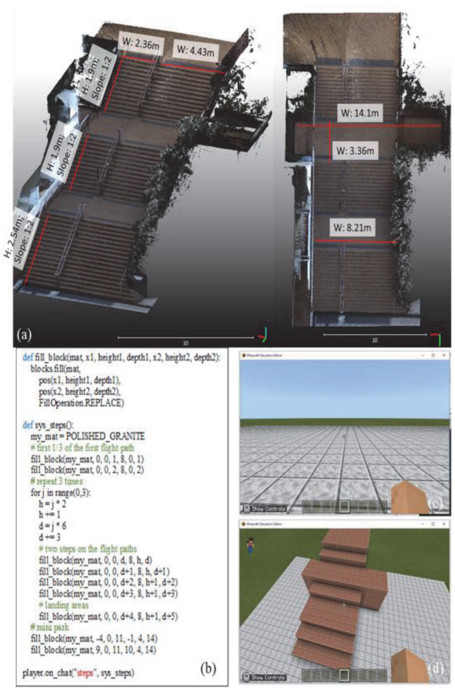

Figure 4: Building a 1:1 Minecraft model of SYS Steps. (a) Dimensions in LiDAR point cloud; (b) Python code; (c) 20m×20m ground to place; (d) automatic 1:1 model

Virtual learning: Virtual campus

Figure 5: Results of LiDAR scanning and Minecraft (1 block = 1m × 1m × 1m)

The second scenario involves experiential learning in the context of a virtual campus. According to Klimová et al. (2021), learning results from synergistic transactions between the learner and the environment. In this scenario, the first stage targets the virtual Main Campus at HKU, including Loke Yew Hall, two library buildings, and SYS Plaza. Students can access this part of the campus model to create their simulations. For example, they can design their floor structures, plant placements, equipment styles, and outdoor scenes to meet their diverse building needs. Furthermore, the virtual campus, distributed to each group of students, is open for simulations such as retrofitting, floods, and fires, which evolve as the real world in Minecraft. The models include a variety of details from real buildings, with finely honed tile textures and realistic scenes reproduced one-to-one. This will allow students to use their rich imagination and excellent creativity to build a unique campus based on the real scene. At the same time, this also allows students to create different experiences.

Virtual learning: Underground structures

This scenario involves T&L about underground building structures. Underground building structures refer to the excavation of underground space that can provide some use while preserving the upper strata. For high-density vertical cities like Hong Kong, underground space is increasingly developed for transportation, business, entertainment, public space, and urban resilience (Chan et al., 2021). Compared to above-ground structures, underground structures have a complex environment characterized by complicated interactions with the surrounding strata. The scenario was designed to enable students to understand the basic principles of underground buildings in the context of T&L about underground structures.

Traditionally, teaching tools for the course of underground structures have mainly been based on textbooks and supplemented by slides, as it is theory-oriented. This scenario includes a simplified railway system beneath the virtual campus ground. It is designed to help students visually understand how railways work and the basis of route planning in a more reasonable way. The interactive railway model also offers new solutions, such as mock-driving in a powered minecart, for T&L about underground structures.

Results and analyses

Results

3D LiDAR surveying

LiDAR scans were collected and reported in students' individual assessments. According to the markings on the assessment reports, all LiDAR scans were successful, and 3D measurements were successful in 90% of students. In the Comments section, approximately 80% of students recognized the functionality of LiDAR-assisted instruction and believed that the accuracy of the mobile LiDAR scanner PX-80 could meet the needs of many engineering practices. The remaining 20% of students, however, questioned the use of LiDAR due to its inconvenient portability, expensive device cost, and unsatisfactory graphical scan monitoring functions.

Based on the group tutorial activities of LiDAR post-processing and as-built 3D modeling, there was a range of observations and attitudes towards the 3D surveying results regarding accuracy and satisfaction. Examples of students' observations and comments are as follows:

- " The performance is excellent in the result of PX-80 3D surveying. It is not only the staircase that we can scan but also surrounding building is inclusive to the area." (Student A)
- "It assists to record down the geography in a much shortened duration. The 360-degree camera allows near full coverage when we are scanning." (Student B)
- "It is noted that skilled technical staff are required in the scanning." (Student C)

- "Some portions of the SYS steps either missing, overlapped or inaccurate, which also weakens the reliability in actual projects." (Student D)

Virtual learning: As-built 3D modeling

Figure 5 shows an example of the reconstruction learning of the SYS steps. All students were involved in this module. Some students reported their learning experiences in their individual assessment reports. The comprehensive nature of the built environment can be observed more intuitively by comparing it with the results of the LiDAR scanning reconstruction. According to the reports, all students believed a Minecraft model is adequate for the gamified "anyone-can-build" project. Some comments are as follows.

- "Minecraft provides a platform and aims [for] the player to build their virtual building or landscaping. It provides many standard building materials, e.g., tiles, wooden panel, and stones. for the player to build their own designed place." (Student E)
- "I think Minecraft is adequate for the gamified "anyone-can-build" project is this game is supported multiplayer function. I think "Anyone" [does] not just mean anybody can play, it also means anybody can join others game environment can play together. I think play together can provide more opportunities for discussion." (Student F)

Virtual learning: Virtual campus

Figure 6 shows students who grew up in the information era showed strong interest and creativity in participating in a virtual 1:1 campus, including Loke Yew Hall, two library buildings, Knowles building, and SYS Plaza. Classroom observations and students' reports indicated that Minecraft can help students learn building design concepts, familiarize themselves with structures, and to some extent, reconstruct and optimize through analysis and simulation. For instance, one group of students set fire to the bushes and trees around SYS Steps and SYS Plaza, which are the fire meeting points of their classroom. They wished to simulate what the next-tier meeting points would be. Through vivid engagement, students reported the potential for AEC education through immersive experiences.

- "There are even more benefits compared with traditional education, such as digital liberty, social skills and online safety." (Student B)
- "Teachers can set design briefs and budgets and participants can be selected to work in teams to achieve a particular outcome, much like real life." (Student F)

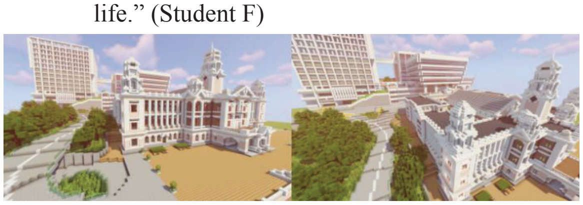

Figure 6: Virtual 1:1 Main Campus of HKU in Minecraft

Virtual learning: Underground structures

In this virtual learning scenario, the immersive interactive environment in Minecraft was useful in understanding underground spaces and facilities. Many students commute below Loke Yew Hall at HKU every day, but a 2D map in Figure 7(a) is not informative enough to visualize the vertical city. Based on the virtual campus model in Minecraft, a virtual subway model was built, as shown in Figure 7(b), according to the 2D map. Note that the depth of the tunnels was simplified, and some blocks were made transparent for visibility. Students could have new experiences by sitting in a row of powered carts with open views, as shown in Figure 7(c). These experiences differed from daily experiences in crowded and confined metro trains.

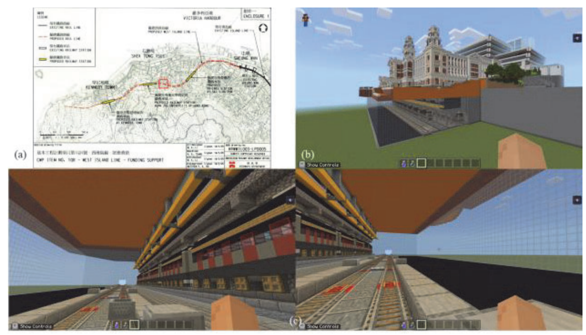

Figure 7: West Island Line under Loke Yew Hall. (a) 2D map (red box = Loke Yew Hall); (b) Simplified model in the virtual campus; (c) a new experience of test-driving

The Minecraft model in the case study introduced examples of teaching and learning of underground engineering courses, for virtual learning and classroom group activities. The Minecraft model encouraged students to ask questions, create communicative experiences, and inspire teaching and learning. Although most students unanimously accepted the immersive experience in Minecraft:

- "[Minecraft] creates a virtual world for users to explore their own learning experience, and it also allows users to create blocking model with pre-stetted materials like brick-and-mortar blocks. Players can easily begin with simple building structure using digital block construction." (Student H)
- " [Minecraft model] is a good and interesting platform to open someone mind and learn the concept of 3D model with information management for a beginner. It is also good to educate and train up [the] new generation to adopt innovative technology." (Student I)

Last but not least, it is not observed that any student was involved in any incidences of abuse of Minecraft or foul actions, cyberbullying, or malicious plagiarizing, which were deemed as potential threats in a previous study (Klimová et al., 2021).

Analysis

For AEC education, the depiction of the built environment in Minecraft was successfully integrated into T&L scenarios. While playing Minecraft, students can experiment with and simulate a range of environmental conditions, such as simulated fires at the fire meeting points. The outcomes of this study are consistent with the findings of García-Fernandez & Mateus (2019). This phenomenon indicates that Minecraft fits appropriately with the effective utilization of visualization tools and hands-on experiential learning in education. Students can take an active role in their learning by playing, exploring, and expanding their understanding in a gaming environment, rather than simply reading or listening to lectures about subject content.

In this study, students were observed to be consistently excited about learning with Minecraft, from the start of the course to its conclusion. No students experienced operational problems in loading Minecraft or accessing their MCEE accounts. With the exploration of possible applications of Minecraft, AEC education is invigorated at different levels. On the technological side, Minecraft was adopted to assist in understanding as-built models of digital twinning. It not only provides an immersive virtual environment but also offers inspiration for a deeper understanding of emerging technology applications. On the teaching practice side, the visualization of architectural design, the digitization of engineering construction, and the interactivity of the built environment offer new inspirations and viable methods for AEC education.

In terms of technology, Minecraft is a popular game with interactive and programmable sandbox simulation functions. Our findings showed Minecraft can serve as an agent in or beyond the classroom for reconceptualization in AEC education. Virtual teaching environments are important for activating AEC education, especially in simulated real-world settings. Undeniably, most technology-mediated learning requires sufficient data to support satisfactorily smooth operations. Although specialized technology can lead to accurate models, it can also cause learning difficulties for students. The integration of Minecraft with AEC education allows students to have a more thorough understanding of their projects. Students can navigate and observe scenes that simulate real buildings in a virtual game space, increasing student interest and engagement. Adopting Minecraft is a promising way to help reduce the separation of roles played by different professionals in the traditional construction process and reduce barriers associated with the rapid growth of professional industry practice.

Conclusions

The emerging technologies and constant industry upgrades have brought many opportunities and challenges to AEC education. For example, current AEC T&L faces three challenges in the new post-pandemic era: non-intuitiveness, high skill requirements, and poor interactivity and collaboration. Therefore, this study explores novel teaching and learning of 3D LiDAR surveying and virtual learning using Minecraft to enrich the pedagogics for AEC education. The results of our collective case studies showed that the interactive gamified environment, such as Minecraft, has potentially positive effects on AEC education by (i) enriching students' learning experiences in an interactive world, (ii) helping educators with 3D interactive teaching, and learning content, and (iii) promoting collaborative creation and multidisciplinary teamwork. Limitations and issues were found in affordability, model quality, and copyrights, which are more difficult to clearly define the contribution share of the model creation process. Future directions include computational quantity and material analytics in Minecraft for AEC education and an open library for sharing and exchanging teaching and learning materials that are neutralized by removing copyrighted parts and sensitive information.

Acknowledgments

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