HOLOGRAPHIC LEARNING ENVIRONMENT FOR BRIDGING THE TECHNICAL SKILL GAP OF THE FUTURE SMART CONSTRUCTION ENGINEERING STUDENTS

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ABSTRACT: *The growth in the adoption of sensing technologies in the construction industry has triggered the need for graduating construction engineering students equipped with the necessary skills for deploying the technologies. One obstacle to equipping students with these skills is the limited opportunities for hands-on learning experiences on construction sites. Inspired by opportunities offered by mixed reality, this paper presents the development of a holographic learning environment that can afford learners an experiential opportunity to acquire competencies for implementing sensing systems on construction projects. The interactive holographic learning environment is built upon the notions of competence-based and constructivist learning. The learning contents of the holographic learning environment are driven by characteristics of technical competencies identified from the results of an online survey, and content analysis of industry case studies. This paper presents a competency characteristics model depicting the key sensing technologies, applications and resources needed to facilitate the design of the holographic learning environment. A demonstrative scenario of the application of a virtual laser scanner for measuring volume of stockpiles is utilized to showcase the potential of the learning environment. A taxonomic model of the operational characteristics of the virtual laser scanner represented within the holographic learning environment is also presented. This paper contributes to the body of knowledge by advancing immersive experiential learning discourses previously confined by technology. It opens a new avenue for both researchers and practitioners to further investigate the opportunities offered by mixed reality for future workforce development.*

KEYWORDS: *Mixed Reality; Sensors; Education; Workforce; Holographic*

1. INTRODUCTION

Uncertainties arising from the complex nature of construction projects have necessitated the need for investing in sensing technologies to improve situation awareness of project teams. Some construction companies are currently utilizing vision and component-based sensing systems such as laser scanners, Radio Frequency Identification (RFID), and Global Positioning System (GPS) for resource tracking (Miller, 2008), safety (Beatty, 2016), productivity (Skanska, 2009) and quality management (Turner, 2016, Skanska, 2009). Miller (2008) reported using passive RFID tags to track precast concrete seats from fabrication to installation during a stadium construction project. Implementation of the RFID tags resulted in a reduction of the project schedule by 10 days and cost savings of one million dollars. Turner (2016) reported deploying GPS for locating existing utilities on an infrastructure project. This resulted in minimal retrofitting of the new utilities and consequently reduced labor and material costs.

Considerable efforts have also been made by researchers: Laser scanners and drones/Unmanned Aerial Vehicles (UAV) have been investigated for capturing as-built data to create 3D models of facilities (Huber et al., 2010, Turkan et al., 2012). RFID, GPS, and ultra-wideband systems have been explored for material, and equipment tracking on the jobsite (Ko, 2010). According to Jang and Skibniewski (2009), tracking construction materials with RFID systems can yield up to a 64% reduction in labor costs over two years. Similarly, the potentials of proximity sensing technologies for improving safety on the jobsite have been explored (Hallowell et al., 2010, Marks and Teizer, 2012). For example, proximity sensors have been used for enhancing situation awareness by tracking workers' proximity to moving equipment (Oloufa et al., 2003, Choe et al., 2013), and automated construction vehicle navigation (Lu et al., 2007). Despite the efficacy and increasing deployment of these technologies, the construction industry is experiencing a shortfall of graduating construction engineering students and existing workforce equipped with the necessary skills to implement the technologies on construction projects (Hannon, 2007, Kapliński, 2018). This opinion was also shared by Zhang and Lu (2008) who posited that students are unaware of the potentials of sensing technologies in the construction industry.

For construction engineering students to acquire technical skills for implementing sensing technologies, it is pertinent to engage them in hands-on learning with the technologies. However, inaccessibility to construction sites for experiential learning and in some cases, high upfront costs of acquiring sensing technologies are encumbrances to equipping construction engineering students with the required technical skills. One way to reduce these barriers is by augmenting digital 3D representations of construction sites and sensing technologies in the form of an interactive holographic scene (HS), a concept of mixed reality, into the physical classroom so that students can explore the technicalities involved in deploying sensing technologies on construction projects. With an interactive holographic learning environment, students can access different difficult situations that are too dangerous to access on real construction sites. The use of the term 'holographic' is meant to refer to augmented reality that appears to users as 3D objects existing in the physical world as popularized by Microsoft.

1.1 Theoretical Underpinning

The development of the holographic learning environment is grounded in competencies-based and constructivist learning theories. Competencies based theory involves connecting classroom learning with activities in the workplace for an accurate representation of the workplace and an easier transition of students into the workforce (Gonczi, 1999). This study supports this theory by identifying and incorporating the required competencies for deploying sensing technologies in the construction industry, in the holographic learning environment. While engaged in the holographic learning environment, students can interact with the jobsite characteristics, explore tasks, identify risks, and select appropriate sensing technology for mitigating the risks. Consequently, they can construct their knowledge of the diverse construction contexts for the application of sensing technologies. This also supports the notion of the constructivist learning theory which posits that students develop knowledge of a particular topic by being actively engaged in a social learning environment (Bada and Olusegun, 2015).

1.2 Mixed Reality Learning Environment

The emergence of digital learning environments such as virtual reality (VR) and Mixed Reality (MR) has spurred a prolific interest amongst researchers and educationists owing to its ability to experientially engage students in a social learning environment. The application of VR environments to enhance education has been embraced in medicine (Liu, 2014), construction (Messner et al., 2003), and industrial (Maffei and Onori, 2019) engineering programs. According to (Pantelidis, 2010), VR leverages on visualization techniques for enhancing the comprehension of abstract classroom concepts. However, the immersive feature of VR environments restricts self-localization of participants in the virtual and real-world (Psotka, 1995). All senses of participants are actively engaged in the virtual environment hence, participants may struggle to simultaneously maintain their position in the virtual and real world. Azhar et al. (2018) who introduced VR for teaching design communication reported that students immersed in a VR learning environment can become motion sick and unstable and often require more supervision from instructors. Contrary to VR, MR merges the real and virtual environment (Fig. 1), by superimposing virtual objects into the real world or integrating real-world objects into a virtual environment (Pan et al., 2006). In this way, students are consciously aware of the real world while engaged in the virtual learning environment. Through active engagement in the learning process, MR has been proven to improve students' learning of spatial structure, and long-term retention of what is taught in the environment (Radu, 2014). MR learning environment affords students a hazard-free sharable virtual learning environment that can accommodate multiple learners (Pan et al., 2006). Furthermore, Azhar et al. (2018) who reported the efficacy of MR in improving design communication skills in construction education, concluded that MR was more effective for educating construction students about design plans when compared to traditional design reading processes. The study further revealed the potentials of MR for supporting hands-on learning in the classrooms. Therefore, this study employed MR for equipping construction engineering students with hands-on learning experience.

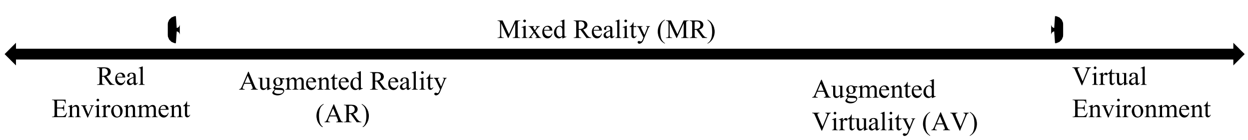

Fig. 1: Reality-Virtuality Continuum (Milgram and Kishino, 1994).

1.3 Research Objectives and Contribution

This study introduces an MR learning environment in the form of HS for bridging the technical skill gap of construction engineering students in deploying sensing technologies on construction projects. To develop the learning environment, the required competencies for implementing sensing technologies on construction projects were identified through a survey of industry practitioners and online case studies of industry applications. The study also explored the extent to which the sensing technologies are taught in construction engineering programs by surveying faculties across the United States (US). The results from the surveys and case studies provided the required competencies for deploying sensing technologies on construction projects. Based on these competencies, the learning contents of the HS were identified. This paper elucidates preliminary findings from the surveys and case studies, and a description of the HS. Implications of the findings and the interactive learning environment for bridging the technical skill gap in the construction industry are also discussed.

2. METHODOLOGY

To develop the interactive HS, the research methodology illustrated in Fig. 2 was adopted. To provide evidence to support the need for the study, construction engineering instructors in institutions in the US were surveyed to capture the extent to which sensing technology-related contents are being taught. To identify the required competencies and learning content for the HS environment, an online survey of industry practitioners was conducted. The survey data were analyzed using cluster analysis and descriptive tools such as averages, and percentages. The study further performed content analysis of the industry case studies on the applications of sensing technologies. To extract the required competencies from the survey results and case studies, a mind mapping of identified applications of sensing technologies was conducted using a readily available mind mapping application. The sensing technologies and applications were modeled in the HS environment in the form of virtual objects using Unity game engine. Specific learning contents were guided by a general set of characteristics identified from the competencies and a taxonomic model of the operational characteristics of sensing technologies.

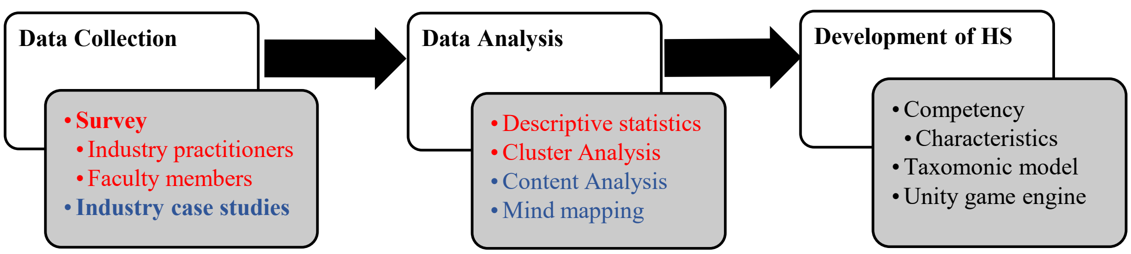

Fig. 2: Research methodology.

2.1 Data Collection

2.1.1 Survey

A total of 73 industry practitioners from 46 construction companies in the US were surveyed to obtain their perceptions on sensing technologies in the industry. The online survey included closed-ended questions regarding the types of sensing technologies currently deployed by construction companies, the current level of adoption of the sensing technologies, future sensing needs of construction companies, and skills required of the future construction engineering workforce to implement the sensing technologies on projects. The survey also included open-ended questions on the specific current and future construction applications of sensing technologies. Responses from the survey provided detailed information on the competencies and learning objectives for the HS. Further details on the characteristics of the respondent's companies are provided in Table 1.

Table 1: Company size of industry participants

Company size based on number of employees	Number
10- 50 employees	9
50 - 100 employees	4
100-500 employees	14
More than 500 employees	15

The study also surveyed a total of 37 faculty members across the US to understand the state of sensing technologies in construction engineering education. Generally, the faculty members were surveyed to obtain data on the percentage of institutions currently teaching sensing technologies curriculum. Close-ended questions were asked to obtain data on the extent to which sensing technologies are being taught in these institutions.

2.1.2 Industry case studies

To acquire a rich set of applications of sensing technologies in the construction industry, online construction industry case studies were reviewed. This involved surveying and documenting cases where different sensing technologies have been implemented on construction projects. A general survey of case studies on construction companies' websites was first conducted. This yielded a total of 17 case studies of laser scanners, drones, RFIDs, and ground-penetrating radar, and GPS from different companies. Thereafter, a thorough web search using "Laser scanner case studies in construction companies" search string was used. "Laser scanner" was then replaced in the search string with each sensing technology. The search was further filtered by omitting search results without the exact words "Sensing technologies", and "construction". Search results from marketers and developers of sensing technologies providers were excluded from this study. The web search produced 14 case studies for only laser scanners. Consequently, a total of 31 industry case studies were considered in this study. Construction applications from these case studies were analyzed for identifying the characteristics of the HS learning environment.

2.2 Data Analysis

Survey data on the types of sensing technologies currently deployed by construction industries, the current level of adoption of the sensing technologies, future sensing needs of construction companies, and skills required of the future construction engineering workforce to implement the sensing technologies on projects were analyzed using descriptive tools. Open-ended questions on different construction applications of sensing technologies were analyzed to categorize similar construction applications/activities for each sensing technology using cluster analysis. Similarly, content analysis of identified industry case studies of construction applications of sensing technologies was conducted. The contents of each case study were classified based on the case study title, sensing technology adopted, specific construction activities, meta description of the activity, identified benefits of the sensing technology, and appropriate website links to the case study. Similar construction activities from the survey and industry case study analysis of each sensing technology were grouped using mind mapping. Fig. 2 illustrates an example of mind mapping of construction applications of laser scanners.

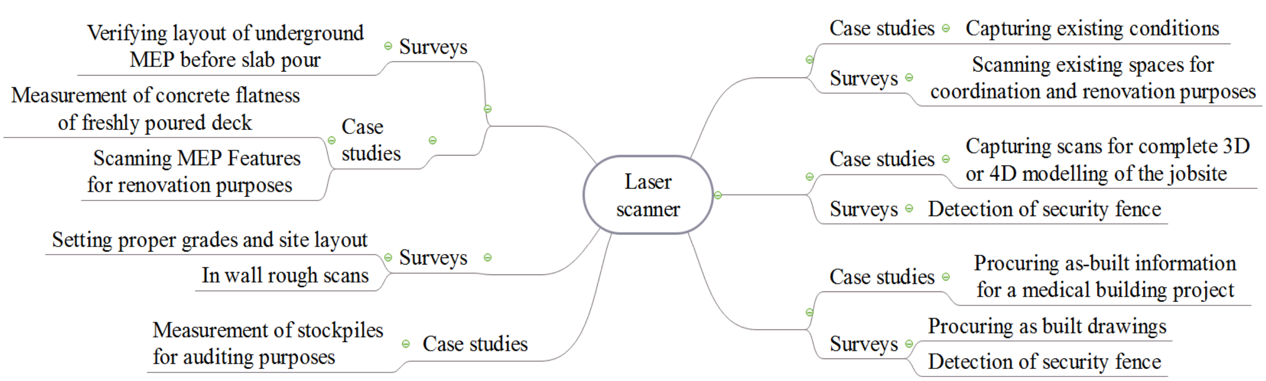

Fig. 2: Mind mapping of laser scanning construction applications.

2.3 Development of Holographic Scene Learning Environment

To develop the interactive learning environment, the characteristics of the HS need to include learning outcomes such as the required skills, knowledge, and abilities for deploying sensing technologies in the industry. These characteristics were categorized into two: (1) the jobsite characteristics which are the identified construction applications of each sensing technology: and (2) the operational characteristics of each sensing technology. To represent key construction applications of each sensing technology in the HS, a set of characteristics (Fig. 3) was developed to guide the process. The characteristics entail the construction applications to be represented, the performance metrics of each construction application, and the resources for executing the applications in the HS. As illustrated in (Fig. 3), construction applications of each sensing technology were classified into performance metrics in the construction industry such as productivity, safety, schedule, and quality control (Hughes et al., 2004, Battikha, 2003). These construction applications were further delineated into the required resources (avatar, materials, and equipment) for representing them in the HS. For example, the jobsite consists of construction materials like stockpiles, 2 partially completed buildings, rebars, and woodpiles. Avatars were used for representing different construction trades like painters, carpenters, and construction craft laborers. Also, construction vehicles such as dump trucks, tower crane, bulldozers were represented as equipment in the holographic scene. Furthermore, to represent the operational characteristics of each sensing technology, a taxonomic model entailing the hierarchal development of each sensing technology was used to guide the development process of the sensing technologies as game objects in the HS. Fig. 4 shows an example of a taxonomic model for the development of the laser scanner in the HS.

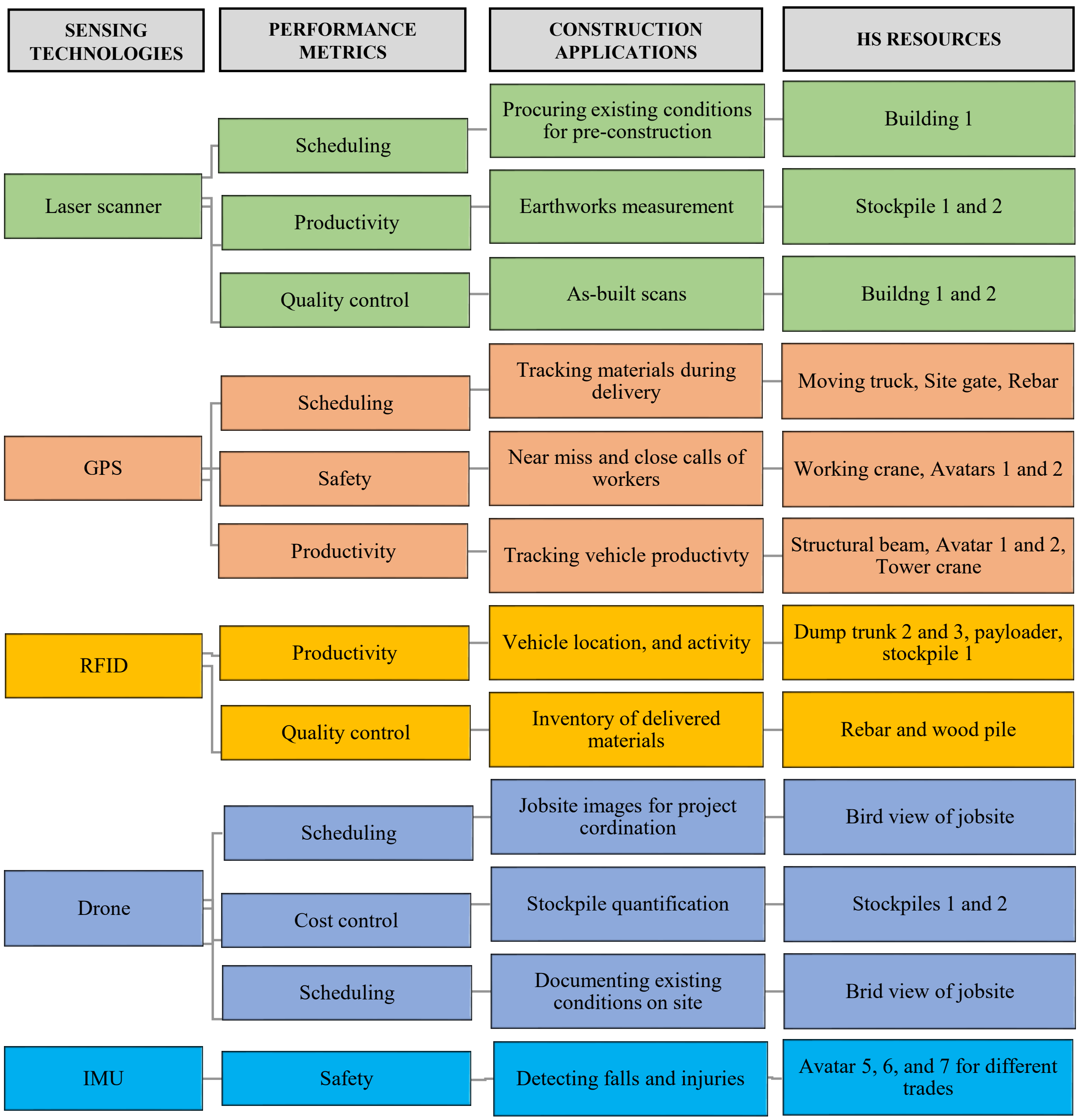

Fig. 3: Set of characteristics needed by the HS learning environment.

The HS was developed using Unity game engine. As shown in the system architecture of the HS in Fig. 5, the HS consists of game objects, MR toolkit (MRTK), and services. The game objects in the learning environment entail the digital representations of the jobsite characteristics and the virtual sensing technologies. Each game object in this scene consists of components that provide the functionalities and essence of each game object. The components of each game object are the mesh collider, transform component, and mobile game objects like avatars. The construction vehicles had animators as an additional component for defining their movements in the HS. Each game objects in the HS have scripts attached to them. The scripts are written in C# programming language in visual studio and allows responses to inputs from the students, and also control the coordination of the learning environment. The MRTK in the HS creates the interactivity when students are immersed in the holographic environment using the Microsoft HoloLens. The MRTK consists of scripts, spatial awareness, camera, gaze, hand, and cursor. This enables the usability of the learning environment in an MR environment using the HoloLens. For example, spatial awareness provides the geometry of the holographic scene and instigates an interaction between the holographic scene and the real world. While the gaze and cursor enable the students to focus on any game object by placing it in the center holographic scene. The Microsoft HoloLens only allows for the selection of objects through hand gestures such as air-tapping. To access the learning environment, the application is loaded into the HoloLens, and students can open the application and interact with it directly. The services enhance the user experience when using HoloLens (Akanmu and Olayiwola, 2019). As the students interact with the learning environment, their interactions are related to a first-person avatar.

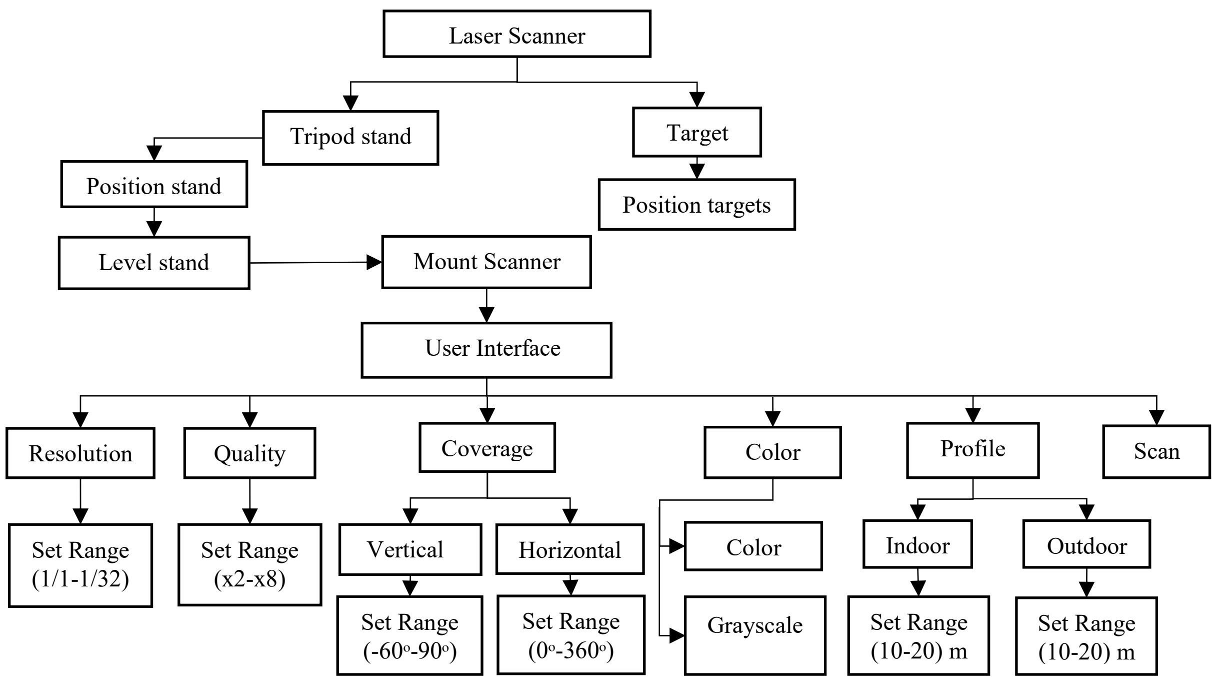

Fig. 4: Taxonomy of operation of virtual laser scanners in the HS.

3. RESULTS

This section presents the preliminary results of this study. Firstly, the results of the online survey of industry practitioners and construction faculty members were presented. The number of industry case studies of construction applications of each sensing technologies was also represented in this section. The developed holographic scene with an example of stockpile measurement using laser scanner was further elucidated in this section.

3.1 Survey Results

3.1.1 Industry Practitioners

Preliminary survey results from the construction industry indicated a high rate of adoption of sensing technologies. 80% of the surveyed construction companies have started adopting sensing technologies while 20% are yet to adopt sensing technologies on their projects (Fig. 6). Fig. 7 revealed the rate of adoption of each sensing technology in the industry with cameras and laser scanners, GPS, RFID, and drones being the most frequently adopted on construction projects.

Respondents from the construction industry were asked to suggest sensing technologies to be included in construction engineering education. Fig. 8 shows the sensing technologies suggested by industry practitioners for inclusion in construction engineering education. Over 90% of the respondents suggested that laser scanner should be included in construction engineering education. The top 5 suggested and frequently adopted sensing technologies were represented in the HS.

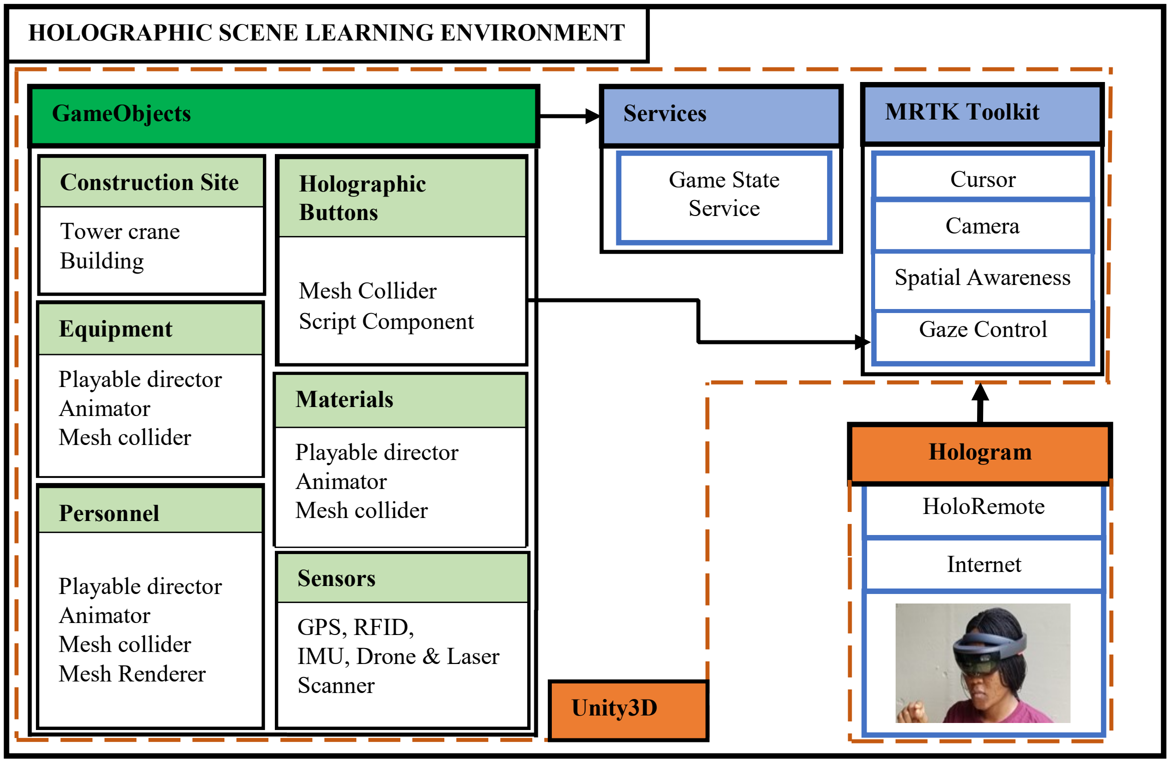

Fig. 5: System architecture of the holographic learning environment (Akanmu and Olayiwola, 2019).

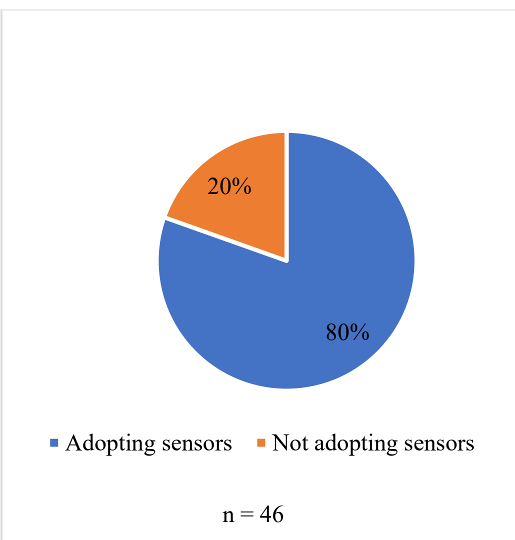

Fig. 6: Level of adoption of sensing technologies.

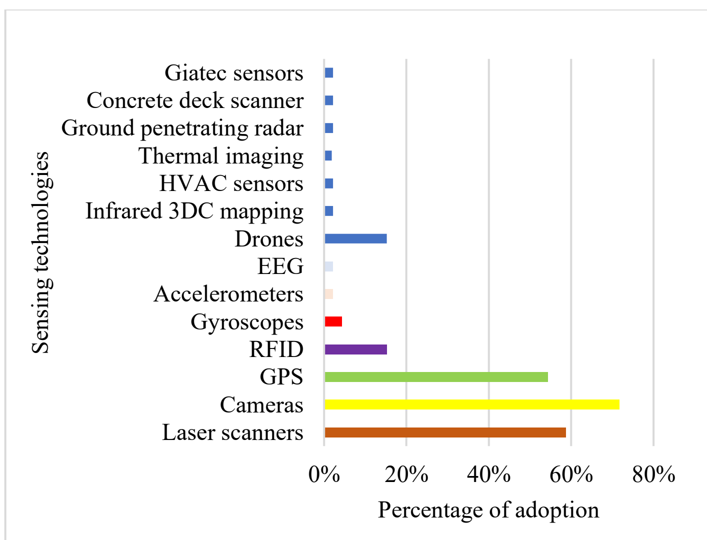

Fig. 7: Adoption rate of each sensing technologies.

3.1.2 Faculty members

Instructors from different institutions across the US were surveyed to explore the extent to which sensing technologies are currently taught in construction engineering education. Fig. 9 shows that 54% of the respondents have started teaching sensing technologies while 46% are yet to include sensing technologies in their curriculum. Fig. 10 reveals the percentages of institutions already teaching each sensing technologies in construction education. Similar to the high adoption rate of laser scanner in the industry (Fig. 7), most faculty members have started including laser scanners in their curriculum.

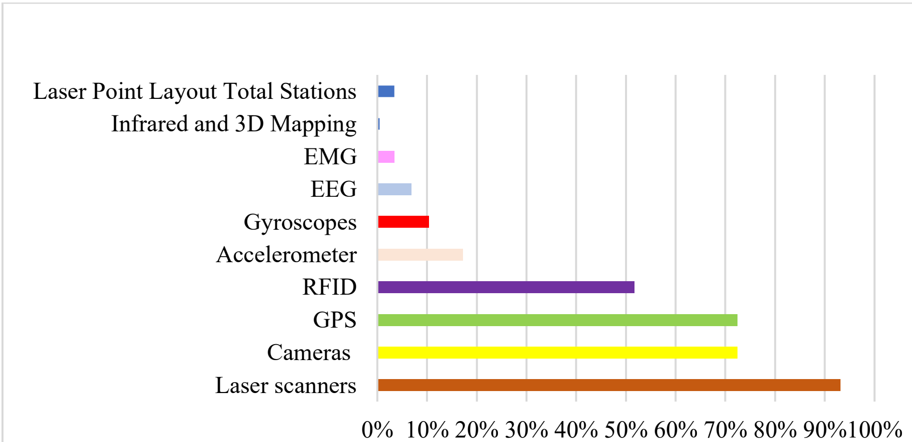

Fig. 8: Suggestions for the inclusion of sensing technologies in construction education.

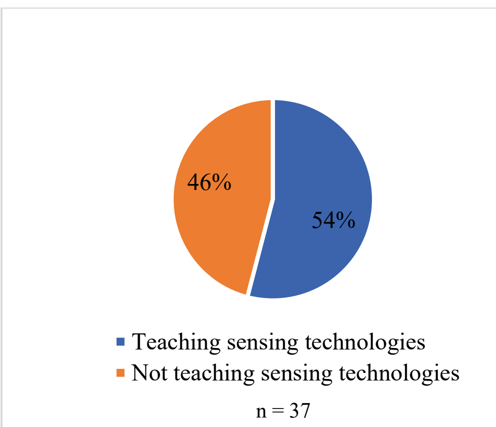

Fig. 9: Extent of teaching sensing technologies.

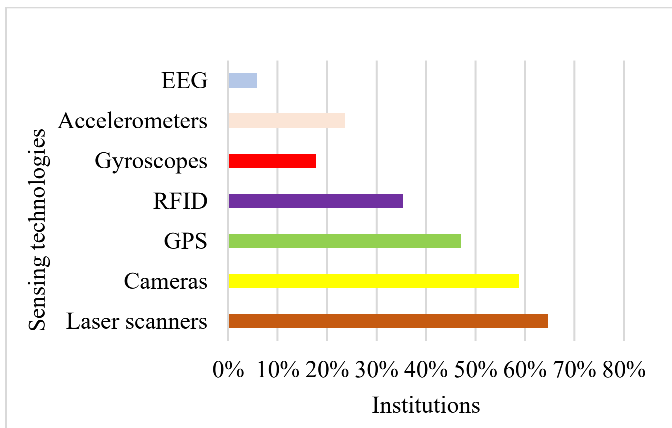

Fig. 10: Institutions teaching sensing technology.

3.2 Industry case studies

Preliminary results from the content analysis of the industry case studies on construction applications of sensing technologies showed that laser scanner has been widely used on construction projects. As depicted in Fig. 11, 18 case studies of laser scanner were retrieved. The construction applications of laser scanners extracted from the case studies include the following: measurement of the volume of metal piles; layout of existing mechanical, electrical, and plumbing systems; measuring existing conditions of buildings for renovation purposes; conducting site layout; and generating as-built models of construction projects.

3.3 Example Scenario of Stockpile Measurement using Laser Scanner

The HS aims to provide an interactive environment where students can digitally explore different construction activities and sensing technologies used in the construction industry. As depicted in Fig. 12, the HS allows students to investigate jobsite characteristics i.e. the tasks, operations, and dependencies. Students are also able to explore the context for use of each sensing technology to address risks of construction projects. For example, to measure the volume of a stockpile in the HS, students were able to explore the stockpile on the jobsite and other surrounding activities. Students will need to decide on the possibility of utilizing the laser scanner or any other sensing technologies for the stockpile measurement. The selection of laser scanner for the stockpile measurement will guide the students in understanding the operations of a laser scanner. By clicking the laser scanner button, the laser scanner accessories such as tripod stand, scanner, targets, and scanner interface will appear on the user interface.

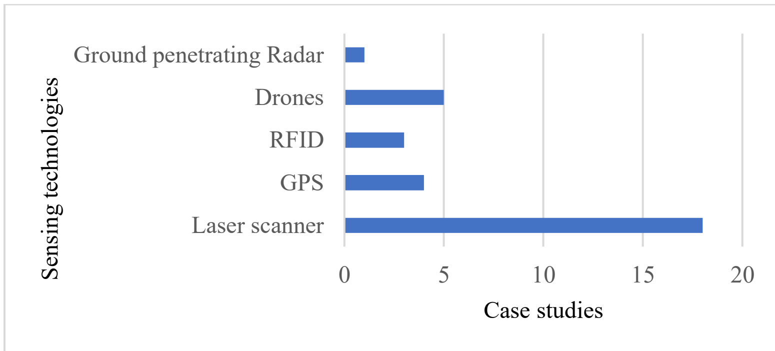

Fig. 11: Sensing technologies identified from the industry case studies

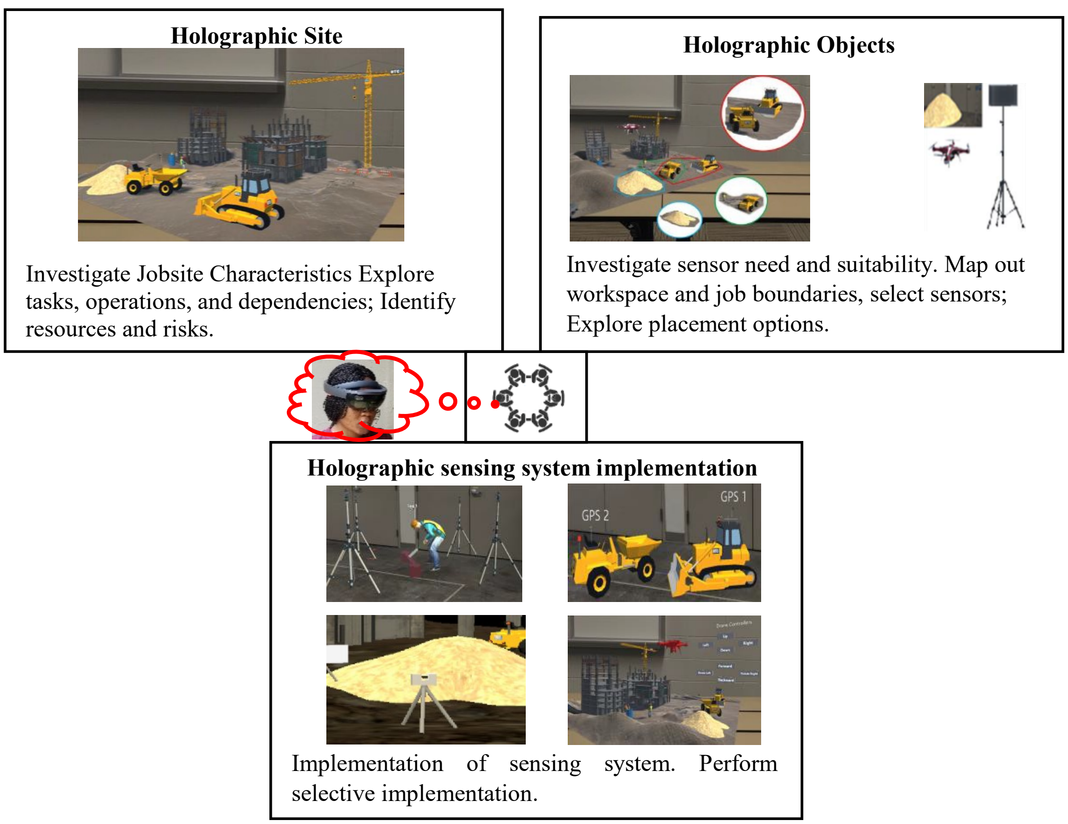

Fig. 12: Example of the HS learning environment (Akanmu and Olayiwola, 2019)

As illustrated in Fig. 13a, students will be required to position the tripod of the laser scanner. Students can decide on the most suitable location to place the laser scanner. This is an important step as the placement decision influences the coverage of the laser scanner and the number of scans captured.

On selecting the scanner button from the menus on the interface, the scanner appears on the tripod stand. The students can also select and position the targets around the stockpile (Fig. 13b) which has similar consequences as the positioning of the tripod. After positioning the targets, students can interact with the scanner interface. As depicted in Fig. 13c, the interface of the laser scanner allows students to select the coverage, resolution, quality, color, and profile of the scans, which engages their decision-making skills. Students will be propelled to engage all the settings displayed on the scanner interface. This is achieved by deactivating the scan button until all settings on the scanner interface have been engaged (Fig. 13d). This process will educate the students on how resolution and quality can affect time taken to scan the stockpile. The higher the resolution and quality of the scan, the more the time required to scan the stockpile. On the selection of the scan button, the laser scanner will commence scanning the stockpile. After the scanning process has been completed, students will have the option of viewing the scans, and saving or discarding the completed scans. If the scans are saved, the students can close the HS learning environment and view their scans via the HoloLens.

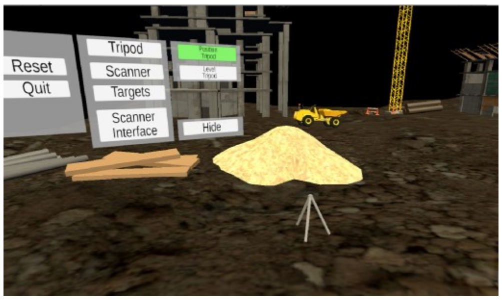

Fig. 13a: Positioning tripod stand

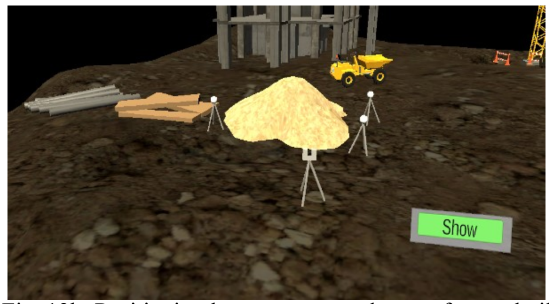

Fig. 13b: Positioning laser scanner and target for stockpile measurement

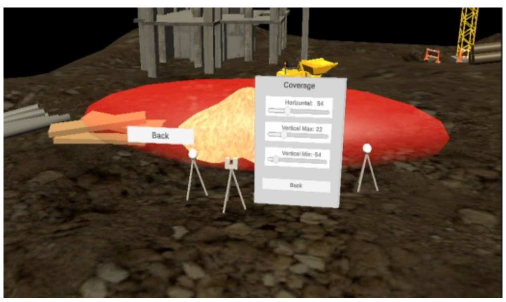

Fig. 13c: Laser scanner coverage

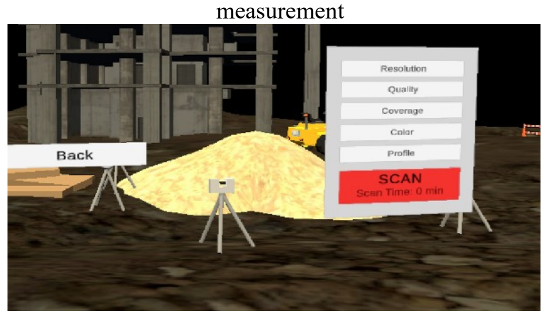

Fig. 13d: Scanner Interface

Fig. 13: Implementation of laser scanner in the HS learning environment.

5. CONCLUSIONS AND FUTURE WORKS

The need for timely and efficient completion of construction projects has resulted in a growing rate of adoption of sensing technologies in the construction industry. This in turn has triggered the need for future construction workforce with the necessary technical skills for deploying sensing technologies on construction projects. This paper presents the development of a flexible and captivating learning environment that affords learners an experiential opportunity to acquire sensing systems application knowledge and improve their risk-identification abilities. As a first step, this study surveyed construction engineering instructors to assess the extent to which sensing technology related contents are being taught in institutions. The study also surveyed industry practitioners to capture the required skills for deploying sensing technologies on construction projects and applications that would also benefit from the technologies. Results from the online survey revealed a gap between the technical skill needs of the construction industry and the offerings of construction engineering programs. Industry case studies were also analyzed to further enrich these skills. Based on the established skills and potential tasks and activities, a general set of characteristics was identified and leveraged for developing the interactive HS learning environment. Within the environment, students can explore the digitally represented activities, and associated risks and resources. Students can also explore the suitability of each sensing system for mitigating the risks of the activities. An example of how volumes of stockpile can be measured with the laser scanner within the learning environment is described. Future work will involve the following:

- Conducting cognitive walkthrough evaluation of the HS learning environment with construction industry practitioners to assess its learnability;
- Conducting usability studies with students to identify characteristics of the HS learning environment that facilitate problem solving with sensing technologies;
- Conducting a comparative analysis of student groups to investigate the potential of virtual sensors within the HS learning environment to enhance addressing construction problems.

6. ACKNOWLEDGEMENT

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