EPiC Series in Built Environment
Volume 2, 2021, Pages 505–513
ASC 2021. 57th Annual Associated Schools of Construction International Conference

Sensing Technologies in Construction Engineering and Management Programs: A Comparison of Industry Expectations and Faculty Perceptions

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The fast-growing adoption of sensing technologies in the construction industry has necessitated a demand for workforce with technical skills. This study explores the current state of sensing technologies in the industry and sensing technology education in construction engineering and management programs. The study investigates the agreeability of industry and academia's perceptions of the integration of sensing technologies in construction engineering and management curricula. The study employs online surveys to capture industry and instructor perceptions of the skills required of graduating construction engineering and management students and the extent of sensing technology education respectively. Comparison of the survey responses reveals differences between sensing technologies and applications deployed in the industry and those taught in construction engineering and management programs. While reinforcing the need for technical skills in the industry, results provide highlights to well-structured sensing technology courses based on required competencies to prepare students for a relevant and successful career in the industry.

Key Words: Sensing technologies, Construction education, Technical skills, Construction industry.

Introduction

Sensing technologies extract information about the context and condition of construction resources and processes during the lifecycle of facilities to improve communication between project participants, enhance project safety and improve quality control (Akinci & Anumba, 2008). These technologies are dynamically evolving, and quickly transforming the way construction projects are delivered. For example, laser scanners are popularly employed for 3D reality captures which fosters as-built modeling of construction projects. Radio frequency Identification devices (RFID) and Global Positioning Systems (GPS) are generally explored for tracking resources on the jobsite (Valero & Adán, 2016). In recent years, these technologies have contributed to reducing some of the performance challenges in the construction industry. As the construction industry continuously adopts sensing technologies, the need for skilled workforce to implement the technologies on construction projects will rise.

A significant barrier to the widespread adoption of these technologies is limited skilled workforce. Construction engineering and management (CEM) programs need to integrate sensing technologies into their curricula as this will ensure that graduating engineers have the requisite knowledge and skills to advance innovation with the technologies in the construction industry. To adequately prepare this future workforce, there is a need to understand what sensing technologies are being deployed by the industry, the extent to which the technologies are being deployed and the industry perception of what should be taught in CEM programs. In parallel, an understanding of the extent of sensing technology education in CEM programs is also vital.

Background

Sensing Technologies in the Construction Industry

Sensing technologies adopted in the construction industry can be classified as component and image-based. For example, while GPS, RFID, ultra-wide bands (UWB) are classified as component-based sensing technologies, drones, laser scanners, ground penetrating radars (GPR) are often regarded as image-based sensing technologies. As explored by several authors, (Sanda, Abdel-Qader, & Akanmu, 2014; Teizer, Lao, & Sofer, 2007) component-based sensors provide status information (e.g., location, humidity, temperature) about tagged resources, and imaging sensors provide digital data (e.g., point cloud and videos) often utilized for modeling purposes (Sepasgozar & Shirowzhan, 2016).

Over the past five years, the rate of adoption of sensing technologies in the construction industry has grown exponentially and the investment in these technologies has been reported to have doubled the investment of 2008-2012 (Dixon, Connaughton, & Green, 2018). There have been multiple reports of how construction companies are deploying sensing systems for tracking real-time performance levels and physical states of construction workers. For example, in 2010, Skanska deployed RFID on the Meadowlands Stadium project in New Jersey for tracking installations of precast concrete seats (Jang & Skibniewski, 2009; Miller, 2008). In 2016, during the Capitol Crossing development in Washington, D.C, Balfour Beatty deployed GPS for tracking work elements such as electrical components in precast concrete, and RFID within hardhats for workforce tracking and safety (BalfourBeatty, 2016). ColonialWebb employed laser scanners for capturing the existing attic space (including the framing members) prior to adding new HVAC systems to the freshman dormitories at the University of Virginia (Systems, 2020). This diffusion of sensing technologies in the construction industry has triggered the demand for workforce with such skills.

Sensing Technology Education in CEM Programs

Till date, scarce studies have reported how sensing technology related education is taught in CEM programs. In civil engineering, Zhang and Lu (2008) presented a study on how smart construction is taught at Lehigh University. Hurlebaus, Stocks, and Ozbulut (2012) investigated smart structures and materials education in civil engineering using a case study of Texas A&M University. However, how sensing technologies are taught in CEM programs and the extent to which they are taught in response to industry demands, are yet to be explored.

Research Objectives

The objective of this study is to investigate the extent to which graduating CEM students are being prepared to implement sensing technologies in the construction industry. To address this objective, this study answers the following research questions:

- How and to what extent is the construction industry deploying sensing technologies?
- What sensing technology skills and knowledge does the industry expect from CEM graduates?
- What is the current status of sensing technology education in CEM program?

Methodology

Two online surveys were implemented to capture the perceptions of industry practitioners and educational institutions after approvals were obtained from the Institutional Review Board of Virginia Tech. The surveys were created in August 2019 and data were received up till September 2020. The first survey, which was administered to construction industry practitioners in the United States, was structured to capture the demographics of the represented construction companies, the type of sensing technologies adopted by the companies, and applications of the sensing technologies. The perceptions of the industry practitioners regarding applications that should be taught to CEM students and the expected skillset from graduating CEM students were also captured. The survey was sent to 869 industry partners via the Myers Lawson school of Construction's listserv. A total of 105 surveys were received, 19 were unfilled, and excluded from the analysis. Hence, a total of 86 participants, and 62 construction companies were represented in the study. Responses were received from the East Coast, Midwest, Southeast, Southwest, Northeast, and Mid Atlantic of the United States (US). Similarly, the second online survey was administered to instructors across CEM programs in the United States to determine the type and applications of sensing technologies taught in educational institutions. The survey was sent to 155 instructors through the Associated School of Construction (ASC) listserv, to represent instructors from regions one to seven. Only instructors in the US were considered in this study. Instructors from region eight were not mailed. A total of 57 surveys were attempted. A total of 48 responses were analyzed for this study. The rest were uncompleted because the participants have not expertise in sensing technologies. Hence a total of 48 useful responses were analyzed for this study.
Survey data for this study were analyzed using descriptive statistical tools, such as frequencies, and percentages, and represented pictorially using charts. Open-ended questions regarding the applications of sensing technologies were analyzed using cluster analysis and represented with mind mapping tools.

Survey Results and Discussions

Trends of Sensing Technologies in the Construction Industry

Industry Practitioners Survey Demographics

Participants were asked *'what is your company size (based on the number of employees)'*, and Table 1 depicts a breakdown of the survey respondents' (industry practitioners) demographic information by company size. This shows that more than 60% of the responses were from companies with over 100 employees, while 32% were from companies with less than 100 employees.

Table 1

Demographic statistics

Company size	**Frequency**	**Percentage**
10-50 employees	14	22%
51-100 employees	6	10%
101-500 employees	21	34%
More than 500 employees	21	34%
Total	62	100%

Adoption of Sensing Technologies in the Construction Industry

Level of adoption. The survey asked participants *'Do you use sensing technologies on your projects?'*. As shown in figure 1(a), 85% of the represented 62 companies, are adopting sensing technologies on their projects while only 15% are yet to adopt sensing technologies. The results further reveal that 89% of companies that are yet to adopt sensing technologies foresee their companies adopting the technologies in the future (figure 1b). This implies that sensing technologies are gaining traction in the construction industry.

Types of adopted sensing technologies. The survey provided a list of sensing technologies (laser scanners, cameras, GPS, RFID, and accelerometers, drone, EEGs, EMGs, gyroscopes, and accelerometers) and asked participants *'Which of the following sensing technologies do you use for your projects?'*. Participants were asked to select all that apply, and state others if not listed. The companies adopting sensing technologies were asked about which sensing technologies they are deploying on their projects. Most of the respondents (over 80% of the companies) reported that they are implementing cameras on their projects, and over 70% have implemented laser scanners and GPS. As shown in Figure 2, the top 5 sensing technologies adopted by the construction companies are cameras (87%), laser scanners (75%), GPS (73%), drones (67%), and RFID (19%), However, less than 10% of the construction companies are using electromyography (EMG), accelerometers, gyroscopes, electroencephalograph (EEG), ground penetrating radar (GPR), and thermal imaging. This indicates that these sensing technologies are gradually being embraced but have not been widely used in the industry.

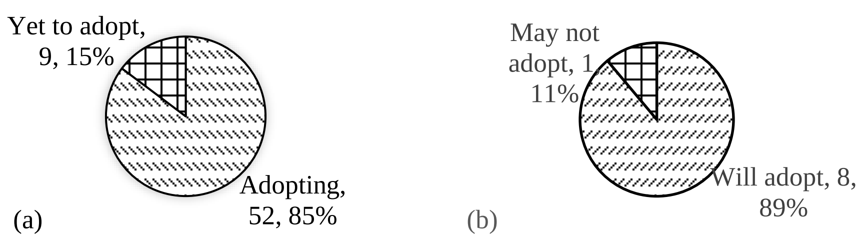

Figure 1. Level of adoption of sensing technologies: (a) Companies currently sensing technologies; (b) potential adoption of sensing technologies

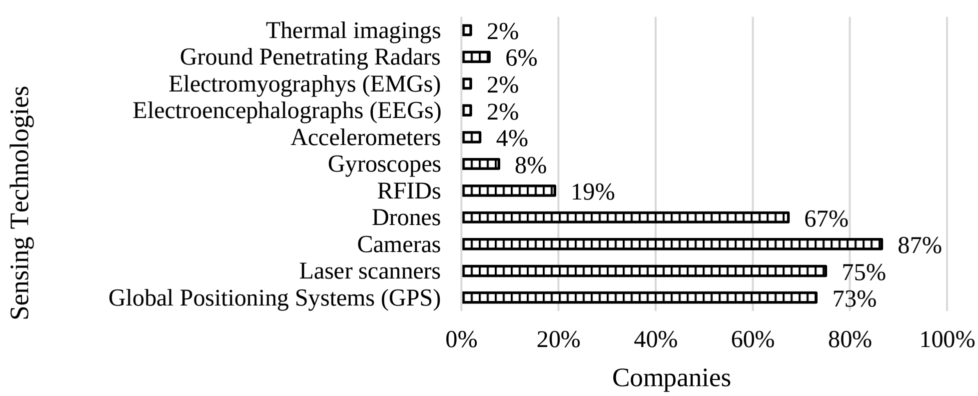

Figure 2. Sensing technologies adopted in the construction industry

Applications of sensing technologies. The survey asked participants who use sensing technologies '*what do you use sensing technologies for?'*. While laser scanners, cameras, and drones have been widely applied in the industry, Table 2 shows that laser scanners are broadly applied in the different phases of project life cycle. In the construction phase, laser scanners are used for layouts, 3D coordination, measuring floor flatness, deck pre-pour scans, grading, and leveling, and exploring field conditions. During the post-construction phase, laser scanners are used to procure existing conditions for renovation purposes. For example, some of the companies use laser scanners for measuring pipe slopes and developing mechanical shop drawings for plumbing and mechanical works. Like laser scanners, the companies also use drones to procure existing conditions for renovation works. Although drones are adopted by 67% of the companies, they are widely used for site inspection and quality checks, project monitoring and documentation, and stockpile qualification. Applications of component-based sensors are shown in Table 3. GPS is used by companies for automated vehicle guidance, site logistics, project controls, building layout, and project documentation. RFID is used for tracking workers, accelerometers are used for monitoring falls and injuries, and gyroscopes are used for monitoring prefabricated bridge movements.

Table 2

Applications of image-based sensing technologies in the construction industry

Sensors	**Applications**
Laser scanner	Insulation thickness, field conditions, floor flatness, layouts, Deck pre-pour scans, pipe slopes, grades and levels, existing conditions, 3D coordination, as-built scans
GPR	Utility location, rebar location
Camera	Quality checks, progress documentation, supplements laser scans, safety, security, material management
Thermal Imaging	Roof leaks
Drone	Quality checks, existing conditions review, stockpile quantification, site inspections, progress monitoring

Industry's Perception of Sensing Technologies in CEM Programs Construction

Skill sets. The survey asked participants *'When you employ graduate (BSc or MSc) engineers from construction engineering and management and/or civil engineering for sensing technology related jobs, what skills and knowledge do you expect him or her to bring from his or her university education?'*. Survey provided participants with four options, data visualization, data storage, data extraction, and programming language, and they were required to select all that apply. Figure 3 shows that 76%, 71%, and 63% of the companies expect graduating CEM students to have data visualization data extraction, and data storage skills, respectively. 17% of companies identified the need for CEM students to have programming skills. It can be inferred that training CEM students on how to process sensor data is more important to the industry than programing the sensing technologies.

Finally, survey provided the same list of sensing technologies, and asked *Which of the following sensing technologies do you think should be taught to civil engineering and CEM students?* participants were required to select all that apply, and state others if not listed. As shown in figure 4, the top four sensing technologies proposed to the industry to CEM programs are laser scanners (91%), GPS (73%), cameras (70%), and RFID (45%). While the top three (laser scanners, GPS, and cameras) are widely used in the industry, gyroscopes and accelerometers, EEG, and EMG are just gradually being embraced in the industry. Although 67% of the companies are already using drones, only 2% proposed their inclusion in CEM programs.

Sensing Technologies in CEM Education

Programs and Course Type

Survey asked participants that *'Do you teach any sensing technology related course or content as part of your assigned construction engineering and management (CEM) and civil engineering courses?',* Out of 48 instructors who completed the survey, 50% indicated that sensing technologies related courses are taught in their institution. The survey further asked, *'Is the course an undergraduate or a graduate course?',* 62% of the instructors teach sensing technologies as part of undergraduate courses while the rest (38%) teach the technologies in their graduate courses (figure 5a). To further assess the course contents, survey asked '*Do you teach sensing technologies as a standalone course*?' For both the undergraduate and graduate courses, 87% of the instructors teach sensing technologies as course contents while the rest teach these technologies as standalone courses (figure 5b). This could imply that limited focus has been placed on teaching sensing technologies as a stand-alone course in CEM programs compared with civil engineering (Zhang & Lu, 2008). Stand-alone sensing technologies courses could enable in-depth teaching of the key sensing technologies with emphasis on the applications and skills required by the industry.

Table 3

Applications of component-based sensing technologies in the construction industry

Sensors	**Applications**
GPS	Documentation, grades, vehicle guidance, surveys, building layouts, equipment location
Gyroscope	Prefab bridge movement
RFID	Tracking workers, managing materials, tracking equipment
Accelerometer	Detecting falls and injuries, supporting excavation

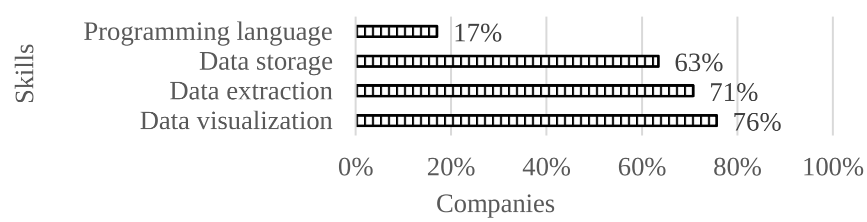

Figure 3. Anticipated skills for sensing technologies

Types of Sensing Technologies

For both graduate and undergraduate courses, the survey provided a list of sensing technologies, and asked '*Which of the following sensing technologies do you teach?'*. Participants were asked to select all that apply, and state others if not listed. Five sensing technologies have been integrated into the undergraduate CEM programs.

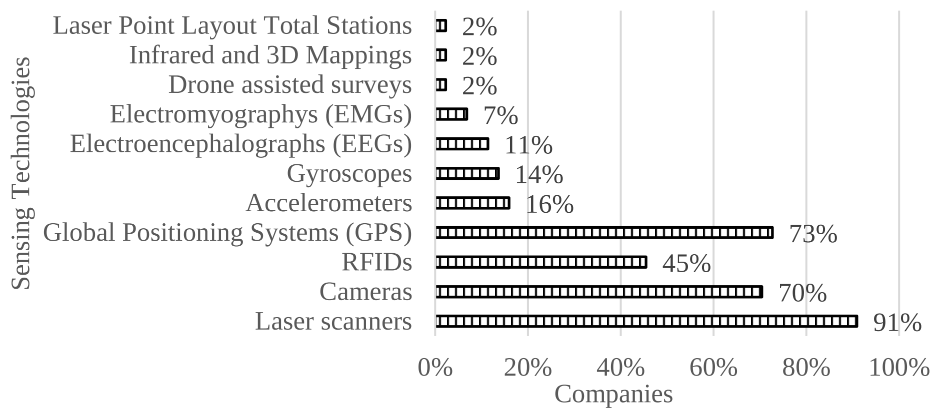

Figure 4. Sensing technologies proposed for CEM education

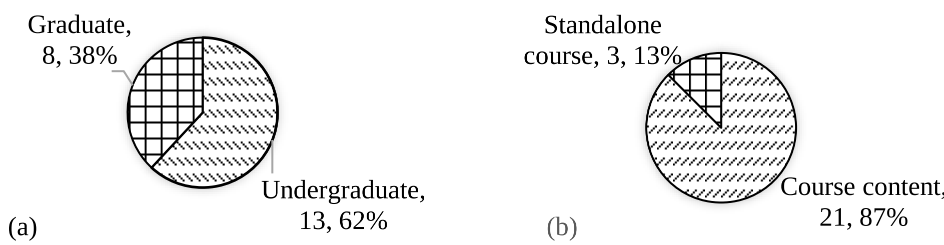

Figure 5a. Sensing technologies in CEM programs Figure 5b. Sensing technologies course type

More than half teach laser scanners, at least 40% of the instructors indicated that cameras, and GPS, are taught as part of other courses, while less than 20% teach accelerometers (see figure 6). In graduate courses, nine sensing technologies are integrated into the graduate CEM curriculum (see figure 6). Cameras and laser scanners are taught by more than 70% of the instructors. Over 35% of the instructors teach GPS and RFID while accelerometers and gyroscopes are taught by more than 20% of the instructors. EMG, EEG, and environmental sensors are only taught to graduate students by 13% of instructors.

Sensing Technology Applications

The instructors were asked *'What construction applications do you use to demonstrate the sensing technologies?* The instructors provided applications of laser scanners, cameras, GPS, RFID, and accelerometers (Table 4). No applications were provided for EEGs, EMGs, gyroscopes, and accelerometers. Students are taught how to leverage laser scanners for capturing as-built and existing conditions, and for monitoring construction progress. Students learn how to use cameras for managing safety and documenting the progress of work on the site. The instructors also teach students how to integrate data from laser scanners and cameras with BIM for as-built modeling. Students also learn how to utilize RFID and GPS for asset and material management. The instructors also teach the use of accelerometers for measuring body movements and postures for workers' ergonomics.

Comparison of Industry Expectations and Sensing Technology Education

Currently, construction companies are adopting 11 different sensing technologies of which 5 are taught at the undergraduate level, and the rest are taught at the graduate level (see figure 6). Since only 62%

of the sensing technologies are covered in undergraduate courses, it is important to incorporate more sensing technologies in their curriculum so as to meet industry skill demand. Similarly, the results reveal that the applications taught in CEM programs are not as comprehensive as the applications implemented in the industry. For example, applications of laser scanners such as detection of pipe slopes and floor flatness measurement do not appear to be covered in CEM education. While institutions need to consider widening the range of applications of sensing technologies covered, they may be constrained by the course type, as 87% of sensing technologies are taught as part of other courses. To ensure extensive coverage of industry applications, it is crucial to consider teaching sensing technologies as a stand-alone course. Students with such extensive sensing technology knowledge and skills will have a competitive edge in the job market.

Table 4

Applications of sensing technologies taught in CEM programs

Sensors	Applications
Laser scanner	As-built scans, existing conditions, progress monitoring
GPS	Facility management
Accelerometer	Ergonomics
RFID	Material tracking, facility management
Cameras	Data for point clouds, Photogrammetry for BIM, Site documentation

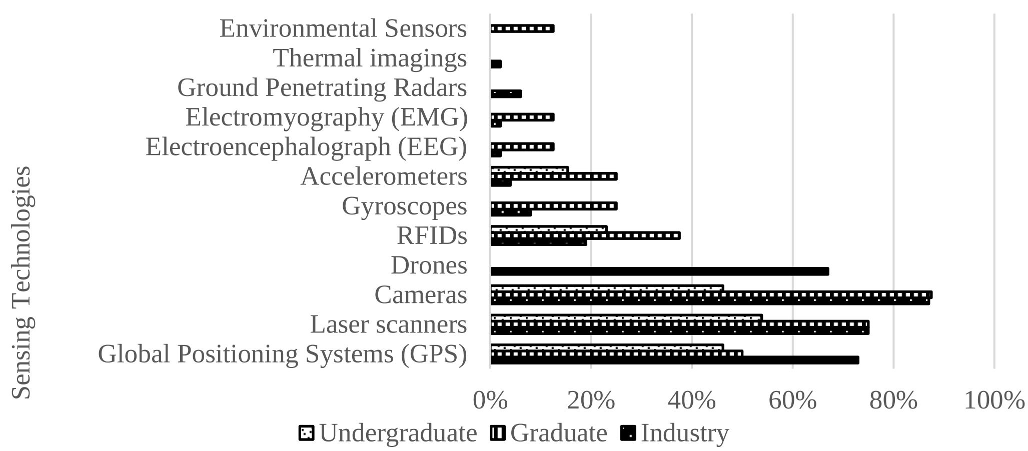

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Figure 6. Comparison of sensing technologies education and adoption in the industry

Conclusions and Future Work

The extent to which graduating CEM students are being prepared to implement sensing technologies in the construction industry was investigated in this study. Industry requirements of graduating CEM students and status of sensing technology education across various institutions in the US were explored. The study reveals that there is a high rate of adoption of sensing technologies in the construction industry, and a growing number of institutions are beginning to teach sensing technologies. It is important to note that laser scanners are widely used in the industry owing to their wide applications across the different phases of a project lifecycle and as such, should be emphasized in CEM curriculum. However, almost 90% of the surveyed instructors teach sensing technologies as contents of other courses. With 87% adoption of sensing technologies in the construction industry and 50% of institutions teaching sensing technologies, the study reveals a potential demand for technically skilled workforce in the industry. It can also be inferred from this study that with more sensing technologies taught at the graduate level, and more sensing technologies courses available for undergraduate students, undergraduate sensing technologies courses should be expanded as well. The study further suggests that the CEM curriculum should be developed to involve more stand-alone courses focused on sensing technologies. This will foster the development of a robust course that entails expected technical skills in the industry. This study sets precedence for future research to address the existing gap in literature by exploring how sensing technologies are taught at the graduate and undergraduate levels. Future study will explore how current accreditation requirements accommodate the technical skills demanded in the industry. As part of a larger study, the required competencies for deploying sensing technologies will be extracted from this study, formalized, and represented in a virtual learning environment to enhance experiential learning of applications of sensing technologies that are yet to be incorporated in CEM programs. The learning environment will also be beneficial when there is limited site access.

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