Mapping the Competencies for Implementing Sensing Technologies in the Construction Industry through Technology-Organization-Environment Framework

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***Abstract*— *Contribution:* This research category full paper contributes to the body of knowledge by identifying competencies in terms of knowledge, skills, and abilities that could potentially guide future investigations into how industry and academia perceive the essential competencies for implementing sensing technologies in the construction industry. The identified competencies provide valuable insights into the training required for both current and future workforces to meet the demands of sensing technology in the workplace. Additionally, they highlight the need for further investigation into learning technologies that can support the acquisition of these competencies. The study also expands the application of the Technology-Organization-Environment framework in the context of the competencies for implementing sensing technologies within the construction industry.**

***Background:* Data sensing technologies, such as laser scanners, radio frequency identification systems, cameras, and unmanned aerial vehicles, are increasingly being adopted in the construction industry to improve productivity, safety, and quality control of construction projects. The continuous adoption of these technologies necessitates a well-equipped workforce with the requisite competencies to sustain innovations in the industry. However, despite the importance of competent workforces in adopting sensing technologies in the construction industry, there is limited knowledge of the competencies for implementing these technologies. This study aims to fill this gap by identifying competencies in terms of knowledge, skills, and abilities required to implement sensing technologies in the construction industry through the lens of the Technology-Organization-Environment framework, thereby providing practical implications for the industry.**

***Research Questions:* (1) what are the applications of sensing technologies in the construction industry? and (2) what are the competencies requisite for implementing sensing technologies?**

***Methodology:* This study adopted a qualitative literature review to identify studies on sensing technologies' applications in the construction industry. Content analysis was used to extract competencies in terms of knowledge, skills, and abilities. The extraction was performed by examining the application of sensing technologies through the Technology-Organization-Environment framework, emphasizing the interplay of factors in the technological, organizational, and environmental contexts.**

***Findings:* The findings of this study showed the competencies encompassing nineteen knowledge, eight skills, and twelve abilities required to implement sensing technologies in the construction industry.**

Keywords*: *Construction industry, Sensing technologies, Competencies, Technology-Organization-Environment Framework

I. Introduction

Data collection is essential for effective management due to the complex and ever-changing nature of construction projects. For this reason, sensing technologies such as laser scanners, cameras, radio frequency identification (RFID) systems, and unmanned aerial vehicles (UAVs) have been adopted for data collection in the construction industry. These technologies have been instrumental in enhancing safety monitoring, productivity, and quality control on construction projects [1]. Industry reports, such as Forum [2], predict that adopting these technologies could substantially reduce global costs, with expected savings ranging from 13 to 21 percent during the design and construction stages and 10 to 17 percent during the operations and maintenance phases. To leverage these technologies effectively, workers need to be equipped with the necessary competencies [3]. However, despite the importance of these competencies, there is limited knowledge about them in the construction industry. A significant barrier to the adoption of technologies in the construction industry is the scarcity of competent workforce [1, 4]. The scarcity of a competent workforce negatively impacts safety performance, cost [5], efficiency, and overall project success [6]. Addressing this gap requires identifying the necessary competencies and equipping the current and future workforce through education, training, and practical experience [7, 8].

Therefore, this study aims to map the competencies required to implement sensing technologies fusing the Technology-Organization-Environment (TOE) framework. The

TOE framework provided a basis for mapping competencies by considering factors within its contexts. The study identified the applications of sensing technologies from existing literature and extracted the relevant competencies in terms of knowledge, skills, and abilities through the lens of the factors within the TOE framework. This study answered the following questions:

1) What are the applications of sensing technologies in the construction industry?
2) What are the competencies requisite for implementing sensing technologies?

By mapping key competencies through the TOE framework, this study contributes to the body of knowledge by offering insights into designing and organizing curricula in construction engineering and management education to align with workplace demands.

II. COMPETENCIES: DEFINITIONS AND THEORETICAL FRAMEWORK

Competency is a combination of knowledge, skills, and abilities required to perform specific tasks [9]. Therefore, a further explanation of competency would imply defining each of its constituents. Knowledge includes the theories and practices accumulated through the learning and experiences of individuals or groups [10]. Ability refers to the inherent capability required to perform a task. Skill is the combination of knowledge and ability to carry out a task effectively [11]. Despite the crucial role of the competencies in implementing new technologies in the construction sector, there is limited research in this area [12]. Theories provide structures for gaining insight into understudied areas [13]. Therefore, the Technology-Organization-Environment framework was adopted in this study to identify competencies for implementing sensing technologies. The framework was proposed by Tornatzky and Fleischer [14] for technology adoption. It contains several unique factors such as complexity, availability, security and risk, research and development, cost, and compatibility within the technology context, management support, organization structure and size within the organization context and industry characteristics, government regulations, government support, and client pressure within the environment context.

Although originally used to explain technology adoption, Clohessy and Acton [15] noted that the TOE framework also helps to identify the competencies workers need to embrace technologies. This suggests that applying the TOE framework could help identify the competencies necessary for sensing technology adoption, as depicted in Fig 1. In this study, competencies required to implement sensing technologies were identified by examining the processes involved in their applications through the factors within each context of the TOE framework. Sensing technologies represent the technology context, construction companies acquiring these technologies represent the organization context, and the construction landscape represents the environment context.

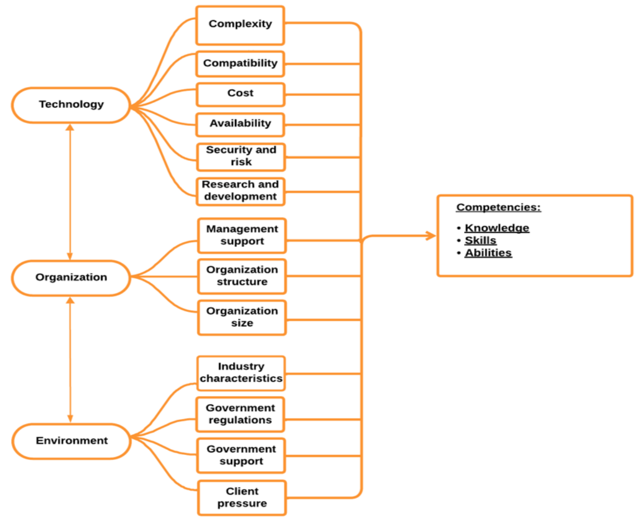

Fig. 1. TOE framework for competency mapping

III. RESEARCH METHODS

This study adopted a systematic literature review (SLR), which refers to a comprehensive aggregation of evidence pertinent to a specific field of study to answer targeted research questions [16]. Fig. 2 shows the steps involved in the SLR in this study: data identification, exclusion criteria, and content analysis of the final articles.

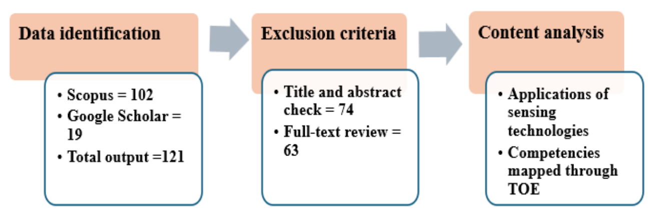

Fig. 2. Overview of the research method

A. *Data Identification*

The literature review was conducted using the Scopus database because it is known for its broad range and rich content, encompassing article titles, abstracts, citations, and keywords drawn from leading journals in science and engineering [16]. Google Scholar was also consulted to ensure that no publication was left out. The search string was "laser scanner and case studies in the construction industry." The laser scanner was replaced with other sensing technologies such as radio frequency identification system (RFID), unmanned aerial vehicle (UAV), camera, electroencephalogram (EEG), electromyography (EMG), ground penetrating radar (GPR), inertia measurement unit (IMU), global positioning system (GPS), ultra-wideband, gyroscope, and accelerometer. The search returned 102 publications from the Scopus database and 19 publications from Google Scholar, totaling 121 publications. To ensure a wide scope of coverage, the search did not place limitations on the document type and year of publications. However, the subject area was limited to engineering, while the language was limited to English. The output from this step went through the exclusion process.

B. Exclusion Criteria

Publications were filtered out by reviewing their titles and abstracts, focusing on those that discussed the applications of sensing technologies in the construction industry, which yielded 74 publications. Subsequently, a full-text review was performed to select the 63 publications that underwent content analysis.

C. Content Analysis

Content analysis of the 63 publications was used to identify the applications of sensing technologies. Content analysis involves reviewing textual data to identify patterns highlighting key features of interest to researchers [17]. Subsequently, the applications of sensing technologies were examined, and competencies, including knowledge, skills, and abilities, were extracted through the lens of the factors within the Technology-Organization-Environment (TOE) framework.

IV. RESULTS

This section presents applications of sensing technologies and competencies in terms of knowledge, skills, and abilities mapped through the factors within the TOE framework.

A. Applications of Sensing Technologies in the Construction Industry

Table I presents the applications of sensing technologies within the construction industry, along with pertinent references. For example, laser scanners are utilized to measure building components [18], monitor road reconstruction progress [19], and perform quality checks for flood wall installations [20]. Cameras are employed to monitor the installation speed of prefabricated materials [21], monitor construction workers' safety [22], and monitor the progress of internal and external construction work [23]. Additionally, ultra-wideband was used to monitor construction progress [24].

B. Competencies Mapped Through the TOE Framework

The factors within the contexts of technology, organization, and environment of the TOE framework stated in Section II were employed to map competencies in terms of knowledge, skills, and abilities, as depicted in Fig. 3. To examine the processes involved in the applications of sensing technologies identified in Table I; the study utilized factors such as complexity within the technology context to extract six types of knowledge, including sensor proprietary software, information modeling, safety management, sensor signal processing, applications of sensing technologies, and sensor integration; four skills areas, encompassing technical skills, data analytics and computational thinking, mapping and visualization, and problem-solving skills; and seven abilities areas, comprising attention to detail, spatial awareness, analytical thinking, critical thinking, creative thinking, safety awareness, and problem-solving abilities.

Other factors within the technology context, such as cost, informed the extraction of knowledge in cost-benefit analysis, lifecycle costing, and market trend analysis. Similarly, availability was pivotal in extracting knowledge of various types of sensing technologies, while compatibility was instrumental in discerning operational knowledge of sensing technologies. Factors pertaining to security and risk were leveraged to discern knowledge in data security, whereas research and development considerations facilitated the extraction of research and development (R&D) knowledge and continuous learning ability.

TABLE I. SENSING TECHNOLOGIES AND CORRESPONDING APPLICATIONS

Sensing Technologies	Applications	References
Laser scanner	Measurement of building components, progress monitoring of road reconstruction work, quality check for flood wall installation along a riverbank, and as-built documentation of existing building.	Nguyen, Nguyen [18], Zhang and Arditi [19], Alizadehsalehi, Koseoglu [20], Li, Zhang [25].
Camera	Monitoring the installation speed of prefabricated materials, monitoring construction workers' safety, progress monitoring of internal and external construction work, and productivity monitoring of earth-moving operations.	Ahmadian Fard Fini, Maghrebi [21], Barbosa and Costa [22], Tran, Nguyen [23], Kim and Chi [26].
Unmanned Aerial Vehicles	Visual inspection of the building, safety and progress monitoring, onsite data collection, and as-built creation.	Falorca, Miraldes [27], Anwar, Izhar [28], Hamledari, Sajedi [29].
Radiofrequency identification system	Materials tracking, compliance checking of PPE usage, and identification of components on large construction sites.	Kelm, Laußat [30], Dardouri, Dakhli [31], Torrent and Caldas [32].
Global positioning system	Tracking the location of materials and workers on the construction site and workers' safety monitoring.	Andoh, Su [33], Pradhananga and Teizer [34], [35]
Electroencephalogram	Construction hazard detection, monitoring workers' attention and vigilance, and construction workers' mental fatigue measurement.	Wang, Li [36], Jeon and Cai [37], Wang, Huang [38].
Electromyography	Measurement of construction workers' muscle fatigue, muscular evaluation with the simulated assembly of medium and high voltage line towers during scaffold construction, and evaluation of neck disorder among construction workers.	Jebelli and Lee [39], Peláez, Bernal [40], Nimbarte [41].
Ground penetrating radar	Mapping the subsurface root system of street trees, geotechnical inspection of pavement and sub-pavement layer, and bridge deck assessment.	Tosti, Bianchini Ciampoli [42], Benedetto, Benedetto [43], Alani, Aboutalebi [44]
Inertia measurement unit	Detection of near-miss accidents, fall risk assessment, recognition of workers' motion, and locating hazards using workers' bodily responses.	Aria, Yang [45], Kim and Cho [46], Kim, Ahn [47].
Accelerometer	Detection of accidental falls, detecting whether safety helmets are worn properly by workers, and detecting fall portent of workers.	Tsai [48], Kim, Wang [49], Fang and Dzeng [50]
Gyroscope	Road condition monitoring and activity recognition of workers in an outdoor construction environment.	Allouch, Koubâa [51], Akhavian, Brito [52]
Ultra-wideband	Prevention of tower crane collision and construction progress monitoring.	Hwang [53]; Zhang, Shen [24]

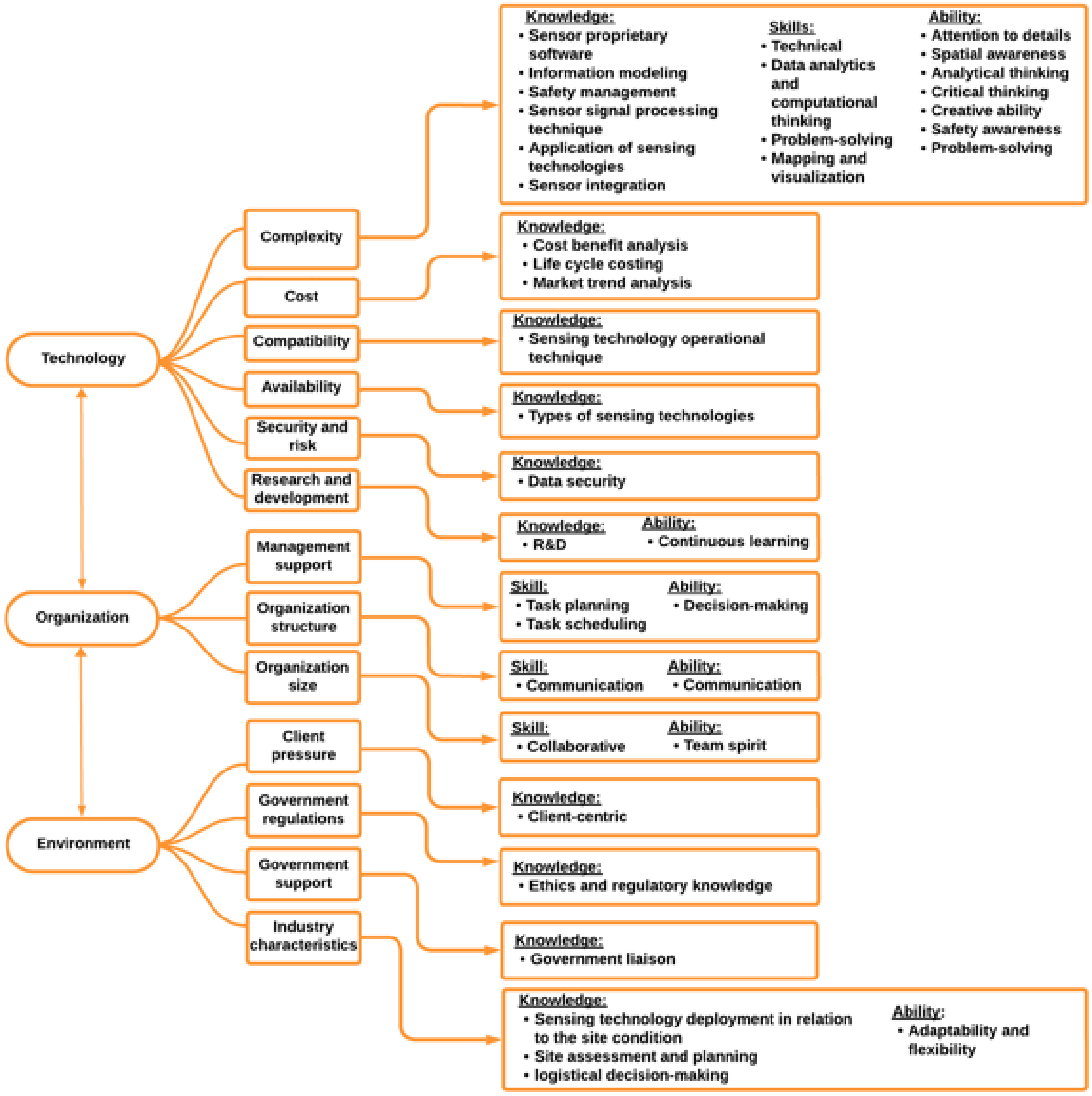

Fig. 3. Competencies mapped through TOE framework.

Within the organization context of the Technology-Organization-Environment (TOE) framework, management support plays a vital role in discerning planning skills, scheduling skills, and decision-making abilities. Organizational structure is the basis for identifying communication skills and abilities, while the organization's size is pivotal in extracting collaborative skills and teamwork abilities. Industry characteristics within the environmental context are crucial in discerning the deployment of sensing technology in relation to site conditions, site assessment and planning, and logistical decision-making knowledge. Government regulations serve as a basis for discerning knowledge in ethics and regulatory compliance, client-centric knowledge, adaptability, and flexibility, while government support is used to discern government liaison knowledge. The mapping process yielded a total of 19 knowledge areas, 8 skills, and 12 abilities.

V. DISCUSSION

The mapping of competencies through the TOE framework highlights essential implications for educating both the current and future workforce in the construction industry. As shown in Table I, the diverse applications of sensing technologies such as laser scanners, cameras, and ultra-wideband systems demonstrate the breadth of technological integration in construction, from quality checks and progress monitoring to safety management and collision prevention [1, 53]. This diversity necessitates a workforce well-versed in multiple competencies. This has been supported by Ogunseiju, Akanmu [54]. The TOE framework’s technology context emphasizes knowledge areas such as sensor proprietary software, safety management, and data security, alongside skills in data analytics and technical problem-solving. These competencies are vital for leveraging technology effectively and ensuring robust project execution. Furthermore, the organizational context highlights the importance of management support, communication skills, and decision-making abilities, essential for maintaining operational efficiency and fostering a collaborative work environment. Within the environmental context, knowledge of regulatory compliance and client-centric approaches ensures that the workforce can navigate industry-specific challenges and adhere to standards. By integrating these competencies into educational curricula, educational institutions can better align training programs with industry needs, reducing the gap between academic preparation and practical application [55]. This approach not only enhances the readiness of graduates but also supports the ongoing development of current professionals. This could ultimately contribute to a more competent and adaptable construction workforce capable of maximizing the benefits of sensing technologies [56].

VI. CONCLUSION AND FUTURE RESEARCH

There is a growing adoption of sensing technologies in the construction industry due to their capacity to offer improved safety monitoring, productivity, and quality control; this paper presents a systematic literature review on the applications of sensing technologies in the construction industry and competencies mapped from the applications of sensing technologies using a TOE framework. The applications of sensing technologies, such as laser scanners, cameras, drones, RFID, GPS, EEG, EMG, UAV, IMU, GPR, GPS, accelerometer, and gyroscopes, were identified. The analysis of the applications of sensing technologies through the lens of the factors within the Technology-Organization-Environment (TOE) framework provided a foundation for mapping nineteen knowledge, eight skills, and twelve abilities (i.e., competencies) essential for deploying sensing technologies. The study expands the application of the TOE framework in the context of competencies for implementing sensing technologies within the construction industry. Moreover, the competencies identified could provide valuable guidance for educational institutions in structuring their curricula to meet workplace demands.

Despite the meticulous methodology, the study acknowledges potential oversights and suggests expanding the database search to enhance study breadth in future research. The findings in this study could inform future research into the competencies deemed essential by industry and academia in the construction industry.

ACKNOWLEDGMENT

This work was supported by the National Science Foundation (NSF) [grant numbers 2241786, 2241785, and 2241787].

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