Comparative Analysis of Instructors' and Practitioners' Perspective on Competencies for Implementing Sensing Technologies in the Construction Industry

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Abstract—Contribution: **This research category full paper contributes to the body of knowledge by revealing the areas of agreement on competencies for implementing sensing technologies by instructors and industry practitioners in the construction industry. The findings will help the instructors equip the future workforce with the competencies to implement sensing technologies through integrated curriculum development. Additionally, the findings could help industry practitioners update the competencies of the current workforce in the construction industry for effective sensing technologies deployment. Consequently, this study's findings will help reduce the misalignment in competencies acquired by the future workforce and the industry-specific competencies for implementing sensing technologies.**

Background: **Adopting data sensing technologies like laser scanners, radio frequency identification systems, cameras, and unmanned aerial vehicles in the construction industry requires a workforce with the necessary competencies. To address this, curriculum content should be balanced to train emerging workers to meet industry expectations for implementing these technologies. This balance is crucial to minimizing the resources employers spend on post-hire training. This study compares the perspectives of instructors and industry practitioners on the competencies required for implementing sensing technologies in the construction industry.**

Research Question: **What are the perspectives of industry practitioners and instructors on the competencies for implementing sensing technologies in the construction industry?**

Methods: **This study employed a three-round Delphi survey administered to instructors in accredited higher education institutions and construction industry practitioners in the United States. Through the successive Delphi survey rounds, the study compares the instructors' and construction industry practitioners' perspectives on essential competencies required for implementing sensing technologies in the construction industry.**

Findings: **The first survey round shows the suitability of instructors' and industry practitioners' expertise in partaking in the study. The second survey round shows a trend toward convergence, indicating potential similarities between instructors' and industry practitioners' perspectives on specific competencies required for implementing sensing technologies in the construction industry. The third round showed the qualitative feedback from instructors and industry practitioners on their perception of the competencies for implementing sensing technologies in the construction industry.**

Keywords— Construction industry, Sensing technologies, Competencies, Delphi Survey

I. INTRODUCTION

The complexity of construction projects introduces significant uncertainties, driving the need for investment in sensing technologies to enhance safety monitoring, quality control, and productivity [1]. For instance, laser scanners have been adopted in the construction industry to improve quality control [2], global positioning systems have been utilized to track equipment and personnel, thereby improving safety monitoring [3, 4], and cameras have been employed for monitoring equipment to boost productivity [5]. The continuous adoption of these technologies requires a competent workforce for successful deployment [6]. However, there is a misalignment between the competencies acquired by recent graduates and those expected to implement sensing technologies. As a result, new employees often undergo additional training to deploy these technologies in the construction industry [7].

To reduce the resources expended by employers on training new hires, educational institutions need to create a robust curriculum that integrates the competency requirement from the instructors' and industry practitioners' perspectives. Therefore, this study aims to perform a comparative analysis of instructors' and industry practitioners' perspectives on the competencies required to implement sensing technologies in the construction industry. To achieve this aim, this study adopted a three-round Delphi study to compare the perspectives of industry practitioners and instructors regarding the necessary knowledge, skills, and abilities for implementing these technologies.

The study contributes to the existing body of knowledge by identifying areas of convergence and divergence between instructors' and industry practitioners' opinions on the requisite competencies for implementing sensing technologies in the construction industry. This could help instructors equip the future workforce with the necessary competencies through integrated curriculum development. Additionally, understanding the areas of convergence of competencies could help industry practitioners update the skills of the existing workforce to facilitate the effective deployment of sensing technologies.

II. COMPETENCIES FOR EMERGING TECHNOLOGIES: PERSPECTIVES OF INSTRUCTORS AND INDUSTRY

Competency is the blend of skills, knowledge, and abilities that empower individuals to perform tasks [8]. Competencies for emerging technologies, such as automation and robotics, prefabricated construction, and building information modeling (BIM), have been defined from the diverging perspectives of instructors and industry. For instance, Kiewit-Construction [9] defined competencies necessary for automation and robotics from industry perspectives according to an automation engineer's role. These competencies include communication skills, skills for testing network and cybersecurity devices, and the capacity to perform circuit coordination and thermal analysis. Conversely, from the standpoint of instructors, Bademosi and Issa [10] defined competencies for automation and robotics by categorizing the competencies into computing, computer science, technology, and attitude, with seventeen subgroups of knowledge, skills, and abilities identified within these categories.

In the context of prefabricated construction, Kiewit-Careers [11] defined competencies based on producing electrical layout and conditioning plans for construction packages and using BIM models. However, from the instructors' view, Ginigaddara, Perera [12] identified interpersonal skills, communication skills, knowledge of offsite construction, and digital skills as the competencies workers require to engage in prefabricated construction.

From the industry perspective, Balfour-Beatty [13] defined competencies for utilizing BIM based on the following: proficiency with Autodesk Revit, skills in managing model coordination and clash resolution, the use of digital applications, and communication abilities. In contrast, from the instructors' perspectives, Rahman and Ayer [14] defined competencies for utilizing BIM by identifying non-technical competencies, including analyzing and solving problems, collaborating effectively in teams, and communicating clearly as crucial competencies for adopting BIM. The divergence in the perception of competencies required to implement emerging technologies in the construction industry is a testament to the need to bridge the gap in competency perceptions of instructors and industry practitioners.

III. METHODOLOGY

This research was designed to compare the perspectives of instructors and industry practitioners on the competencies identified from the literature through a Delphi study approach. Fig. 1 shows an overview of the research methodology.

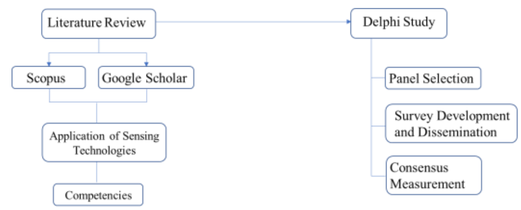

Fig. 1. Overview of the research method.

A. *Literature Review*

The literature review was conducted using the Scopus and Google Scholar search engines to explore the literature on the applications of sensing technologies in the construction industry. The search string "Application of laser scanners-case studies in the construction industry" was initially used, with "laser scanner" subsequently replaced by other sensing technologies such as radio frequency identification systems (RFID), ultra-wideband (UWB), drones, global positioning systems (GPS), electroencephalogram (EEG), electromyography (EMG), inertia measurement units (IMU), ground penetrating radar (GPR), gyroscopes, accelerometers, and cameras. The search included research papers, reports, and conference proceedings and was limited to documents written in English. No restriction was placed on the years of publication, but the subject area was limited to engineering. Competencies in terms of knowledge (n = 19), skills (n = 8), and abilities (n =12) were extracted from the applications of sensing technologies identified in the literature review.

B. *Delphi Study*

Through its iterative process, the Delphi method enables researchers to gather high-quality data from experts in the relevant field [15]. In this study, the Delphi method was used to compare the perspectives of instructors and industry practitioners on the competencies requisite for implementing sensing technologies. This method was chosen because it requires an iterative approach, which is ideal for comparing perspectives. The steps followed for the Delphi method are selecting expert panels, survey development and dissemination over three rounds, and measuring consensus. The study was approved by the Institution Review Board (IRB) of Virginia Tech under IRB # 23-1116, and all participants were provided with informed consent for information on the Delphi survey.

1) *Panel selection:* The participants, consisting of instructors from accredited higher institutions and industry practitioners in the US, were invited through the LinkedIn platform and emails. The criteria for industry practitioners include being an active member of a construction company, having professional experience, having a history of academic and industry presentations on topics related to sensing technologies, and having experience in the use of sensing technology. The criteria for instructors include being faculty in

an accredited higher institution, having scientific publications on topics related to sensing technology, teaching courses on sensing technology, and having a history of academic and industry presentations on topics related to sensing technologies. These selection criteria for industry practitioners and instructors are in tandem with the perspectives of Alomari, Gambatese and Tymvios [16]. The instructors and industry practitioners were de-identified throughout the study to aid confidentiality.

2) *Survey development and dissemination:* Drumm, Bradley and Moriarty [17] noted that consensus typically emerges within two to three rounds involving ten or more experts. Consequently, this study employed three rounds of the Delphi survey. The survey was developed and conducted via QuestionPro, with each round lasting approximately 7 minutes. The first round ascertained experts' eligibility through carefully formulated questions aligned with selection criteria. Subsequently, the second round concentrated on confirming the suitability of competencies identified from the literature, as perceived by instructors and industry practitioners. This was achieved by asking instructors and practitioners open-ended questions regarding the importance of acquiring each competency identified from the literature using a 5-point Likert scale. Finally, the third round sought qualitative feedback from experts on the outcomes of the second round.

3) Consensus measurement: Consensus denotes a unified perspective and agreement regarding a topic [18]. In this study, the mean ($\bar{x}$) was employed to rank competencies based on the average of experts' opinions regarding their importance. Standard deviation (SD) was used to measure the divergence of expert viewpoints from the mean ($\bar{x}$). Consensus regarding the perceived importance of the competencies for implementing sensing technologies identified from the literature is achieved when the SD < 1.50. This aligns with the view of Akhanova, Nadeem [19], which states that SD < 1.50 depicts agreement, and SD ≥ 1.50 means no agreement.

IV. RESULTS AND DISCUSSION

A. Survey Rounds

In the first round, 19 responses were received from industry practitioners and 16 from instructors. Among the industry practitioners, 4 respondents were deemed ineligible due to failure to meet selection criteria, while 2 instructors were similarly disqualified. Consequently, 15 industry practitioners and 14 instructors advanced to the second round. The combined professional experience of industry practitioners in utilizing sensing technologies within the construction industry totals 484 years (Mean ($\bar{x}$) = 32.3 years). The collective research experience of instructors on topics pertinent to sensing technologies within the construction industry amounts to 368 years (Mean ($\bar{x}$) = 26.30 years). Additionally, their cumulative teaching experience in courses related to sensing technologies reaches 210 years (Mean ($\bar{x}$) = 15 years). These figures justify the suitability of participants for the study, validating their expertise. For the second round, 2 participants from industry practitioners and 1 participant from the instructors dropped out, yielding industry practitioners (n = 13) and instructors (n = 13).

The consensus of the perceived importance of knowledge (see Table 1), skills (see Table 2), and abilities (see Table 3) was achieved because the SD < 1.50. For the third round, qualitative feedback on the results of the second round was sought from industry practitioners and instructors. Comments such as *"This list makes sense in its order," "The table is ranked really well"* from industry practitioners and *"It makes sense," "Seems accurate,"* and *"The ranking is logical"* from the instructors suggest agreement among participants on the perceived importance of the competencies identified from literature for implementing sensing technologies.

B. Comparison of Industry Practitioners' and Instructors' Perspectives on Competencies

1) Comparison of Industry Practitioners' and Instructors' Perspectives on Knowledge

The knowledge ranking in Table I facilitates comparative analysis, revealing areas of divergence and convergence in the perspectives of industry practitioners and instructors on the knowledge for implementing sensing technologies. The study showed that industry practitioners emphasize knowing the types of sensing technologies, whereas instructors perceive safety management as the most significant knowledge required for implementing sensing technologies in the construction industry. The divergence in perspective is depicted more in the ranking of sensor proprietary software and logistical decision-making, with industry practitioners ranking them as 2nd and 7th, respectively, while instructors ranked them 12th and 14th. This suggests that industry practitioners attach more importance to practical knowledge from workers, which is in tandem with the view of Kines, Andersen [20] that professionals rely on on-site practical training, which is required to implement technologies successfully. Other areas of divergence are research and development, ethics, and regulatory knowledge, with instructors ranking both 6^{th,} respectively, while industry practitioners ranked them much lower, at 16th and 13th.

The areas of convergence showing the same ranking from the perspective of instructors and industry practitioners include sensor operation knowledge (rank = 2), sensing technology deployment in relation to the nature of the construction site (rank = 6), and knowledge of information modeling (rank = 11). The similarities in the ranking of the sensor operation knowledge from instructors and industry practitioners indicate a unanimous agreement on the importance of hands-on training on various sensing technologies. Engaging students in practical training on how to utilize technologies on construction projects enhances their involvement and connects theoretical concepts with practical applications through hands-on experiences [21]. Similarly, the agreement in the ranking of sensing technology deployment in relation to the nature of the construction site depicts a need for adaptive strategies in dynamic construction environments. According to Braga, Tahir [22], the topography of a construction site can greatly influence the implementation and efficiency of technologies. This suggests that users of technologies require situational analysis to be able to adopt the technology. It could also be implied that there is a need to promote the development of specialized courses in situational analysis and decision-making. Such courses would further

improve the practical decision-making skills of the emerging workforce.

2) Comparison of Industry Practitioners' and Instructors' Perspectives on Skills

Table II shows the areas of divergence and convergence in the perceptions of instructors and industry practitioners on the necessary skills required to implement sensing technologies. There is a divergence in the rank assigned to technical skills and mapping and visualization skills, with industry practitioners ranking them 1st and 2nd, respectively, while instructors place them at 6th and 8th. Further divergences are observed in communication, problem-solving, and data analytics and computational thinking skills. Industry practitioners ranked these skills as 4th, 6th, and 6th, respectively, whereas instructors ranked them 1st, 2nd, and 4th.

TABLE I. COMPARISON OF INDUSTRY PRACTITIONERS' AND INSTRUCTORS' PERSPECTIVES OF KNOWLEDGE REQUIRED TO IMPLEMENT SENSING TECHNOLOGIES.

Knowledge	Industry Practitioners			Instructors		
	Mean ($\bar{x}$)	*Standard deviation (σ)*	*Ranking*	*Mean ($\bar{x}$)*	*Standard deviation (σ)*	*Ranking*
Types of sensing technologies	4.77	0.44	1	4.31	0.85	5
Applications of sensing technologies	4.62	0.65	2	4.23	0.83	6
Sensor proprietary software	4.62	0.77	2	4.00	1.08	12
Safety management	4.62	0.77	2	4.46	0.88	1
Sensing technology operation	4.62	0.65	2	4.38	0.87	2
Sensing technology deployment in relation to the nature of the construction site	4.54	0.66	6	4.23	0.73	6
Data security	4.38	0.77	7	4.38	0.87	2
Sensing technology integration and site adaptation	4.38	0.87	7	4.23	0.73	6
Logistical decision-making	4.38	1.12	7	3.92	0.95	14
Sensor signal processing techniques	4.31	0.95	10	3.77	1.09	17
Information modeling	4.23	0.93	11	4.08	0.95	11
Site assessment and planning	4.15	1.07	12	4.38	0.65	2
Client-centric	3.92	1.12	13	4.00	1.08	12
Ethics and regulatory knowledge	3.92	1.19	13	4.23	0.83	6
Cost-Benefit Analysis	3.85	1.34	15	3.92	0.95	14
Research and development	3.77	1.09	16	4.23	0.83	6
Life cycle costing	3.62	1.26	17	3.92	1.19	14
Government liaison	3.46	1.33	18	3.62	1.04	19
Market trend analysis	3.46	1.33	18	3.77	1.09	17

TABLE II. COMPARISON OF INDUSTRY PRACTITIONERS' AND INSTRUCTORS' PERSPECTIVES ON SKILLS REQUIRED TO IMPLEMENT SENSING TECHNOLOGIES.

Skills	Industry Practitioners			Instructors		
	Mean ($\bar{x}$)	*Standard deviation (σ)*	*Ranking*	*Mean ($\bar{x}$)*	*Standard deviation (σ)*	*Ranking*
Technical skills	4.77	0.44	1	4.38	0.96	6
Mapping and visualization skills	4.62	0.77	2	4.15	0.80	8
Collaborative skills	4.62	0.77	2	4.62	0.65	2
Communication skills	4.54	0.78	4	4.69	0.63	1
Task planning skills	4.54	0.78	4	4.46	0.66	5
Data analytics and computational thinking skills	4.38	0.77	6	4.54	0.66	4
Problem-solving skills	4.38	0.96	6	4.62	0.77	2
Task scheduling skills	4.31	0.95	8	4.23	0.83	7

This suggests a need for integrated curriculum development to align the perspectives of industry practitioners and instructors. There is a need to align the skills requirements for technology deployment embedded in the curriculum with the job market requirements by industry practitioners [23]. Table II depicts collaborative skill (rank = 2) as the only area of convergence between industry practitioners and instructors. This suggests an agreement on the importance of proficiency in working with other construction professionals to deploy sensing technologies. The success of construction projects typically demands interdisciplinary cooperation among architecture, engineering, construction, and various other fields, highlighting the importance of collaborative skills [24].

3) Comparison of Industry Practitioners' and Instructors' Perspectives on Abilities

Table III shows a divergence in the perspectives of industry practitioners and instructors on the abilities required for implementing sensing technologies. For instance, industry practitioners perceive that the most significant abilities required for implementing sensing technologies are problem-solving abilities, whereas instructors perceive that it was decision-making abilities. Industry practitioners ranked both adaptability and flexibility and communication ability 3rd, while they were both ranked 7th by instructors. Similarly, continuous learning was ranked 2nd by instructors, while industry practitioners ranked it 7th. Areas of convergence between industry practitioners and instructors are analytical thinking (rank = 7) and spatial awareness (rank = 11). Spatial awareness ability is an inherent trait that develops over time through personal experiences and interactions with the surrounding physical environment [25]. Construction professionals frequently utilize spatial awareness [26] to make informed decisions and transform abstract designs into tangible, finished products [27].

TABLE III. COMPARISON OF INDUSTRY PRACTITIONERS' AND INSTRUCTORS' PERSPECTIVES ON THE ABILITIES REQUIRED TO IMPLEMENT SENSING TECHNOLOGIES.

Abilities	**Industry Practitioners**			**Instructors**		
	Mean ($\bar{x}$)	***Standard deviation (σ)***	***Ranking***	***Mean ($\bar{x}$)***	***Standard deviation (σ)***	***Ranking***
Problem-solving abilities	4.85	0.38	1	4.77	0.44	2
Decision-making	4.77	0.44	2	4.92	0.28	1
Critical thinking	4.69	0.48	3	4.77	0.44	2
Adaptability and flexibility	4.69	0.48	3	4.62	0.65	7
Safety awareness	4.69	0.63	3	4.77	0.44	2
Communication	4.69	0.63	3	4.62	0.51	7
Continuous learning	4.62	0.51	7	4.77	0.44	2
Attention to detail	4.62	0.65	7	4.69	0.63	6
Analytical thinking	4.62	0.65	7	4.62	0.51	7
Team spirit	4.38	0.65	10	4.15	0.69	12
Spatial awareness	4.38	0.87	10	4.38	0.51	11
Creative ability	4.23	0.73	12	4.54	0.52	10

V. CONCLUSION AND FUTURE RESEARCH

This study provided insights into the perspectives of instructors and industry practitioners regarding the competencies required for implementing sensing technologies in the construction industry. The Delphi study highlighted the convergent and divergent views of these two groups. Industry practitioners emphasize the importance of knowing the types of sensing technologies, whereas instructors prioritize safety management as the most significant knowledge area. Industry practitioners perceive technical skills as the most important skill for implementing sensing technologies, whereas instructors highlight communication skills as essential. Regarding abilities, industry practitioners and instructors value problem-solving and decision-making, respectively.

The findings of this study will help the instructors equip the future workforce with the competencies to implement sensing technologies through an integrated curriculum development that will align instructors' and industry practitioners' perspectives on competencies. Additionally, the findings could help industry practitioners update the competencies of the current workforce in the construction industry for effective sensing technologies deployment. Future research directions could explore formalizing and incorporating competencies into a learning environment to improve the experiential learning of the future workforce.

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