WIP: Industry and Academia Perception of Competencies for Human-Robot Collaboration in the Construction Industry

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***Abstract*—This research category work-in-progress paper presents industry and academic perceptions of competencies for human-robot collaboration in the construction industry. Perceptions of competencies by industry professionals and academic experts vary significantly. Industry professionals prioritize competencies like technical skills and hands-on experience that directly enhance productivity and profitability. In contrast, academic experts prioritize scientific and theoretical understanding and intellectual development to promote innovation through research and education. Identifying the perceptional differences and consensus is crucial for successfully integrating robotics in the construction industry and developing training programs to prepare the current and future workforce. This study investigates the perceptions of industry professionals and academic experts regarding competencies for human-robot collaboration in construction to identify areas of agreement and divergence. A three-round Delphi survey was conducted to collect industry professionals' and academic experts' perceptions concerning the competencies for human-robot collaboration in construction. Cronbach's alpha was used to assess the reliability and internal consistency of the data collected, while the standard deviation and interquartile range were used to measure the consensus of the expert's opinion on competency for human-robot collaboration in construction. Thirteen industry practitioners and fourteen academic experts participated in the survey. Results of the Delphi survey reveal areas of consensus in the perceptions of industry and academia concerning some competencies for human-robot collaboration, which include human-robot interface ranked as the most significant HRC knowledge, safety management, technical skills, regulation standards and compliance, data analytics and management, and application of machine learning algorithms skills ranked equally in different positions, and safety awareness ranked as the most important ability for HRC. There are differences in the perceptions of both panels of experts concerning the remaining competencies for human-robot collaboration. This study underscores the perspective of industry professionals and academic experts on the competencies crucial for facilitating safe and effective collaboration with robots in the construction industry.**

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***Keywords*—Human-robot collaboration, Industry professionals, Academic experts, Delphi Study, Competency development, Construction Industry, Workforce development.**

I. Introduction

The advent of robotic automation in the construction industry has introduced new competency requirements to ensure safe and efficient human-robot collaboration (HRC). Current and future construction workers must develop competencies that will enable effective teamwork with robots on construction tasks. However, there is a noticeable disparity between the perceptions of industry professionals and academic experts regarding competencies. For instance, a study by Tablatin [1] on information technology (IT) competencies revealed significant differences between the views of industry practitioners and IT faculty members. This divergence highlights a gap between the competencies taught in universities and those the industry needs. Another study by Li, Zhang [2] revealed that practitioners' expectations of new hires' scheduling knowledge do not align with the content of current construction planning and scheduling courses. These discrepancies stem from the distinct focuses of each group [3, 4]. Industry professionals prioritize technical skills and hands-on experience to drive productivity and profitability, while academic experts focus on scientific understanding and intellectual development to foster innovation [4]. Such differences often result in a mismatch between the competencies required by the industry and those possessed by graduate students [5].

Therefore, it is imperative to investigate and understand the perception of both the industry and academia regarding competencies for facilitating HRC in the construction industry. This study aims to evaluate these perceptions to bridge the gap between industry needs and academic offerings, which could aid in developing training programs for the current and future construction workforce.

II. Background

A. Overview of Human-Robot Collaboration in Construction

Human-robot collaboration in construction involves the integration of robotic systems with human workers to enhance efficiency, safety, and precision on job sites [6]. Robots can perform repetitive, hazardous, or physically demanding tasks, such as bricklaying, concrete pouring, or material transport, which reduces the risk of injury and allows human workers to focus on more complex and decision-intensive activities [7]. Collaborative robots, or cobots, are designed to work alongside humans, aiding in tasks that demand precision and strength. They can assist in lifting heavy materials, conducting precise measurements, or performing quality inspections [8]. The integration of robots' strengths with human capabilities elevates work quality and fosters safer construction environments.

B. Competencies for Human-Robot Collaboration

Competency for HRC in the construction industry includes the integration of knowledge, abilities, and skills that translate into behaviors necessary for successful job performance [9]. It refers to the success factors required to achieve significant results in an organization's specific job or role [10]. In HRC, competencies include theoretical knowledge of key principles and components of robotics automation, such as robot programming [11], sensing technologies [12], human-robot interaction [13], robot types and applications [14], robot anatomy and technical specifications [15], and robot operating systems [16, 17]. Understanding safety protocols and regulations is also crucial for ensuring successful collaboration between humans and robots in construction [18]. Skills necessary for HRC include technical skills [19], safety management [18], and maintaining efficient workflow on construction sites [20, 21]. Effective communication is essential for clear instructions and coordination between human workers and robots to optimize productivity and safety in the construction industry [22]. Abilities such as problem-solving [14], adaptability [23], and attention to detail [24] are also important for effective collaboration. These HRC competencies are synthesized into HRC knowledge, skills, and abilities presented in Table I.

TABLE I. COMPETENCIES FOR HUMAN-ROBOT COLLABORATION IN THE CONSTRUCTION INDUSTRY

HRC Knowledge	HRC Skills	HRC Abilities
Types of robots	Effective communication	Teamwork
Construction robot applications	Task planning	Communication
Robot anatomy and technical specifications	Regulation standard compliance	Continuous learning
Sensors	Safety management	Problem-solving
Task planning	Technical skill	Adaptability
HRC ethics and regulation	Programming	Attention to details
HRC safety and standards	Data analytics and management	Analytical aptitude
HRC evaluation	Human-robot interface proficiency	Decision making
HRC related fields	Application of Machine Learning Algorithms	Critical thinking
Immersive virtual environments	Simulation and modeling	Spatial awareness
Communication modes and technologies		Cultural and social awareness
Human-robot interface		Safety awareness
Robot control system		
System integration		
Programming		
Modeling and simulation		
Data analytics and machine learning		
Robot learning methods		
Computation design		
Robot operating system		

III. Methodology

This section presents the method, including literature review and content analysis, Delphi survey, and method of data analysis adopted in this study as presented in Fig. 1. A qualitative literature review and content analysis was adopted to identify the competencies for HRC in construction (see Section II). Afterward, a three-round Delphi survey was used to collect industry and academic experts' opinions concerning the HRC competencies presented in Table 1. Industry participants were recruited through emails sent to the industry advisory board of Virginia Polytechnic Institute and State University (Virginia Tech). Participants from academia were contacted for participation in the study through the ASCE Construction Research Council listserv. Social media postings on LinkedIn were also used to recruit participants from both sectors in the United States.

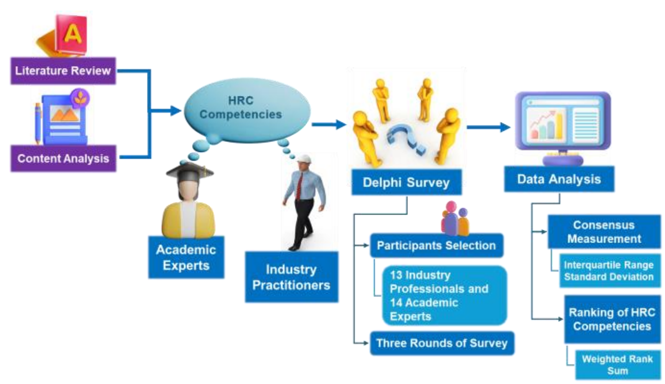

Fig. 1. Overview of research methodology.

The first round involved collecting demographic and professional information to determine participants' eligibility for the study. In the second round, experts rated each HRC competency on a Likert scale of 1 to 5 (5 = extremely significant, 4 = very significant, 3 = moderately significant, 2 = slightly significant, and 1 = not significant). In the third round, experts reviewed the rankings derived from the ratings in the second round and indicated their agreement with these rankings.

Eligibility to proceed to the second round as an expert panel member was determined using the criteria described by Hallowell and Gambatese [25] and modified for this study as presented in Table 2. Fourteen industry professionals and fifteen academic experts who scored above the minimum 20 points, based on their educational, professional experience and prominence, and experience with robotic technology in construction, qualified to proceed to the second round of the survey; however, due to attrition, thirteen industry professionals and fourteen academic experts completed the survey.

TABLE II. POINT GRADING SYSTEM FOR PARTICIPANTS' QUALIFICATION

Experience /Achievement	Points (Each)	Minimum Score
Educational qualification		
Associate degree	2	4
BS	4	
MS	2	
PhD	4	
Professional experience		
Faculty member at an accredited university/work in a relevant industry	3	3
Year of professional experience in the construction industry	1	1
Professional prominence		
Professional registration	3	3
Membership of a committee	1	
Chair of a committee	3	
Peer-reviewed journal /technical article/technical report publication	2	2
Conference papers publication	1	1
Book publication	2	2
Conference presentation	1	1
Experience with robotic technology		
Years of experience in robotic technology	2	2
Use of robotic technology/research with robotic technology	1	1
Patents	5	
Total		20

Cronbach's alpha was used to evaluate the reliability and consistency of experts' Likert scale ratings [26]. Cronbach alpha's value of the industry expert's panel includes 0.89 for knowledge, 0.76 for skill, and 0.82 for abilities. Academic experts had 0.93 for knowledge, 0.91 for skills, and 0.96 for abilities, underscoring the internal consistency of the data collected from both categories of experts. Interquartile range (IQR) and standard deviation (SD) were used to measure consensus among experts because they provide robust measures of variability and dispersion [27, 28], indicating the degree of agreement or disagreement in the experts' responses. The industry panel had an IQR ranging from 0.25 to 2.00 for knowledge, 0.00 to 2.00 for skills, and 0.00 to 2.00 for abilities, with a standard deviation ranging from 0.89 to 1.29 for knowledge, 0.57 to 1.30 for skills, and 0.77 to 1.31 for abilities. The academic panel had IQR values from 0.50 to 2.00 for knowledge, 1.00 to 1.50 for skills, and 1.00 to 2.00 for abilities, with SD values from 0.49 to 1.30 for knowledge, 0.64 to 1.15 for skills, and 0.64 to 1.46 for abilities. These values met consensus requirements (IQR $\leq$ 2.5 and SD $<$ 1.5) [29], indicating satisfactory agreement among experts. The final ranking of the competencies was done by calculating the weighted rank-sum (WRS) [30] of the Likert rating data from the second round after reaching a consensus.

IV. RESULTS AND DISCUSSION

This section presents the ranking of the perception of industry and academia panels of experts on the knowledge, skills, and abilities required to facilitate HRC in the construction industry.

A. *Industry and academic experts' ranking of HRC knowledge*

Industry and academia ranked human-robot interface as the most important knowledge for facilitating HRC in the construction industry (see Table III). This emphasizes the importance of understanding components such as brain-computer interfaces, immersive virtual reality interfaces, haptic interfaces, and graphical user interfaces. Effective collaboration with robots on construction sites requires the current and future workforce to be proficient in human-robot interfaces [13, 19]. However, the ranking of the other HRC knowledge areas varies between the two groups of experts, as presented in Table II. The findings contribute to the documented perceptional differences between industry and academia [2]. In addition, HRC is an emerging field in the construction industry. Jang, Kim [31] noted that industry and academia usually have differing views on the competencies required to implement emerging concepts or technologies in the construction industry.

TABLE III. INDUSTRY AND ACADEMIC EXPERT PANELS RANKING OF HRC KNOWLEDGE

Industry Expert Panel Ranking		Academic Expert Panel Ranking	
HRC Knowledge	**WRS**	**HRC Knowledge**	**WRS**
Human-robot interface	67	Human-robot interface	70
Construction robot applications	65	HRC safety and standards	70
HRC safety and standards	65	Robot control system	69
Task planning	64	HRC ethics and regulation	66
Robot control system	62	Construction robot applications	65
Types of robots	60	Sensors	63
System integration	60	Communication modes and technologies	63
Sensors	58	Task planning	62
Modeling and simulation	58	System integration	62
Communication modes and technologies	56	Types of robots	58
Robot learning methods	56	Robot anatomy and technical specifications	58
Programming	55	HRC evaluation	58
Robot operating system (ROS)	53	Robot learning methods	58
Immersive virtual environments	52	Modeling and simulation	54
Data analytics and machine learning	52	Data analytics and machine learning	54
Robot anatomy and technical specifications	50	Robot operating system (ROS)	54
HRC evaluation	49	HRC related fields	52
HRC ethics and regulation	47	Immersive virtual environments	52
Computation design	47	Programming	52
HRC related fields	45	Computation design	51

B. *Industry and academic experts' ranking of HRC skills*

Both industry and academia expert panels ranked safety management as the most important skill required for HRC in the construction industry. Similarly, both expert panels agreed on the importance of technical skills for HRC. This consensus highlights the importance of these skills for fostering safe and efficient collaboration between humans and robots in construction. However, industry and academia have varying perceptions regarding other necessary HRC skills, as presented in Table IV. For example, while industry and academia agree on some key skills, they differ on others, such as task planning, human-robot interface proficiency, effective communication, simulation and modeling, and programming skills. These differences could potentially lead to a mismatch between the skills graduates acquire academically and industry expectations [32].

TABLE IV. INDUSTRY AND ACADEMIC EXPERT PANELS RANKING OF HRC SKILLS

Industry Expert Panel Ranking		Academic Expert Panel Ranking	
HRC Skills	**WRS**	**HRC Skills**	**W RS**
Safety management	66	Safety management	68
Task planning	66	Human-robot interface proficiency	67
Technical skill	65	Technical skill	65
Human-robot interface proficiency	59	Task planning	63
Effective communication	58	Effective communication	63
Regulation standard compliance	52	Regulation standard compliance	63
Simulation and modeling	51	Simulation and modeling	50
Programming	45	Programming	50
Data analytics and management	44	Data analytics and management	48
Application of Machine Learning Algorithms	43	Application of Machine Learning Algorithms	48

C. Industry and academic experts' ranking of HRC abilities

The industry and academia expert panels ranked safety awareness as the most important ability required for HRC in the construction industry. This ranking consensus underscores the importance of safety in HRC in the construction industry. However, the ranking of the other abilities required, as shown in Fig. V, shows perceptional differences between industry and academia. This disparity underscores the differing views on the abilities needed to facilitate effective HRC in the construction industry.

TABLE V. INDUSTRY AND ACADEMIC EXPERT PANELS RANKING OF HRC ABILITIES

Industry Expert Panel Ranking		Academic Expert Panel Ranking	
HRC Abilities	**WRS**	**HRC Abilities**	**WRS**
Safety awareness	68	Safety awareness	68
Continuous learning	65	Teamwork	65
Problem-solving	63	Communication	64
Critical thinking	63	Adaptability	64
Spatial awareness	63	Continuous learning	63
Teamwork	61	Decision making	62
Adaptability	61	Spatial awareness	62
Decision making	60	Critical thinking	61
Attention to details	59	Problem-solving	60
Communication	55	Attention to details	60
Analytical aptitude	50	Analytical aptitude	58
Cultural and social awareness	42	Cultural and social awareness	57

V. CONCLUSION

This research evaluated the perceptions of industry and academia concerning the competencies for HRC in the construction industry. Findings revealed areas of consensus and differences between the industry and academic panel of experts concerning HRC competencies. The study showed that industry and academia agreed that the most important competencies required for HRC in the construction industry are human-robot interface (knowledge), safety management (skill), and safety awareness (ability). However, industry and academia differ on the importance of other knowledge, skills, and abilities required for HRC in the construction industry. This study highlights the industry's HRC competency needs and academia's offerings towards HRC in the construction industry. Understanding these perceptual differences could help bridge the construction engineering and management curricula gap on the competencies required for HRC in the construction industry.

Future work could focus on aligning industry and academia's perceptions of educating students to develop competencies for HRC in construction by developing interdisciplinary curricula and training programs that integrate practical industry needs with theoretical academic knowledge. Additionally, different pedagogical approaches, such as experiential learning methodology involving developing virtual and immersive environments where students can interact and collaborate with robots to execute construction tasks, could be investigated.

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