Skills Assessment for Robotics in Construction Education

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Abstract. The construction industry is considered one of the least digitized industries around with most of its processes being repetitive and labor-intensive. However, recently, the industry has witnessed an upsurge in the volume of new technologies implemented in practice. One prospective opportunity for innovative technologies in construction is the implementation of robotics and automation technologies. With these disruptive technologies being implemented in the industry, there is a need to improve pedagogic methods to address the changing demands of the workforce and equip new employees with the abilities required to drive construction robotics processes. The principal purpose of this research is to examine the current applications of robotics technologies in the construction industry in order to identify the foundational knowledge, skills, and abilities (KSAs) construction students must possess to perform in the future workforce successfully. This paper presents the background of construction robotics, the research framework and initial assessment of essential KSAs.

1. Introduction

In recent years, the architecture, engineering, construction, and operations (AECO) industry has witnessed an increase in the volume of new technologies implemented in practice, and the development of innovative technological solutions has evolved to make an impact on the industry as a whole. One prospective opportunity for innovative technologies in construction is the implementation of robotics and automation, which is the application of autonomous machines that carry out construction tasks and operations automatically through intelligent programming and controls (Kamaruddin et al. 2016). Robotics has been introduced into the construction industry as a solution to its productivity problem since the 1960s (Bock 2007). Presently, many advanced technologies are being employed in the field of construction robotics, such as unmanned aerial systems, laser scanning, virtual and augmented reality, autonomous and robotic systems, additive manufacturing, and mobile computing (Oesterreich and Teuteberg 2016). Some of these technologies have already been widely applied while some are just emerging into the market. Consequently, construction companies are increasingly incorporating these advanced construction technologies integrated with a central platform of connected building information modeling (BIM) on construction projects (Oesterreich and Teuteberg 2016).

With these disruptive technologies being implemented in the AECO industry, there is a need to improve the pedagogic methods in training and education to address the changing demands of the workforce. Furthermore, in the face of troubling skilled labor shortages, it is crucial for new recruits to join the construction workforce with the skills and exposure to technologies to drive construction robotics processes and higher levels of precision in construction. Therefore, it is imperative to teach construction robotics and automation to AECO students in institutions of higher learning in order to expose them to advanced construction technologies and equip them with the necessary inter-disciplinary skills and abilities required to thrive in the workforce of the industrialized era. The primary purpose of this research is to identify and examine the current applications of robotics technologies in the construction industry in order to identify the essential knowledge, skills, and abilities (KSAs) construction students must possess to perform in the future workforce successfully. Therefore, the two main objectives of this study are to:

1. Identify the current technology trends and applications of robotics and automation in the construction industry.
2. Determine the perceived critical construction robotics KSAs required to perform construction robotics tasks in the industry.

2. Literature Review

With most of its processes being monotonous and labor-intensive, the construction industry remains one of the least digitized industries around. The industry still operates traditionally, resulting in relatively low productivity when compared to other industrial sectors. The industry calls for more efficient construction companies, effectual and practical construction processes, and advanced construction methods to productively contend for relevance under the pressure of growing urbanization, globalization, technological innovations, and industry competition in the twenty-first century (World Economic Forum 2016). One of the primary problems the construction industry is facing is the stagnant levels of productivity (Barbosa et al. 2017). According to the Bureau of Labor Statistics (2018), the productivity levels in the construction have been on a decline for the past few years when compared to other mature industries, such as the manufacturing industry. The adoption of modern, innovative technologies and processes is very critical for the industry, as an improvement in productivity will have a significant impact on the global economy. Another major challenge associated with the construction industry is the skilled labor shortages, which has sustained a recurrent cyclic trend for the past thirty years (Karimi et al. 2018).

A promising opportunity to improve the productivity, safety, and quality aspects of the construction industry lies in the implementation of innovative robotics and automation technologies Construction robots are intelligent machines operated by smart controls with a variable range in levels of sophistication, and are generally intended to enhance speed and boost the precision of construction processes (Buswell et al. 2007). Construction automation is the application of automated and computerized techniques in construction to perform mechanical operations aimed at reducing time, labor intensity, and risk of exposure to harm, while at the same time preserving and even enhancing the quality of the finished products (Hewitt and Gambatese 2002). Both the terms robotics and automation have been broadly recognized in the construction industry and customarily describe mechanization, unmanned processes, and robotization of construction tasks and processes (Kamaruddin et al. 2016). Therefore, the definition of construction robotics and automation can be synthesized as the application of autonomous machines that carry out construction tasks and operations automatically through intelligent programming and controls.

2.1 Construction Robotics Technologies

The progression in digital technology encountered in several mature industries over the past decade has transformed these industries, thus leading them into a new technological era identified as the Fourth Industrial Revolution, also known as the era of industrialization (Schwab 2017). The term of Industry 4.0 has been used as a concept to describe new developments in manufacturing, and it has been deemed reasonable to use the Industry 4.0 technology as a benchmark to identify the advanced technologies ushering in the era of digitization and industrialization in the construction industry (Oesterreich and Teuteberg 2016). To present the Industry 4.0 technologies in construction effectively, Oesterreich and Teuteberg (2016) completed a content analysis review of several articles. The review method required a broad search of articles by applying the keywords 'Industry 4.0' and 'construction.' The results of the study by Oesterreich and Teuteberg (2016) comprised almost all the leading-edge topics in construction robotics, besides laser scanning. In addition, some of the technologies identified are similar or belong to the same technical sphere. Accordingly, similar technologies are grouped, and the final identified construction robotics technologies are listed in Table 1.

Table 1. Trends in current construction robotics research

Construction robotics technologies	
Reality computing technology	Laser Scanners
	Rovers
	Unmanned Aerial Systems
Simulation technology	Augmented Reality
	Mixed Reality
	Virtual Reality
Automation technology	Additive Manufacturing
	Autonomous Vehicles
	Prefabrication and Modularization
	Robotics systems
Smart Technology	Artificial Intelligence
	Big Data
	Cloud computing
	Cyber-Physical Systems
	Human-Computer Interaction
	Internet of Things (IoT)
	Radio-Frequency Identification

2.2 Applications of Robotics Technologies in Construction

Significant efforts to automate aspects of the construction process and enhance efficiency in the industry have been prevalent since the nineteenth century, as seen in the various manifestation of large and technologically complex construction like long-span bridges (Romero et al. 2014). Construction activities that employed the use of pieces of machinery as an alternative to human labor were new modes of mechanization in construction. By the end of 1970, robotic equipment with the abilities to lay masonry blocks were developed, and by late 1980, there was a growing demand for construction robots in Japan (Kamaruddin et al. 2016). From the review of current literature, it is observed that the range of application of construction robotics and automation technologies is extensive, spanning over all the different phases of the lifecycle of construction projects. These technologies can be implemented post-construction for maintenance and operation activities, until eventual deconstruction. However, the level of robotics and automation technologies implementation differs significantly throughout the different stages of construction, with the actual construction phase being the most prevalent. Some of the current applications of robotics technologies in construction research are shown in Table 2. These applications were selected as a result of focused and organized review of current literature within the last year that showcase state-of-the-art construction robotics technologies and applications.

2.3 Robotics and Automation in Construction Education

The new era of digitization in construction offers immense benefits for the construction industry, the environment, and the economy. The technological disruption of the AECO industry calls for a change in the pedagogic methods in AECO education to address the future of work. The advent of construction robotics technology such as prefabrication, 3D printing, robotic arm systems, big data, and predictive analysis and IoT should influence construction education. It is critical for institutions of higher learning to introduce these new technologies and processes into construction education, to equip students adequately with the knowledge and skills required to thrive in the workforce of the industrialized era. Furthermore, in the face of troubling skilled labor shortages, it is crucial for employees to be equipped with the necessary abilities and exposure to technologies to drive construction robotics processes and higher levels of precision in construction as they join the workforce.

Although research in construction automation and robotics has become well established over the years, transferring the knowledge gained in these fields through classroom teaching has not gained as much traction (Bayne 2015). Furthermore, there is a lack of a collective establishment of fundamental KSAs relevant to the implementation of construction robotics within existing research. As these technologies continue to evolve and continue to make significant advancement in the industry, developing and recruiting young talent will be vital for accelerating innovation and should be a high priority for the industry. Integrating robotics and automation in the broad AECO curriculum will be a significant and viable solution to the growing demand for a strong robotics talent pipeline. This research is a primary action in establishing the essential KSAs necessary to meet workplace job-task performance requirements related to construction robotics in order to develop skilled talent for the future workforce.

3. Methodology

3.1 Framework

To identify the essential KSAs required for construction robotics competency, three primary phases were developed for this study, with each being built upon by a subsequent phase. Figure 1 shows these phases as literature review, semi-structured interviews, and Delphi study. This research is on-going and this paper presents the preliminary results for the first phase, which has been completed.

Literature Review

The first phase of the research was an extensive review of literature on construction robotics and automation. Information on construction robotics technologies was gathered through a comprehensive evaluation of academic literature to establish a foundation for the general knowledge for this study. The especially relevant conference proceedings explored include The American Society of Civil Engineers (ASCE), Construction Research Congress (CRC), The

Institute of Electrical and Electronics Engineers (IEEE), International Symposium on Automation and Robotics in Construction (ISARC), the ASCE Computing Division Computing Workshops, and The Joint Conference on Computing in Construction (JC3) conference series. The journals searched were the Automation in Construction Journal, Journal of Computing in Civil Engineering, Journal of Construction Engineering and Management, Journal of Information Technology in Construction (ITCon), and Journal of Educational Technology. Several academic papers on current construction robotic technologies implemented in the construction industry, with a focus on the United States, were evaluated. Furthermore, the literature review assisted in the preliminary identification of essential KSAs required to meet performance requirements related to construction robotics tasks in the industry. This phase has been completed, and the results are presented in this paper.

Table 2. Current trends in the applications of construction robotic technologies

Authors	Robotics technologies	Construction applications
Wang and Zhang (2019)	Robotic crawler and arm system	Nail and screw recycling
Agnisarman et al. (2019)	Micro aerial vehicles Autonomous robotic systems Unmanned aerial systems Remotely operated vehicles	Routine inspection and maintenance
Camacho et al. (2018)	Additive manufacturing (Robotic 3D printing)	Fabrication of building elements
Zhang et al. (2018)	Mobile robot 3D printers	On-site fabrication of concrete structure
Goessens et al. (2018)	Unmanned aerial systems	Transporting, handling and laying masonry in masonry construction
Kim et al. (2018)	Automated robotic excavator	Earthwork processes
Chen et al. (2018)	Automated robots Robotic 3D printing Digital fabrication	Construction tasks automation
Louis and Dunston (2018)	Internet of Things	Real-time and automated decision-making in repetitive construction operations
Bogue (2018)	Robotic systems Unmanned aerial systems Autonomous ground vehicles Robotic 3D printing	Bricklaying Glazing installation Surveying Project progress monitoring Stockpile and inventory logistics Health and safety assessment Excavation and earthmoving operations Building and infrastructure construction
Lee et al. (2018)	Robotic arm systems	Maintenance work for high-rise building Curtain wall building façade cleaning

Semi-Structured Interviews

The next step in this research is to conduct one-on-one interviews with construction industry and educational professionals considered to be subject matter experts (SME) in robotics and automation. The interviews will be semi-structured to permit deeper investigating and consequently collect a large quantity of data, as the interviewees will be encouraged to examine the research topic and share their opinions based on their experiences. The industry professional expertise solicited in the semi-structured interviews is essential in providing an understanding of the application of robotics and automation technologies in their respective companies. In addition, educators who have been at the forefront of construction robotics research and have introduced construction robotics to students in their classrooms will be sought after. The interviews will establish a baseline for categorizing the vital KSAs considered necessary for construction robotics proficiency. The interview participants will be offered the chance to take part in the subsequent Delphi phase. The findings of the interview will be used to support and cross-validate the findings of the literature review.

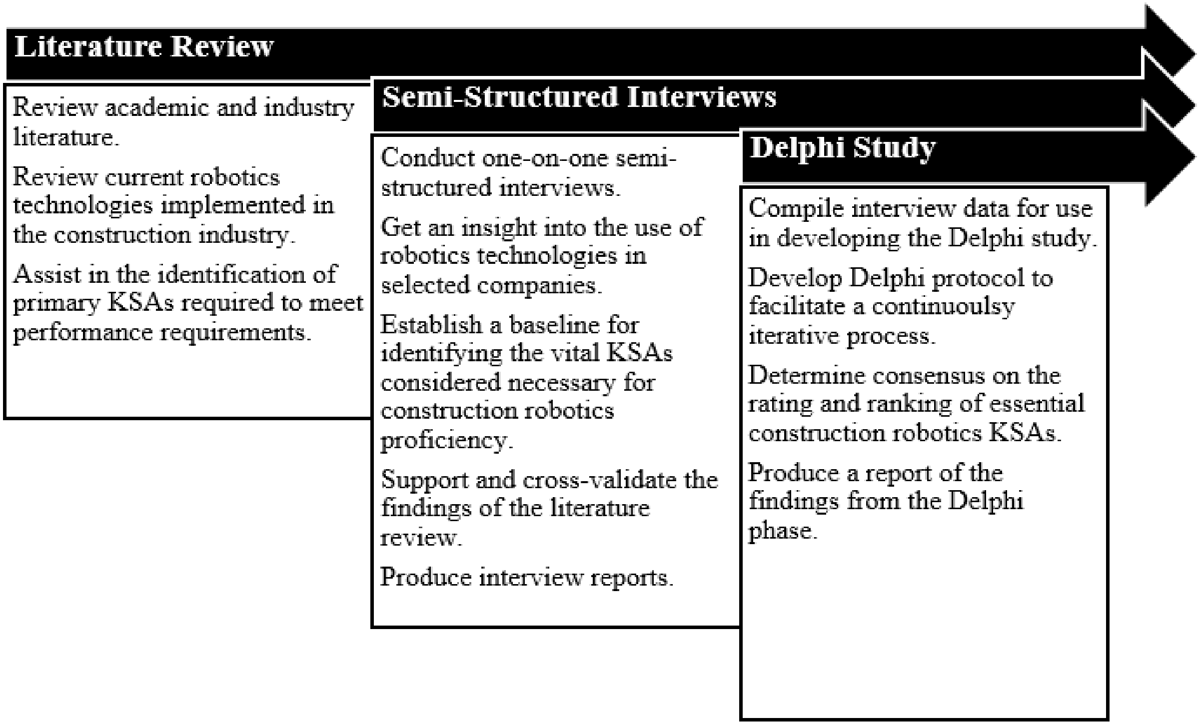

Figure 1: Research Methodology Phases

Delphi Study

The third and final phase of the research will involve the development and execution of a Delphi study with participants from the SME pool identified during the interview phase. During the interview phase, possible involvement in a Delphi study will be discussed with the SMEs and the expectations regarding their participation, time commitment and anticipated outcomes of the Delphi study will be clearly outlined. The list of participants who agree to participate will be created as they are being interviewed and upon completing the informed consent forms. The Delphi study itself will be conducted in multiple stages of development. The Delphi study for this research will be conducted in three iterations. During the first round, a preliminary list of the required construction robotics KSAs will be generated, and the first round will serve as an open discussion among the Delphi panelists to expand the preliminary list and determine the relevance and applicability of each item on the list. Consensus evaluation will be conducted throughout the second and third rounds. At the end of the Delphi study, a final report will be generated to present the perceived important KSAs related to construction robotics according to their ratings and rankings.

4. Results

4.1 Initial Assessment of Construction Robotics KSAs

A content analysis based review technique was employed to develop a preliminary list of the essential construction robotics KSAs. Given the absence of an established framework for determining construction robotics KSAs, several research articles were reviewed to corroborate the implementation of construction robotics technologies and applications, and the research development process and technical requirements associated with them. Inferences were then made by systematically identifying specific characteristics in the articles. The techniques required the review of several publications, from which results were drawn and highlighted in Table 3. The content analysis-based review was carried out in two parts to achieve a systematic review of literature from 2009 to 2019, as shown in Figure 2. A thorough exploration of literature using the Google Scholar search engine using various keywords such as automation, robotics, robotic technologies, construction, construction education, and robotic skills was completed in Phase 1.

Phase 1 resulted in the identification of 53 related articles mostly from the Automation in Construction journal, the International Journal of Advanced Research in Computer Science, the Journal of Computing in Civil Engineering, and the Journal of Information Technology in Construction. The contents of these articles were reviewed and screened in Phase 2 in order to extract publications that were deemed irrelevant to the study. Upon completion of the screening procedure, 34 articles were selected for further analysis. While this two-phase search and review method may not deliver the maximum amount of publications eligible to be evaluated, it adequately presents a substantial volume of significant research, from which this research could extrapolate conclusions and advance to the next phase of the research. From the articles selected for further examination at the end of Phase 2, 29 publications facilitated the development of the preliminary list of the essential KSAs required to perform construction robotics related tasks.

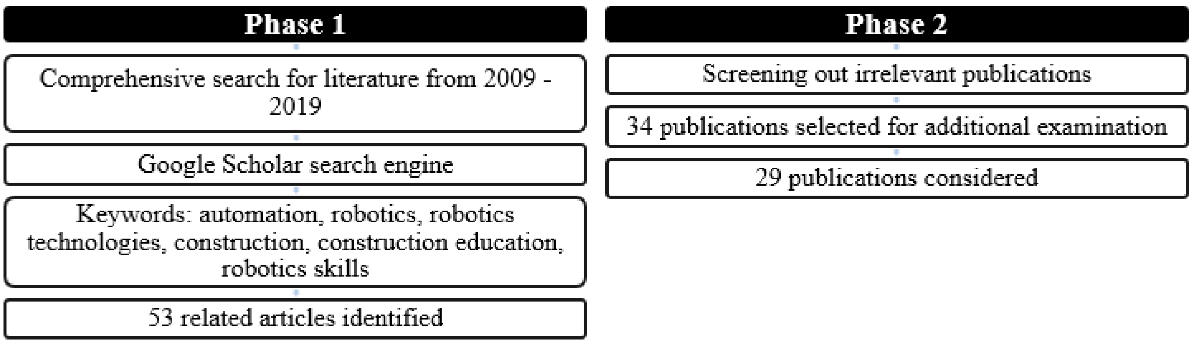

Figure 2: Content Analysis Based Review Method

From the literature review and content analysis based review, the fundamental KSAs that were required to complete the job tasks highlighted in the articles were extracted based on a broad mention in multiple applications, aimed at capturing the complex dynamics of the technologies and processes. These identified KSAs can be broken down into two major categories: computing KSAs and computer science KSAs, as shown in Table 3. The preliminary list will be expanded on and validated during the semi-structured interview phase of this research. After which, the list will be further evaluated during the Delphi study phase where the panel will reach a consensus on the essential KSAs.

Table 3. Identification of foundational construction robotics skills

KSA category	KSAs
Computing skills	Building information modeling
	Cloud computing
	Collaborative environments
	Electronic communications
	Parametric design
	Programming
	Specialized engineering software
Computer science skills	Algorithms and computational complexity
	Automated reasoning in artificial intelligence
	Big data analytics
	Computational mechanics
	Computer graphics
	Database concepts (computer-based databases)
	Data structures
	Geometric modeling
	Knowledge systems for decision support
	Machine learning
	Object representation and reasoning
	Optimization and search

5. Conclusions

Robotics and automation have been employed in the construction industry for several decades. However, very few research studies have tried to uncover the shift in robotics technologies. Through a systematic review of conference proceedings and journal articles, this research assesses and highlights some of the current technology trends and applications of automation and robotics in the construction industry, uncovering the focal point of construction robotics research. In addition, through a two-phase content analysis based review method, this research provides insight into the perceived critical construction KSAs required to perform construction robotics tasks in the industry. Additional systematized review and evaluation of the list of construction robotics KSAs will be accomplished through a series of one-on-one semi-structured interviews with construction industry and education professionals followed by a rigorous three-round, consensus-building Delphi study.

6. Future Study

Upon completion of the study, a significant area of future research is the development of a construction robotics competency benchmark and performance assessment framework to assist educators and industry professionals in cultivating talent and advance innovations in construction robotics. The research priorities are as follows:

1. Develop a model of student learning objectives for construction robotics training and education curricula with the integration of effective assessment measures.
2. Benchmark the desired student learning outcomes and career-specific competency in developing talent in construction robotics.
3. Evaluate the possibilities of integrating construction automation and robotics in construction education curriculum.
4. Guide the development of a training course to ensure the proposed competency benchmark and performance assessment framework provide meaningful outcomes to educators for developing and assessing the competency of students.
5. Test and validate the developed competency benchmark and performance assessment framework.

The developed skills benchmark is expected to make significant contributions to construction robotics curricula, training development, and competency cultivation in academia, as well as industry.

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