Preparing the Future Workforce of Architecture, Engineering, and Construction for Robotic Automation Processes

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Abstract

The evolution of robotics automation and artificial intelligence technologies is transforming the landscape of our future jobs, especially in the fields of Architecture, Engineering, and Construction (AEC). Despite the myth that these technologies may lead to job displacements, research data based on AEC workforce qualifications demonstrate the need to advance and alter skill profiles, thus, promising to support economic growth by producing new work skills without having to replace jobs. For example, tasks that previously could not be done because of several limitations, complexities, and/or required extended durations can now be pursued in a more efficient practice through automation and robotics. This research captures the opportunities offered by automation through planning, designing, and developing a pilot Robotic Academy, a cloud-based set of training resources to cultivate a more talented workforce. To date, integrating robotics in AEC disciplines is perceived as a challenging and time-consuming task, yet training our future workforces through a Robotic Academy that deploys available technologies will be the first step to hedge against those challenges. In this planning phase of the study, the primary goal is to: (1) understand the reasons behind the lack of adopting robotics technologies and Artificial Intelligence (AI) techniques in the construction industry within South Florida; (2) identify the need of robotic-operation training modules; (3) design and develop educational courses for a Robotic Academy and; (4) assess and evaluate the effectiveness of the implemented pilot study while training the first cohort of trainees. To achieve this, the authors conducted interviews and survey questionnaires distributed to leading construction firms in South Florida. Additionally, the study conducted surveys to evaluate the pilot training courses at the Robotic Academy to record students' perspectives and learnings. The authors developed an ordered probit regression model to determine the variables influencing the expected student enrollment in the designed courses. Results indicate that students with experience and knowledge in the field are more likely to enroll in the training. Thus, to broaden the reach, the academy could incorporate entry-level courses tailored to prospective minority students, based on their needs and knowledge levels. Overall, the findings of the study show that a new pedagogy is urgent to meet the workforce demand for AI robotic driven construction industry. This on-going research initiative develops cutting-edge immersive cloud-based training modules suitable for all facets of careers in AEC to improve the workforce's preparedness towards a more automated workplace.

Introduction and Background

Increasing automation and AI deployment may be the most economically disruptive event since the dawn of the industrial age. According to the US Department of Commerce, 40% of existing US jobs could potentially be automated within the next ten years [1]. The McKinsey Global Institute estimates that by 2030, 60% of all occupations will use automated machines and intelligent systems in some way, and up to 375 million workers worldwide will be forced to amend their skill sets to adapt to the evolving industries and technologies [2]. This paper will precisely focus on the United States construction industry, which is suffering from a lack of productivity compared to other industries [3]. This is due to the nature of the construction projects that provide little room for efficiency from scaling productions, the sporadic arrival of work, high costs and high risk because of the high level of uncertainty, and the need for transiency of skilled labor [4]. Robotic technology has been considered a potential alternative to tackle ongoing issues with construction projects in the industry [5]. As with other industries where smart manufacturing and artificial intelligence methods have been successfully applied, the construction industry can benefit from these advances across the board, including all aspects of project planning, monitoring, coordination, and control, as well as safety diagnosis and quality control [6]. Although robotic implementation in the construction industry holds immense potential to improve performance across the life cycle of projects, the construction industry's overall productivity has remained nearly stagnant for the last couple of decades due to its slow adoption and adaption to new technologies than other industry sectors. Known for being resistant to change and well-established, the industries aversion towards development is expected to retard the diffusion of these technologies [7].

The US construction industry is in desperate need of innovative solutions and approaches to resolve its declining state, increase its quality, productivity, and safety [3]. The construction industry not only struggles to deliver projects that meet their targeted budget and schedule but also is affected by safety hazards, which, in turn, disturb the construction progress [8]. Technological innovations such as robots and automated devices are launching a significant leap forward, overcoming many of the construction limitations [9]. From applications such as surveying to enhancing workers' performance and 3D printing entire structures, robotics has the potential to replace and/or support various processes and applications in the construction environment [10]. When using robotic applications in construction, this advanced technology can accelerate the construction process as well as minimize hazards, waste, and cost, thereby reducing the reliance on human resources [11]. However, there is a lack of immersive training and educational resources to prepare the workforce in operating robotic. That said, immersive technologies, simulation, visualization, and geospatial datasets are creating new opportunities for education and training. Virtual Reality (VR) and Augmented Reality (AR) provide computer-generated simulations of the real or an imagined world that can serve as a rich and engaging context for learning [12]. Research shows that these environments facilitate training and the assessment of learning by providing a safe and low-cost setting for practice and rehearsal. Successful examples of these environments have been implemented in multiple fields with applications in medicine and education [13], [14]. Hence, designing and developing personalized custom training modules through Artificial Intelligence for robotics operation in construction not only improves safety, but also offers an aggregate value to companies, by increasing competitiveness, creating new job opportunities for skilled workers, and ultimately bolstering economic growth.

Construction projects incorporate dynamic and complex outdoor environments that are not amenable to the artificial environmental control obtained in closed spaces [15]. These characteristics of varying complex locations greatly increase the inherent uncertainty in planning construction operations [16]. Although adopting automated technologies can facilitate effective execution of the construction activities in these locations, success is largely dependent on a skilled workforce controlling the overall operation [17]. To exploit the opportunity and address this challenge, a team of interdisciplinary researchers is planning, designing, and developing an experimental Robotic Academy. A defining characteristic of the construction industry is that construction will surely expose the workforce to new scenarios, characteristics, and conditions [18]. Therefore, the academy, cloud-based set of training resources, is geared towards cultivating a more talented and skillful workforce capable of handling such different construction sites, conditions, and unforeseen challenges through AI. Ultimately, the approach would support the AEC workers, academic professionals, business professionals, entrepreneurs, and policymakers for driving the transition to an economically prosperous AEC industry.

Methodology

This research seeks to study the necessity, challenges, and opportunities for robotic adoption by preparing our future workforce within the AEC industry. To achieve this, the study is categorized into 3 phases, as shown in Figure 1. The first phase initiated high-level interviews with AEC industry leaders to identify their perspectives, vision, challenges, and opportunities pertaining to the integration of robotic and AI technologies. This phase also included surveying more than a dozen construction professionals representing South Florida firms. Those interviews and survey data helped understand the barriers, lessons learned, and applicability when adopting robotic technologies within the construction industry. The second phase piloted three workshop modules (computational thinking for robotic processes, fundamentals of industrial arms, and parametric design for robotic processes), that trained students and professionals at the robotic academy in a minority-serving institute. Phase one and two severed to inform the development of an initial training curriculum. In phase three, the robotic academy students' were surveyed to report about their current understanding of the course and level of improvement after the training courses.

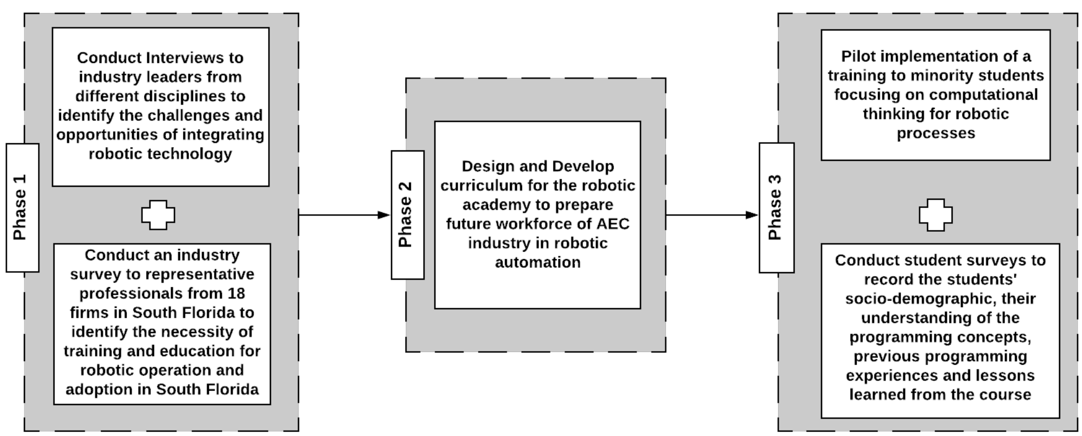

Figure 1: Research Overview

An ordinal probit regression analysis is conducted to determine which independent variable has a statistically significant effect on the dependent variable, as well to determine how well the model predicts it. An ordered probit regression analysis is selected as an analysis for the collected data, as this is fit for the generalization of cases of more than two outcomes of an ordinal dependent variable (a variable with potential values such as poor, fair, good, excellent) [19]. For this model, the dependent variable is defined as Expected Enrollment in Robotics Academy, while the independent variables are race, understanding of computational thinking, understanding of algorithms, understanding of abstract thinking, and understanding of computational thinking in buildings. The ordinal probit regression model utilizes these parameters through the following equation:

$$y_i^* = X_i\beta + \varepsilon \quad (2)$$

Where y_i^* is a latent variable measuring the interest of the ith participant on robotics academy courses; X_i is a (k x 1) vector of observed nonrandom explanatory variables; β is a (k x 1) vector of unknown parameters, and; error factor (ε) captures the reality that the expected enrollment is not perfectly predicted by the regression equation. For a given number of participants willing to pursue a certain period of robotics academy course, it is reasonable to expect that a high interest of participants in the courses, y_i^*, will be translated into a high level of observed interest in the courses,y_i. Therefore, the observed expected enrollment, y_i is determined from the model as follows:

$$y_i = \begin{cases} 1 \text{ if } -\infty \leq y_i^* \leq \mu_1 \text{ (Unlikely to enroll in robotics academy courses)} \\ 2 \text{ if } \mu_1 \leq y_i^* \leq \mu_2 \text{ (Somewhat unlikely to enroll in robotics academy courses)} \\ 3 \text{ if } \mu_2 \leq y_i^* \leq \mu_3 \text{ (Somewhat likely to enroll in robotics academy courses)} \\ 4 \text{ if } \mu_3 \leq y_i^* \leq \mu_4 \text{ (Likely to enroll in robotics academy courses)} \end{cases} \quad (3)$$

In equation 2, the partial change in y^* with respect to X_i is β_i units. This implies that for a unit change in X_i, y^* is expected to change by β_i units, holding all variables constant.

Results and Discussion

This section presents the results of the three phases: interviews conducted with and industry stakeholders to understand their perception on robotic operations and their required training; Curriculum Design and Development for the Robotic Academy based on surveying the professionals, and surveying minority trained students to post the pilot implementation of the designed courses at the Robotics Academy. The detail discussion of these three different phases is provided in the subsequent sections.

Phase 1: Identification of industry stakeholders' perception of robotic operation training

To develop an educational program that trains our future AEC workforce, a team of interdisciplinary researchers from minority-serving institutions initially collected detailed data through interviews to understand the industry's standard benchmark. The interviews involved representatives from the three AEC businesses who have already adopted robotics and AI technology, as well as other stakeholders who have not. Professionals from different disciplines maintained different perspectives on challenges and opportunities to the adoption of robotics, as shown in Figure 2. For instance, Automation engineers and educators indicated that there is a lack of mentors and real-time support for training the future workforce. Also, all the interviewees reported a lack of common terminology and limited training content, which also hinder the progress in such a preeminent domain. Similarly, designer, system integrators, software developer, and building technologist shared their perspective, which included challenges such as lack of affordable training resources and opportunities such as confidence in job security, new opportunities for entrepreneurship, and job opportunities.

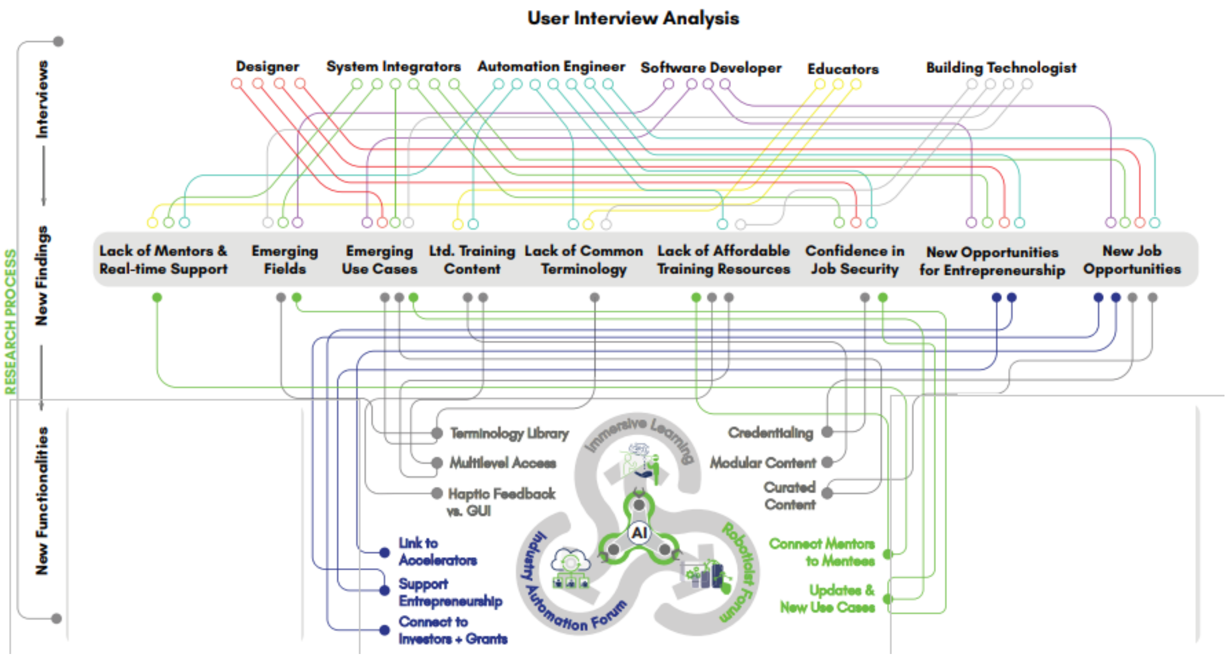

Figure 2: AEC Industry Professionals Interview Results

In the same phase, 18 industry professional construction representative in South Florida were surveyed. Those professionals represent a targeted sample associated with the Construction Industry Advisory Board at the Minority Serving Institution, thus reflecting a representative sample to the construction companies in South Florida [20], [21]. The stakeholders were surveyed about the current status of automated technology adoption, barriers that have impacted robotic adoption, the necessity of robotic operation training in Construction Management curricula, as well as their background information. Boxplots were created using R-Studio to showcase respondents' ratings on the impact of the barrier on the adoption of new trends, as shown in Figure 3. It can be inferred from the results of boxplot that the unskilled workforce has a higher impact on robotic adoption with a median rating of four. This indicates a need for training and education to prepare the future workforce for the proper operation of robots. Similarly, the nature of the construction industry and intense competition have the second-highest impact based on the median expert rating of 3.5, indicating that construction processes require a paradigm shift towards automated technology incorporation. Lastly, job security and easy access to labor have a median rating of three. Since the integration of robotic technology in the construction industry is not eradicating jobs but is producing new job opportunities, job security, and easy access to labor have a lesser impact on robotic adoption.

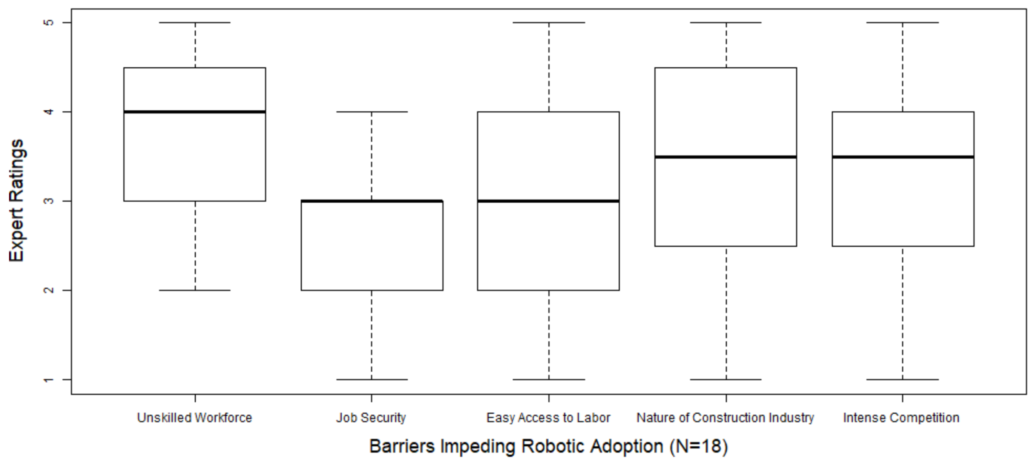

Figure 3: Boxplots of expert ratings on barriers impacting robotic adoption

The industry professionals were also surveyed about their likelihood of implementing robotics and AI technology in their respective firms; approximately 64 percent were Somewhat Likely to integrate the new technological trends, while 18% were Somewhat Unlikely, as shown in Figure 4. Besides, all the respondents indicated that cutting edge automated technological tools should be taught as part of construction management curricula at universities since the construction industry is rapidly being reshaped by the use of advanced automated machines. Approximately 94% of respondents consider robotic and AI technology as beneficial for the industry, which shows a potential growth in its adoption and highlights the necessity of a training module to prepare future workforce in the robotic driven industry.

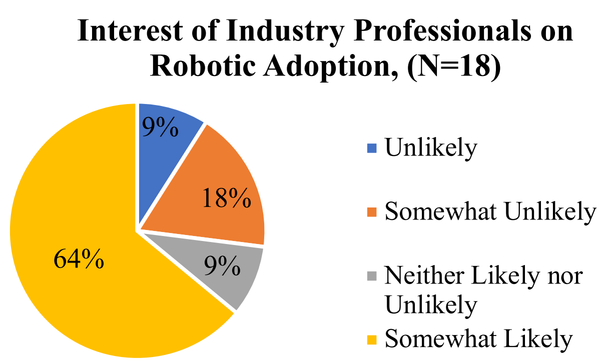

Figure 4: Interest of Industry professionals on robotic adoption

Phase 2: Curriculum Design and Development for the Robotic Academy

Construction jobs in the U.S. are expecting advancements in robotics technology to enhance their performances. Training our future workforces through a web-based training program, which deploys available technologies, is at the forefront to help the construction workforce develop such skills and sustain future job opportunities. Therefore, the robotics academy designed and built an immersive learning curriculum, a roboticist forum, and an automation forum to prepare the future workforce of the AEC Industry and drive evolution towards a prosperous automation economy. Immersive learning deals with preparing the AEC workers to be capable of working with multi-media content. For accommodating an interactive user course, lessons were provided in VR, AR, and other media applications for which the contents were supported on mobile devices, laptops, as well as Head-Mounted Displays for both individual and group training [21]. The content of the curriculum was developed based on a modular training structure such that it allows continuous growth without the constant requirement of restructuring. The curriculum is divided into mini courses, which initially includes computational thinking, fundamental of robotic arms, and parametric design. Those mini courses will help workers to understand the fundamental concepts of robotics, including their respective software and hardware features. Furthermore, the trainees who complete the curriculum will receive micro-credentials in terms of badges, which can be recognized amongst different AEC firms and be included in their resumes and LinkedIn accounts. On the other hand, the roboticist forum will provide an open knowledge platform for supporting the sharing and advancement of knowledge with the interaction between experts and other users. Similarly, an automation forum is an information exchange platform that will facilitate open knowledge networking among different AEC professionals, workers, and other users through a combination of social media platforms and GitHub features.

Phase 3: Pilot Implementation of Training and Education to Minority Students

In this phase, a pilot implementation of the curricula was developed with an introductory course, as well as lessons of robotic-use and programming for AEC industries. This pilot course would help gather critical information about the course and develop the foundation courses for the robotics academy. Minority students in the robotics academy will be provided with AI-based virtual and augmented reality training where they would receive hands-on robotic operation. The pilot course will also teach the students about the fundamentals of current and new robotic design and software for different student skill levels. Additionally, it will focus on creating modules that guide the trainee to understand the safety factors that should be considered during robot-human interaction. This pedagogical approach also includes learning about the use of Machine Learning (ML) algorithms for evaluating the user performance and to inform individuals designing curricula to make necessary alteration and improvement. To this end, AI and robotic technologies have the potential to disrupt careers, change skill profiles of workers in their current jobs, and bring a paradigm shift to how people work. Hence, this program will essentially capture these opportunities and minimize the imminent impact of automation adoption in the construction industry by fostering problem based-training resources in an academic environment [22].

The data collected in phase three was analyzed using ordered probit analysis. In this analysis, the authors analyzed the impact of students' previous technological knowledge on their likelihood to enroll in the training. Table 1 provides the estimated results of the Expected Enrollment with a Pseudo R^2 value of 0.4656. The regression coefficient values of Race (R), Understanding of Computational Thinking (CT), Algorithm (A), Understanding the Abstract Thinking (AT), Understanding of Computational Thinking in Building (CTB) are 0.0129, 0.019, 0.036, 0.036, and 0.088, respectively. Based on these results, it can be inferred that students expected enrollment in the Academy is highly influenced by their previous knowledge in this area, such as computational and abstract thinking, and computational thinking for buildings. Factors such as Race has been found to be insignificant since it has a P-value of 0.129; thus the factor does not fit the ordered probit model.

Table 1. Coefficients and P-Value from Ordered Probit Analysis

Variables	Coeff. (β)	Std. Error	Z	P-Value
Race (R)	-0.85	0.56	-1.52	0.129
Understanding of Computational Thinking (CT)	3.08	1.31	2.35	0.019
Indicator variable for Understanding of Algorithms (A)	-1.032	0.5	-2.09	0.036
Understanding of Abstract Thinking (AT)	1.57	0.75	2.09	0.036
Understanding of Computational Thinking in Buildings (CTB)	1.52	0.89	1.71	0.088
$\boldsymbol{\mu}_1$	9.2	4.7		
$\boldsymbol{\mu}_2$	10.15	4.8		
$\boldsymbol{\mu}_3$	12.94	5.6		

Based on these results, it can be inferred that additional innovative recruitment methods should be implemented to attract additional prospective students into the program. Since students with prior knowledge in this area are those enrolling in the course, additional entry-level courses could be incorporated to support those interested in this field and without required prior knowledge. The program curricula could be tailored to these new prospective students based on their needs and knowledge level.

Limitation and Future work

One of the most challenging hurdles to the mass adoption of robotic technologies in AEC is the lack of training and resources to train and prepare our workforce. To address this gap, the authors conducted interviews and a questionnaire survey to identify the perception of the key stakeholders in the construction industry on necessary topics for course development. Although the authors successfully completed these objectives, there were some limitations. One of the limitations was that perception of the interviewed designer, system integrators, automation engineers, software developers, educators, and building technologists might be subjective due to personal opinion and self-judgments. Since South Florida has been comparatively lagging in terms of adopting new technologies in construction, this research mainly focused on this region, which may not be representative of other regions in the US. The future work includes implementing the cloud-based training program for the robotics academy, which consists of immersive training, a collaborative knowledge base, and an automation forum. Software development planning, economic research, curriculum development, and testing, and evaluation groups are some of the key deliverables of the project, which will be led by the executive and management team. At the end of this phase, a report will also be developed on the economic impacts of automation on the AEC industries.

Conclusion

At the brink of the fourth industrial revolution, there is a growing need for a skilled workforce which has profound knowledge of operating robotic and AI technology in the AEC industry. This study is geared towards addressing the gap for which the authors conducted interviews with key stakeholders of the industry and identified primary challenges to adopt robotics. The identified challenges mainly included the lack of real-time training and affordable resources. Therefore, the interdisciplinary research team researched, planned, designed, and prototyped a pilot Robotic Academy, a cloud-based set of resources to support the Architecture, Engineering, and Construction (AEC) workforce using Artificial Intelligence, Virtual and Augmented Reality. The pilot implementation of the program in the Robotics academy primarily consisted of three components: (1) Immersive learning, (2) Roboticist Forum; and (3) Automation Forum. The students involved in the Robotic Academy provided relevant information, such as their socio-demographic profile and previous knowledge. Based on the results, trained students involved in the Robotics Academy already possess a certain level of skills in the topics covered within the training. However, additional innovative recruitment methods should be implemented to attract additional prospective students into the program, as well as tailor the curricula to fit minority and underrepresented students' needs. Therefore, the study opens a new avenue in AEC through the development of innovative pedagogy that trains and prepares our future workforce with required skill sets.

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References

[1] M. Y. Bin Yahya, Y. Lee Hui, A. B. M. Yassin, R. Omar, R. O. anak Robin, and N. Kasim, "The Challenges of the Implementation of Construction Robotics Technologies in the Construction," *MATEC Web Conf.*, vol. 266, p. 05012, 2019.

[2] S. S. J. manyika, S. Lund, M. Chui, J. Bughin, J. Woetzel, P. Batra, R. Ko, "Jobs lost, jobs gained: Workforce transitions in a time of automation," 2017.

[3] K. Afsari, S. Gupta, M. Afkhamiaghda, and Z. Lu, "Applications of Collaborative Industrial Robots in Building Construction," *54th ASC Int. Conf. Proc.*, no. August, 2018.

[4] A. Jayaraj and H. N. Divakar, "Robotics in Construction Industry," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 376, no. 1, 2018.

[5] V. S. S. Kumar, I. Prasanthi, and A. Leena, "Robotics and automation in construction industry," *Proc. AEI 2008 Conf. - AEI 2008 Build. Integr. Solut.*, vol. 328, 2008.

[6] L. S. Bryson, C. Maynard, D. Castro-Lacouture, and R. L. Williams, "Fully autonomous robot for paving operations," *Constr. Res. Congr. 2005 Broadening Perspect. - Proc. Congr.*, pp. 371–381, 2005.

[7] J. G. Everett and H. Saito, "Construction automation: Demands and satisfiers in the United States and Japan," *J. Constr. Eng. Manag.*, vol. 122, no. 2, pp. 147–151, 1996.

[8] D. H. Autor, "Why are there still so many jobs? the history and future of workplace automation," *J. Econ. Perspect.*, vol. 29, no. 3, pp. 3–30, 2015.

[9] J. M. Davila Delgado *et al.*, "Robotics and automated systems in construction: Understanding industry-specific challenges for adoption," *J. Build. Eng.*, vol. 26, no. July, p. 100868, 2019.

[10] D. Lattanzi and G. Miller, "Review of robotic infrastructure inspection systems," *J. Infrastruct. Syst.*, vol. 23, no. 3, pp. 1–16, 2017.

[11] R. D. Schraft, U. Bräuning, T. Orlowski, and M. Hornemann, "Automated cleaning of windows on standard facades," *Autom. Constr.*, vol. 9, no. 5, pp. 489–501, 2000.

[12] S. Vassigh *et al.*, "Integrating Building Information Modeling with Augmented Reality for Interdisciplinary Learning," in *Adjunct Proceedings of the 2016 IEEE International Symposium on Mixed and Augmented Reality, ISMAR-Adjunct 2016*, 2017, pp. 260–261.

[13] M. Elzomor and O. Youssef, "Living and learning in practice: University of Arizona engineering innovation building (EIB)," in *49th International Conference of the Architectural Science Association 2015*, 2015, pp. 33–44.

[14] D. L. Davis, S. Vassigh, H. Alhaffar, A. J. Elias, and G. Gallardo, "Learning building sciences in virtual environments," *ASEE Annu. Conf. Expo. Conf. Proc.*, vol. 2018-June, 2018.

[15] C. Balaguer, A. Giménez, J. M. Pastor, V. M. Padrón, and M. Abderrahim, "A Climbing autonomous robot for inspection applications in 3D complex environments," *Robotica*, vol. 18, no. 3, pp. 287–297, 2000.

[16] J. Louis and P. S. Dunston, "Methodology for real-time monitoring of construction operations using finite state machines and discrete-event operation models," *J. Constr. Eng. Manag.*, vol. 143, no. 3, pp. 1–10, 2017.

[17] J. Maeda, "Current research and development and approach to future automated construction in Japan," *Constr. Res. Congr. 2005 Broadening Perspect. - Proc. Congr.*, pp. 393–403, 2005.

[18] K. Lin, "Computing in Civil Engineering (2009)," vol. 1, no. 2005, pp. 593–602, 2009.

[19] K. M. Kockelman and Y. Kweon, "Driver injury severity : an application of ordered probit models," *Accid. Anal. Prev.*, vol. 34, pp. 313–321, 2002.

[20] "Industry Advisory Council - Moss Department of Construction Management." [Online]. Available: https://cm.fiu.edu/research/industry-advisory. [Accessed: 30-Jan-2020].

[21] "About - South Florida Associated General Contractors | 2020." [Online]. Available: https://sfagc.org/about. [Accessed: 30-Jan-2020].