Teaching Construction Robotics for Higher Education Students: “Imagine and Make”

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Abstract –

The use of robotics in construction projects is still in its infancy despite the opportunities that robots can present to the improvement of construction practices. One of the strategies to effectively increase the reliance on robots in construction is increasing the knowledge and improving the educational programs about robotics for university students. This paper contributes to the ongoing efforts around the world to improve the teaching methods about construction robotics through the presentation of a novel method that is called “Imagine and Make”, in which students learn how to integrate robotics in different aspects and practices in construction projects. The method has been applied at Centrale Lille in France since 2018. The results of the application of “Imagine and Make” in the first semester in 2021-2022, evaluation by students, and teaching outcomes are reported in this paper.

Keywords –

Robotics; Construction management techniques; Construction 4.0; Robotics teaching; France

1 Introduction

Poor productivity, resistance to adopting technology, shortage of skilled workers, and poor quality are amongst the most serious challenges that face the construction industry [1–4]. Studies showed that while many sectors (e.g. manufacturing) are witnessing a noticeable increase in productivity rates, productivity has been decreasing in the construction industry for years [1]. Additionally, the industry is threatened by the decreasing numbers of skilled young laborers. Research reported difficulties in replacing aging and retiring laborers in construction projects and resistance by the young workforce to enter the sector due to the great physical efforts while performing repetitive and difficult construction activities, high levels of injuries, and poor safety standards [5], [6].

Robotics can contribute to providing solutions to face these difficulties. This is because robots can be integrated into countless activities and provide workers with assistance to manage dangerous activities and perform repetitive tasks [3], [7–15]. The use of robots in these activities may not only contribute to productivity and efficiency improvements but also may help to improve safety standards and to attract more workforce to enter the construction industry and face the workforce shortages problems [6]. Moreover, the use of robots in construction operations can help to improve the precision, speed, and quality of construction work and avoid defects due to the use of advanced technologies (e.g. sensors, laser-based methods…etc.) [3], [16–18].

Nevertheless, despite the presence of some studies that expect a remarkable increase in robots’ use in the construction projects in the next few years [6], and despite the presence of some cases in which robots were used on construction sites since the 1980s [4], robotics face several barriers to be normalized in the construction industry and their adoption levels in the industry are still very low. In addition to the impact of the cost and time-related barriers, the lack of sufficient knowledge about new managerial principles and technological advances, lack of skilled team, resistance to change and to adopt new practices and technologies by managers and employees, and poor leadership are amongst the most affecting factors to adopt robotics in the construction industry [19–25].

The role of educators in educational institutes is not only to provide higher levels of knowledge about advanced concepts, technologies, and construction practices but also to prepare future leaders who can create and lead the transformation and reduce the resistance to change. Nevertheless, the literature still has only a limited number of studies that reported construction robotics teaching experiences for students [6], [26–28].

Within the scarcity of the studies about robotics teaching in the field of construction, this paper tries to contribute to the efforts that have been made so far and aims to report an experience about the use of a method that is called “Imagine and Make”. This method was used to deliver training about construction robotics for students at a school of engineering "Centrale Lille" in France. The following section presents the materials and methods of the study by explaining the bases of "Imagine and Make", the design of the study, the participants in the study, and the evaluation of the results. Then, the paper reports the prototypes and the results of the study. Finally, the paper reports the conclusion, implications, limitations, and direction for future research.

2 Materials and Methods

This section explains what is "Imagine and Make" and shows how it was developed, the theoretical basis behind it, how it is usually organized, and what are the evaluation criteria that are used to evaluate the provided projects by students. The section also explains the design of the current study, the participants, and the used methods to evaluate the effectiveness of "Imagine and Make".

As part of previous research, the authors of this paper have done extensive research in developing a systems engineering framework for the holistic development of novel construction robot applications [29–31]. The authors have tested this framework as part of several industry-grade and research-grade robot development projects (for example, [32]). The work presented in this paper, states an attempt to translate the gained experiences in tune with project-based, iterative state-of-the-art teaching methodologies (for example, [33], [34]) into a hands-on teaching methodology. The development of construction robots needs to follow a systematic approach since it is conducted in an extremely interdisciplinary and complex area in which the lack of data and previous experience poses a high risk for developers and investors.

Through "Imagine and Make" students shall learn to understand the underlying value chains of innovation processes. After the participation in the course, they shall be able to handle actively a complex process that interlinks and iterates between analytical thinking, abstract planning skills, project-based integration, and technology transfer strategies. As such the students will be able to initiate and guide digital, robotic innovation in the organizations for which they will work in the future.

2.1 What is "Imagine and Make"

Centrale Lille is a graduate engineering school that is located in the north of France and has roots that go back to 1854. The school has different engineering programs for master's students and doctoral candidates. The Centralien Engineering Programme is the teaching program that gathers students who finished two/or three years of undergraduate studies and allows them to spend three years and get a master's degree in engineering.

In 2018, Centrale Lille started a new teaching method that is called "Imagine and Make" for its students in the Centralien Engineering Programme. This method is based on gathering students for one week (five working days) and allowing them to work on a selected topic during this week.

The targeted topic for the last three years was construction 4.0. In this module, students have opportunities to have lectures about construction 4.0, read and see some practical examples, interact with experts from research and industry, work in teams, make prototypes, and present the results of their work. Accordingly, students have the chance to learn from:

- Lectures
- Reading materials
- Audio-visual tools
- Demonstration
- Discussion within the team and with experts
- Conducting research
- Practicing by doing prototypes
- Presenting their results

The lectures are mainly divided into two types of lectures; the first one is the introductory lecture, which aims to explain the overall structure of "Imagine and Make", objectives, and evaluation criteria for the prototypes (3 hours). While the second type of lecture is presentations that are provided by experts from industrial partners (9 hours). The lectures provide students with audio-visual tools, some useful references, success stories, and practical examples about some new managerial principles and technological advances in the field of construction. Apart from the time that is devoted to the lectures, students have to use their time freely to develop their ideas (Imagine) in two days and to translate the idea into a physical prototype in the other three days (Make).

2.2 Design of the study

Figure 1 shows the structure of "Imagine and Make". The discussed topic for the year 2021-2022 was "Construction robotics". During this year, two rounds of "Imagine and Make" were conducted; the first one was in October and the second was in November. To study the targeted topic, students were asked to use "Spot®" from "Boston Dynamics" (shown in Figure 2) as an example of a type of robot that can be used in the construction industry and to develop a prototype that explains one of the applications of the robot in the industry. Spot® is a new robot that was presented to the market in late 2019 and its launching was faced by the impact of the COVID-19 crisis; however, it has shown promising applications in different fields and operations [35–37]. Therefore, Spot® serves as a clear example of mobile robots that can be understood by students, and its use may bring positive attitudes about the usability of robotics in the construction industry.

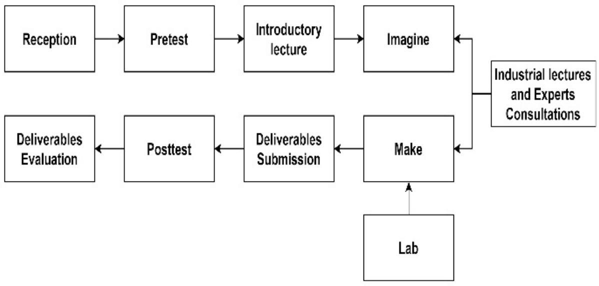

Figure 1. Structure of "Imagine and Make"

Figure 1. Spot® Robot [38]

The work in the two rounds started with the reception of the participants (179 students: 93 in the first round and 86 in the second round). Students were in their second year in Centralien Engineering Programme.

The introductory lecture presented an introduction to the concepts of industry 4.0, construction 4.0, advanced techniques in construction management, and robotics in construction. It also presented some examples of the use of different types of robots in construction and the use of Spot® in other industries. It also summarizes the objectives of the week, the structure of “Imagine and Make”, the requested deliverables, and the evaluation criteria for the deliverables. The deliverables of the week and the grade given for each deliverable are as follows:

- Physical Prototype (40%)
- Final report (30%)
- 3-minute video about the prototype (15%)
- 5-minute oral presentation (pitching) (5%)
- Business plan and annexes (10%)

The deliverables have to address the following criteria:

- Clarity of the design and the idea
- Functionality of the prototype
- Collaborative work and roles within the team
- Sustainability and environmental impact
- Benchmarking, originality, and relation to the literature and research
- Clarity of the used methodology
- Marketing and commercial considerations.

During the whole week, students were able to reach eight experts and researchers in the fields of construction 4.0 and project management. The role of experts included explaining the objectives, answering questions about research sources, and supervising the overall progress. Students were also able to get assistance from the lab of the engineering school (FabLab), which helped students to find needed materials for the prototypes and to cut and handle materials.

2.3 Survey development

In addition to the value of the deliverables provided by the students and the live experience of dealing directly with robots, two surveys were used at the beginning (pretest) and the end of the week (posttest) to evaluate the effectiveness of “Imagine and Make”. The two surveys shared two sections, which are “self-efficacy” and “knowledge gain”, and an additional section was added to the posttest and which aimed to assess the levels of satisfaction among students with the experience of “Imagine and Make”.

Self-efficacy is one of the most important measures in business, educational, and psychological sciences [39], [40]. Self-efficacy refers to the beliefs of the individuals about their capacities in a given situation and their abilities to organize and execute a specific set of tasks and actions [41], [42]. High levels of self-efficacy are associated with better quality and higher efficiency and effectiveness in the work environment and low levels of self-efficacy are among the reasons for having incomplete tasks even with the presence of high levels of knowledge and skills [42]. With students, self-efficacy affects objectives setting, goals achievement, future choices of activities, and learning outcomes [39], [43], [44].

According to Selby et al [45], teaching robotics should aim at increasing self-efficacy for learners to increase their intrinsic interest in dealing and interacting with robots. Therefore, the pretest and post-test surveys in this study used a set of items to assess the improvements in the levels of self-efficacy due to the presentation of “Imagine and Make”, and the current study tests the following hypothesis:

H1: “Imagine and Make” helped to improve self-efficacy levels toward robotics use among the students.

To assess the levels of self-efficacy before and after “Imagine and Make”, ten items were adopted from the studies of Selby et al [45] and Mallik et al [46]. For this section, students were asked to put their answers using a five-point Likert scale ranging from “Not confident at all to do the following task” to “Completely confident that I can do the task”.

The second section of the survey aimed to assess the knowledge gained by using six questions that were developed to study the improvement in familiarity with some terms in the field of robotics. The six questions were about the term “robotics”, robots’ characteristics, robots’ components, degrees of freedom, and design of robots. For each question, the choices carried only one correct answer, one choice of “I do not know”, and other wrong choices (four wrong choices for all questions except one question that was a True/False and “I do not know” question”). The knowledge gain was assessed based on the improvements in the number of correct answers.

The post-test had an additional section to assess the levels of satisfaction among the students with “Imagine and Make”. The section had seven items, in which a five-point Likert scale was used to test the satisfaction with different statements and ranges from “strongly dissatisfied” to “strongly satisfied”. The section also included two open-ended questions to report the most liked things about “Imagine and Make” and the areas for improvement in future experiences.

The survey was developed using Google Forms and distributed to the students at the beginning and at the end of the week to be filled online. Out of 179 students, 166 responded to the survey with a response rate of 92.74%.

3 Results

3.1 Deliverables

By the end of each week in the two rounds of “Imagine and Make”, students were able to deliver all the requirements including porotypes, videos, reports, presentations, and business models for their work. The total number of the groups was 22 delivering different ideas about the use of the dog robot in the construction.

The ideas aimed to solve several problems and challenges faced in construction projects and covered different aspects such as safety and security on the construction site, productivity improvement, logistics management, and sustainability. Furthermore, in addition to making things by hand in the lab (Figure 3), students used several applications to deliver their ideas; including artificial intelligence (AI) and machine learning (ML), 3D printing, sensors, 2D and 3D plans, and drawings, simulation, cameras, thermal analysis, and others.

Figure 3. A picture from the lab during “Imagine and Make”

Examples of the developed prototypes included detection of construction tools and delivery them to workers, detection of physical wastes that can hinder the safe movement of workers on site (Figure 4), inspection of cracks in buildings and elements, identification of potential hazards onsite (ledges, under cranes areas, misplaced tools) (Figure 5) inspection for intruders on site (Figure 6), inspection for commitments to personal protective equipment (PPE) onsite (Figure 7), presenting cooling system for workers that are working in a hot climate (Figure 8), development of a system to repair gas pipes (Figure 9), guiding people with vision impairment (Figure 10), marking on construction site (Figure 11-12), managing materials storage using Radio Frequency Identification (RFID)-based system (Figure 13), and others.

Figure 4. Detection and collection of wastes onsite

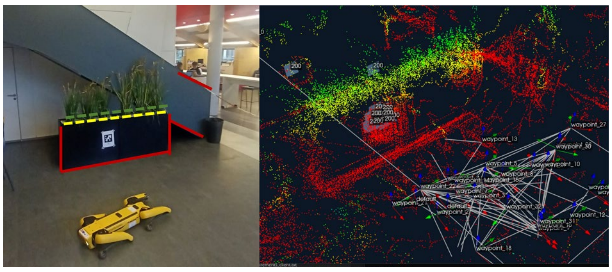

Figure 5. AI-controlled robot to make a Simultaneous localization and mapping (SLAM) of the environment to identify potential hazards on site

Figure 6. Use of MA to inspect for intruders onsite

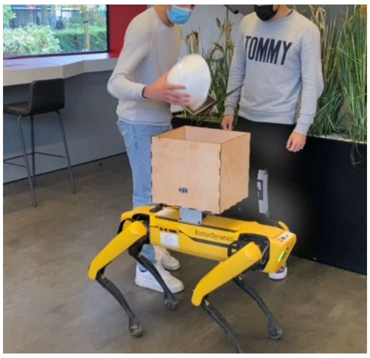

Figure 7. Inspection for hard hat onsite

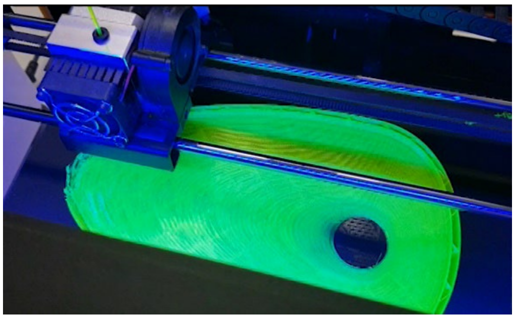

Figure 8. Use of 3D printing to design a cooling system for workers in hot climates

Figure 9. Development of a system to repair leaks areas in gas pipes

Figure 10. Use of robot dog to guide people with vision impairments

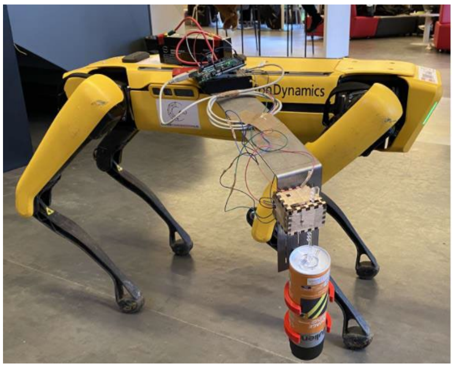

Figure 11. Use of Spot® Robot to do marking onsite

Figure 12. RFID-based system to manage materials

3.2 Survey Results

The analysis of the collected data was done using the statistical package for the social science (SPSS) version 25.0, and it covered the follows:

- Testing the reliability of the measurement tool by testing the consistency in the tool across the time and the different items using Cronbach's Alpha, which is supposed to be higher than 0.6 [47].
- Calculating the means and standard deviations to identify the levels of pre and post-training self-efficacy and satisfaction among students at the end of the training.
- Testing the hypothesis H1 (improvements in self-efficacy levels) using "Paired t-test", which is an inferential statistical method that compares the differences in the mean values when the data is collected in pairs (e.g. pretest and post-test) [48].
- Calculating the frequencies of the correct answers to the questions about the familiarity with robotics to assess the knowledge about the topic before and after the training.

Additionally, a qualitative analysis was conducted to analyze the results from the open-ended questions. The analysis was based on inductive thematic coding analysis through analyzing the text to find the frequent, significant, and emerging themes that are inherent in the data [49].

3.2.1 Reliability

The analysis showed that Cronbach's Alpha was (0.872) for the pretest survey and (0.920) for the posttest survey. As the value of Cronbach's Alpha exceeds 0.6, this indicates that the used scale is reliable and has a high level of internal consistency.

3.2.2 Self-efficacy

Self-efficacy levels are shown in Figure 13. The analysis revealed that the overall self-efficacy had a mean of (2.35), and raised after the training to reach (3.27). The analysis showed increases in the means for all items that were used to assess self-efficacy. The highest increase was in "Know how to program a robot or additive tool", "Perform a design for a robot", and "construct a robotic prototype".

The results from paired t-test showed significant differences between the pretest and post-test means for all items and the overall self-efficacy P-value was less than (0.001) for all comparisons. This indicates that hypothesis H1 could not be rejected and that "Imagine and Make" helped to improve self-efficacy levels toward robotics use among the students.

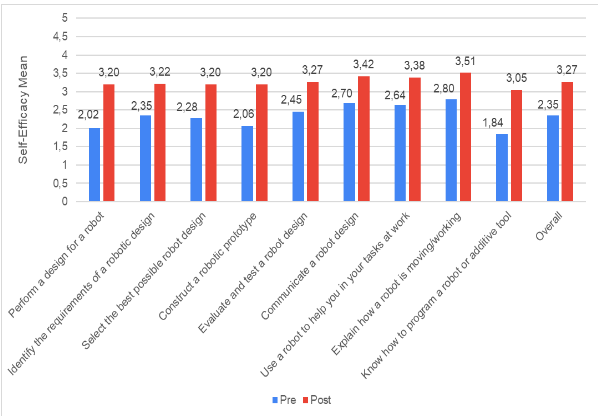

Figure 13. Self-Efficacy levels before and after "Imagine and Make"

3.2.3 Knowledge gain

Figure 14 shows the number of correct answers for each question used in the pre and post-tests. The figure shows an increase in the number of correct answers for all questions; especially question three, which was about the components of the robot.

3.2.4 Satisfaction with "Imagine and Make"

Table 1 shows the level of satisfaction with "Imagine and Make". The analysis showed that, overall, students were satisfied with the experience of "Imagine and Make" as the mean value was (3.97) out of (5.00). The highest rate was for the opportunity the students had to think about the different practices in the construction projects, then helping them improve their teamworking skills.

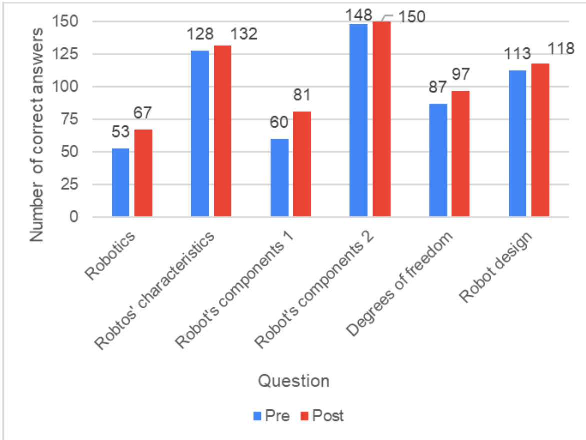

Figure 14. Knowledge gain before and after "Imagine and Make"

Table 1. Satisfaction levels with "Imagine and Make"

Item	**Mean**	**SD**
I am satisfied with "Imagine and Make"	4.084	0.81
My interest in robotics increased after "Imagine and Make"	3.663	0.99
"Imagine and Make" helped me to understand the use of robots in construction	3.910	0.89
"Imagine and Make" helped me to think about different practices in the construction industry	4.187	0.87
"Imagine and Make" helped me to enhance my innovative thinking	3.934	0.84
"Imagine and Make" helped me to improve my team working skills	4.072	0.92
"Imagine and Make" met my expectations	3.940	0.96
Overall Satisfaction	3.970	0.69

The qualitative analysis revealed that team working and collaboration, freedom of prototype development and topic selection for the teams, challenging deliverables, ability to work on a practical topic and deal with a real robot, presentations by the experts, and ability to do things by hand in the lab were among the most frequent themes mentioned by the students when they were asked about the things that they like most in "Imagine and Make". In turn, the most frequent suggestion was increasing the time allocated to the training for more than one week.

4 Conclusion

This paper reports a novel method to teach construction robotics by giving the students the opportunity to freely and collaboratively search for the applications that can integrate robotics into the construction field. This method helped students to be in touch with both academic literature and practical applications. It also allowed them to integrate different types of technologies and tools while making their prototypes. This pedagogic method can be applied in several areas in construction 4.0 and even in other fields and sciences.

References

[1] T. Bock, "The future of construction automation: Technological disruption and the upcoming ubiquity of robotics," *Autom. Constr.*, vol. 59, pp. 113–121, Nov. 2015.

[2] W. Albalkhy and R. Sweis, "Assessing lean construction conformance amongst the second-grade Jordanian construction contractors," *Int. J. Constr. Manag.*, pp. 1–13, 2019.

[3] Z. Dakhli and Z. Lafhaj, "Robotic mechanical design for brick-laying automation," *Cogent Eng.*, vol. 4, no. 1, Jan. 2017.

[4] E. Forcael, I. Ferrari, A. Opazo-Vega, and J. A. Pulido-Arcas, "Construction 4.0: A Literature Review," *Sustain. 2020, Vol. 12, Page 9755*, vol. 12, no. 22, p. 9755, Nov. 2020.

[5] A. H. Behzadan, A. Iqbal, and V. R. Kamat, "A collaborative augmented reality based modeling environment for construction engineering and management education," *Proc. - Winter Simul. Conf.*, pp. 3568–3576, 2011.

[6] C. J. Liang, V. R. Kamat, and C. C. Menassa, "Teaching robots to perform quasi-repetitive construction tasks through human demonstration," *Autom. Constr.*, vol. 120, p. 103370, Dec. 2020.

[7] S. N. Yu, B. G. Ryu, S. J. Lim, C. J. Kim, M. K. Kang, and C. S. Han, "Feasibility verification of brick-laying robot using manipulation trajectory and the laying pattern optimization," *Autom. Constr.*, vol. 18, no. 5, pp. 644–655, Aug. 2009.

[8] J. K. Oh, G. Jang, S. Oh, J. H. Lee, B. J. Yi, Y. S. Moon, J. S. Lee, and Y. Choi, "Bridge inspection robot system with machine vision," *Autom. Constr.*, vol. 18, no. 7, pp. 929–941, Nov. 2009.

[9] S. Hou, B. Dong, H. Wang, and G. Wu, "Inspection of surface defects on stay cables using a robot and transfer learning," *Autom. Constr.*, vol. 119, p. 103382, Nov. 2020.

[10] D. Lattanzi and G. Miller, "Review of Robotic Infrastructure Inspection Systems," *J. Infrastruct. Syst.*, vol. 23, no. 3, p. 04017004, Feb. 2017.

[11] O. Kontovourkis and G. Tryfonos, "Robotic 3D clay printing of prefabricated non-conventional wall components based on a parametric-integrated design," *Autom. Constr.*, vol. 110, p. 103005, Feb. 2020.

[12] T. Linner and T. Bock, "Evolution of large-scale industrialisation and service innovation in Japanese prefabrication industry," *Constr. Innov.*, vol. 12, no. 2, pp. 156–178, 2012.

[13] T. Linner, W. Pan, C. Georgoulas, B. Georgescu, J. Güttler, and T. Bock, "Co-adaptation of Robot Systems, Processes and In-house Environments for Professional Care Assistance in an Ageing Society," *Procedia Eng.*, vol. 85, pp. 328–338, Jan. 2014.

[14] C. Georgoulas, T. Linner, and T. Bock, "Towards a vision controlled robotic home environment," *Autom. Constr.*, vol. 39, pp. 106–116, Apr. 2014.

[15] T. Linner, J. Güttler, T. Bock, and C. Georgoulas, "Assistive robotic micro-rooms for independent living," *Autom. Constr.*, vol. 51, no. C, pp. 8–22, Mar. 2015.

[16] L. Song and D. Liang, "Lean construction implementation and its implication on sustainability: A contractor's case study," *Can. J. Civ. Eng.*, vol. 38, no. 3, pp. 350–359, Mar. 2011.

[17] R. Bogue, "What are the prospects for robots in the construction industry?," *Ind. Robot An Int. J.*, vol. 45, no. 1, pp. 1–6, Jan. 2017.

[18] M. Jeong Kim, H.-L. Chi, X. Wang, M. Jeong, K. · H.-L. Chi, and · Lieyun Ding, "Automation and Robotics in Construction and Civil Engineering Special Issue for Sensors 'Intelligence Sensors and Sensing Spaces for Smart Home' View project Automation and Robotics in Construction and Civil Engineering," *Artic. J. Intell. Robot. Syst.*, vol. 79, pp. 347–350, 2015.

[19] W. Al Balkhy, R. Sweis, and Z. Lafhaj, "Barriers to Adopting Lean Construction in the Construction Industry—The Case of Jordan," *Buildings*, vol. 11, no. 6, p. 222, May 2021.

[20] W. Albalkhy and R. Sweis, "Barriers to adopting lean construction in the construction industry: a literature review," *Int. J. Lean Six Sigma*, vol. 12, no. 2, pp. 210–236, Mar. 2020.

[21] D. J. Trujillo and E. Holt, "Barriers to Automation and Robotics in Construction," *Epic Ser. Built Environ.*, vol. 1, pp. 257–265, 2020.

[22] R. Mahbub, "Framework on the Barriers to the Implementation of Automation and Robotics in the Construction industry," *Int. J. Innov. Manag.*, vol. 3, no. 1, pp. 21–36, 2015.

[23] J. M. Davila Delgado, L. Oyedele, A. Ajayi, L. Akanbi, O. Akinade, M. Bilal, and H. Owolabi, "Robotics and automated systems in construction: Understanding industry-specific challenges for adoption," *J. Build. Eng.*, vol. 26, p. 100868, Nov. 2019.

[24] J. Buchli, M. Giftthaler, N. Kumar, M. Lussi, T. Sandy, K. Dörfler, and N. Hack, "Digital in situ fabrication - Challenges and opportunities for robotic in situ fabrication in architecture, construction, and beyond," *Cem. Concr. Res.*, vol. 112, pp. 66–75, Oct. 2018.

[25] G. Carra, A. Argiolas, A. Bellissima, M. Niccolini, and M. Ragaglia, "Robotics in the construction industry: State of the art and future opportunities," *ISARC 2018 - 35th Int. Symp. Autom. Robot. Constr. Int. AEC/FM Hackathon Futur. Build. Things*, 2018.

[26] B. Bogosian, L. Bobadilla, M. Alonso, A. Elias, G. Perez, H. Alhaffar, and S. Vassigh, "Work in

Progress: Towards an Immersive Robotics Training for the Future of Architecture, Engineering, and Construction Workforce," *EDUNINE 2020 - 4th IEEE World Eng. Educ. Conf. Challenges Educ. Eng. Comput. Technol. without Exclusions Innov. Era Ind. Revolut. 4.0, Proc.*, Mar. 2020.

[27] P. Adami, P. B. Rodrigues, P. J. Woods, B. Becerik-Gerber, L. Soibelman, Y. Copur-Gencturk, and G. Lucas, "Effectiveness of VR-based training on improving construction workers' knowledge, skills, and safety behavior in robotic teleoperation," *Adv. Eng. Informatics*, vol. 50, p. 101431, Oct. 2021.

[28] H. Yi, "Robotics application for the advanced integration of design and technology in architecture," *Comput. Appl. Eng. Educ.*, vol. 29, no. 5, pp. 1146–1162, Sep. 2021.

[29] C. C. Cheah, T. Bock, J. Cao, T. Linner, Y. H. Liu, A. Yamashita, and L. Yang, "Guest Editorial Introduction to the Focused Section on Mechatronics and Automation for Constructions," *IEEE/ASME Trans. Mechatronics*, vol. 26, no. 6, pp. 2819–2825, Dec. 2021.

[30] T. Linner, W. Pan, R. Hu, C. Zhao, K. Iturralde, M. Taghavi, J. Trummer, M. Schlandt, and T. Bock, "A technology management system for the development of single-task construction robots," *Constr. Innov.*, vol. 20, no. 1, pp. 96–111, Jan. 2020.

[31] M. Pan, T. Linner, W. Pan, H. Cheng, and T. Bock, "Structuring the context for construction robot development through integrated scenario approach," *Autom. Constr.*, vol. 114, p. 103174, Jun. 2020.

[32] K. Iturralde, M. Feucht, R. Hu, W. Pan, M. Schlandt, T. Linner, T. Bock, J. B. Izard, I. Eskudero, M. Rodriguez, J. Gorrotxategi, J. Astudillo, J. Cavalcanti, M. Gouttefarde, M. Fabritius, C. Martin, T. Henninge, S. M. Normes, Y. Jacobsen, A. Pracucci, J. Canãda, J. D. Jimenez-Vicaria, C. Paulotto, R. Alonso, and L. Elia, "A cable driven parallel robot with a modular end effector for the installation of curtain wall modules," *Proc. 37th Int. Symp. Autom. Robot. Constr. ISARC 2020 From Demonstr. to Pract. Use - To New Stage Constr. Robot*, pp. 1472–1479, 2020.

[33] L. O. Wilson, "Anderson and Krathwohl Bloom's Taxonomy Revised Understanding the New Version of Bloom's Taxonomy," 2016. [Online]. Available: https://quincycollege.edu/wp-content/uploads/Anderson-and-Krathwohl_Revised-Blooms-Taxonomy.pdf. [Accessed: 28-Feb-2022].

[34] R. Moen and C. Norman, "The History of the PDCA Cycle," in *The 7th Asian Network for Quality*, Tokyo, Japan, 2009.

[35] BBC, "Robot cheerleaders support Japanese baseball team Fukuoka SoftBank Hawks - BBC Sport," 2020. [Online]. Available: https://www.bbc.com/sport/av/football/53352676. [Accessed: 03-Nov-2021].

[36] offshore-mag.com, "'Spot' deployed on Aker BP's Skarv FPSO | Offshore," 2020. [Online]. Available: https://www.offshore-mag.com/business-briefs/equipment-engineering/article/14187978/spot-deployed-on-aker-bps-skarv-fpso-offshore-norway. [Accessed: 03-Nov-2021].

[37] Boston Dynamics, "Boston Dynamics COVID-19 Response | Boston Dynamics," 2021. [Online]. Available: https://www.bostondynamics.com/resources/COVID-19. [Accessed: 03-Nov-2021].

[38] Boston Dynamics, "Spot® - The Agile Mobile Robot | Boston Dynamics," 2021. [Online]. Available: https://www.bostondynamics.com/spot. [Accessed: 03-Nov-2021].

[39] C. Salavera, P. Usán, and L. Jarie, "Emotional intelligence and social skills on self-efficacy in Secondary Education students. Are there gender differences?," *J. Adolesc.*, vol. 60, pp. 39–46, Oct. 2017.

[40] J. Cherian and J. Jacob, "Impact of Self Efficacy on Motivation and Performance of Employees," *Int. J. Bus. Manag.*, vol. 8, no. 14, 2013.

[41] A. Bandura, W. H. Freeman, and R. Lightsey, "Self-Efficacy: The Exercise of Control," *J. Cogn. Psychother.*, vol. 13, no. 2, pp. 158–166, Jan. 1999.

[42] A. Bandura, "Self-efficacy mechanism in human agency," *Am. Psychol.*, vol. 37, no. 2, pp. 122–147, Feb. 1982.

[43] J. Jakešová, P. Gavora, J. Kalenda, and S. Vávrová, "Czech Validation of the Self-regulation and Self-efficacy Questionnaires for Learning," *Procedia - Soc. Behav. Sci.*, vol. 217, pp. 313–321, Feb. 2016.

[44] K. R. Wentzel, K. Muenks, D. McNeish, and S. Russell, "Peer and teacher supports in relation to motivation and effort: A multi-level study," *Contemp. Educ. Psychol.*, vol. 49, pp. 32–45, Apr. 2017.

[45] N. S. Selby, J. Ng, G. S. Stump, G. Westerman, C. Traweek, and H. H. Asada, "TeachBot: Towards teaching robotics fundamentals for human-robot collaboration at work," *Heliyon*, vol. 7, no. 7, p. e07583, Jul. 2021.

[46] A. Mallik, S. B. Rajguru, and V. Kapila, "Fundamental: Analyzing the effects of a robotics training workshop on the self-efficacy of high school teachers," *ASEE Annu. Conf. Expo. Conf. Proc.*, vol. 2018-June, Jun. 2018.

[47] U. Sekaran and R. Bougie, *Research methods for business: A skill building approach*. 2019.

[48] H. Hsu and P. A. Lachenbruch, "Paired t Test," *Wiley StatsRef Stat. Ref. Online*, Sep. 2014.

[49] D. R. Thomas, "A General Inductive Approach for Analyzing Qualitative Evaluation Data:," *http://dx.doi.org/10.1177/1098214005283748*, vol. 27, no. 2, pp. 237–246, Jun. 2016.