Investigating the Need for Integrating Automation in Construction Curricula

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Abstract

Automation has been playing an increasingly important role in the manufacturing sector for decades, to the point where it is now impossible to imagine that a robot-less manufacturing facility could even exist. As a matter of fact, automation has not been limited to manufacturing but has touched almost every sector of the global industry, including agriculture, pharmaceutical facilities, sorting facilities, and many others. In construction, automation is being heavily used in fabrication facilities such as structural steel fabrication shops and plants that produce prefabricated and precast building components. At the same time, there seems to be a serious effort being expended to adjust construction means and methods to make them more prone to automation. With an expected shortage in skilled labor that can be crippling, automation may become more and more of a necessity in many sectors of the construction industry. The objective of this paper is to examine the state-of-the-art in construction automation, investigate the need for incorporating automation in construction management and related programs, and develop a methodology by which automation can be gradually incorporated in these programs to prepare future professionals for better serving an increasingly automated industry. This study utilizes a design science research methodology to generate new insights about the applicability of automation in construction curricula. The findings of this study are expected to support the construction workforce development in preparation for an expected increase in the adoption of automation in the construction industry.

Purpose of the study

The objectives of the study reported herein were twofold: the first was to assess the competencies that would be required of construction managers to be effective in a work environment that includes automation, and second to propose a way to integrate these competencies into educational curricula related to construction management. These objectives are being achieved by an examination of literature dealing with the subject and by conducting a students' survey to assess their familiarity with automation and their perception of its importance. The following research questions were investigated in this study:

1) How is automation important in construction management education?
2) How to promote automation in the construction management curriculums?

Automation in the construction industry

It can easily be argued that the main advantage of automation is increasing productivity, but other benefits that can be achieved include solving labor shortage problems, improving safety, ensuring a better quality of construction, and the execution of construction tasks that would be practically impossible to do without resorting to machines, among other possible benefits. Although research and publications on construction robotics can be traced back to the 1970s [1], it is widely accepted that development and adoption of automation technologies have evolved at a much slower pace in construction than they have in the manufacturing industry. However,

significant advances in computer and robotics technologies in the last couple of decades are making it, not only easier, but practically essential to incorporate more automation in construction processes.

In a study to assess the state of the art and future possibilities for construction automation, Folkesson and Lönnroos [2] conveyed that since the 1990s, manufacturing productivity has increased while construction productivity has decreased. They attributed the increase in manufacturing productivity to automation, as established by Frohem et al. [3], and addressed the automation in construction problem by asking three questions:

1. What is possible to automate on the construction site with today's technologies?
2. What Are the benefits of automation on the construction site?
3. What are the challenges for implementing automation on the construction site?

To obtain answers to these questions, Folkesson and Lönnroos [2] conducted eleven interviews with people from ten different companies within the construction and manufacturing industries. For the first question, they identified tasks that are, in general, monotonous and repetitive as prime candidates for automation. These include tasks such as drywall installation, bricklaying, spraying of concrete, drilling and cutting, timber assembly, additive manufacturing of steel walls, and autonomous guiding of vehicles. For the second question, the surveys revealed higher production rates, increased safety, lower costs, better accuracy, fewer errors, faster completion of projects, and better ergonomics as possible benefits from automation. The challenges that were identified through the third question can generally be classified into two categories. Most of these challenges are directly related to the nature of the construction industry. These include the dynamic and ever changing environment of construction project sites, preconceptions about automation, concerns about safety, the reluctance in the adoption of new strategies, and the design-bid-build method that tends to hinder collaboration. The other challenges have to do with resources and include the availability of adequate budgets for research and development in the field, the need to allocate more resources at the start of each project to integrate automation, and the need to ensure that digital models are continuously updated as they are an important component of the automation process. Chen, de Soto, and Adey [4] identified other challenges including concerns about information security and overcoming issues related to the exchange of information among the various stakeholders. They also stated that providing an overview of construction management may be a challenge because different people have a different interpretation of construction automation meant. This observation must obviously be taken into consideration while designing a curriculum that integrates automation into construction education.

In their conclusion, Chen, de Soto, and Adey [4] stated that construction automation has the potential to increase construction productivity, although exactly how and the possible benefits and challenges of construction automation are not clear for everyone. This makes a strong case for incorporating education into the educational system of construction professionals at all levels. They went on and made six suggestions for advancing the use of construction automation and provided justifications for their suggestions, which are:

1) to reengineer business structures and processes
2) to increase the scale of adoption
3) to assess project performance

4) to develop building information protocols,
5) to develop appropriate contracts, and
6) to integrate building information through standard data schema.

Clearly these are formidable tasks that require the involvement and the willingness to adapt of each stakeholder in the construction industry, and it is therefore imperative of educational institutions to fulfill their primordial role of adequately preparing future professionals to be effective in an automated construction environment. As a matter of fact, the idea of incorporating the coverage of automation in construction education and related fields is not new. For example, Boles and Wang [5] proposed course options for introducing construction automation and robotics in civil engineering education programs. Their recommendations will be explored further in other sections of this paper, but they did point out that there is a difficulty in implementing automation and robotics technologies in the classroom and in the industry, reflecting the conservative nature of the industry. They also indicated a perceived lack of interest among civil engineering students at that time in learning about construction automation and robotics.

Current status of incorporating automation in construction education

Incorporating automation-related concepts and practices in the construction management education curriculum is important for preparing future professionals to navigate the rapidly evolving landscape of the construction industry [6]. The construction sector increasingly embraces technological advancements in planning, design, construction, and operation/maintenance, posing a need that students must be equipped with the knowledge and skills to leverage automation effectively. Construction Management students who are familiar with automated processes can be well-positioned to optimize workflows, reduce manual errors, and improve project delivery times [7]. This knowledge is essential for future managers who will be responsible for overseeing complex construction projects. Additionally, automation plays an important role in enhancing construction safety and provides efficient prevention strategies to construction hazards and accidents on construction sites [8]. By leveraging students' knowledge of these automation practices, it is expected to help ensure a safer working environment. Construction employers are increasingly seeking graduates with hands-on experience in automated tools and technologies [7]. Therefore, integrating practical training, internships, and certifications in automation into the curriculum enhances graduates' employability and career prospects.

The existing literature shows several challenges to incorporate automation in construction education [9, 10]. First, adopting automation technologies requires significant initial investment and implementation costs, which can be challenging for educational institutions. Second, the introduction of automation changes the nature of work in the construction industry which requires Construction Management students to acquire new skills and engage in comprehensive training programs and continuous education. Third, the current practices of automation in construction management raise questions about liability and ethical guidelines, which need to be addressed in the curriculum. Finally, the adoption of automation in the Construction Management curriculum needs to maintain a balance between physical skills and new technological competencies to ensure the technological usability for students.

Construction automation has been gradually incorporated into the construction engineering and management programs across the United States. The content analysis of 77 U.S. institutions that offer the construction management program showed that construction automation and its relevant components have been fully and partially incorporated into twelve institutions, as described in Table 1. There are four institutions that have specific and dedicated construction automation courses while eight institutions that have started incorporating automation and its relevant concepts and practices into the construction management program. The automation components are taught together with construction robotics, advanced technologies, and building control systems using practical applications and case studies.

Table 1. Twelve U.S. Institutions Incorporating Automation in Construction Education.

No.	Institution	Construction Automation Incorporated	Program	Course
1	Central Connecticut State University	Yes	Graduate	CM 550: Automation and Emerging Technologies in Construction
2	North Dakota State University	Yes	Undergraduate/Graduate	CM&E 487/687: Building Automation and Control Systems
3	Virginia Polytechnic Institute and State University	Yes	Undergraduate	CEM 4624: Construction Robotics and Automation
4	Purdue University	Yes	Graduate	CM 58100: Automation in Construction Management
5	Illinois State University	Partially	Undergraduate/Graduate	Automation-related contents in various course topics
6	Indiana University Purdue University Indianapolis	Partially	Undergraduate/Graduate	Automation-related contents in various course topics
7	Michigan Technological University	Partially	Undergraduate/Graduate	Automation-related contents in various course topics
8	Missouri State University	Partially	Undergraduate/Graduate	TCM 760: Special Investigations. TCM 740: Agile Management of Innovation and Technology Seminar
9	Arizona State University	Partially	Undergraduate	Automation-related contents in various course topics
10	California State University, Long Beach	Partially	Graduate	CE 574: Methods, Analysis and Design of Construction Operations
11	Colorado State University	Partially	Undergraduate	Automation-related contents in various course topics
12	Pennsylvania College of Technology	Partially	Undergraduate/Graduate	Automation-related contents in various course topics

Automation proficiencies required for construction managers

As automation is increasingly being incorporated in construction processes, it is imperative that upcoming industry professionals be well prepared to manage the construction projects of the future. How this will be done will inevitably require a lot of effort and a good coordination

between the industry, educational institutions, vocational schools, and other organizations such as labor unions and some government agencies. For a significant integration of automation in construction to succeed, all parties that may be involved in a construction project must have a clear understanding of the new processes to be used and of their respective roles within those processes.

The first research question regarding how automation is needed in construction management education was addressed by using an online survey questionnaire. One hundred and two students (n = 102) from civil engineering and construction management programs, from two different institutions and at various levels of post-secondary education, participated in the survey. Figure 1 shows the distribution of the students from college freshmen to graduate students and reflects of the size of each class in the programs

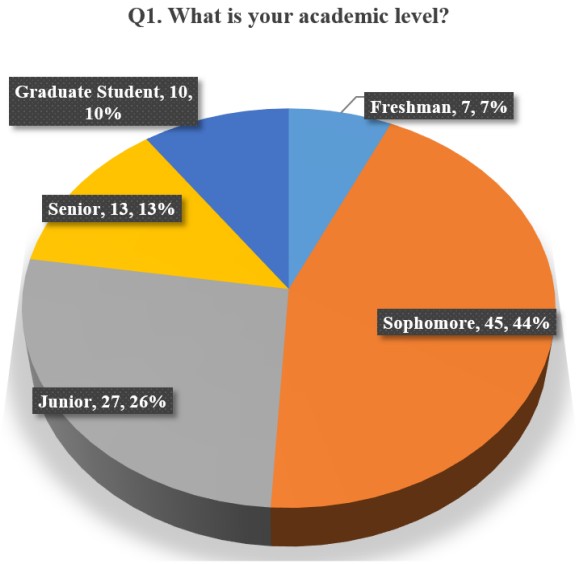

Figure 1. Academic levels of students participating in the survey (n =102)

Figure 2 provides information about the level of knowledge and experience the surveyed students feel they have about automation. While most of the students (60%) feel they have some knowledge from reading about automation or hearing about it, 29% of them stated that they have no knowledge of it. Most of the latter group of students represented one third of the sophomores and one third of the juniors, and only one senior, two freshmen, and two graduate students were part of this group. Ten of the students indicated they had some exposure to automation at work or during an internship, and only one of all the students indicated substantial exposure to automation at a job or during an internship. The fact that nearly 90% of the students, mostly from the sophomores and juniors, said that they either had no or just some knowledge about construction automation indicates that the topic is not adequately covered in the classes they took.

Figure 3 shows the areas of construction where surveyed students used or observed automation, if any. Half of the participating students (51) indicated no exposure to or experience with automation, while the other half indicated experience in ten different areas. Structural steel fabrication and construction was the field in which the most students indicated experience in,

followed by precast concrete fabrication and construction, reinforced concrete fabrication and construction, wood fabrication and construction, aluminum fabrication and construction, and control systems. Only 4% of the students indicated that they had experience in the automation of curb building, inspection, non-reinforced concrete construction, and welding.

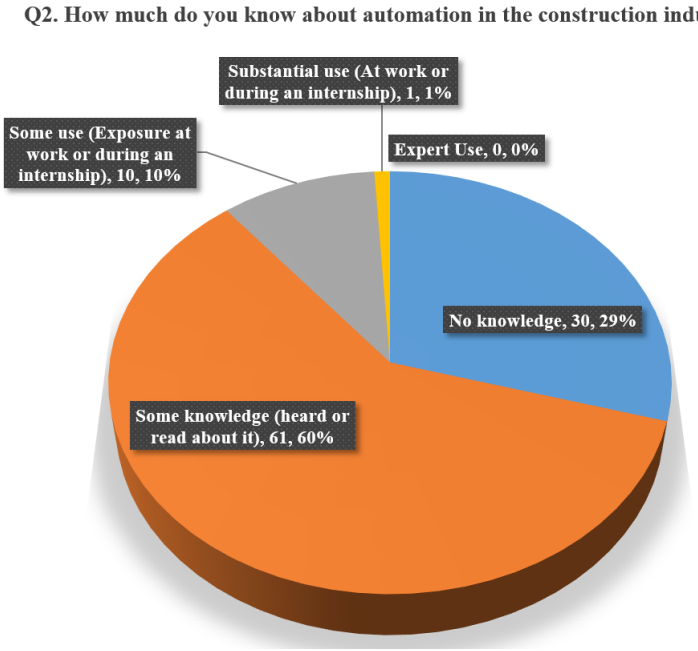

Figure 2. Level of students' familiarity with automation in the construction industry (n = 102)

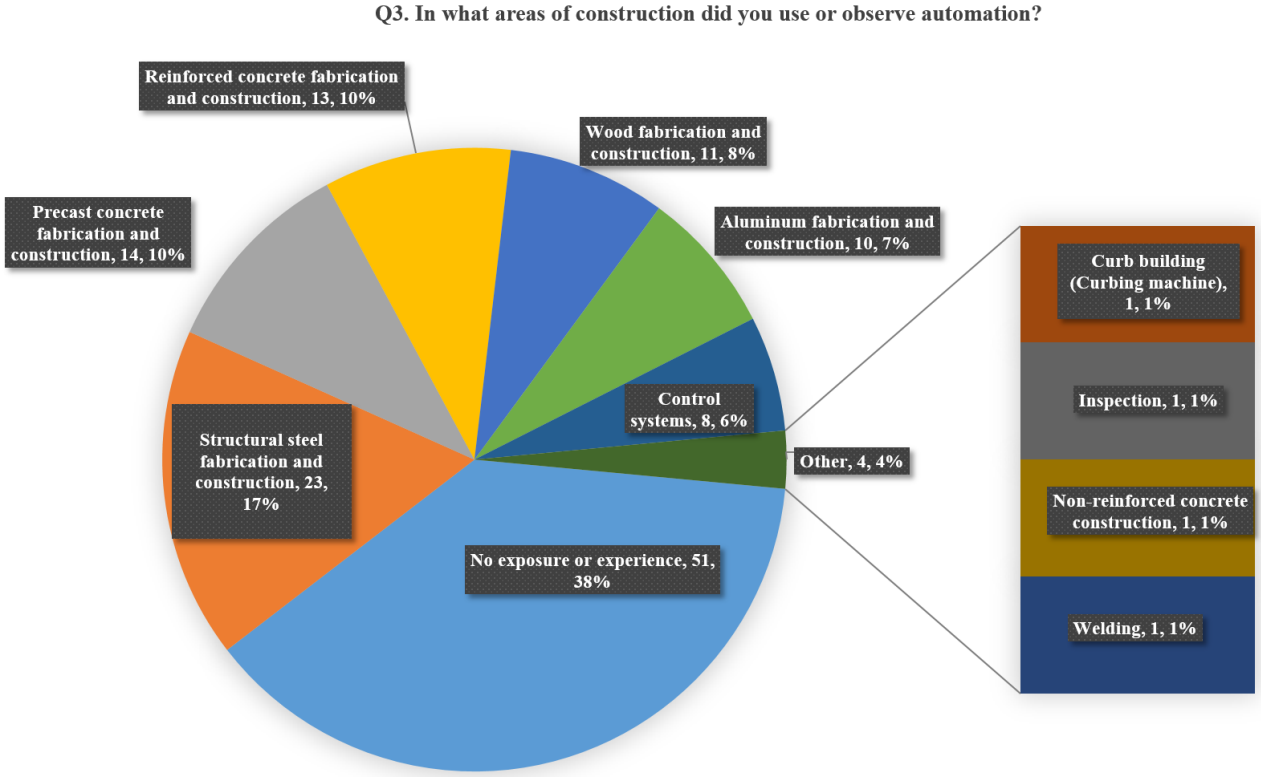

Figure 3. Areas of construction where automation was used or observed (n = 134)

The students were subsequently asked if automation should be taught in a college curriculum. Ninety-three of the students (91%) said yes while the remaining nine students did not feel it was necessary. When asked about possible topics to include in a construction management curriculum that incorporates automation, the students provided 512 entries identifying ten distinct topics, as shown in Figure 4. Four of the identified topics are of a general nature and include introduction to automation, areas of automation in construction, 3D printing, and drone technology. Three of the topics are activity specific covering the automation of construction component fabrication processes, the automation of excavation processes, and the automation of material transportation processes, and the remaining three are material specific and cover the automation of steel, concrete, and wood construction processes. The identified areas cover a wide range of construction related activities and would provide students with the required skills and a healthy background in construction automation principles if incorporated into the curriculum. It should also be understood that issues related to automation equipment, including robots, the estimating of the cost and the scheduling of automated processes, contracting, ethical considerations, and other construction management related matters would be inherently encompassed within the various topical areas to be covered. However, special attention would need to be given to the topic of safety as automation brings its own share of safety issues and challenges.

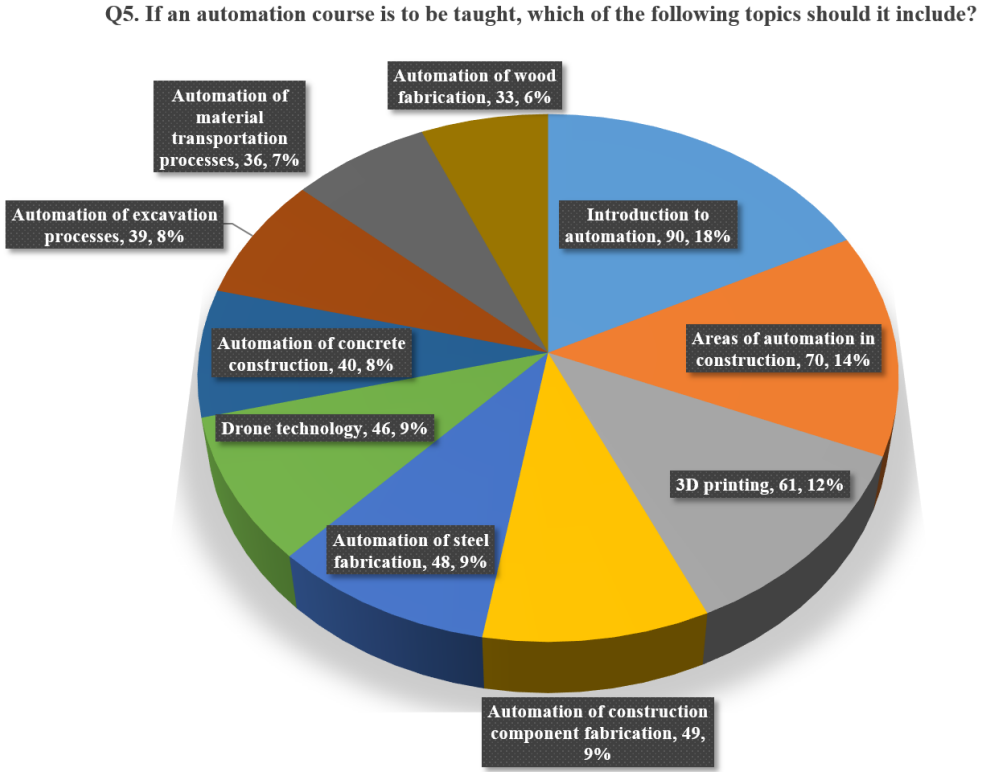

Figure 4. Topics that need to be included in a construction automation course (n = 512)

The last two questions of the survey asked the students if a course on automation should be required or elective and if they would be interested in taking it if it was to be offered. A majority of the students (82%) expressed a preference for an elective course, and 79% of them indicated that they would be interested in taking the course. The information collected from this survey was valuable in the ability to propose a viable approach to incorporate construction automation into current educational curricula.

A proposed approach for incorporating automation in construction curricula

The second research question regarding how to promote automation-related topics in construction management curriculums was addressed using the content analysis of the existing literature of construction automation and education. In an article dedicated to study the impact and opportunities of automation in construction, Chui and Mischke [11] made a comprehensive presentation of the subject matter and addressed issues related to the effect of automation on construction work and wages and how can the industry manage any workforce skills transition. They proposed that automation will create an increasing skill mismatch in construction, as has been observed in other industries, and that adjusting to automation in construction will require efforts from the public and the private sectors of the industry as well as from industry associations. Clearly, institutions of higher learning also will have to play their role in preparing future construction managers, and possibly other construction professionals, for contributing to increasingly automated project sites.

Boles and Wang [5] had the foresight to tackle the issue of incorporating robotics and construction automation into civil engineering educational programs. They included in their study a good discussion with respect to whether it would be more beneficial to offer construction automation principles in dedicating courses or to integrate those principles in the various courses of a given program. Their recommendation was that automation topics should be integrated into existing classes, but ultimately proposed options for both approaches. The first option was a set of topics to be taught as part of an existing undergraduate course using a total of fourteen lecture hours, the second option was also a set of topics to be taught as part of an existing graduate course using a total of twenty-seven lecture hours, including those proposed for Option 1, and the third option was a set of topics for a dedicated graduate level course that includes topics from Options 1 and 2 with additional advanced topics. They also proposed lectures and laboratory sessions for a possible laboratory component. Their proposals are reproduced here for the benefit of the reader and summarized in Table 2.

The curriculum proposed by Chui and Mischke [11] can very well be used as a starting point for the development of a curriculum for today's construction management programs with needed updates made to take advantage of recent and emerging technologies. However, since the field of automation has grown in so many directions in recent years, it may not be possible for any one program to cover all of the aspects of construction automation without at least offering a minor or a certificate in automation. In general, a curriculum in construction automation can be built up from the following three major classifications of subjects:

1. Introduction to automation
    a. History
    b. Benefits and challenges
    c. Areas of applicability
    d. Impact on society and the environment
    e. Current technologies and emerging trends
    f. Automation equipment
    g. Impact on project outcomes, including safety, quality, cost, and risk
    h. Ethical and legal considerations

Table 2. Automation topics and lecture distributions as proposed by Chui and Mischke [11]

Options (Hours)			Topic	Lecture hours
Option 3 – Dedicated graduate course (42)	Option 2 – Graduate (27)	Option 1- Undergraduate (14)	Background and historical development Automation and robotics Applications in construction	2
			Potential benefits including economic, safety, and quality discussions on potential labor issues	1
			Terminology and typical system components	2
			Stationary versus mobile robotics	2
			Problem identification methodologies	1
			Feasibility analysis	2
			Systems development methodologies	1
			Case studies	2
			Additional terminology and typical system Components	1
			Additional problem identification methodologies	2
			Additional feasibility analysis	2
			Additional systems development methodologies	2
			Systems integration and environmental constraints	2
			Electromechanical interface	2
			Data acquisition, processing and control techniques	2
			Robot and kinematics	4
			Machine vision	4
			Sensor modalities and data fusion	2
			Obstacle avoidance for mobile robots and path planning	4
			Teleoperation, shared control	4
Laboratory Component (8)			Basic electronics (Lab lecture)	1
			Digital electronics (Lab lecture)	1
			Reflective tape following vehicle exercises with additional robotic arm programming exercises for graduate courses (laboratory)	6

2. BIM integration
    a. Integration of automation information in BIM models
    b. Integration of cost information associated with automation
    c. Integration of automation productivity information
    d. Integration of automation equipment information for simulation and possibly maintenance purposes
    e. Integration of automation safety information
3. Advanced automation equipment and systems
    f. 3D Printing and 3D printing equipment and robots
    g. Construction robots and robot programming languages
    h. Drones and drone technology
    i. Material handling
    j. Demolition and layout

k. Inspection robots
l. Human-machine interaction
m. Data acquisition and control systems

It is important to note here that the list provided above is not meant to be exclusive nor comprehensive. It is only intended to provide a starting point for two-year and higher construction management programs to start incorporating automation into their curricula. More importantly, case studies should be used to demonstrate the benefits of automation, such as improved efficiency, cost reduction, and enhanced safety. For instance, the use of robotics and autonomous machinery in tasks such as bricklaying, 3D printing, and excavation can be discussed using project-based assignments, capstone projects, workshops, and research projects. Feedback from students, alumni, and industry stakeholders should be considered to refine course content and update the curriculum to include emerging technologies and trends in construction automation. Since the construction sector is witnessing a skills gap as the adoption of automation increases, the systematic integration of automation into the curriculum can address this gap by equipping students with relevant technical skills and knowledge. The long-term success of this integration hinges on fostering strong construction industry-academia partnerships, investing in faculty development, and maintaining a flexible, future-focused construction management curriculum. The efforts will ensure that the next generation of construction managers is well-prepared to lead in an increasingly automated and data-driven industry.

Conclusion and Recommendations

The construction industry is at a point in time where it most likely will not be able to make any real progress without seriously embracing more automation. This will require a serious effort and participation from all the industry stakeholders to ensure the availability of competencies that can plan and safely execute construction projects in increasingly automated environments. From a construction management point of view, it is the responsibility of all players in the academic sector to work together to build capacity and produce construction project managers that have the knowledge and skills required to be successful in an automated project site, and institutions of higher learning, accreditation agencies, certain government agencies, and the private sector must all work together to achieve this goal.

University level construction management programs have many options available to them to start incorporating automation in their educational programs, depending on the resources that are available to them. At a very minimum, construction management programs, either at the associate or bachelor degree level, can start by providing an overview of construction automation in an introduction to construction course. Some programs may opt to incorporate a selection of topics into a number of courses within their curriculum. For example, a selection of introduction to automation topics may be integrated into an introduction to construction course, while others may be covered in their related courses (ethics, contracts, sustainability, …). Similarly, a selection of BIM integration topics may be integrated into a BIM-focused, an estimating, a scheduling, or a simulation course. And finally, a selection of the advanced automation equipment and systems courses may be integrated into a construction means and methods course or in a construction equipment course. At the other end of the spectrum, a program may choose to offer a number of courses to deal in detail with any of the subjects identified in the previous

section, and some may even add a laboratory component to the courses to provide students with some hands on experience. For example, a full course can be dedicated to the topics under the introduction to automation subject, and a number of separate courses can be developed to cover BIM integration or any of the advanced automation equipment and systems topics to varying levels of detail.

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