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Investigating the Challenges of Maximizing Construction Automation Sustainability

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Significant advantages of automation including less reliance on human laborers in hazardous conditions, and reduced generation of wastes create substantial sustainability potentials. In order to maximize the benefits from these potentials, policies for aligning automation with long-term sustainability goals are required, yet hard to find. Consequently, the high potentials of automation are not sufficiently applied in the industry. Therefore, the stepping stone is identifying the existing issues from the lens of experts. This paper introduces a holistic approach to integrate and maximize construction automation's contribution to the triple bottom lines of suitability. A comprehensive review of publications will be used to identify the potential barriers. Constructional industry professionals and automation researchers will then be interviewed to analyze and formulate the approach. In each section, the barriers to applying integration practices are also discussed. The paper is expected to contribute to the goal of progressing automation to create safe, productive, and environmental-friendly construction approaches.

Key Words: Construction, Automation, sustainability, human laborers

Introduction

Immense adverse impacts of the construction industry have caused global concern about its consequences, particularly on the environment, if they are not detected and mitigated (Tafazzoli, 2016). More than 1/3 of the world's CO2 emissions and between 45 to 65% of landfilled wastes are caused by this industry alone (Zea Escamilla et al., 2016). Figure 1 shows the remarkable share of the built environment in going house gas emissions, as well as portable water, electricity, and energy consumption. Yet, the construction industry holds 13% of the world's gross domestic product (GDP) (Ribeirinho et al., 2017; Bamgbade, et al., 2020) and is a primary generator of jobs worldwide. The pivotal role of the construction industry in sustainable development explains why without making extensive improvements and modifications in the current construction methods and practices the goal of a sustainable future remains a dream.

Despite the revolutionary improvements in various industries in the last few decades, the construction industry has been shown to be less responsive in remarkably modifying its methods and practices. Due to this belatedness, construction productivity is significantly lower than other manufacturing industries. Low productivity and efficiency are both detrimental to sustainable development as they are connected to higher consumption of resources and increased or prolonged detrimental impacts on the triple bottom line of sustainability. Therefore, a fundamental requirement for sustainable construction is focusing on shifting conventional construction methods into more progressive manufacturing methods that are significantly more efficient and productive.

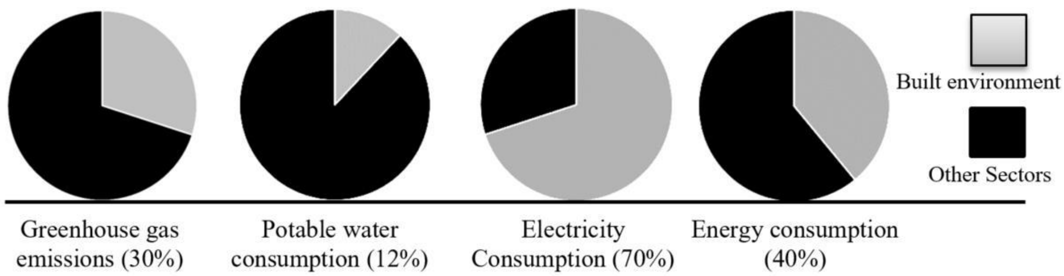

Figure 1. The share of the built environment in four environmental concerns (Tafazzoli, 2017)

The primary reason for the higher success rates of the manufacturing industries is the controllability of the environment and resources resulting from performing the tasks in indoor environments. Additionally, the production occurs in repetitive cycles, by almost unchanging resources, that primarily rely on automatic systems enabling the managers of the system to minimize the risks and reach high levels of productivity and safety.

The massive lost productivity in the construction industry on one hand and the alarming concerns about lack of materials, high accident rates in construction projects, and substantial negative impacts of this industry on the environment indicate how critical it is to invest in standardizing this industry and improve its controllability (Karji, et al., 2020). To this end, the fundamental solution is shifting the conventional methods of the construction industry into manufacturing industrialization. Simply put, the more we try to industrialize the construction process, the higher productivity we can achieve.

Automation plays an integral role in increasing the controllability and predictability of the construction processes both of which can, directly and indirectly, benefit the triple bottom lines of sustainable development. Shifting the reliance on construction projects from being a labor-intensive industry to automated processes is the next evolution of this industry that has already been launched. Although the pace for the widespread transition from conventional to automated approaches might vary in different countries and regions, the significant rewards of automation are expected to conquer the resistance to change inherited in the construction industry.

Large-scale implementation of automation is expected to create both challenges and opportunities that are unfamiliar to the industry. Some of these aspects have links with sustainable development and its triple bottom lines. The analysis of the connection between automation and sustainability enables us to better prepare for the adoption of new technologies in construction, mitigate their potential negative impacts, and optimize their utilization.

It should be noted that considering that both construction automation and sustainable construction are fairly new transformations that are evolving quickly, the connection between these two topics could potentially have other aspects that are not included in this chapter. The goal of this chapter is to reflect on what is known about the positive impacts of automation on sustainable construction and some possible negative impacts, such as reducing job opportunities for construction workers, have not been investigated.

Methodology

This study attempts to find the major barriers to maximizing construction automation's contribution to sustainable development. In doing so, the following steps were taken.

Step 1. Investigating the potential barriers in the literature

This was done in two steps: 1) Reflecting the findings of the existing research. A comprehensive review of the research discussing sustainable construction was performed. The major barriers that were mentioned in the research were listed. 2) Interviewing the Construction industry professionals. A Sample of ten construction professionals including general contractors and construction managers and highly experienced field engineers were interviewed and asked about their concerns and challenges of adopting automation in construction.

Step 2. Conducting a Survey for Critical Ranking of the Barriers

A survey was developed to rank the barriers based on the survey results. Using an online questionnaire and hard copies the survey was distributed. Respondents were asked to rate each potential barrier with a number between '1' and '5', where '1' indicated the lowest and '5' indicated the highest level of criticality. The survey tool made it possible to check how much time the respondent spent answering the survey; this allowed the administrator to eliminate the responses that were generated too quickly.

Step 3. Analyzing the Data and Interpreting the Results

The results of the survey were analyzed using the Relative Importance Index (RII) method. RII is a method that aids in finding the contribution a particular variable makes to the prediction of a criterion variable both by itself and in combination with other predictor variables (Tafazzoli and Shrestha, 2017). Equation 1 was used.

$$\text{RII}=\frac{\Sigma W}{A\ X\ N} \qquad (0\leq \text{RII}\leq 1) \tag{1}$$

where:
W = the weight given to each factor by respondents and ranges between 1 and 5
A = the highest weight (i.e. 5 in this case) and;
N = the total number of respondents

Step 4. Developing Policy Recommendations Based on the Results

Based on the results, some policy recommendations to handle the barriers were provided. Some of the recommended policies are based on reflecting the facts about sustainable construction that can help to handle the barrier caused by having inaccurate judgments about the challenges of applying sustainable practices. Other recommendations reflect some required approaches and changes to break through the barriers.

Results

The barriers to maximizing the sustainability of automation in construction were investigated by reflecting on the findings of similar research and combining them with the outputs of the pilot survey. The barriers in the viewpoint of the investors and developers are categorized into four major categories and using the RII method, they were ranked. Figure 2 shows the results:

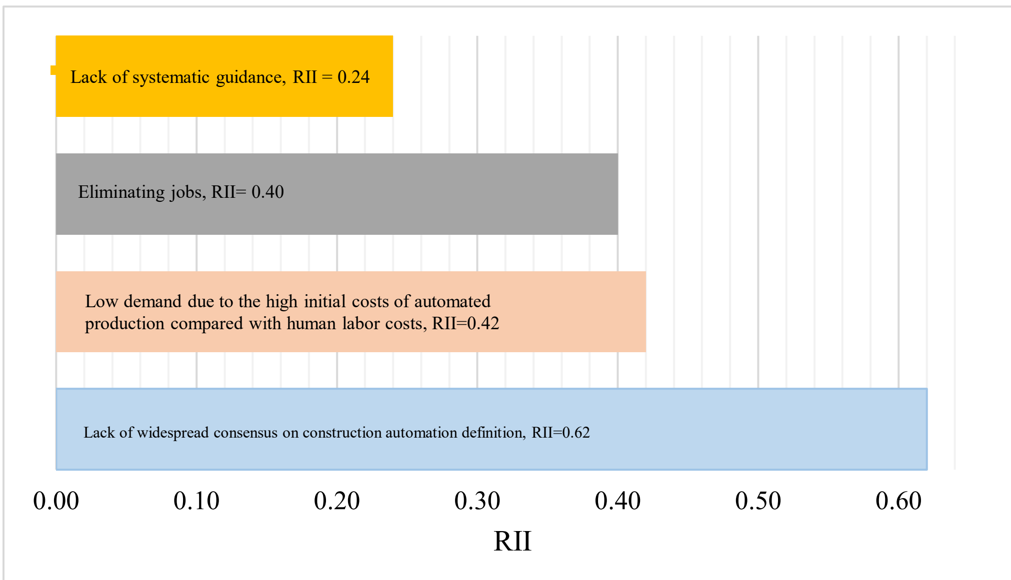

Figure 2. Relative importance index of the four barrios from the statistical analysis

1. Lack of Widespread Consensus on Construction Automation Definition

Despite the significant progress of automation, the widespread adoption of construction automation technologies is still an unachieved goal. According to Mahbub (2008)., the driving force of construction automation in most of the developed countries including North America and Europe are universities, and contractors' willingness to invest in adapting or contributing to the associated technologies is limited.

Considering the gradual formation of automation techniques and robotics in the construction industry the way they are defined has evolved throughout the years. Automation nowadays encompasses a significantly wider range of construction functions than it would a few decades ago. This has caused a lack of a universally agreed definition and therefore scope of construction automation. Simply put, the term construction automation could be used to address a wide variety of technologies with huge differences.

Some of the tools that would normally be associated with automation are teleported technologies, utilizing self-controlled, intelligent, or semi-autonomous mechanical or electrical tools or equipment, as well as performing, analyzing, or managing construction activities remotely, collecting an analysis of data to name a few. As can be imagined, each category of these technologies involves different techniques that are connected to dissimilar skills, tools, equipment, requirements, and products.

The vast variation which exists between these categories creates a challenge to develop strategies and policies that can effectively contribute to all categories of construction automation. Different associated costs and effectiveness of investment in each category exacerbate the challenge to make comprehensive management policies about automation without breaking them down into category-specific measures. A clear-cut boundary between different available technologies is expected to facilitate addressing them and developing management policies that are particular to each category.

2. Low Demand Due to The High Initial Costs of Automated Production Compared with Human Labor Costs

The high price of automated technologies compared with the traditional workforce is the primary hindrance to their extensive adoption for on-site use (Pan, et al., 2018; Mahbub, 2008; Bock & Linner, 2015; Cousineau & Miura, 1998). Although human laborers account for 20% to 50 % of project costs, in many cases, they are less expensive than designing, installing, and operating automated processing technologies. While the public's image and assumptions about the associated expenses of automation may be exaggerated or not precise, for many construction tasks that are conventionally done by human laborers, the replacement costs with machines will not make an economic sound. To improve the willingness of the industry in adapting on-site automated construction technologies we need to invest in reducing the costs and difficulty associated with shipping and installing the associated equipment.

3. Eliminating Jobs

The common concern about the widespread utilization of automation in the industry is affecting the job market and the possible massive unemployment by replacing human laborers with machines. Some studies have discussed and validated this concern (Manyika, et al., 2013; Wolfgang, 2016; Brynjolfsson & McAfee, 2011; Ford, 2015). However, a closer look indicates a variety of jobs that are created as a result of automation. Manufacturing, shipping, operating, and maintenance of these machines is a generator of various and numerous new jobs. Nevertheless, the type of these new jobs could be different from the jobs that are eliminated as a result of automation. Thus, creating alternative jobs for the laborers who might lose their jobs due to automated processing, remains a challenge (Vermeulen et al., 2018).

It should also be noted that a variety of construction automation technologies function as an addition to existing operations. Some examples are automated technologies used to improve project administration, monitoring, and control. For instance, an image processing technology that could detect the hazardous situation on a job site is a type of technology that is not intended to physically progress the project and therefore cannot have an impact on the associated jobs.

4. Lack of Systematic Guidance

The current trend toward the advancement of automation in construction is more focused on information and communication technologies. Significant advancements in image processing such as using drones for monitoring the field have been achieved. However, the high potentials of automation seem to lack effective systematic guidance that can improve its reliability, transferability, accessibility, and cost-effectiveness. Studying the research and investigating the barriers to automation indicates that widespread adoption of automation is far-fetched, particularly for on-site operations, unless these systems evolve and transform in these directions.

Discussion: Potentials for Enhancing Construction Automation

Understanding the barriers to construction automation is the prerequisite to lead us to the potential solutions for enhancing its adoption in the industry. These barriers were discussed in the previous part of the chapter. In this part, the potential and opportunities for enhancing construction automation are discussed.

Prefabrication, Mass Production, and Modular Construction

One requirement for automation to make economic sense is mass production. Enormous costs of investing in the design, manufacture, installation, training, and maintenance of automated technologies cannot be returned unless the production is pursued in large numbers and for long periods. It was mentioned at the beginning of this chapter that industrialization is the key to utilizing automation in the construction industry.

The uniqueness of project design can hinder the creation of a template for repetitive processes which is one of the primary elements of industrialization. Modular construction reduces the variation of design as it requires the mass production of units with the same specifications and dimensions. It is therefore an effective response to the process of construction industrialization. From the lens of sustainable construction, shifting conventional construction into modular and mass production has numerous benefits and is in perfect alignment with multiple sustainability goals.

These benefits indicate why the major goal of making the construction industry more sustainable, has close ties with promoting and investing in modular construction. Among these befits, the possibility of reusing materials dismantled from a modular facility is particularly significant as it can contribute to a massive volume of material waste reduction and, therefore, reduced demands for raw materials which is a fundamental environmental concern created by the construction industry.

Prefabrication was conventionally the common definition or understanding of construction automation (Pan et al., 2018). Utilizing automation in prefabrication is particularly integral for modular construction which is booming significantly in recent decades. Prefabrication is not limited to modular projects and this can increase its demand as it can be applied to various types of projects. Figure 3 shows the connection between the enablers of construction automation. As seen in this figure, mass housing and modular construction can facilitate using prefabrication methods and prefabrication is a primary enabler of automated construction.

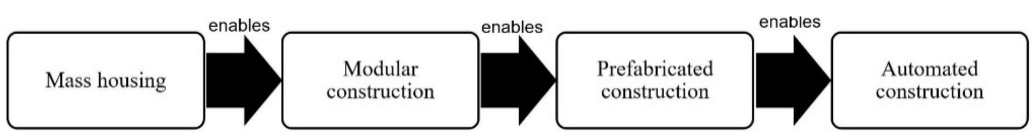

Figure 3. The chain of enablers of automated construction

Promoting Onsite Use of Automation Technologies

The uniqueness of design creates a constraint for modular construction which is one of the primary approaches in construction automation. In the meantime, researchers and developers of automated construction technologies, believe that the potential of automation should not be limited to off-site manufacturing and prefabrication. While prefabrication has been shown to have considerable sustainability advantages, some of the shortcomings inherited in this technology can limit its utilization. One example is the difficulty of making changes in the shipped materials and the time-consuming process of returning the manufactured compartments or replacement of defective pieces. Similarly, adherence to architectural specifications in prefabricated parts, as well as a low level of customizability, are some of the other barriers to the widespread adoption of prefabrication.

Limiting automation to off-site production and prefabrication can significantly reduce the positive sustainability impacts of automation and utilizing automation techniques on-site should remain an indispensable goal in the industry. Despite the fast growth of modular construction, a high percentage of fabrications in construction projects still happen on-site. Moreover, increasing productivity and contributing to safety, as two of the major benefits of construction automation are more influential in a construction field where there is a high potential for wastes and job site accidents. Applying automation to the project's field can expand the capabilities and positive outcomes of emerging on-site technologies, and at the same time, it will maintain the possibility of customizing compartments on the field where modular construction is not pursued.

To promote on-site utilization of automation in construction its technology must be directed to improve its flexibility to be used in a variety of operations, as well as accessibility to be transferred to different projects' locations at reasonable expenses. Additionally, the flexibility of these robots to perform a variety of tasks is expected to encourage constructors to be more welcoming to adapting them in their projects.

Improving the Cost-Effectiveness of Automation

In expanding the use of automation in construction three factors must be taken into consideration: 1) Limiting utilization of construction automation to offsite construction only, will not allow us to benefit from many of its advantages on sustainability, 2) for contractors and investors, such technologies are attractive primarily if they can lead to cost-savings, and 3) in the competition to reduce project costs construction automation has a difficult job to transform and evolve in a way that they can be less expensive than human laborers.

The possible conclusion from these facts is that automation must invest in reducing the project costs not only by eliminating human laborers but by facilitating the entire process of design and construction and performing the operations more cost-effectively. Figure 4 shows some of the expected advancements of construction automation in the future.

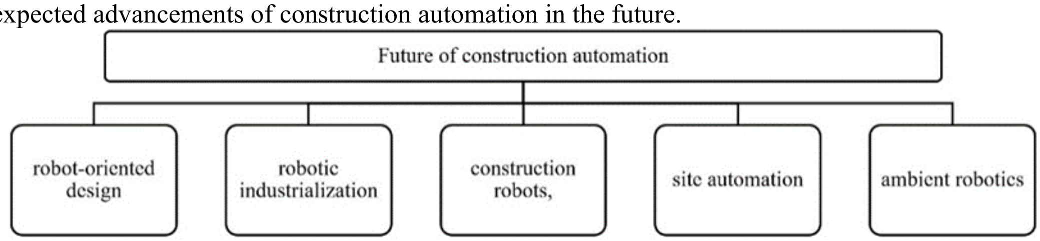

Figure 4. The Future of construction automation

The limited interest of private owners and investors to contribute to the considerable costs of the transition to automation explains why governmental support is pivotal in accomplishing this goal. As an example, in Europe, The European Union provides funding to projects that utilize automation and prefabrication and therefore have a more efficient energy performance (BERTIM, 2016).

Summary and Conclusion

The poor performance of the construction industry compared with manufacturing industries indicates that increasing controllability and standardization are the keys to making the construction industry more productive, sustainable, and safe. The contributions of construction automation were discussed in each of the three bottom lines of sustainability. The possibility of reducing labor intensiveness by replacing humans with robots was identified as the primary source of these contributions. By mitigating the possibility of human errors, construction automation can lead to multiple positive impacts on sustainability including added precision to construction activities leading to efficient use of materials and reduction of wastes benefiting both environment and economy; improved safety, healthier, more desirable work environment, and job satisfaction which contribute to social sustainability; and increased productivity that shrinks project duration and benefits all sustainability bottom lines.

The indirect benefits of automation on sustainability were also discussed. It was also argued that the transition to automation in the construction industry which is labor-intensive and resistant to adopting new technologies is a challenge. The barriers to construction automation including higher initial and maintenance costs as well as the lack of skilled individuals who can operate and maintain associated tools and equipment were discussed. It was highlighted that to accelerate the pace of automation in the construction industry economic incentives act stronger than environmental or social benefits. This means by investing in progressing these technologies to make the construction process more efficient and less costly, automation can be more widely and quickly adopted in the industry. It is important to keep in mind that construction automation is an evolving transition in this industry and by identifying the existing shortcomings of conventional methods and analyzing the potentials of automation, its capabilities can be more effectively directed to resolve the existing issues and make more contributions to the construction industry.

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