Assessing Construction Automation and Robotics in the Sustainability Sense

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Abstract:

Building growth technology is rapidly recognized globally as a key aspect in the future of construction projects. However, construction robotics and automation (CRA) have yet to undergo significant reality deployment. The latest substantial sustainability requirement is the necessary cause for the more extensive implementation of construction robotics and automation. Nevertheless, there are small attempts at a detailed investigation of the effect of using construction robotics and automation on the sustainability efficiency of buildings and construction. Still, structured advice for the building industry is lacking in this sense. The study in this paper represents the first step towards addressing by analyzing and examining the construction robotics and automation techniques and available innovations and, for the first time, creating a coherent system of metrics for measuring the sustainability efficiency of construction robotics and automation usage in buildings. The ultimate objective of the study must therefore be the creation of a rigorous and consistent methodology for evaluating, within this framework, the feasibility of construction robotics and automation in the construction projects context.

Keywords: Construction robotics and automation, Sustainability, Building Indicators

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1. Introduction

Automation and robotics have been regarded as leading areas of innovation in construction projects for the betterment of the industry [1], [2]. Research has been spread out for decades, and new automation and robotics technologies continue to develop for the general manufacturing and construction industries [3]. In the meantime, the building sector has received increasing attention under the worldwide agenda for sustainable development since buildings account for more than 30% of global greenhouse gas (GHG) emissions and more than 40% of global energy consumption [4]. Nevertheless, the development of sustainable buildings (SBs) has experienced problematic implementation at all levels of design, construction, and operation [3].

The term "construction" is about to transform into a notion of "construction creation." Construction robotics and automation are increasingly recognized globally as emerging technology that can create a foundation for the "making" of buildings in the future as it does in other industries [5]. That has led to a host of R&D projects both in academia and industry for decades. However, Construction robotics and automation have never seen a large-scale, real-world deployment (especially on the building site). One of the main reasons for this is that, to date, construction robotics and automation have lacked "killer applications," which would have been a significant situation for its wider use [6]. Among many others, the costs of human workers in building up to date have never been so high that construction robotics and automation are very costly technology would have been the viable solution.

The growing need for sustainability can be used as a catalyst for the large-scale use of construction robotics and automation, particularly in combination with economic and efficiency factors [7]. In this sense, formal regulation for the building industry is absent, and few efforts have been made to examine the effect of construction robotics and automation use on building and building sustainability efficiency [7]. The study in this paper is the first attempt to address the research gap. It analyzes and examines the current construction robotics and automation strategies and innovations. Besides, it establishes for the first time a coherent system of sustainability assessment metrics using construction robotics and automation in the construction industry.

1.1 Background

This section includes and addresses the production context of construction robotics and automation and approaches of sustainability appraisal in the construction industry to build the basis for the study and precisely define the analysis limitations. While construction robotics and automation (CRA) typically encompass a variety of technology, a consistent description remains lacking in consensus. Researchers suggested different concepts of " construction automation, or construction robot" [8]. The designation of construction automation is a definition of engineering and construction methods with telecontrolled, numerical, semi-autonomous, or independent installations. On the other hand, building robots are classified as specialized equipment that can be teleoperated, acquired sensory data, analyzed, numerically directed, or autonomous tasks [9]. Construction robotics and automation (CRA) is the application of automatically performing construction and operation using mechanical and electronic self-regulation machinery with intelligent regulatory systems. Used terminology and meanings vary, including applications ranging from human-handled automatic equipment and semi-automated or remote-controlled machines to autonomous robotics with more sensors and control capabilities [10]. For this report, CAR is considered to provide a broad range of machinery and software to automate infrastructure processes in the construction process [1].

Studies by [11] are well documented, and it is also well acknowledged that the combination with a new technical enabler and the growing need for effective, economic, and sustainable construction has turned the large-scale construction of robots into an active field for study. Construction robotics and automation (CRA) explicitly concerns embedded, autonomous, multi-rotor systems which change a shared environment to meet high-level user targets. To reach scalability and adaptability, the CRC combines closely architectural architecture, construction, mechanisms, and power. This study outlines the developments in science, open questions, and success measurements.

Over time, extensive literature has developed [12]. While evaluating longevity and risk potential, product generation management requires a comprehensive approach to life cycle management, particularly concerning obsolete component management. Although, until now, the economic effect or gain of events connected to such life cycles is only sometimes clear. This paper provides a nuanced approach to identifying

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unexploited business capital through the creative Life Cycle-Managerial Index Method (LY-MIT) to success discovery to enable a company to detail its visualization, using seven cluster capacities in critical places.

The authors [13] and [14] employed a 3D printing methodology that prescribes the use of 3D printing technology has gained widespread interest in many sectors, allowing mass manufacturing and personalized production in a minimal amount of time. 3D printing has already been well-studied in the building industry. Analysis patterns in 3D printing in a building are also shown in studies. The primary focus of these experiments was on tools, materials, and associated software. However, only particular fragmentary aspects have been addressed, such as the number of publications written annually or developments in a study by nation. Therefore, these papers aim to expand the dialogue by extracting keywords from articles published in the last twenty years. Hence, this paper aims to expand the debate, using text-mining relationship analysis to extract keywords from papers published over the last twenty years that point to research trends in 3D printing. These findings enable us to recognize the fields of research needed for 3D printing in the future building industry.

The paper [8] began with a short review of the literature regarding industrial robots (IRs) that are the main motor of the production activities of advanced manufacturing systems to make their production activities more automotive and productive. However, it is essential for sustainable production facilities of IRs to be centralized and formal to achieve successful jobs and innovative configurations in cloud manufacturing environments. This document builds on functional characteristics, structural detail, operational and process conditions, and the IR model's coherent, sustainable manufacturing capability (SMC) [5].

The method for describing interval-state energy consumption is recommended in parts of the IR procedure. Based on the design, the capabilities of the IR, including stability, energy consumption, and production power, are specified in three types of regulations [6].

Many authors in the literature [1] discussed that construction robotics should have transformative effects on the construction industry, but there still needs more use. While technological progress has received much recognition, more must be achieved to understand the broader cultural challenges of using this technology entirely. This article aims to provide a holistic analysis of the factors which influenced the potential use of building robots in a systems way, analyze the relationships between these factors, and recognize those which influence technological transformation most.

2. Development of Sustainability Assessment Methods

Sustainable growth or sustainability, as described broadly by the World Conference on Environment and Development, is recognised as development that satisfies present needs without undermining the capacity of future generations to respond to their demands. In the construction sector, the words 'sustainable construction' or 'sustainable building' have been defined in various forms [15]. Recommended in the First International Conference on Sustainable Building, an early concept of sustainable construction is developing a balanced built environment based on resource-efficient and ecological values [16]. The expression of sustainable construction has been used since 1996, and its use has gradually grown since that time [17]. In addition, it explains a specific building or illustrates an integrated approach to building environmentally sustainable development. Appraisals have been thoroughly developed to understand sustainable concepts and information combined with appropriate principles and methods for sustainability [17].

3. The conceptual framework of sustainability issues of construction robotics and automation (CRA)

Frameworks for metrics were built to tackle complex aspects of sustainability in multiple industries. This article's frameworks relating to architecture, technology, or invention are particularly significant from a construction project standpoint.

The authors in [15] established the core sustainability criteria in several important fields covering potential impacts, including environmental impact, economic and financial benefit, benchmarking strategy, and the construction sector for a sustainability framework. The criteria combine LEED performance criteria with TBL general indicators of project-level considerations that affect corporate sustainability efficiency.

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4. Identification of Sustainability Performance Issues of Construction Robotics and Automation (CRA)

The sustainability concerns concerning construction robotics and automation (CRA) are initially described and explored in this study on the foundation of the philosophical context. They will be explicitly addressed in the next section.

4.1 Performance issues at the project level

At the project stage, construction robotics and automation (CRA) use will impact TBL project efficiency by optimizing building procedures, use of resources, recycling systems, and replacing the dangerous and heavy workforce. In particular, the environmental performance issues are related to the usage of resources and environmental impacts of products, power, soil, air, and water resources. The possible economic advantages of using construction robotics and automation (CRA) and the costs are addressed by financial performance problems. Well-being issues, such as safety and health, are listed for sustainability responsibilities, including using supply chain stakeholders and external populations [18].

4.2 Performance issues at the technology level

Technological robustness, adaptability, and usability considerations are considered at the technology level, which is vital for sustainable success. Robustness means that technology is valid and reliable in use. Adaptability is the technology's ability to be used and synchronized with multiple artifacts under varying operating environments. In the foreseen application cases, Accessibility examines whether the machine and its modules are readily available [18]. Those considerations outside the technology's relevant life cycle are omitted from electricity, production costs, and dismantling.

5. Identification of sustainability indicators of construction robotics and automation (CRA)

Sets of parameters governing the selection process have been developed to obtain and describe feasible metrics based on the study of literature and the examination of current processes in line with established performance problems. The parameters are:

(i) Observable: quantitatively or qualitatively easy to calculate [17].

(ii) Relevant: the assessment specifically concerns a significant component.

(iii) Comprehensible: targeted groups interpret it.

(iv) Reliable: explain the root problems correctly and reliably.

(v) Data sharing: Focused on readily accessible and accessible data and knowledge.

(vii) Cost: to calculate cost-effectively.

(viii) Provision of information on time.

5.1 Indicators of environmental performance.

Environmental efficiency has also been underlined in construction assessments in the field of sustainability. In operational terms, applying construction robotics and automation (CRA) may have some possible environmental effects, such as optimization of resource usage, pollution reduction, extra power demand for service, etc. In strategic terms, improving environmental sustainability often plays an essential role in achieving company environmental priorities and enforcement.

5.1.1 Material recourse

The robot can generally perform the task better and more effectively. Materials can be effectively catalyzed in many ways by computer algorithms. For example, systemic programming and automation in prefabrication plants under complex conditions may ensure the optimization of resource use [19]. Sensor-based monitoring not only can screen for improved interaction materials and parts but also identify waste product geometry to be reused. The obvious advantage of A/ROFs is also decreased waste. A/ROFs are also used to easily reuse materials and parts by BIM in conjunction with CAR [17]. Consequently, automation and robotics will reduce the use of raw and recycled materials and decrease building waste and demolition (C&D) relative to manual work.

5.1.2 Energy recourse

Energy intake and GHG emissions are two of the most common metrics for evaluating building sustainability during building operations. Energy

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production in facilities and machinery can lie in evaluating construction robotics and automation (CRA). Automation and robotics can help maximize the resources in a much leaner workflow. However, automatic engines or robots will use much electricity and emit GHG emissions through non-renewable energy during service.

5.1.3 Land resource

Construction robotics and automation (CRA) have multiple impacts on the efficient usage of land resources. Second, digital approaches can simplify the site's architecture and maximize land use. C&D operations also produce large quantities of waste, and waste disposal in many countries remains a crucial solution to dealing with C&D waste. Construction robotics and automation (CRA) can help reduce C&D waste, thus reducing waste space and soil contamination [20].

Moreover, urban mining is facilitated by construction robotics and automation (CRA). For instance, with A/ROFs, the deconstructed building can be systemically disassembled instead of demolition or explosives, and (steel-based) components do not have to be disassembled for substantial energy efficiency.

Moreover, (steel-based) parts must be kept intact for heavy power processing. However, they can be replaced and reused immediately in the construction of another building without having to cause significant deformation, truing an existing mine building stock [21]. Therefore, some automatic devices are bulky and need a specific operating environment, requiring extra space to operate and store them.

5.1.4 Air resource

By causing air pollution and noise emissions, C&D will adversely affect the nearby air quality. Therefore, construction robotics and automation (CRA) may also mitigate adverse effects on air supplies where air quality is very close to social impacts, despite minimizing pollution, generating safe and dust-free working environments, and speeding up building job paces.

5.1.5 Water Resource

Water is one of the essential construction materials used for activities such as preparing mortar, mixing and treating concrete, washing, etc. Construction robotics and automation (CRA) are designed to use water supplies and water conservation methods more effectively than human labor. Additionally, pollution of the water from C&D waste can be reduced by automation and robotics since construction robotics and automation (CRA) arrives typically in conjunction with an organized workplace.

5.1.6 Environmental goals

Companies have to release their sustainability targets to increase their environmental efficiency. Integrating automated technology at the project stage achieves improved environmental sustainability [10]. The effect of construction robotics and automation (CRA) on environmental objectives and how this affects these objectives should also provide a central indicator for managers.

5.1.7 Environmental Compliance

Several governments, regions, and cities have adopted environmental laws, regulations, and guidelines promoting environmental observance to ensure that the planned developments do not have significant environmental effects.

Implementing the construction robotics and automation (CRA) technology will be a key to achieving conformity with environmental elements of regulations, policies, and practices for programs or enterprises that aim to increase their environmental efficiency.

5.2 Indicators related to economic performance

The application of construction robotics and automation (CRA) is generally accepted to be cost-effective because of the high capital and repair costs associated with construction robotics and automation (CRA) technology. Its economic output could vary from one technology to another. [21] has been confirmed from realistic experience in the 80s that most of the single-task robots used at the time showed bad economic efficiency [21]. a weather-automated building system for reinforced concrete building high-level buildings has been built, and tests taken during the system application have confirmed it as an economical means of building structures above twenty stories.

5.2.1 Economic benefits

Using construction robotics and automation (CRA) to support, cooperate, or substitute human labor will provide various direct and indirect economic

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benefits. Direct economic advantages include mostly labor cost cuts and resource and waste disposal costs. In contrast, indirect economic advantages related to saving time, cutting red tape, improving construction efficiency, and potential incentives for governments to apply creativity. In automation experiments in prefabrication, these advantages have been well recognized. For example, authors [10] developed technological guidelines to underpin industrialization and show the economic importance of prefabrication mechanization and automation. Automation is not only advantageous for labor savings and accuracy, according to his reports, but also decreases template and mold transformation costs for small batch orders. The paper [6] indicates that by reducing labor costs and building delays, the automation of prefabrication processes can yield economic benefits.

Moreover, the usage sense impacts economic benefits, and labor cost discrepancies between regions have various benefits due to the decrease of labor obtained by using automation and robotics. In terms of indirect economic advantages [22], digital tools have shown that their time duration used for major construction operations has been substantially reduced, with much higher production efficiency and reduced costs for rework and scrapping. Innovation incentives by using construction robotics and automation (CRA) are often considered indirect economic advantages.

5.2.2 Costs

The related incremental costs are also significant, while construction robotics and automation (CRA) can produce substantial economic benefits. Direct costs are resulting from automatic system acquisition, operation, and repair. Most automated and robotic technologies have substantial capital costs, especially A/ROFs, which are often seen as a major obstacle to actual word adoption. The paper [22] has carried out a comparative cost estimate for a four-story construction scheme, with three other buildings being designed by A/ROF. The floor unit costs of A/ROF buildings are around six times that of the conventional construction system. Data suggests the cost declines as the number of building stories increases and repeated lamentation is appreciated. Moreover, the introduction of construction robotics and automation (CRA) requires considerable expertise, resulting in indirect costs to staff and contractors.

5.2.3 Economic value

At the company strategy, long-term economic benefits in terms of payback time and investment gain can be evaluated in terms of financial viability for investing in construction robotics and automation (CRA) [10]. Studies suggest that economic sustainability will be accomplished only if construction robotics and automation (CRA) are implemented repeatedly. The long-term economic potential of technology reuse should also be adequately justified to enable robotic technologies to be broadly embraced by building enterprises.

5.2.4 Business development

Construction robotics and automation (CRA) is also responsible for distinguishing the markets that can take advantage of business growth, particularly long-term business opportunities. There will be other trade options, such as the technology owner or investor [22]. Besides, prestige as a technology breakthrough company can be achieved, and technical sustainability, which is conducive to the long-term market development of the company, can be accomplished.

5.3 Indicators of technological performance

In the sense of sustainability should also be evaluated in respect of factors impacting technical success in terms of robustness, adaptability, and usability [22]. The required technological efficiency is a desirable condition for achieving beneficial sustainability influences.

5.3.1 Robustness

Robustness is an essential consideration for ensuring the durability and efficiency of construction robotics and automation (CRA), especially regarding validity and trustworthiness [6]. Validity of technology refers to the efficiency of the technology, which can be measured by comparison to the industry-wide penetration and prestige and readiness level of the technology, initially intended to determine the maturity level of the technology. Technological stability means taking into account the reliability of an operating machine and can be assessed between medium maintenance time and medium time between failures. Frequent failures or extended maintenance may occur in poor economic performance.

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5.3.2 Adaptability

"Convenient to use" is an important problem to be incorporated with conventional architecture. Automated and robotic systems should work in a diverse environment, and metrics should be regarded as user-friendly and mobile interfaces for human work. The robotic systems must communicate, cooperate, and function smoothly with human employees to establish a synergistic partnership between robots and workers [6].

Furthermore, the use of ICT systems is increasing, and automated technology and robotics must be able to interconnect harmoniously with specific ICT instruments to build information models. Besides, ICT solutions are increasingly becoming used, and automated robotic technology should be able to interlink harmoniously with these ICT tools, like building information modeling (BIM) [10]. Besides, construction robots must be small in size, lightweight, robust, consistently powered, and highly versatile for work in unstructured, complex construction sites.

6. Conclusions

Sustainability considerations need guideline strategies for integrating construction automation technology linked to decisions in terms of sustainability development trends. The recent increasing requirement for sustainability has a high potential to work as the necessitated target for construction robotics and automation (CRA) as large-scale deployment. However, the systematic decision that can help to make a direction for the construction project is missing. The study shown in this paper has indicated the first step to fill this gap by enhancing the consistent framework that describes the sustainability performance of using construction robotics and automation (CRA) for construction projects. Therefore, this paper describes the conceptual framework of sustainability issues of construction robotics and automation (CRA) and identifies sustainability performance issues of construction robotics and automation (CRA). Being aware that the suggested study is yet far from delivering a complete, all-embracing assessment tool for real-world application (which is the ultimate goal of the research group), future research is planned. The overall goal of our research is to develop, through several CRA, a robust and reliable assessment approach that can be utilized in a different context to meet the sustainability of construction projects that consider using CAR.

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