ZIBELINE INTERNATIONAL™ PUBLISHING

Engineering Heritage Journal (GWK)

DOI: http://doi.org/10.26480/gwk.02.2022.73.77

ISSN: 2521-0904 (Print)
ISSN: 2521-0440 (Online)
CODEN: EHJNA9

CrossMark

REVIEW ARTICLE

ASSESSING CONSTRUCTION AUTOMATION AND ROBOTICS IN THE SUSTAINABILITY SENSE

Mabrouka Shahat Younis, Elfargani

Civil Engineering Department, Al Gubba, University of Derna, Libya.
****Corresponding Author Email: M.Shahat@uod.edu.ly; mabroukaelshaary@gmail.com.***

ARTICLE DETAILS

Article History:

Received 09 September 2022
Revised 10 October 2022
Accepted 18 October 2022
Available Online 25 October 2022

ABSTRACT

Building growth technology is rapidly recognised at a global level as being a key aspect in the future of construction projects, although construction robotics and automation (CRA) has undergone any major reality deployment to date. Nevertheless, the latest, substantially sustainability requirement is potentially the necessary cause for the larger implementation of construction robotics and automation. There are nevertheless small attempts at the detailed investigation of the effect of using construction robotics and automation on the sustainability efficiency of buildings and construction, but structured advice for the building industry is lacking in this sense. The study in this paper represents the first step towards addressing by analysing and examining the construction robotics and automation techniques and innovations available 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

1. INTRODUCTION

Automation and robotics have been regarded as a leading area of innovation in construction projects, for the betterment of the industry (Pan et al., 2020; Yang et al., 2018). Research has been spread out for decades, and new automation and robotics technologies continue to be developed for the general manufacturing industry as well as for the construction industry (Pan et al., 2018). 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 gases (GHG) emissions and more than 40% of global energy consumptions (Dubor et al., 2019). Nevertheless, the development of sustainable buildings (SBs) has experienced problematic implementation on all levels of design, construction and operation (Pan et al., 2018).

The term "construction" is about to be transformed into a notion of "construction creation." Construction robotics and automation are increasingly recognised globally as emerging technology that can create a foundation for the "making" of buildings in the future as it does in other industries (Wuni et al., 2020). This 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 lacked "killer applications," which would have been a significant situation for its wider use (Chen et al., 2018). 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 now can be used as a catalyst for the large-scale use of construction robotics and automation, particularly in combination with economic and efficiency factors (Davila et al., 2019). In this sense, formal regulation for the building industry is absent and few efforts have been made to examine in-depth the effect of construction robotics and automation use on building and building sustainability efficiency (Davila et al., 2019). The study in this paper is a first attempt to address this research gap through analysis and examination of the current construction robotics and automation strategies and innovations and the first time that a coherent system of sustainability assessment metrics has been established of using construction robotics and automation for in the construction industry.

1.1 Background

This section includes and addresses the production context of the construction robotics and automation and sustainability appraisal approaches in the construction industry, to build the basis for the study and specifically 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, construction robots or construction robots (Zhao et al., 2017). The designation of construction automation is a definition of engineering and construction method with tele controlled, numerical, semi-autonomous or independent installations while building robots are classified as specialised equipment which can be teleoperated, sensory data acquired, analysed and numerically directed or autonomous tasks carried out (Eglash et al., 2020).

Construction robotics and automation (CRA) defines that the application of automatically performs 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, semi-automated or remote-controlled machines to autonomous robotics with more sensors

Quick Response Code	Access this article online	
	Website: www.enggheritage.com	**DOI:** 10.26480/gwk.02.2022.73.77

Cite The Article: Mabrouka Shahat Younis, Elfargani (2022). Assessing Construction Automation and Robotics in The Sustainability Sense. *Engineering Heritage Journal, 6(2): 73-77.*

and control capabilities (Yang et al., 2019). For this report, CAR is considered to provide a broad range of machinery and software for the automation of infrastructure processes in the whole construction process (Pan et al., 2020).

Studies of are well documented, it is also well acknowledged that the combination with a new technical enabler, the growing need for effective, economical and sustainable construction has turned the large-scale construction of robots into an active field for study (Petersen et al., 2019). 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 provides an outline of the developments in science, open questions and success measurements.

Over time, an extensive literature has developed (Niemann and Pisla, 2018). 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, it is not always clear the economic effect or gain of events connected to such life cycles. This paper provides a nuanced approach to identifying unexploited business capital through the use of the creative Life Cycle-Managerial Index Method (LY-MIT) to success discovery to enable a company to detail its visualization, using seven cluster capacity in key places.

The authors employed a 3D printing methodology which prescribes the use of 3D printing technology has gained widespread interest in many sectors, allowing mass manufacturing and personalised production in a minimal amount of time (Lee et al., 2019; Bong et al., 2019). 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 such as the number of publications written annually or developments in a study by nation have been addressed. These papers aim therefore to expand the dialogue through the extraction of keywords from publications published in the last twenty years. The goal of this papers is, therefore, to expand the debate, using text-mining relationship analysis to extract keywords from papers published over the last twenty years which point to research trends in 3D printing. These findings enable us to recognise the fields of research needed for 3D printing in the future building industry.

This paper begins with a short review of the literature regarding the industrial robots (IRs) are the major motor of the production activities of advanced manufacturing systems to make their production activities more automotive and productive (Zhao et al., 2017). However, it is essential for sustainable production facilities of IRs to be centralised and formal to achieve successful jobs and smart configuration in cloud manufacturing environments. This document builds on functional characteristics, structural detail, operational and process conditions, a coherent sustainable manufacturing capability (SMC) of the IR model (Wuni et al., 2020). 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 (Chen et al., 2018).

This has been discussed by a great number of authors in literature (Pan et al., 2020). Construction robotics ought to have transformative effects on the construction industry, but there is still a lack of use. While technological progress has received much recognition, little has been achieved to understand the wider cultural challenges involved in using this technology completely. The goal of this article is to provide a holistic analysis of the factors which influenced the potential use of building robots in a systems way, analyse the relationships between these factors and recognise those which influence technological transformation most.

Construction robotics ought to have transformative effects on the construction industry, but there is still a lack of use. While technological progress has received much recognition, little has been achieved to understand the wider cultural challenges involved in using this technology completely. The goal of this article is to provide a holistic analysis of the factors which influenced the potential use of building robots in a systems way, analyse the relationships between these factors and recognise 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 (Liu et al., 2019). Recommended in the First International Conference on Sustainable Building, an early concept of sustainable construction is the development of a balanced built environment based on resource-efficient and ecological values (Jamil and Fathi, 2016). The expression sustainable construction has been used since 1996, and its use has gradually grown since that time (Bechtsis et al., 2017). In addition to that, it explains a specific building or illustrates an integrated approach to building environmentally sustainable development. To understand sustainable concepts and inform combined with appropriate, principles and methods for the sustainability appraisal have been thoroughly developed (Bechtsis et al., 2017).

3. The Conceptual Framework of Sustainability Issues of Construction Robotics and Automation (CRA)

Frameworks for metrics was built to tackle complex aspects of sustainability in multiple industries. Frameworks relating to architecture, technology or invention are of special significance for this article. From a construction project standpoint. The authors ISO 21929-1:2011 established core sustainability criteria in several important fields covering potential impacts including, environmental impacts, economic: financial benefit, benchmarking strategy and the construction sector sustainability framework, which combines LEED performance criteria with TBL general indicators project-level considerations affect corporate sustainability efficiency (Liu et al., 2019).

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 and 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 optimization of building procedures, use of resources, recycling systems, the replacement for 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 and air, and water resources; the possible economic advantages of using construction robotics and automation (CRA) and associated 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 as well as external populations (Cruz et al., 2019).

4.2 Performance Issues at The Technology Level

Technological robustness, adaptability and usability considerations are taken into consideration at the technology level, which is important for sustainable success. Robustness means that technology is valid and reliable in use. Adaptability is the technology's ability to be used and synchronised with multiple artefacts under varying operating environments. In the foreseen application cases, Accessibility examines whether the machine and its modules are readily available (Cruz et al., 2019). 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 be able to obtain and describe feasible metrics based on the study of literature and the examination of current processes in line with established performance problems; (i) Observable: quantitatively or qualitatively easy to calculate (Bechtsis et al., 2017). (ii) Relevant: the assessment specifically concerns a meaningful and meaningful 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.

In construction assessments in the field of sustainability, environmental efficiency has also been underlined. 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 important role in the achievement of 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 catalysed in many ways by computer algorithms. For example, systemic programming and automation in prefabrication plants under complex conditions may ensure optimization of resource use (Miranda et al., 2019). 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 for easy re-use of materials and parts by BIM in conjunction with CAR (Bechtsis et al., 2017). Therefore, automation and robotics will reduce the use of raw materials, 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 operation. Energy production in facilities and machinery can lie in evaluating construction robotics and automation (CRA). Automation and robotics can help maximise the resources in a much leaner workflow. However, automatic engines or robots will use a lot of electricity and emit GHG emissions by using 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 architecture of the site and maximise 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 (Oesterreich and Teuteberg, 2016). 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 strong energy efficiencies. And (steel based) parts must not be melted for processing that uses heavy power but can be replaced and reused immediately in the construction of another building without having to cause significant deformation, truing an existing mine building stock (Pan et al., 2020). Some automatic devices are therefore bulky and need a specific operating environment, thereby 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, by minimising pollution generating safe and dust-free working environments and speeding building job paces, construction robotics and automation (CRA) may also mitigate adverse effects on air supplies, Air quality is also very close to social impacts.

5.1.5 Water Resource

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

5.1.6 Environmental Goals

Companies have to release their sustainability targets to increase their environmental efficiency. By integrating automated technology at the project stage, improved environmental sustainability is achieved (Yang et al., 2019). 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

To ensure that the planned developments do not have significant environmental effects, several governments, regions and cities have adopted environmental laws, regulations and guidelines promoting environmental observance. Implementation of the construction robotics and automation (CRA) technology will be used as a key to achieve conformity with environmental elements of regulations, policies and practises for programmes 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. A group researcher has been confirmed from realistic experience in the 80s, that most of the single-task robots used at the time showed bad economic efficiency (Pan et al., 2020). 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

The use of construction robotics and automation (CRA) to support, cooperate, or substitute human labour will provide a variety of direct and indirect economic benefits. Direct economic advantages include mostly labour cost cuts, resource costs and waste disposal costs, while indirect economic advantages relate 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 recognised. Such as, developed technological guidelines to underpin industrialization and showed the economic importance of prefabrication mechanisation and automation (Yang et al., 2019).

Automation is not only advantageous for labour savings and accuracy according to his reports, but also decreases template and mould transformation costs for small batch orders. Indicates, by reducing labour costs and building delays, that automation of prefabrication processes can yield economic benefits (Chen et al., 2018). Moreover, the usage sense impacts economic benefits, and labour costs discrepancies between regions have various benefits due to the decrease of labour obtained by the use of automation and robotics. In terms of indirect economic advantages, 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 (Willmann et al., 2016). Innovation incentives by the use of construction robotics and automation (CRA) are often considered to be indirect economic advantages.

5.2.2 Costs

The related incremental costs are also significant while construction robotics and automation (CRA) can produce huge economic benefits. Direct costs resulting from automatic system acquisition, operation and repair. The majority of automated and robotic technologies have substantial capital costs, especially A/ROFs, which are often seen as a major obstacle to real word adoption. A group researcher has carried out a comparative cost estimate for a four-story construction scheme, with three other buildings being designed by A/ROF (Willmann et al., 2016). The floor unit costs of A/ROF buildings are around six times that of the conventional construction system and data suggests the cost decline 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 benefit in terms of payback time and investment gain can be evaluated in terms of financial viability for investing in construction robotics and automation (CRA) (Yang et al., 2019). Studies suggest that only if construction robotics and automation (CRA) is implemented repeatedly will economic sustainability be accomplished. 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 the distinction of the markets that can take advantage of business growth, particularly long-term business opportunities. There will be other trade options, as the technology owner or investor (Willmann et al., 2016). 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 (Willmann et al., 2016). The required technological efficiency is a desirable condition for achieving beneficial sustainability influences.

5.3.1 Robustness

Robustness is the most basic consideration for ensuring the durability and efficiency of construction robotics and automation (CRA), especially when it comes to validity and trustworthiness (Chen et al., 2018). 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 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 long maintenance may occur in poor economic performance.

5.3.2 Adaptability

"Convenient to use" is an important problem to be more incorporated with conventional architecture. Automated and robotic systems should work in a diverse environment and metrics should be regarded as user-friendly and extremely mobile interfaces for human work. The robotic systems must be able to communicate, cooperate, and function smoothly by human employees to establish a synergistic partnership between robots and workers (Chen et al., 2018). Furthermore, the use of ICT systems is increasing increasingly, and automated technology and robotics must be able to interconnect harmoniously with certain ICT instruments, as building information model. Besides, ICT solutions are increasingly becoming more and more used and automated robotic technology should be able to interlink harmoniously with these ICT tools, like building information modelling (BIM) (Yang et al., 2019). Besides, construction robots have to be small in size, lightweight, robust, consistently powered and with high versatility for work in the unstructured, complex construction site.

6. Conclusions

Sustainability considerations need guideline strategies for integrating construction automation technology linked to decisions in term of sustainability development trends. The recent importantly 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 showed in this paper has indicated the first step to fill this study gap by enhancing the consistent framework of describes for the sustainability performance of using construction robotics and automation (CRA) for construction projects. In this paper, therefore, the descries the conceptual framework of sustainability issues of construction robotics and automation (CRA) and identification of 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.

References

Bechtsis, D., 2017. Sustainable supply chain management in the digitalisation era: The impact of Automated Guided Vehicles. Journal of Cleaner Production. Elsevier Ltd, 142, Pp. 3970–3984. DOI: 10.1016/j.jclepro.2016.10.057.

Bong, S.H., 2019. Method of optimisation for ambient temperature cured sustainable geopolymers for 3D printing construction applications. Materials, 16 (6). DOI: 10.3390/ma12060902.

Chen, Q., García de Soto, B., and Adey, B.T., 2018. Construction automation: Research areas, industry concerns and suggestions for advancement. Automation in Construction. Elsevier, 94, Pp. 22–38. DOI: 10.1016/j.autcon.2018.05.028.

Cruz, C.O., Gaspar, P., and de Brito, J., 2019. On the concept of sustainable sustainability: An application to the Portuguese construction sector. Journal of Building Engineering, Elsevier Ltd, Pp. 25, 100836. DOI: 10.1016/j.jobe.2019.100836.

Davila Delgado, J.M., 2019. Robotics and automated systems in construction: Understanding industry-specific challenges for adoption. Journal of Building Engineering. Elsevier Ltd, 26, Pp. 100868. DOI: 10.1016/j.jobe.2019.100868.

Dubor, A., Izard, J., and Cabay, E., 2019. On-Site Robotics for Sustainable Construction, Robotic Fabrication in Architecture, Art and Design 2018. Springer International Publishing. DOI: 10.1007/978-3-319-92294-2.

Eglash, R., 2020. Automation for the artisanal economy: enhancing the economic and environmental sustainability of crafting professions with human-machine collaboration. AI and Society. Springer London, 35 (3), Pp. 595–609. DOI: 10.1007/s00146-019-00915-w.

Jamil, A.H.A., and Fathi, M.S., 2016. The Integration of Lean Construction and Sustainable Construction: A Stakeholder Perspective in Analysing Sustainable Lean Construction Strategies in Malaysia. Procedia Computer Science. Elsevier Masson SAS, 100, Pp. 634–643. DOI: 10.1016/j.procs.2016.09.205.

Lee, Dongyoun, 2019. Trends in 3D Printing Technology for Construction Automation Using Text Mining. International Journal of Precision Engineering and Manufacturing. Korean Society for Precision Engineering, 20 (5), Pp. 871–882. DOI: 10.1007/s12541-019-00117-w.

Liu, H., 2019. Towards sustainable construction: BIM-enabled design and planning of roof sheathing installation for prefabricated buildings. Journal of Cleaner Production. Elsevier Ltd, 235, Pp. 1189–1201. DOI: 10.1016/j.jclepro.2019.07.055.

Miranda, J., 2019. Sensing, smart and sustainable technologies for Agri-Food 4.0', Computers in Industry. Elsevier B.V., 108, Pp. 21–36. DOI: 10.1016/j.compind.2019.02.002.

Niemann, J., and Pisla, A., 2018. Sustainable potentials and risks assess in automation and robotization using the Life Cycle Management Index Tool-LY-MIT. Sustainability (Switzerland), 10 (12). DOI: 10.3390/su10124638.

Oesterreich, T.D. and Teuteberg, F., 2016. Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry', Computers in Industry. Elsevier B.V., 83, Pp. 121–139. DOI: 10.1016/j.compind.2016.09.006.

Pan, M., 2018. A framework for utilizing automated and robotic construction for sustainable building. Proceedings of the 21st International Symposium on Advancement of Construction Management and Real Estate., (209889), Pp. 79–88. DOI: 10.1007/978-981-10-6190-5_8.

Pan, M., Linner, T., Pan, W., Cheng, H., 2020. Influencing factors of the future utilisation of construction robots for buildings: A Hong Kong perspective. Journal of Building Engineering. Elsevier Ltd, Pp. 101220. DOI: 10.1016/j.jobe.2020.101220.

Pan, M., Linner, T., Pan, W., Cheng, H., 2020. Structuring the context for construction robot development through integrated scenario approach. Automation in Construction. Elsevier, 114(March), Pp. 103-174. DOI: 10.1016/j.autcon.2020.103174.

Petersen, K.H., 2019. A review of collective robotic construction. Science Robotics, 4 (28), Pp. 1–10. DOI: 10.1126/scirobotics.aau8479.

Willmann, J., 2016. Robotic timber construction - Expanding additive fabrication to new dimensions. Automation in Construction. Elsevier B.V., 61, Pp. 16–23. DOI: 10.1016/j.autcon.2015.09.011.

Wuni, I.Y., Shen, G.Q. and Hwang, B.G., 2020. Risks of modular integrated construction: A review and future research directions. Frontiers of Engineering Management, 7 (1), Pp. 63–80. DOI: 10.1007/s42524-019-0059-7.

Yang, Y., 2018. Towards sustainable and resilient high-density cities through better integration of infrastructure networks. Sustainable Cities and Society. Elsevier B.V., 42, Pp. 407–422. DOI: 10.1016/j.scs.2018.07.013.

Yang, Y., Pan, M. and Pan, W., 2019. Co-evolution through interaction" of innovative building technologies: The case of modular integrated construction and robotics. Automation in Construction. Elsevier, 107(August), Pp. 102932. DOI: 10.1016/j.autcon.2019.102932.

Zhao, Y., 2017. Dynamic and unified modelling of sustainable manufacturing capability for industrial robots in cloud manufacturing', International Journal of Advanced Manufacturing Technology. The International Journal of Advanced Manufacturing Technology, 93 (5–8), Pp. 2753–2771. DOI: 10.1007/s00170-017-0634-1.