Application of Robotic Technology for the Advancement of Construction Industry in Sri Lanka: A Review

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Abstract The construction industry is one of the least automated industries, and robot implementation at the construction site is limited. Moreover, the industry has traditionally not been a favorable area for the application of robotics. However, with the discovery of more cost-effective applications and motives such as reducing the labor force population, the aging of skilled workers, and safety issues, their use will undoubtedly increase, especially in the developed countries. Robotic technology provides many benefits for the advancement of the industry while the local construction industry is not fully geared to entirely implement such increased technological applications. Therefore, there is a need to investigate the feasibility of introducing robotic technology for the advancement of the construction industry in Sri Lanka as a developing country. Hence, this paper aims to review the importance and application of robotic technology to the local construction projects by critically studying the secondary data on global construction automation and to further discuss benefits and challenges. The paper also presents a view on the application of robotic technology in the Sri Lankan construction industry by reviewing secondary data and basing this upon the opinions from the preliminary survey.

Keywords Application · Advancement · Construction · Robotics · Technology

1 Introduction

In highly developed nations, the impacts of human capital reduction are predominantly controlled by supplementing human capital with capital intensity and advances in technology. With this nature, digital technology becomes a vital contribution to

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economic growth by improving the quality of life (Clough et al. 2000). Recently, many organizations proceed with digital technology. It has further penetrated most of the products, services, and operations of many industries. With the fourth industrial revolution (Industry 4.0), most countries bring digital technology innovation to a world of process control and operational technology domains (Woodhead et al. 2018). Further, in this context, the term Industry 4.0 includes a variety of technologies to allow the advancement of an automated and digital manufacturing environment and the digitization of the value chain (Lasi et al. 2014). Moreover, extra value for the user is acquired through digital innovation with better functionality than analog options. In every industry, digital technology is utilized to achieve better output. Hence, there is a need to investigate the application of Robotic Technology (RT) for the advancement of the construction industry in Sri Lanka as a developing country, since it is successfully applied worldwide. This paper is organized as follows: First, an introduction to RT, discussing its applications in different industries with more emphasis on the construction industry, followed by reviewing benefits and challenges in implementing. Next, the RT in Sri Lanka is discussed.

2 Research Method

In any research work, conducting a methodical literature review reinforces and enriches the research process initially. Iqbal (2007) stated that a literature review is essential in order to identify any gap in the knowledge, and a researcher can successfully claim a gap with evidence in the existing knowledge. This paper was written based on the comprehensive literature review of on-going research on application of robotics for the advancement of the construction industry in Sri Lanka. The paper elaborated the existing research gap and the way forward. Mainly, literature evidence was taken by referring to books, journal articles, conference proceedings, published and unpublished bibliographies, industry reports and documents. During the literature survey, key terms like robotics, construction industry, drivers, and barriers were used. Further, three preliminary interviews were held with industry experts with more than 25 years of working experience in the construction industry and knowledgeable about innovative technologies before the detailed survey.

3 Introduction to Robotic Technology

Robots could be identified as machineries or devices that function automatically or by remote control (Kurfess 2005). They are sophisticated and valuable systems employed in the industry for several decades (Liljebäck et al. 2012). With the development of the technology, the utility and capability of robots have improved dramatically (Robins and Dautenhahn 2014). After the introduction of the word “construction robot”, more than 550 systems have been developed for the unmanned operation, automation, and robotization of construction works in Japan (Obayashi 1999). As per the International Association of Automation and Robotics in Construction (IAARC 2004), compared to Japan, pure industry-based work in North America is far less apparent, but most of the universities are collaboratively working with Japanese companies to invent RTs. However, in Europe and other countries, work related to RT is on a minor scale and they still focus on other specific areas of construction.

As per Gambo and Balaguer (2002), research activities related to robotics and automation in the construction industry can be divided into two main categories as civil infrastructure and building. As per IAARC (2004), construction robots and automation can be elaborated under three main headings; (1) improvement to existing construction plant and equipment (2) task-specific dedicated robots (3) intelligent machines. As per Bernold (1987), smart technologies will find their way into construction related issues such as safety, quality, job enrichment, fading craftsmanship, and preventive maintenance, and optimal usage of resources are the basic enablers to study the application of robot systems to the construction industry. Hewit and Gambatse (2002) identified that contractors who used robot technology in projects have advantages such as cost savings, reduced project duration, improved quality, and consistency. In construction, the scope of RT application is relatively broad, encompassing all stages of the construction life cycle. Even after completing the building or the structure, technologies can still be applied for the maintenance, and demolition or dismantling of the structure. However, the degree of application varies significantly from one stage to another (IAARC 2004).

4 Applications of Robotic Technology

Robots are intensely beneficial to various industries as their positive impact is increasing while they provide services to multiple areas of daily life (Calo 2014). Table 1 describes various applications of RT and its benefits to the respective industry as depicted in literature.

5 Involvement of Robotic Technology in the Construction Industry (CI)

The technological level of the construction industry was very high during the historical period. For example, the ancient societies have built long lasting structures such as pyramids, acropolis, canals, and churches, and these innovative methods are also used within the modern standard building procedures (Deplazes 2008). Some of the present construction processes have undergone fewer changes. For instance, the building construction process has not altered largely over the past centuries. However, the old pulleys are replaced by cranes, and they are more developed than

Table 1 Application of robotic technology in different industries

No.	Industry/sector	Uses	Benefits
1	Medical	• Preparing medications • Used in surgeries and prosthetics	• Capability to perform surgeries with minor incisions • Minimal scar tissue • Minimal recovery times
2	Space exploration	• Use as flyby probes, landers, rovers, atmospheric probes, and robot arms • Transmitting information back to earth	• Useful assistants for science exploration • Possibility to reach remote planets • No need to return to earth
3	Military	• Use to remove humans from a dangerous place • Send into the field to sweep for landmines	• Eliminating the danger • Performing tasks better than humans • No human loss
4	Education	• Support to learn difficult subjects • Support to teach subjects that are directly related to robotics field	• Ability to perform repetitive tasks precisely • Develop cognitive and social skills of students • Flexible robots have the potential to engage young people with a broader range of interests
5	Agriculture	• Used in crop cultivation, transplanting, water spraying, and selective harvesting	• Improved harvest • Minimal cost • Reduced negative environmental impacts
6	Oil and Gas industry	• Used for inspection, maintenance, and renovation of plant facilities with increased frequency and precision	• Increased productivity under extreme environmental conditions • Eliminate health and safety issues • Reduced production cycle, floor area, and number of workers
7	Textile	• Sewing, cutting, folding, and packing • Carry out endless repetitions with persistent accuracy	• Improves the efficiency and quality of production • Mitigate impacts of the rising labor cost • Remove the employee's inefficiencies relating to the working environment

Sources Lin et al. (2013), Chang and Wagner (2015), Ratnakumar and Smart (2007), Kurfess (2005), Calo et al. (2016), Cheng et al. (2017), Felicia and Sharif (2014), Bloch et al. (2017), Bechar and Vigneault (2017), Shukla and Karki (2016), Nayak and Padhye (2015), Gries and Lutz (2018) centuries ago, but still operate with the same old principles (Balaguer and Abderrahim 2008). Recently, the most important researches of the service robotics field were focused around the construction industry. Warszawaki (1984) explained the sequential stages in construction automation considering five basic classifications as illustrated in Fig. 1. During the 90s, the research and development activities in the robotic and automation construction field were mainly manipulated by Japanese organizations and universities (O'Brien 1991).

Using electronic and mechanical means in construction tasks has been described as Construction Automation (CA) (Hewitt and Gambatse 2002). As per the authors, the primary purpose of CA is to attain automatic operation to reduce time, effort, and potential exposure while maintaining or improving the quality of work. Construction Robots have been identified as intelligent machineries that use ingenious control and designed to enhance the speed and precision of operations in the construction field (Stein et al. 2002). These robots can be useful to automate various construction processes in building and infrastructure construction and they are also suitable for interior building finishing, bricklaying, modular building erection, tunnel construction, road paving, excavator controlling, infrastructure inspection and bridge construction (Thomas 2008). During the 19th century, when more technologically improved constructions were increasingly commissioned, many efforts were taken to automate the construction process to increase the speed and productivity. However, mechanically operated fabrication, assembly, and erection were identified as early forms of automation (IAARC 2004). Warszawaki (1984) suggested four different groups of building activities, which can be designed at the optimal robotic systems. They are (1) handling and positioning of large elements, (2) interior finishing and connecting activities, (3) finishing of large horizontal surfaces and (4) finishing of exterior walls. The author mentioned that activities like plastering, painting, spraying, trowelling, further welding, bolting and jointing can be robotized in buildings having proper adaptation of sensory devices. Moreover, Table 2 presents examples of robots used in different stages of construction processes, by reviewing the secondary data.

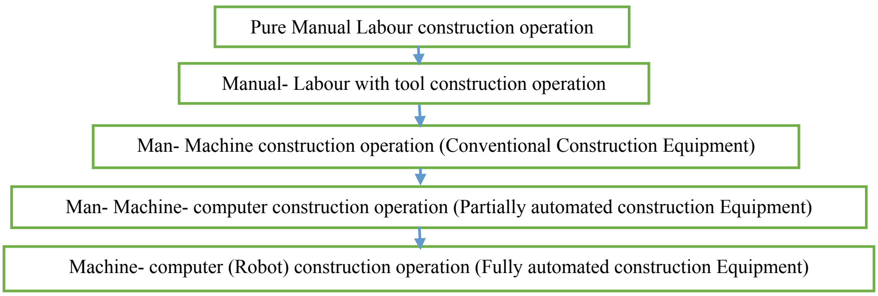

Fig. 1 Sequential stages in construction automation process. *Source* Kangari (1986)

Table 2 Robots in construction projects

Robot	Description
Bricklaying robot	• A New York-based company developed the first bricklaying machine in 2014 *Partially automated robots* • Lay 2000–3000 bricks per day • Use conveyor belt, robotic arm, gripper, and a concrete pump for operation • An onboard propane generator provided electrical power and air • Use lasers and sensors to measure important operational variables e.g., SAM 100 *Fully-automated robots* • Lay around 1000 bricks per hour • Creates 3D CAD brick laying designs of the structure by identifying the location of every brick through calculations • Cut and lay the bricks from a fixed location by creating a program • With a sequence determined by the program, pressurized mortar is delivered to the laying head and applied on the brick • Within 15-h time period, the robot can complete an entire masonry work of a house e.g., Hadrian X
Additive manufacturing/contour crafting	• Often termed as 3D printing • This technique can be utilized to fabricate building components with a fully-automated operation • It has not achieved the stage of building a whole structure with a satisfactory precision • Produce components with high geometric complexity • Aimed at constructing concrete houses, storerooms, commercial buildings, free-standing structures and prefabricated modules • Reduce cost of transportation, time duration and material wastage e.g., Cazza X1, Cazza X1 Core, and R 3Dp
Autonomous ground vehicles	• The concept hasn't been used in the construction industry yet • Komatsu, one of the largest construction companies in the world, has built a working prototype • Use augmented global positioning system (GPS) for navigation • By combining satellites and on-site base station, location information is produced with a centimeter resolution • Ability to withstand environments with high vibrations • Robot's responsibilities can be defined with an iPad by establishing the site perimeters and inserting project details • Can measure the quantity of material in the scoop

(continued)

Table 2 (continued)

Robot	Description
Unmanned aerial vehicles (Drone)	• Use the support of sensors and high-resolution cameras for the operation • Used for site surveying, progress monitoring, health and safety evaluation, possible hazards detection, transport logistics, inventory monitoring, promotional photography and marketing • Ability to translate sensor data into topographical maps, three dimensional structural models, and volumetric measurements with suitable computing tools • Reduce the risks of survey workers and provide economic benefits
Concrete crusher robot	• Faster and quieter robot. Even take place at night. • Adjacent work can continue uninterrupted
Demolition robot	• Used in the confined space and for selective demolition works
Prefabrication robots	• Mainly employed to manufacture modular and prefabricated segments such as ceilings, roofs and walls • Three projects have used robotic prefabrication in construction: (1) ROCCO, (2) FutureHome, (3) ManuBuild *ROCCO* • Includes a software system which assists in wall partitioning, logistics planning, and layout planning • The software system was capable of generating automatic manufacturing commands and robot assembly tasks to build prefabricated elements
	FutureHome • The project aimed to produce fully-manufactured houses instead of building only prefabricated parts • Automatically perform the construction process AUTOMOD3 software system generated assembly sequences and motion paths for robots • Provides a simulation tool which allowed to visualize and inspect the assembly process before the execution *ManuBuild* • The project facilitated the incorporation of mass customization in the construction industry

Sources Bogue (2018), Dakhli and Lafhaj (2017), Howard et al. (2017), Bang et al. (2017), Kespry 2019, Kasperzyk et al. (2017), Akshatha et al. (2017), Jaillon et al. (2009)

6 Benefits and Challenges of Using Robotic Technology in the CI

This section presents the common benefits and challenges of implementing new technologies relating to robotics within the field of construction. These benefits and challenges were mainly identified through a comprehensive literature review.

6.1 Benefits

Labor shortage is a primary factor that forces industries to mechanize production in many countries. This makes a positive impact on economies with serious labor shortage issues and with full employment to reduce the rising pressures on wages (Mahbub 2015). Foreign labor is also a national issue for most developing countries. Implementing a structured and effective robotic and automation in the construction process will help to overcome this issue by reducing the foreign labor component in the economy (Kamaruddin et al. 2015). Problems connected with the construction industry such as declining quality and productivity, workplace safety, and inferior working conditions have highlighted the importance of integrating advanced solution to the industry, such as further use of industrialization, CA, and robotics application on site (Mahbub 2015). Robotics and related technologies have proven the improvement of the construction process in all aspects.

The most popular advantage of robotics and automation in construction is that it speeds up the construction processes by reducing the production time. Moreover, it is accepted that mechanization and automation are quicker than labor at work operations. Therefore, contractors can complete their projects faster to save money with the use of these technologies (Idoro and Bamidele 2011). Robotic and automation can also improve working conditions of the environment, avoid dangerous work, stabilize quality, increase the degree of design freedom, reduce debris, and undertake work that is difficult for people to perform. Adopting robotic and automation will minimize the number of construction activities on site, and thus, become less complicated. Further, cost reductions can be achieved due to the reduction in workload per task such as eliminating or reducing the scaffolding usage, security system and supplementary transport equipment (Kamaruddin et al. 2015).

6.2 Challenges

Capital cost, skill resources, maintenance, and availability of technology are the obstacles to implementing robotic and automation in the construction industry identified (Kamaruddin et al. 2015). Out of these challenges, purchasing cost of plants and machinery is the main barrier. Moreover, robotic and automation is a specialized area, which requires high technological machines and skilled operators, which will always lead to an increase in the overall cost. Further, the operational and maintenance cost of robotic and automation should be considered before its implementation in the industry. Investments on heavy equipment and mechanized construction systems are low due to its high investment cost. Moreover, it is challenging for new local companies to compete for opportunities with international competitors that are stronger in terms of financial capability, technology, or specialization. Therefore, the contractors prefer not to use automation as they find it easier to stick to traditional construction methods. This is because adopting a new system means there is a need for a substantial and sustained budget, allocated time for training of labor, and specialized equipment and machinery (Rahman and Omar 2006).

In addition, Mahbub (2015) identified many challenges to the application of automation and robotics in the construction industry. They are the financial costs in purchasing and maintaining the technologies, fragmented nature of the industry which limit the application of new technologies, technologies that are difficult to use and understood, incompatibility of the technologies with current construction operations and existing practices, inadequate technological knowledge of project participants, the need for re-training of workers, difficulties in acquiring the technology that are unavailable locally, and non-acceptance of technologies by workers. As per Neubauer (2017), the insufficient experience of contractors in using robotic and automation, and inadequate knowledge to apply it in projects, limit the industry to implement robotic and automation to realize its full potential. High complexities of the robot control system and programming procedure leads to its awkward introduction in the construction industry (Kahane and Rosenfeld 1999).

7 Robotic Technology in Sri Lanka

This section elaborates literature findings and the opinions of the experts relating to the application level of RT in Sri Lankan construction industry. During preliminary interviews, it was revealed that the local construction industry is challenged by a shortage of skilled workers due to insufficient training facilities, low interest in the construction sector shown by younger generation and worker migration to overseas countries. Due to this skilled labour shortage, project delays, poor quality of works and less productivity of labour is experienced. Thus, while technology is developed by making everyone's lives convenient, robots and artificial intelligence are likely to substitute citizens in Sri Lanka in the next 50 years. Moorthy (2018) mentioned that experts from the apparel, property, travel, and innovation sectors accepted that technology has taken over some of the work that people have been doing. Further, the author stated that the future of Sri Lanka looks bright to some extent as people are talking and communicating with computers and robots. As revealed from preliminary interviews, historically, Sri Lanka was equipped with a craft-based construction technology, developed through the experience collected over 2000 years. This level of technology was adequate to fulfill the construction needs even during the post-independence era. However, as stated by Silva et al. (2008), due to the rapid development occurred in the fifties in large-scale projects such as irrigation, power, and industrial building, construction work was launched demanding a massive technology input. However, it revealed the local construction industry was not fully prepared to meet this increased technological demand. Due to this lack of technological development, some major construction projects were performed by foreign contractors. As per Moonesinghe (2017), Sri Lanka needs to utilize industrial robotics to survive in this economic climate. It cannot perform with a haphazard rush but must be carefully arranged by the government in co-operation with the universities and the corporate sector. One interviewee highlighted that it is first necessary to identify the fields which are in the extreme need of automation, and whether the requirement can be satisfied by off-the-shelf products, or whether customized robots must be made. Reducing accidents and greatly increasing prodcutivity are highlited as some benefits of implementing robotic in cosntruction projects. Requirement of research and development towrads this end in Sri lanka is identified. While considering the current usage of RT in the Sri Lankan construction industry, central expressway project is using unmanned aerial vehicles or drones to review site progress and ensure site safety. Department of Forestry and Environmental Science (2016) initially planned to use them for aerial surveys; however, due to lack of resources and techniques, only desktop studies and surface surveys are performed. As per the interviewees, great opportunities are available through the application of robotics in the construction industry such as efficiency and reducing cost, but its impact on the initial overall construction cost is identified as a leading negative aspect. Further, they believe that the rise of robotics is likely to create new job roles and opportunities in construction that cannot be imagined today.

8 Conclusions and Way Forward

Robotics are considered an essential part of the next technological revolution. Although robotics solution may be possible for the labor shortage and increase quality and speed of construction outcome in Sri Lanka, automation needs to be more carefully managed. Further, the government and private sector can play a significant role since this promotes the requisite innovative capacity of the country. This paper mainly considers the theoretical aspects to review the application of RT and presents the finding of the preliminary survey. The next step of the study investigates the feasibility in terms of economic, technical and need-based aspects in Sri Lankan Construction Industry. Further, future trends & opportunities, real challenges and benefits of implementing robotics technology in the construction industry in Sri Lanka as a developing country will be discussed. Moreover, the study will make recommendations to encourage the use of robotics and automation in construction. Therefore, the findings of this study will be beneficial to other developing countries during the process of adopting RT in construction projects to overcome challenges and to strengthen benefits.

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