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Automation and Robotics in Industrialized Building System (IBS): The Potential Criteria for Measurement

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Abstract
The problems of Industrialised Building System (IBS) associated with construction such as decreasing quality and productivity, unskilled labour, occupational safety, and inferior working conditions have hampered on the implementation of IBS in Malaysia but opened the possibility of more revolutionary solutions within the industry. One of the prospective options is the implementation of automation and robotics in IBS. Integrating automation and robotics into the design, manufacturing and construction processes of IBS offers not the only improvement in accuracy, consistency and efficiency, but also opportunity to improve the construction industry regarding productivity, safety, quality and increase the implementation rate of IBS in Malaysia. All the data and information gathered directly from libraries, books, articles and other printed materials searched in the international and national journals, proceeding and bulletin. This paper aims to identify the potential criteria for measurement of automation and robotics in IBS.
Keywords: Automation, Robotics, Industrialised Building System, Success Criteria

Introduction

Throughout the years, private projects and the huge-scale public have dominated the activities of the Malaysian construction sector, driven by authorities and government shareholder efforts to enforce following five-year plans targeted at turning into a developed nation. The 11th Malaysia Plan (11MP), covering the years between 2016 to 2020, focuses on transforming the construction industry to be environmentally sustainable, highly productive, with globally competitive players while focused on safety and quality standards among other economic areas (Ali et al., 2018). However, low productivity, dependency on foreign workers and high level of construction wastage still being the major issues in the industry (Abd Rashid et al., 2018a). This relatively low productivity level reflects the industry needs to adopt modern technologies and practices (CIDB, 2016). Extensive use of modern and high technology tools is able to support the different IBS processes by enabling more accurate documents and hence good conditions for an effective production where errors are

discovered early and problems in the manufacturing and assembly phases can be avoided (Noor et al., 2018)
In meeting the government's agenda of transforming Malaysia to be a developed nation with a sustainable high-income economy, the Construction Industry Transformation Program (CITP) was developed to enact a transformation of the construction industry into one which is modern and updated; and act as the catalyst in generating a succession of interlinked multiplier effects on a host of sectors (CIDB, 2016; Mahbub, 2016). The CITP’s four main strategic thrusts are, firstly, raising the overall productivity level of the industry; secondly, environmental sustainability being incorporated in the design, construction, and subsequent maintenance of buildings and infrastructure; thirdly, focusing on improving competitiveness in the capability and capacity of industry players to foray internationally; and fourthly, improving the overall quality, safety and professionalism of the industry (CIDB, 2016; Mahbub, 2016). The potential capability of Automation and Robotics is to generate higher output at a lower unit cost; with better quality products could, in turn, improve global competitiveness. Therefore, it is crucial to promote the uptake of IBS in Malaysia along with strong human capital development to undertake the industrialized construction work by increasing technology and modern Practices focusing more on Automation and Robotics.

Methodology
The methodology adopted is primarily based on a thorough review of the relevant literature on regarding Industrialised Building System (IBS) and automation and robotics. All the data and information gathered directly from libraries, books, articles and other printed materials searched in the international and national journals, proceeding and bulletin.

Automation and Robotics in IBS
The IBS agenda in Malaysia begun in the early 1960s when the Ministry of Housing and Local Government of Malaysia visited a number of European countries and evaluated their housing development programmes. Following the successful visit, the government initiated an IBS pilot project in 1964 which aimed to speed up the delivery time and to build affordable and quality houses (Abd Rashid et al., 2018). IBS is a construction technique in which the components are manufactured in a controlled environment (on or off-site), transported, positioned and assembled into a structure with minimal additional site work (Mohamed et al., 2018). It consists of pre-cast concrete system, steel framing system, timber framing system, block work system, formwork system, an innovative system (Azman et al., 2012; Din et al., 2012). With the urgency to improve productivity, sustainability, quality and safety the use of modern method construction such as automation and robotics is crucial to overcome this problem (CIDB, 2016). Construction automation and robotic describes the field of research and development focused on automating and robotizing construction processes. In short, construction automation and robotics deal with applying the principles of industrial automation and robotics to the construction sector, whether in building construction, civil engineering (roadways, dams, bridges, etc.) or in prefabrication/IBS factory of construction components (Saidi et al., 2016).

Historically, the first introduction of automation and robotics in construction can be traced back to the manufacturing of IBS components and the prefabrication of modular homes in Japan in the 1970s (Pan et al., 2018). But Arshad (2012) argue that the research of automation and robotics in IBS was started in the 1950s and In 1970s they were enjoying fruits of their efforts on labour productivity and labour conditions that were much improved such as Sekisui Heim in figure 1 and Toyota Home in figure 2 (Linner & Bock, 2012). Nevertheless, the introduction laid the foundation for later worldwide exploration of automation and robotics in construction. In 1975s a research and development of automation and robotics been carried out to produce single task construction robots (SCTR) for ease installation of IBS components and in 1980s the first appearance of this STCR is in place. SCTR in Figure 3 is a Robots designed to perform a specific activity that is typical on construction sites (Saidi et al., 2016). Some existing robots perform tasks like façade installation, painting, concrete compaction, concrete distribution, concrete levelling, concrete finishing, interior finishing, fireproof coating, positioning systems, steel welding, reinforcement, tile setting and etc. Big Japanese construction companies are leaders in the development and implementation of such robots. Some of these companies are Kajima, Takenaka, Fujita and Tokyu Construction (Pachon, 2012).

The main focus of the development of new single-task robots to perform activities that fall into the categories of difficult, dirty or dangerous (3D) (Bock, 2015; Pachon, 2012). But soon they realized that the STCR in construction can execute one specific construction process. Since these robots can only perform in an environment isolated from construction workers, they cannot be integrated within a larger network, making most of them incompatible within the construction process (Afsari et al., 2018). The evaluation of the first generations of developed and deployed STCRs and the identification of the above-mentioned problems led step by step from 1985 onward to the first concepts for integrated automated/robotics sites. Concepts for site automation integrated STCRs and other elementary technology as sub-systems into a controlled, factory-like environment set up on the construction site (Bock, 2015). In 1990s the first integrated on-site automation and robotics was deployed by Shimizu Corporation called Shimizu Manufacturing with Advance Robotic Technology (SMART) in Figure 4 followed Obayashi Automated Building Construction System (ABCS) in figure 5. Since then almost twenty

Integrated on-site automation and robotics have been implemented by different companies such as Taisei, Takenaka, Kajima, Maeda, and Kumagai (Saidi et al., 2016).

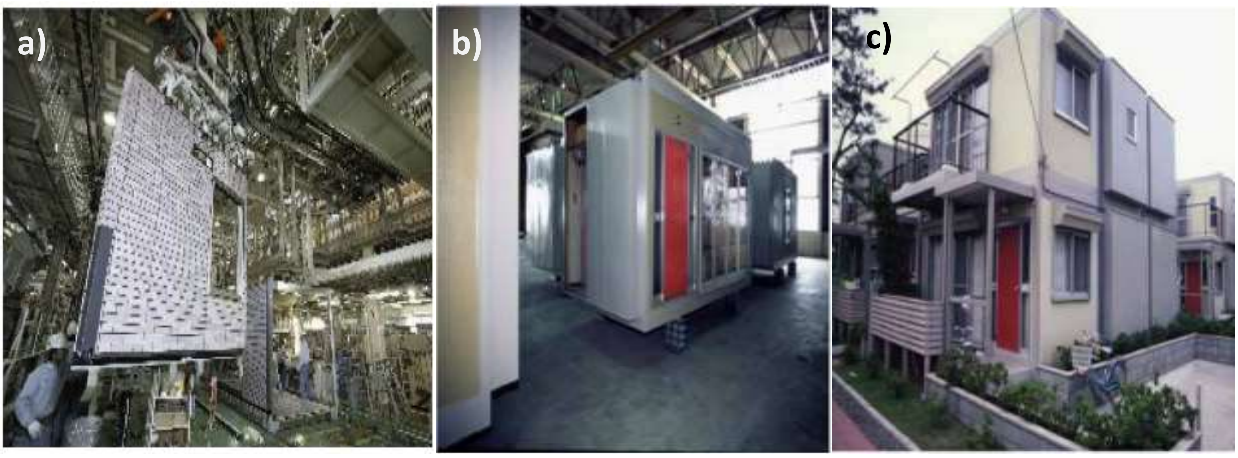

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Figure 1 (a) Sekisui Heim wall elements production (b) Sekisui Heim Module (c) completed the installation of Sekisui house adopted from (Linner & Bock, 2012)

b)

Figure 2 (a) Toyota Home Module fabrication at Toyota Home factory in Japan (b) Rendering of one of Toyota customizable home designs adopted from (Abulfahem, 2012)

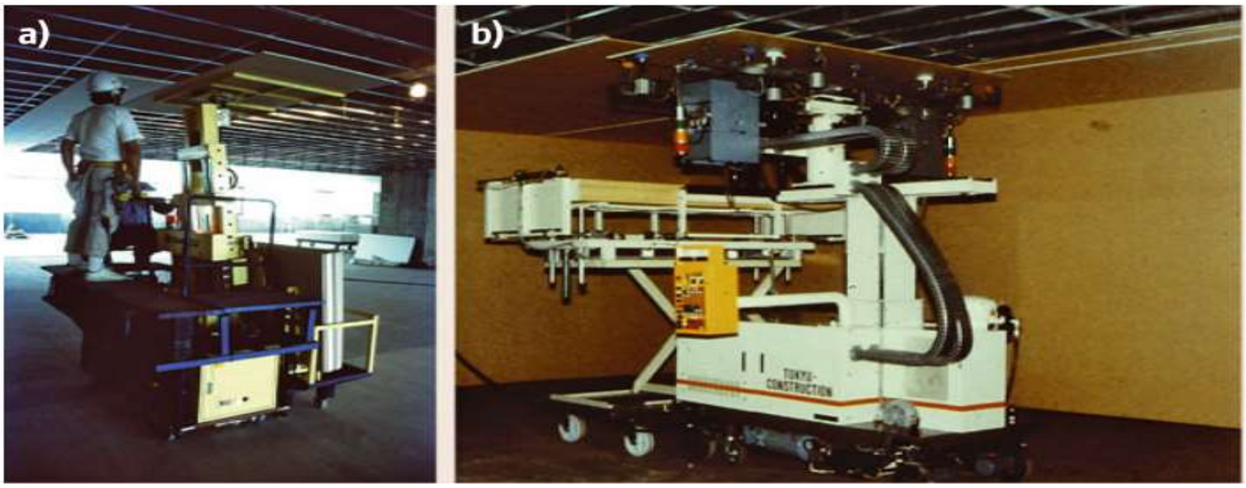

Figure 3 (a) Shimizu CFR 1 – Interior finishing robot; (b) the Tokyu ceiling panel installation robot adopted from (Saidi et al., 2016)

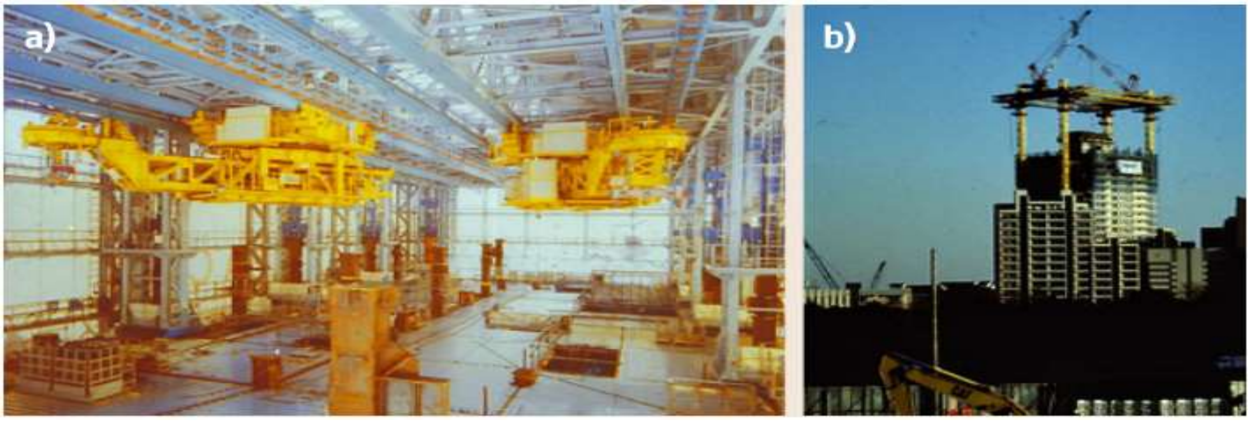

Figure 4 (a) Robotic trolleys for transporting and positioning of beams, columns, floor panels, building services units and facades, in Shimizu SMART system; (b) SMART roof field factory view adopted from (Saidi et al., 2016)

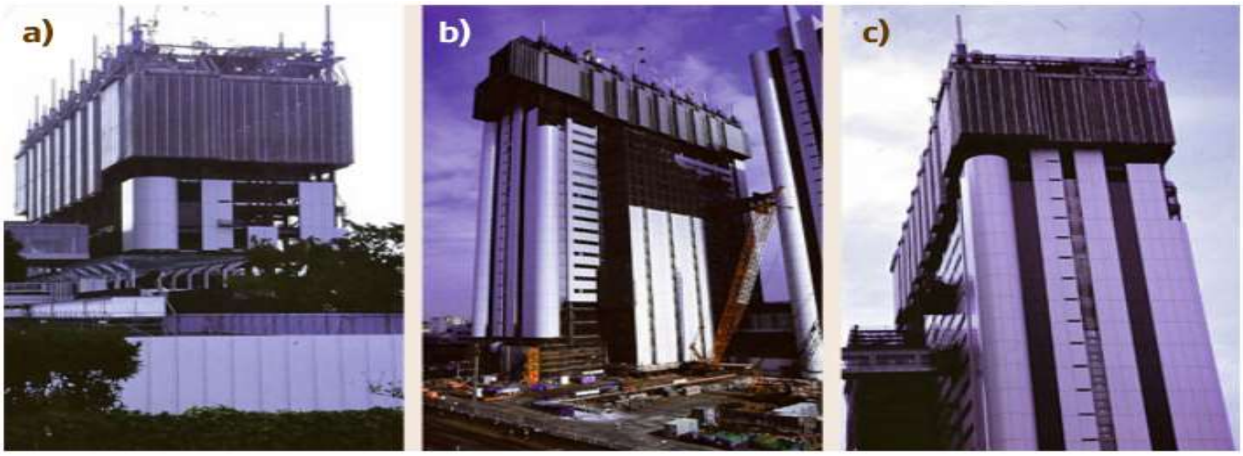

Figure 5 Obayashi Automated Building Construction System (ABCS) (a) early construction phase; (b) intermediate construction phase; (c) final construction phase adopted from (Saidi et al., 2016)

Potential Success Criteria of Automation and Robotics in IBS

Wai, Yusof, & Ismail (2012) defined success criteria as a principle or standard by which something may be judged or decided. Moreover, the success criteria should be observable and measurable. It is worth noting that success criteria differ from success factors in the sense that success criteria are the variables used to measure success, whilst success factors are efforts to reach pre-determined objectives. The statement was also supported by Korbijn (2014) as he defines success criteria are the set of principles, standards or measures used to judge the success or failure of a project. These are the dependent variables that measure success. Success criteria answer the question: how do you determine if a project is successful. Therefore, this study had identified 11 potential success criteria of automation and robotics in IBS as it been presented in table1 that will be discussed in details in the next section.

Table 1: Potential Criteria of Automation and Robotics in IBS adapted from {Formatting Citation}

Bil	Potential Success Criteria	Author/Year																	
		Wakisaka. 2000	Cobb. 2001	Kapliński et al.. 2002	Kumar et al.. 2008	Neelamkavil. 2009	Hill. 2011	Lim et al.. 2012	Waris et al.. 2013	Yunus et al.. 2015	Ardinv et al.. 2015	Kamaruddin et al.. 2016	Silva et al.. 2016	Hanafi et al.. 2016	Boafo et al.. 2016	Mohammad et al.. 2016	Abanda et al., 2017	Pan et al.. 2018	Abd Rashid et al. 2018b
1	Client Satisfaction				x					x			x						
2	High Quality Product	x	x	x	x	x					x	x	x		x	x	x		x
3	Improved Occupational Safety & Health	x	x	x	x	x		x			x	x	x	x			x	x	x
4	Higher Productivity	x	x		x	x			x			x			x		x		x
5	Reducing Production Time				x		x						x				x		x
6	Reduction of labour workforce		x		x			x						x	x		x		x
7	Reduce Overall Cost	x	x	x	x	x		x			x	x	x	x	x	x	x	x	x
8	Reduce Construction Period	x			x			x	x			x	x	x	x	x	x		x
9	Improvement of working Condition	x	x	x	x						x	x	x				x	x	x
10	Lower Construction Waste														x	x	x	x	x
11	Increase Work Efficiency								x										x

Client Satisfaction

Client satisfaction is considered as a potential measurement of automation and robotics in IBS due to the perception and reputation of IBS is depending on the user. Client satisfaction is depending on the time, cost and quality (Hamid et al., 2011; Yunus et al., 2016). In Addition, 'many of the benefits of automation and robotics are realised elsewhere in the construction processes, such as through reduced labour on-site. A study conducted by Lawson & Ogden (2010) shows that the labour costs in production are reduced by at least 30% relative to on-site work, and the number of site personnel is reduced by over 70% and this lead to a reduction of the overall cost of construction.

High-quality product

Martinez et al., (2008) stated that the quality of the operations and product increases with the automation and robotics in IBS since they are typically carried out with less variability than human workers. The Production of IBS components are repetitive and can deliver good quality products consistently limiting defect and rework rates (Eren et al., 2011). (Alazzaz & Whyte, 2014) states a key quality benefit of off-site construction is its potential for continuous improvement and quality management over time. Due to standardisation, modules constructed off-site can be continuously improved as time goes by, something which cannot be done with the 'one-off, unique project approach in traditional on-site construction. On top of that, the CITP 2016-2020 strongly emphasises the improvement of quality standards in the industry. It lays out initiatives to increase the implementation of the Quality Assessment System in Construction (QLASSIC). QLASSIC is a system that measures the quality of workmanship of a building based on the Construction Industry Standard that acts as a yardstick for the industry, as well as serving as broader quality assurance for construction (CIDB, 2016).

Improved Occupational safety & health

Martinez et al., (2008) stated automation and robotics in IBS Increases work safety as the automated systems may carry out their work in environments and zones of danger for humans, making it possible to reduce labour accidents. Routine or repetitive tasks can be handled through automation removing the human factor and their associated health issues from the work environment (Eren et al., 2011). Averages of 2.2 million working days were lost to work-related injuries and ill health in the construction sector each year between 2013/14 and 2015/16. At its most extreme this led to 43 fatal injuries, representing nearly a third of all fatal workplace injuries in the UK. Automation and robotics in IBS has the potential to significantly reduce the risk of accidents and ill health by providing a controlled, clean and warm environment, uses production line techniques and standards, reduces the need to work at height or below ground and reduces exposure to UV light (Oakley, 2014).

Higher Productivity

Higher productivity can be achieved when Increases in labour productivity, the Automation and robotics in IBS manufacturing operations may increase production rates and labour productivity, yielding greater output rates per hour of labour (Eren et al., 2011). However, Alazzaz & Whyte (2014) stated that a broader view indicates that greater productivity can be viewed as the overriding benefit of automation and robotics in IBS, with the reduced time, higher quality and lower cost of projects ultimately meaning that the process is more productive per unit of input than on-site construction. (Eastman & Sacks, 2008) Automation and robotics in IBS fabrication allows manufacturing technologies to be applied such as information technology (IT) that give impacts on productivity, including design automation, numerical control machinery, and other forms of production automation, data integration and management, instrumentation for quality control, enterprise resource management, automated data collection and materials tracking, and other advanced technologies that are broadly available in manufacturing. These benefits will eventually bring about greater improvement to the total productivity and hence the industry's image (Ting & Jin, 2000).

Reducing production time

Automation and robotics in IBS made the activities increases the speed of production. It is also increased by disengaging the operation of the limitations of the human factor. A study conducted by (Martinez et al., 2008) shows a dramatic time reduction to weld 1m steel 2mm thick using a robot. By manual metal arc welding, it takes about 600 s, 10 min, and by laser welding, it can be executed within 7 s. on top of that, automation and robotics in IBS Reducing the manufacturing lead time. Reduce the elapsed time between customer orders to product deliveries, making production and resources planning more consistent, Repetitiveness and consistency to makes predictions regarding cycle times and material usages more successful (Eren et al., 2011).

Reduction of Labor Workforce

According to Martinez et al (2008), the activity ceases to be directly linked with the operator, avoiding problems related to quality and the repetitiveness of work carried out. Costs may also be reduced by reducing labour since fewer operators are needed for the automation and robotics system. (Eren et al., 2011) also suggested that using automation and robotics in IBS will result in reducing labour costs due to the automation and robotics can be used to substitute for human labour to reduce unit product costs. On top of that (Alazzaz & Whyte, 2014) based on their study found that the construction stakeholders favouring automation and robotics in IBS were the fact that it relieves skills shortages in the construction industry. Automation and robotics in IBS essentially enables the construction process to be 'outsourced' to another environment, requiring less labour to be invested into traditional on-site processes and addressing the problem of over dependency on foreign workers (Bari et al., 2012) and lacking of skilled workers (Amin et al., 2017).

Reduce Overall Cost

The reduction in the cost of human labour and the decrease in material loss, among other factors, reduce the cost of the operation (Martinez et al., 2008). This may be explained by the fact that IBS construction is more predictable and less likely to suffer from cost blowouts caused by unknown factors such as the weather (Alazzaz & Whyte, 2014). (Goodier & Gibb, 2007) makes a similar point when they note that other criteria of automation and robotics in IBS construction, such as better quality and reduced remedial work, are often not included in costing. This 'life cycle cost' across an assets usable life being an often overlooked aspect for an industry that emphasises initial capital costs predominantly. On top of that, Rahimian et al (2017) stated that Waste & Resources Action Plan UK (WRAP) also identified that savings can be achieved by using automation and robotics in IBS as a result of waste reduction.

Reduce Construction Time

The most significant benefit of off-site construction is the time savings that it brings about. By transferring a significant proportion of the construction work to a factory facility, the time spent on-site installation is reduced. The more predictable conditions of the factory and the economies of scale that they generate can also ensure that construction deadlines are met more effectively. Automation and robotics in IBS enabled less time to be spent on site and a reduction in commercial risk as a result of faster time frames for projects (Alazzaz & Whyte, 2014). Similar to other countries, construction projects are often delayed due to issues such as material shortage, skills shortage and poor weather conditions are inherently addressed, since most of the building components are manufactured in factories and transported to site for speedy installation with predictable times and specialised workforce. Furthermore, due to the potential of performing parallel activates, foundations, manufacturing and installation, there is a chance of 30–50% faster completion (Rahimian et al., 2017).

Improvement of Working Condition

Construction workers are often exposed to various inherent risks associated with working conditions on construction sites. Although various approaches have been implemented in order to prevent accidents, the statistic indicates further improvement needs to be taken fast (Hamid et al., 2019). Automation and robotics in IBS reduced heavy physical work (Linner, 2013). It moves work away from the building site to a factory condition. For the builders, this is an enormous improvement because working conditions are checked and managed far more effectively (Maas & Van Gassel, 2005). The safer working environment at the factory production of building components means faster construction over labor costs (Hashemi, 2017). By providing working conditions show respect to those working in the building; or that enable the workforce to achieve high levels of productivity; or to provide a quality of finish that creates an excellent impression to customers and potential customers (Oostra & Claeson-Jonsson, 2007).

Lower Construction Waste

Traditional methods are associated with 10%-20% raw material wastage, however with more advanced automation and robotics in IBS, for example, the use of CAD/CAM, IBS construction can produce the same assets with just half of the waste (Oakley, 2014). A study conducted by (Tam & Hao, 2014) found that up to 100% of waste can be reduced in plastering, Timber formwork could reduce waste from about 73.91% to 86.87%., waste resulting from concrete can be reduced from about 51.47% to 60%. And the waste of steel bars can be reduced from about 35% to 55.52%. It shows that automation and robotics approaches in IBS can catalyst the efficient use of materials in many ways (Pan et al., 2018).

Increase Work Efficiency

These same factors also lead to IBS construction being associated with speedier project completion. This is also facilitated by the fact that activities can take place concurrently and be scheduled for “just in time” delivery when needed on site(Oakley, 2014). He also added that the NAO previously demonstrated that IBS construction methods could reduce onsite build time for housing by over 50% and more recent work at the BRE innovation site has shown that a house can be built in just one day. Industry case studies suggest that overall this means that homes constructed using automation and robotics can be built 30% more quickly with 25% lower costs. Lawson & Ogden (2010) summarized work efficiency as i) More efficient materials use and ordering of materials, ii) Less wastage and more recycling of material, iii) Higher productivity in factory production, iv) Less work on site in difficult conditions, v) More reliable performance of the completed building.

Conclusion

Based on the review toward automation and robotics as well as IBS in the construction industry it can be concluded that automation and robotics in IBS will contribute to the 11th Malaysian plan in general and CITP (2016 – 2020) specifically in improving the overall quality, safety and professionalism; environmental sustainability; improving the overall productivity; improving competitiveness in the capability; and capacity of industry players to foray internationally. However, there is a lack of significant measures of automation and robotics in IBS to address this challenge. This paper has identifies eleven potential of success criteria which is Client Satisfaction, High-quality product, Improved Occupational safety & health, Higher Productivity, Reducing production time, Reduction labor workforce, Reduce overall cost, Reduce Construction Time, Improvement of working condition, Lower construction waste and Increase work efficiency that could be used to measure the performance of automation and robotics in IBS.

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References

Abanda, F. H., Tah, J. H. M., & Cheung, F. K. T. (2017). BIM in off-site manufacturing for buildings. *Journal of Building Engineering*, *14*(March), 89–102.

Rashid, A. M. N., Abdullah, M. R., & Ismail, D. (2018a). Critical Success Factors CSFs to Automation and Robotics in Industrialized Building System IBS Critical Success Factors CSFs to Automation and Robotics in Industrialized Building System IBS. *International Journal of Academic Research in Business & Social Science*, *8*(12), 2207–2221.

Rashid, A. M. N., Abdullah, M. R., & Ismail, D. (2018b). Key Elements Towards Automation and Robotics in Industrialised Building System (IBS). In *Proceedings of the ASEAN Post Graduate Conference (APGC) 2018, University of Malaya, Kuala Lumpur* (pp. 152–160).

Rashid, A. M. N., Abdullah, M. R., Ismail, D., & Mahyuddin, M. N. (2018). Towards Automation And Robotics In Industrialised Building System (IBS): A Literature Review. In *3rd International Conference On Rebuilding Place (ICRP 2018)*. Ipoh, Perak.

Abulfahem, M. F. (2012). Mass customization limitation and guidelines in prefabricated construction. In T. Bock, C. Georgoulas, & T. Linner (Eds.), *Proceedings of the CIB*IAARC W119 CIC 2012 Workshop*.

Afsari, K., Ph, D., Gupta, S., Afkhamiaghda, M., & Lu, Z. (2018). Applications of Collaborative Industrial Robots in Building Construction, (August).

Alazzaz, F., & Whyte, A. (2014). Uptake of Off-site Construction : Benefit and Future Application. *International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering*, *8*(12), 1168–1172.

Arshad, M. I. (2012). Automated Horizontal Building Construction – A new Paradigm.

Proceeding of the CIB W 119 CIC 2012 Workshop Advanced Construction and Building Technology For Society, (November), 6–16.

Azman, M. N. A., Ahamad, M. S. S., & Hussin, W. M. A. W. (2012). Comparative Study on Prefabrication Construction Process. *International Surveying Research Journal (ISrJ)*, 45–58.

Bari, N. A. A., Abdullah, N. A., Yusuff, R., Ismail, N., & Jaapar, A. (2012). Environmental Awareness and Benefits of Industrialized Building Systems (IBS). *Procedia - Social and Behavioral Sciences*, *50*(December 2012), 392–404.

Bock, T. (2015). The future of construction automation: Technological disruption and the upcoming ubiquity of robotics. *Automation in Construction*, *59*, 113–121.

CIDB. (2016). *Construction Industry Transformation Program 2016 - 2020*.

Cobb, D. W. (2001). Integrating automation into construction to achieve performance enhancements. *CIB World Building Congress*, (April), 1–11.

Din, M. I., Bahri, N., Dzulkifly, M. A., Norman, M. R., Kamar, K. A. M., & Hamid, A. Z. (2012). The adoption of industrialised building system (IBS) construction in Malaysia: The history, policies, experiences and lesson learned. *2012 Proceedings of the 29th International Symposium of Automation and Robotics in Construction, ISARC 2012*, *1*, 8.

Eastman, C. M., & Sacks, R. (2008). Relative Productivity in the AEC Industries in the United States for On-Site and Off-Site Activities. *Journal of Construction Engineering and Management*, *134*(7), 517–526.

Eren, H., Sirinterlikci, A., Karaman, A., & Imamoglu, O. (2011). Automation and Robotics in Processes. *Instrument Engineers' Handbook*, 158–168. http://doi.org/10.1201/b11093-11

Goodier, C. I., & Gibb, A. G. F. (2007). Future opportunities for offsite in the UK. *Construction Management and Economics*, (June 2007), 585–595.

Hamid, Z. A., Kamar, K. A., Alshawi, M. (2011). *INDUSTRIALISED BUILDING SYSTEM (IBS): STRATEGY, PEOPLE AND PROCESS*.

Hamid, A. R. A., Noor Azmi, M. R. A., Aminudin, E., Jaya, R. P., Zakaria, R., Zawawi, A. M. M., … Saar, C. C. (2019). Causes of fatal construction accidents in Malaysia. *IOP Conference Series: Earth and Environmental Science*, *220*, 012044.

Hashemi, A. (2017). Prefabrication in the UK housing construction industry. *5th International Conference on Zero Energy Mass Customised Housing - ZEMCH 2016*, (February), 1–15.

Kapliński, O., Werner, W., Kosecki, A., Biernacki, J., & Kuczmarski, F. (2002). Current state and perspectives of research on construction management and mechanisation in Poland. *Journal of Civil Engineering and Management*, *8*(4), 221–230.

Korbijn, G. (2014). *Success criteria and critical success factors for contractors of urgent and unexpected projects A multiple case study within the maintenance & repair sector Master thesis October 2014 Success criteria and critical success factors for contractors of urgent*.

Kumar, V. S. ., Prasanthi, I., & Leena, A. (2008). Robotics and Automation in Construction. *Building Integration Solutions*.

Lawson, R. M., & Ogden, R. G. (2010). Sustainability and Process Benefits of Modular Construction. *8th CIB World Building Congress*, 38.

Lim, S., Buswell, R. A., Le, T. T., Austin, S. A., Gibb, A. G. F., & Thorpe, T. (2012). Developments in construction-scale additive manufacturing processes. *Automation in Construction*, *21*(1), 262–268.

Linner, T. (2013). *Automated and Robotic Construction: Integrated Automated Construction*

Sites.

Linner, T., & Bock, T. (2012). Evolution of large-scale industrialisation and service innovation in Japanese prefabrication industry. *Construction Innovation*, *12*(2), 156–178.

Maas, G., & Van Gassel, F. (2005). The influence of automation and robotics on performance construction. *Automation in Construction*, *14*(4), 435–441.

Mahbub, R. (2016). Enhancing the Adoption of Mechanization and Automation Technologies for Small Medium Enterprise (SME) Contractors in Malaysia. *4th Annual International Conference on Architecture and Civil Engineering (ACE 2016)*, (July), 93–100.

Martinez, S., Jardon, A., Navarro, J. M., & Gonzalez, P. (2008). Building industrialization: a robotized assembly of modular products. *Assembly Automation*, *28*(2), 134–142.

Ali, M., Haslinda Abas, N., Affandi, M. H., & Ain Abas, N. (2018). Factors impeding the industrialized building system (IBS) implementation of building construction in Malaysia. *International Journal of Engineering & Technology*, *7*(4), 2209–2212.

Mohamed, M. R., Mohammad, M. F., Mahbub, R., Ramli, M. A., & Jamal, K. A. A. (2018). The Issues and Challenges of Small and Medium-Sized Contractors in Adopting the Industrialised Building System. *International Journal of Engineering & Technology*, *7*(3.25), 432–436.

Mohammad, M. F., Baharin, A. S., Musa, M. F., & Yusof, M. R. (2016). The Potential Application of IBS Modular System in the Construction of Housing Scheme in Malaysia. *Procedia - Social and Behavioral Sciences*, *222*(June), 75–82.

Amin, M. A., Abas, N. H., Shahidan, S., Rahmat, M. H., Suhaini, N. A., Nagapan, S., & Rahim, A. R. (2017). A review of the current issues and barriers of Industrialised Building System (IBS) adoption in Malaysia's construction industry. *IOP Conference Series: Materials Science and Engineering*, *271*(1).

Noor, M. S. R., Yunus, R., Abdullah, A. H., Nagapan, S., & Mazlan, S. M. S. (2018). Insights into the adoption of lean management in the Industrialised Building System (IBS) implementation: the drivers and challenges. *International Journal of Engineering & Technology*, *7*(3.23), 22–31.

Neelamkavil, J. (2009). Automation in the prefab and modular construction industry. *International Symposium on Automation and Robotics in Construction ISARC*, 24–27.

Oakley, M. (2014). *The Value of Off-site construction to UK Productivity growth*.

Oostra, M., & Claeson-Jonsson, C. (2007). *Best Practices: Lessons learned on building concept*. *Open Building Manufacturing Open Building Open Building Manufacturing Manufacturing Core Concepts and Industrial Requirements*.

Pachon, A. G. (2012). Construction Site Automation : guidelines for analyzing its feasibility, benefits and drawbacks. *Joint CIB International Symposium of W055, W065, W089, W118, TG76, TG78, TG81 and TG84*, 38–45.

Pan, M., Linner, T., Cheng, H. M., Pan, W., & Bock, T. (2018). A Framework for Utilizing Automated and Robotic Construction for Sustainable Building. In *Proceedings of the 21st International Symposium on Advancement of Construction Management and Real Estate*.

Pan, M., Linner, T., Pan, W., Cheng, H., & Bock, T. (2018). A framework of indicators for assessing construction automation and robotics in the sustainability context. *Journal of Cleaner Production*, *182*, 82–95.

Rahimian, F. P., Goulding, J., Akintoye, A., & Kolo, S. (2017). Review of Motivations, Success Factors, and Barriers to the Adoption of Offsite Manufacturing in Nigeria. *Procedia*

Engineering, *196*(June), 512–519.

Saidi, K. S., Bock, T., & Georgoulas, C. (2016). Robotics in Construction. *Springer Handbook of Robotics*, 1493–1520.

Tam, V. W. Y., & Hao, J. J. L. (2014). Prefabrication as a mean of minimizing construction waste on site. *International Journal of Construction Management*, *14*(2), 113–121.

Ting, S. K., & Jin, H. F. (2000). PREFABRICATION IN THE SINGAPORE CONSTRUCTION INDUSTRY HUMAN RESOURCE PROBLEM IN THE SINGAPORE CONSTRUCTION. *2000 Proceedings of the 17th ISARC, Taipei, Taiwan*, 1–6.

Wai, S. H., Yusof, A. M., & Ismail, S. (2012). Exploring success criteria from the developers' perspective in Malaysia. *International Journal of Engineering Business Management*, *4*(1), 1–9.

Yunus, R., Abdullah, A. H., Yasin, M. N., Masrom, M. A. N., & Hanipah, M. H. (2016). Examining the performance of Industrialized Building System (IBS) implementation based on contractor satisfaction assessment. *ARPN Journal of Engineering and Applied Sciences*, *11*(6), 3776–3782.