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Success Criteria for Automation and Robotics in Industrialised Building System (IBS)

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Abstract

Automation and robotics in the Industrialised Building System (IBS) hold much promise for the Malaysian construction industry to move towards the fourth industrial revolution. Previous studies lacked in-depth exploration of stakeholder perception for measuring automation and robotics success within the industry. This paper examined the stakeholder perception of success criteria for measuring automation and robotics in IBS. The study was conducted through a questionnaire survey with wide-ranging IBS stakeholder that yielded two-hundred and one (201) effective response. A total of nineteen (19) success criteria for measuring automation and robotics in IBS were analysed through exploratory factor analysis, mean score and ANOVA. The findings reveal that reduce construction time, reduce production time, reduce waste, reduce material consumption, and improved occupational safety and health are the most important criteria for measuring automation and robotics in IBS. This paper contributes to the literature of automation and robotics in IBS and providing new insights for future research and development.

Keywords: Success Criteria, Automation and Robotics, Industrialised Building System.

Introduction

As a developing country, Malaysia depends on the construction industry to provide employment opportunities and enhance its economic development. However, several problems need to overcome to improve industry productivity (Yunus et al., 2016). The previous researcher highlighted that this industry has a poor record for project success in cost, quality, safety and time completion. One of the promising solutions was the introduction of industrialised building system (IBS). However, the issues of quality of the overall finished work, less productive, more costly, and cause the delay of the project had hampered the implementation of IBS (Hung et al., 2015; Mohamed et al., 2019, 2018). Hence, a move towards automation and robotics in IBS was the only way for IBS to progress in the industry (Rashid et al., 2018). Automation and robotics are categories as smart machines or smart devices that are programmable to execute tasks automatically, creating a wide range of

research topics in both well-engineered industrial workplaces and domain-oriented applications operating in dangerous or harsh environments (Mahbub, 2015; Pan & Pan, 2020; Saidi et al., 2016). The implementation of automation and robotics in IBS also includes the incorporation of related technologies and systems, such as smart sensing systems, building information modelling (BIM), Internet Of things (IoT), virtual reality (VR) and artificial intelligence, which have now been widely promoted to reshape the construction industry (Linner & Bock, 2012; Rashid et al., 2018a, 2018b; Saidi et al., 2016).

A lot of research has been conducted to prove the reliability of automation and robotics in IBS. Richard (2005) introduces the concept of reproduction for IBS that seeks innovative processes capable of shortcutting the repetitive linear operations of craftsmanship. Qiu (2007) develop RFID-enabled automation in support of factory integration to improve productivity on the shop floor relies on efficient and accurate information flow from process to process, from shop floor to shop floor, and from manufacturer to manufacturer. Son et al. (2010) conducted a detail trend analysis of research and development in automation and robotics. They summarized four (4) categories: planning and design, construction robotics, intelligent job-site management and operation and maintenance. All these categories were intended to improved productivity of IBS construction. Mahbub (2012) conducted a study on the readiness of automation and robotics in the Malaysian construction industry and concluded that the industry is ready to a certain degree to embrace the technologies in limited areas such as prefabrication and assembly the design, planning and costing phases. Kehoe et al. (2015) surveyed application of cloud robotics and automation for data processing and information exchange remotely with access to dynamic global datasets to support various functions. Kasperzyk et al. (2017) develop a new approach of an automated re-prefabrication system that introduces a robotics-based prefabrication system called RPS to increase the design flexibility of current IBS production practice. Ilhan et al. (2018) discussed automation and robotics technology to achieve success toward sustainability. Rashid et al. (2018a) examined the critical success factors for automation and robotics in IBS. Yang et al. (2019) has developed a new theory of 'co-evolution through interaction' modular integrated construction robotics. However, previous studies lacked in-depth exploration of stakeholder perception for measuring automation and robotics success within the industry. Hence, this paper aims to determine the most critical success criteria for measuring the success of automation and robotics in IBS.

Success Criteria for measuring Automation and Robotics in IBS

Wai et al. (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 because success criteria are the variables used to measure success, whilst success factors are efforts to reach pre-determined objectives. This statement was in line with Korbijn (2014) as he defines success criteria are the set of principles, standards or measures used to judge the success or failure. These are the dependent variables that measure success. Success criteria answer the question: how do you determine if a project is successful and with the context of this study how we assess the success of automation and robotics in IBS.

Automation and robotics are increasingly recognised as the most promising solutions to address the multifaceted challenges confronting the construction industry and as advanced

techniques to underpin buildings' production (Pan et al., 2020). According to Kapliński et al. (2002) mechanisation, automation and robotics significantly increase work efficiency with improvement in working conditions, the safety of the builders and progress in the quality of work done or product. Another aspect that could be taken into account is the cost reduction, mostly due to the decrease in workload per task, and eliminating or cutting down the need to use scaffolding, security system and additional transport equipment. On top of that, a study conducted by Cobb (2001) ranks the outcome of using automation and robotics technologies in construction, which is productivity improvements, improvement in quality and reliability, improving safety, improvement in working conditions, savings on labour costs, standardisation of components, overall whole-life cost savings, simplifying operations, and shortage of workforce. Besides, Kamaruddin et al. (2016) had also listed other impacts of automation in construction which are: improvement of productivity, quality stability, short construction period, and a high degree of design freedom, improvement of the construction environment, safety parameters, reduction of debris and overall cost reduction.

Automation and robotics have been progressing to reduce the time and cost of operation. For instance, lowering the cost could be done by replacing human workers with robots. Apart from the economic aspect, construction robotics has technical features to enhance the operations' quality and efficiency (Ardiny et al., 2015). Moreover, robots could potentially perform construction tasks where human presence is impossible, undesirable, or unsafe, for instance, construction in hazardous areas after natural or human-made disasters such as earthquakes and nuclear accidents, construction under difficult physical conditions such as undersea or outer space locations, and construction in areas that are not readily accessible to humans or that require an initial structure to prepare the environment for human arrival (Rashid et al., 2018). Moreover, Son et al. (2010) stated that automation and robotics improved productivity and efficiency make construction more affordable. Besides, the use of automation and robotics technology spurs market growth through the provision of new or improved products and services as well as reductions in the cost of production. Also, the extent of the harmful environmental effects of construction-related activities is reduced by adopting improved components and technologies. Lim et al. (2012) stated that several drivers are pushing construction towards automation and robotics in IBS, reducing labour, improved safety, reducing construction time on site, reducing production costs, and increasing architectural freedom. In his study, Waris & Khamidi (2013) suggested that by adopting mechanisation, automation and robotics will constitute reducing construction time, enhance productivity, quality, efficiency, and high-class quality. Abanda et al. (2017) stated that automation and robotics improved quality, good health and safety, better working conditions, higher tolerances, lower costs, reduced labour re-works, lower construction waste, and simplified construction processes. These products are factory tried and tested, predictable sustainability performance, better control and consistency in products and processes.

On top of that, the adoption of automation and robotics has demonstrated multiple benefits including a substantial reduction of waste, significant time saving, flexible working conditions, improved quality, Affordability, Improved productivity and Improved safety Pan et al. (2018a). Increased client satisfaction towards the product quality also measured success criteria for automation and robotics in IBS (Yunus et al., 2016, 2015). The introduction of automation and robotics in IBS has undoubtedly impacted the industry, but so far it has not

achieved the level of the technology adopted by developed countries (Rashid et al., 2018; Kamaruddin et al., 2013). To conclude, automation and robotics offer many benefits to the Malaysian construction industry's betterment. However, many aspects of our industry still have much room for improvements. Measuring automation and robotics in IBS will improve the industry and fulfil the government's target to move towards the 4th Industrial revolution (Rashid et al., 2019). Table 1 summarised the success criteria for measuring automation and robotics success in IBS.

Table 1. Success Criteria for Automation and Robotics in IBS

N	Success Criteria	References	Total
1	Client Satisfaction	[5] [6] [10] [16]	4
2	High Quality Product	[1] [2] [3] [5] [7] [11] [12] [13] [16] [17] [18] [19]	12
3	Improved Occupational Safety & Health	[1] [2] [3] [5] [7] [8] [11] [12] [13] [14] [18] [19]	12
4	Higher Productivity	[1] [2] [5] [7] [10] [12] [16] [18] [19]	9
5	Reducing Production Time	[5] [13] [18] [19]	4
6	Reduction of labor workforce	[2] [5] [8] [14] [16] [18] [19]	7
7	Reduce Overall Cost	[1] [2] [3] [5] [7] [8] [11] [12] [13] [14] [16] [17] [18] [19]	14
8	Reduce Construction Time	[1] [5] [8] [10] [12] [13] [14] [16] [17] [18] [19]	11
9	Improvement of working Condition	[1] [2] [3] [5] [11] [12] [13] [18] [19]	9
10	Waste Reduction	[16] [17] [18] [19]	4
11	Material Recycling	[9] [19]	2
12	Saving in Material Consumption	[9] [19]	2
13	Employee Satisfaction	[6] [18] [19]	3
14	Technology validity	[4] [6] [19]	3
15	Technology Reliability	[4] [19]	2
16	Ease of Use	[15] [19]	2
17	Technology Flexibility	[3] [4] [12] [15] [19]	5
18	Technology Availability	[4] [6] [19]	3
19	Technology Acceptability	[4] [6] [19]	3

Note: [1] Wakisaka et al. (2000); [2] Cobb (2001); [3] Kapliński et al. (2002); [4] Dunmade (2002); [5] (Kumar et al. (2008); [6] Mahbub (2008); [7] Neelamkavil (2009); [8] Lim et al.

(2012); [9] Lachimpadi et al. (2012); [10] Waris & Khamidi (2013); [11] Ardiny et al. (2015); [12] Kamaruddin et al. (2016); [13] Silva et al. (2016); [14] (Hanafi et al. (2016); [15] Bock & Linner (2017); [16] Boafo et al. (2016); [17] Mohammad et al. (2016); [18] Abanda et al. (2017); [19] Pan et al. (2018a)

Methodology

A quantitative method was adopted in this research, and questionnaires were distributed to the companies in Kuala Lumpur and Selangor. The Questionnaires were distributed using Google forms which can help the researcher collect the information quickly. The questionnaire was first pre-tested to 6 experts on the field for comments and suggestion. Then the questionnaire was pilot to 30 respondents for its reliability. The questionnaires were sending randomly based on the company's email. A total of 1183 sets of questionnaires were distributed to the respondents consisting of IBS contractor, IBS consultant dan IBS manufacturer from August 2019 until November 2019 of which, 210 were returned with 201 usable formats. A seven-point Likert scale was used to determine the level of agreement of the criteria for measuring automation and robotics in IBS. The adopted scale was as follows: 1=Strongly Disagree and, 7=Strongly agree.

The quantitative data were converted using SPSS version 23 software for descriptive and statistical analyses. Exploratory factor analysis (EFA) was conducted using the principal component method with varimax rotation on the items of success criteria to reduce the dimensions of the derived factors. There are several criteria and guidelines for EFA to assess the data suitability, factor selection, and reliability (Hair et al., 2014). The measure of sampling adequacy (MSA) or KMO test, which should be higher than 0.5, and Bartlett's test of sphericity, which should be significant ($p < 0.05$), were conducted to assess the suitability of the collected data for EFA. Items with communality higher than 0.5 and factor loading greater than ± 0.50 but not cross-loaded significantly were considered practically significant. The reliability of the extracted factors was assessed by Cronbach's α , with a satisfactory value was considered to be above 0.7 (Hair et al., 2014).

The standard deviations were calculated to illustrate the respondents' degree of difference. The mean score method is used to explore the importance of the criteria. If two or more criteria have the same mean score, the one with the lower standard deviation (SD) is assigned a higher rank (Jiang et al., 2018; Ojoko et al., 2018). Nevertheless, this mean score value (Pan et al., 2020; Yunus et al., 2017) was used for ranking variables or items. A higher mean value indicates higher perceived importance of the survey participants about the target item. The ANOVA tests were then applied to assess the statistical consistency of the perceptions from different stakeholder groups. When the p-value of ANOVA is smaller than 0.05, there is a statistically significant difference among the different groups. When the p-value of ANOVA is larger than 0.05, there is no statistically significant difference among different groups (Jiang et al., 2018).

Results and Discussion

Background Information of Respondents

The profiles of the questionnaire survey participants are summarised in Fig. 1. Through their primary organisational affiliations, the participants effectively covered the three key stakeholder groups related to the use of automation and robotics in the industrialised

building system. The groups were (1) contractors (including main contractor and sub-contractor) (72%); (2) consultant (16%); and (3) manufacturer (12%). More than 50% of the questionnaire participants had more than ten years of experience. More than 70% of questionnaire participants were from the management level, which ensured good-quality, reliable data about how automation and robotics in IBS have been used and perceived.

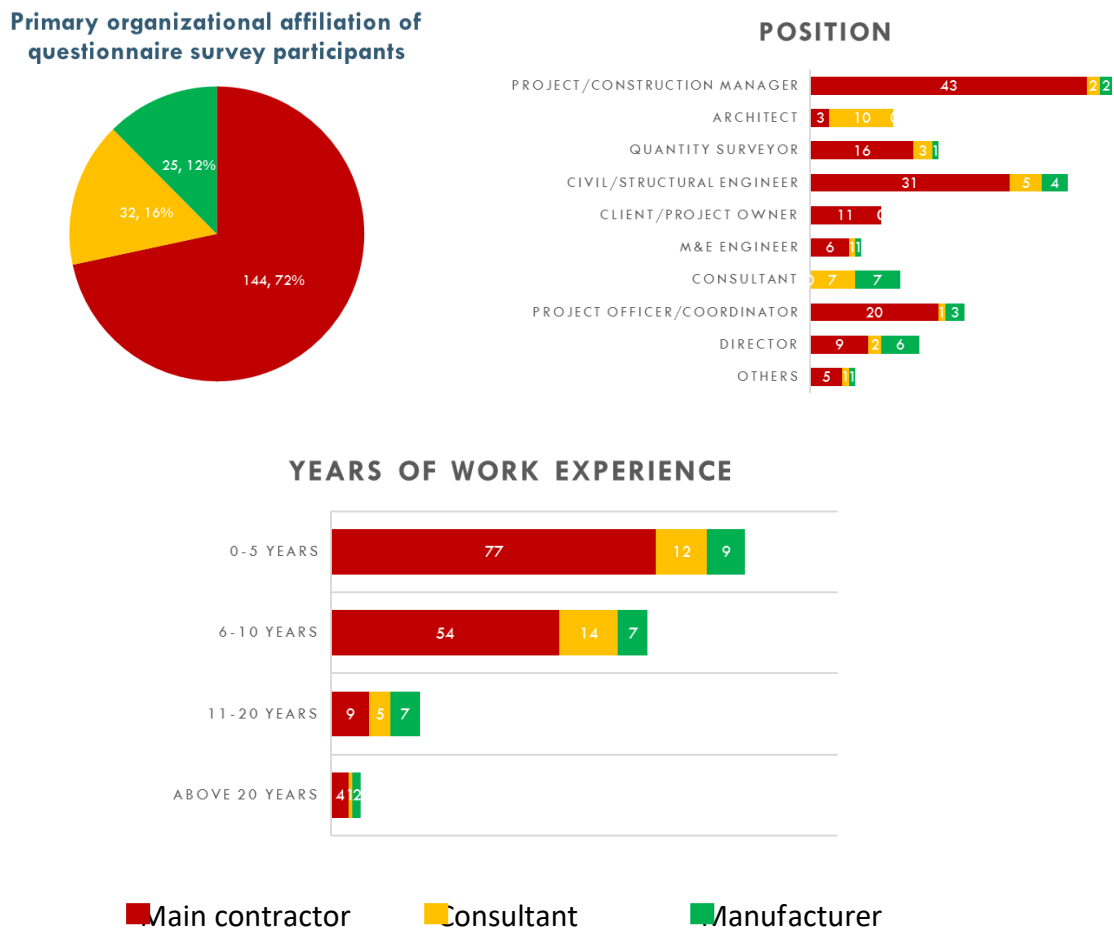


Figure 1. Primary organisational affiliation, work experience and position of questionnaire survey participants (n = 201)

Exploratory factor analysis of the success criteria for measuring automation and robotics in IBS

Before conducting EFA, the Cronbach's α was checked and produced a value of 0.958 for the whole scale, and was over 0.7, indicating acceptable reliability (Hair et al., 2014). Cronbach's Alpha reliability test was conducted to determine the reliability of each respondent's responses to the success criteria listed in the questionnaire. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy achieved a value of 0.940, exceeding the recommended minimum value of 0.6. Bartlett's test of sphericity was also statistically significant (less than 0.05) with a value of 0.000, thus supporting the correlation matrix's factorability, as shown in Table 2. Therefore, factor analysis could be used for this study. The second step is communalities, which shown in Table 3, after the third run, sixteen (16) assessed factors have communalities figures of above 0.5. Following the data's suitability, factor analysis was conducted using principal component analysis (PCA) with varimax

rotation. A screen plot was used to determine which components to extract and retain. Table 4 shows one (1) component with eigenvalues greater than one (1) that were extracted. The total variance explained by the component extracted is 63.24 per cent. Table 5 shows the extracted components and the variables loading on them. Components with 0.5 and above are recognised as important (Hair et al., 2014).

Table 2. KMO and Bartlett's test for Success Criteria

KMO and Bartlett's Test			
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.			0.940
Bartlett's Test of Sphericity	Approx. Chi-Square		3242.435
	df		171
	Sig.		0.000

Table 3. Communalities

Code	Success Criteria	Initial	1 st Run	2 nd Run	3 rd Run
SAR1	Reduced cost	1.000	.234	-	-
SAR2	Increased Productivity	1.000	.531	.533	.539
SAR3	High-Quality Product	1.000	.555	.553	.563
SAR4	Reduced Production Time	1.000	.561	.572	.584
SAR5	Reduced construction Time	1.000	.598	.604	.611
SAR6	Recycled Waste Material	1.000	.587	.600	.607
SAR7	Reduced Material Consumption	1.000	.610	.614	.627
SAR8	Workforce Reduction	1.000	.624	.638	.649
SAR9	Improved Occupational Safety and Health (OSH)	1.000	.608	.617	.618
SAR10	Reduced Waste	1.000	.613	.623	.632
SAR11	Improved Working Condition	1.000	.630	.635	.633
SAR12	Employee Satisfaction	1.000	.654	.653	.650
SAR13	Client Satisfaction	1.000	.681	.684	.685
SAR14	Valid Technology	1.000	.714	.727	.723
SAR15	Reliable Technology	1.000	.702	.704	.690
SAR16	User-Friendly Technology	1.000	.654	.652	.633
SAR17	Technology Flexibility	1.000	.693	.684	.672
SAR18	Technology Availability	1.000	.385	-	-
SAR19	Technology Acceptance	1.000	.508	0.480	-

Table 4. Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	10.118	63.236	63.236	10.118	63.236	63.236
↓	↓	↓	↓			
14	.169	1.056	98.335			
15	.138	.863	99.199			
16	.128	.801	100.000			

Extraction Method: Principal Component Analysis.

Table 5. Rotated Component Matrix

Success Criteria for Automation and robotics in IBS		Component
		SAR
SAR2	Increased Productivity	.734
SAR3	High-Quality Product	.750
SAR4	Reduced Production Time	.764
SAR5	Reduced construction Time	.781
SAR6	Recycled Waste Material	.779
SAR7	Reduced Material Consumption	.792
SAR8	Workforce Reduction	.806
SAR9	Improved Occupational Safety and Health (OSH)	.786
SAR10	Reduced Waste	.795
SAR11	Improved Working Condition	.796
SAR12	Employee Satisfaction	.806
SAR13	Client Satisfaction	.828
SAR14	Valid Technology	.850
SAR15	Reliable Technology	.830
SAR16	User-Friendly Technology	.796
SAR17	Technology Flexibility	.820

Extraction Method: Principal Component Analysis.

a. 1 components extracted.

Ranking of Success Criteria for Measuring Automation and Robotics in IBS

The study then evaluated the perceived success criteria in different contexts that could measure the success of automation and robotics in IBS. Nineteen (19) influencing factors were identified by reviewing the literature and documents in automation and robotics-related to IBS (Rashid et al., 2019). The results are presented in Table 6. According to the mean values, all the success criteria were considered influential (with mean values larger than 5) for measuring automation and robotic in IBS in Malaysia. Notably, reduced construction time was ranked the highest criteria by all stakeholder. It attracted a mean score value of (5.79). The finding agrees with (Linner & Bock, 2012; Saidi et al., 2016) as the

components and module need a just in time delivery for onsite installation, resulting in reduced project completion time. Reduce production time (5.69) was perceived to have the second-highest influence on measuring automation and robotics success in IBS. This rating aligns with the remark of (Linner & Bock, 2012; Saidi et al., 2016). A significant reason is that from conception to manufacturing, the whole process is aid by the automation and robotics technology. The high degree of information and communication ICT, the integration of devices by the internet of things (IoT) and, utilisation of CAD/CAM systems supported by building information modelling or applicable ERP system has made the production time reduce significantly (Rashid et al., 2018; Johansson et al., 2015; Niccolini et al., 2018).

Waste reduction was rated third, and it attracts a mean score value of (5.67). The finding is consistent with the previous researcher (Hamid et al., 2012; Pan et al., 2018b). The use of robotic technology in IBS production has also resulted in a consistent quality of products and less waste in factories, due to computer-assisted planning and programming, only the necessary amount of concrete is being provided from the batching plant (Ilhan et al., 2018; Vähä et al., 2013; Yin et al., 2019). Fourthly, reducing material consumption was considered an influential success criterion with a mean score value (5.66). The finding concurs with (Bock & Linner, 2015; Pan et al., 2018b). Generally, the machine can do the job more precisely and efficiently. Automated approaches can catalyse the efficient use of materials in many ways. For instance, the optimisation of resource utilisation can be achieved by systematic scheduling and automation in IBS factories under dynamic circumstances. Sensor-based control can track the material and components for better interactions and detect the geometry of waste component for reuse (Neelamkavil, 2009). Fifthly, improved occupational health and safety received a mean score value (5.66). In this regard, machines can replace human workers in these hazardous, dull, dangerous, and dirty tasks and reduce injuries and fatalities.

Additionally, equipped with automation and robotics, negative impacts of construction work on human labours' health can be mitigated by vastly reducing dangerous physical works and providing better physical working conditions (Linner & Bock, 2012; Pan et al., 2018b). Although the 'reduced construction time', 'reduce production time', 'reduced waste', 'reduce material consumption' and, 'improved occupational safety and health' success criteria has the highest mean score and rated as top five, the other success criteria should not be taken lightly. All the sixteen (16) success criteria which show a mean score value above (5.00) indicates that they are also essential criteria for measuring automation and robotics in IBS. On the other hand, the ANOVA test results showed no significant difference between different stakeholder groups. These findings indicate that the various stakeholders' opinions generally were not statistically significantly different from each other, means that a mutual consensus on the agreement of the criteria for measuring automation and robotics was achieved.

Table 6: Importance of Success Criteria for Measuring Automation and Robotics in IBS

Success Criteria of Automation and Robotics in IBS	Mean	Std. Deviation	Rank	ANOVA significance	Factor Loading
SAR5 Reduced construction Time	5.79	1.072	1	0.877	0.781
SAR4 Reduced Production Time	5.69	1.013	2	0.668	0.764
SAR6 Reduced Waste	5.67	1.021	3	0.483	0.779
SAR7 Reduced Material Consumption	5.66	1.061	4	0.720	0.792
SAR9 Improved Occupational Safety and Health (OSH)	5.66	1.089	5	0.426	0.786
SAR11 Improved Working Condition	5.65	1.004	6	0.480	0.796
SAR2 Increased Productivity	5.64	1.059	7	0.781	0.734
SAR6 Recycled Waste Material	5.62	1.134	8	0.483	0.779
SAR8 Workforce Reduction	5.61	1.118	9	0.257	0.806
SAR3 High Quality Product	5.60	1.123	10	0.818	0.750
SAR14 Valid Technology	5.59	1.055	11	0.622	0.850
SAR15 Reliable Technology	5.57	1.071	12	0.666	0.830
SAR13 Client Satisfaction	5.54	1.095	13	0.530	0.828
SAR16 User Friendly Technology	5.48	1.205	14	0.270	0.796
SAR17 Technology Flexibility	5.46	1.100	15	0.705	0.820
SAR12 Employee Satisfaction	5.45	1.024	16	0.728	0.806

Conclusion

Automation and robotics in IBS are undoubtedly the future of the Malaysian construction industry. However, there is a lack of studies on the success criteria for measuring automation and robotics in IBS. This paper investigated IBS stakeholders' perspectives on the success criteria for measuring automation and robotics in IBS. Nineteen (19) success criteria for measuring automation and robotics were identified through a literature review. Two-hundred and one (201) valid questionnaire were collected. Exploratory factor analysis (EFA) was conducted, three (3) items were deleted due to low communalities, leaving sixteen criteria to further analysed using mean score method to establish the critical criteria. Findings reveal that the top five (5) criteria for measuring automation and robotics in IBS are reduced construction time, reduced production time, reduced waste, reduced material consumption, and improved occupational safety and health. Test of ANOVA also reveals no statistical difference among the IBS stakeholder, which means that there was an agreement of the success criteria among the IBS stakeholder.

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