Journal of Design and Built Environment
E-ISSN: 2232-1500 |Print ISSN: 1823-4208
https://ejournal.um.edu.my/index.php/jdbe
Special Issue VII, 2025, 142-159

Critical Success Factors (CSFs) for Implementation of Automation and Robotics in Malaysia's Industrialised Building System (IBS)

Mohd Najib Abd Rashid[1*], Low Sui Pheng[2], Mohd Reeza Yusof[3], Mohamed Rizal Mohamed[3], Sallehan Ismail[1] and Muhammad Naim Mahyuddin[1]

[1]Department of Built Environment Studies and Technology, Faculty of Built Environment, Universiti Teknologi MARA Perak, Malaysia.

[2]Department of Built Environment, College of Design and Engineering, National University of Singapore, Singapore.

[3]Centre of Study for Construction, Faculty of Built Environment, Universiti Teknologi MARA (UiTM) Shah Alam, Selangor Darul Ehsan, Malaysia.

*Corresponding author: mohdn613@uitm.edu.my

Article info:
Submission Date: 16th May 2025
Acceptance Date: 17th September 2025

Keywords:
automation and robotics, Industrialised Building System (IBS), Critical Success Factors (CSFs)

Abstract

The use of automation and robotics in IBS commonly deals with uncertainties and complexities, thus requiring strategies to achieve successful results. Despite the support and assistance from various government departments and private sector for the development of automation and robotics in IBS, this has been the subject of very few studies. Nevertheless, there is increasing awareness among the IBS stakeholders of the use of automation and robotics to influence IBS project success. Thus, this study is carried out to identify the Critical Success Factors (CSFs) and determine the relationship between identified CSFs with successful use of automation and robotics in Malaysian IBS, indirectly developing the CSFs conceptual model. The conceptual model is composed by exogenous latent variables (LVs); namely Strategy, People, Process and Technologies and one endogenous LV which is Success Criteria for Automation and Robotics in Malaysian IBS. The study presents empirical evidence from a survey in Klang Valley, where 201 sets of questionnaires were analysed using PLS-SEM to test the conceptual model. The indicators for these enablers and result criteria were extracted from the past literature and by a pilot study. The finding indicates that Strategy (β=0.151; t-value=1.749), Process (β=0.524; t-value=5.432) and Technology (β=0.175; t-value=2.11) have a significant relationship with the successful use of automation and robotics in IBS. However, the People element (β=-0.006; t-value=0.078) was found to have a statistically insignificant relationship, thus suggesting the moderating role for this element as a topic for future research.

1.0 INTRODUCTION

Industrialised Building System (IBS) refers to a construction method where building components are manufactured in a factory setting, then transported to the construction site for assembly (CIDB, 2016: Abdullah et al., 2024). The focus of IBS is to standardize, prefabricate and streamline the building process to reduce time, waste, and cost. The use of IBS leads to greater control over the construction process, improved quality, and enhanced efficiency, as well as increased safety and reduced risk of error (Dzulkalnine, 2019). IBS also enables quicker construction times, as the components are pre-manufactured and ready to be assembled on site. This results in a more controlled, efficient, and reliable construction process (Rashid et al., 2022). Automation and robotics in construction refer to the use of advanced technologies to automate tasks, reduce labour costs, increase efficiency, and improve the quality of construction projects. These include the use of drones, robots, and other automated tools for tasks such as surveying, excavation, material handling, and more (Carra et al., 2018). The goal of automation and robotics in construction is to improve safety, reduce errors, and increase productivity, while robotics aims to perform tasks that are difficult or dangerous for humans to complete (Yang et al., 2019). The level of adoption of automation and robotics in the Malaysian construction industry is still relatively low compared to more developed countries. However, industry is starting to recognize the benefits of these technologies, and their adoption is gradually increasing. In recent years, the Malaysian government has been promoting the adoption of new technologies, including automation and robotics in the construction industry as a way to improve efficiency and competitiveness (CIDB, 2020). Some construction companies in Malaysia have already started to invest in automation and robotics, primarily in areas such as material handling, site preparation, and building foundation work. However, the widespread adoption of these technologies remains limited, mainly due to a lack of awareness and technical expertise, as well as the high cost of investments (Rashid et al., 2021). Nevertheless, it is expected that the adoption of automation and robotics in the Malaysian construction industry will continue to grow in the coming years, driven by the increasing demand for more efficient and sustainable building practices.

2.0 LITERATURE REVIEW

Rockart & Bullen (1981) define the CSFs as the limited number of areas where satisfactory results are essential to ensure successful competitive performance for an individual, department, or organisation. CSFs are the few key areas where "things must go right" for the business to flourish and reach its goals. They categorized CSFs into five domains: industry, competitive strategy, environmental factors, temporal factors, and organisational factors. Hamid et al. (2013) conducted a study on leveraging ICT in FM and found that people, process, environment, and infrastructure technology are the elements underlying critical success factors. They urged that the most effective utilisation of ICT requires that people should be adequately trained, processes correctly defined, infrastructure should support the needs of ICT usage, and the environment should be ready for ICT. Nadim & Goulding (2011) highlighted several concerns and opportunities which they categorised under five main patterns: the process, the product, the technology, the people, and the market. Similarly, the study by Els et al. (2012) found that human management, process, organisation and an additional contractual and technical category are critical elements in the implementation of a construction project. The critical success factors, which seem to evolve from the people, process, and technology, will ensure the successful implementation of automation and robotics in IBS. For this research, the study will use the framework proposed by various authors which emphasises the element of strategy, people, process, and technology as shown in Table 1.

Table 1. Critical Success Factors (CSFs) in fields related to IBS.

No	Author /Year	CSFs Elements						
		Strategy	People	Process	Environment	Technology	Policy	Organization
1	Alshawi, 2007		x	x		x		
2	Nadim & Goulding, 2011		x	x		x		
3	Kamar, 2011	x	x	x		x		
4	Els et al., 2012	x	x	x				x
5	Lou & Kamar, 2012	x	x	x		x		
6	Goulding et al., 2012		x	x		x		
7	Abd Hamid et al., 2013		x	x	x	x		
8	Soon Ern et al., 2016		x	x		x	x	
9	Musa et al., 2017		x	x		x		
10	CIDB, 2020		x		x	x	x	
	Frequency	3	10	9	2	9	2	1

2.1 Hypotheses Development

This study identified potential CSFs for automation and robotics in IBS. The CSFs are adapted from extensive review of past research. The CSFs are primarily categorised according to Strategy, People, Process and Technology.

2.1.1 Strategy

From the strategy factors, a total of twelve variables were identified. According to Lou & Kamar (2012), the primary purpose of construction businesses is to generate profit. To achieve optimal business returns, effective business strategies are essential for success. A clear, top-down corporate vision and direction must be established with all levels of decision-makers in a mature company fully understanding and aligning with it. Adopting IBS requires a business strategy which is essential in assessing the viability of the project. Hamid et al. (2011) stated that strategy is significant to contractors, as companies need a strategy to improve their approach to projects in order to maintain their business sustainability. Contractors are recommended to establish clusters, consortia, or integrated teams by creating IBS business partnerships when and where needed. However, there remains a lack of systematic and rigorous study of strategy and failure to identify the factors that contribute to IBS success for contractors (Hamid et al., 2011). A study by Mohamad et al. (2016) found that most of the respondents agreed that the essential factor that influenced the decision to adopt IBS and new technology was a commitment and decision from the Director/Top management board who are closer to the organisational strategy to be implemented successfully. Furthermore, new organisations should acquire knowledge or have joint-venture projects with established adopters to ensure successful implementation (Lou & Kamar, 2012). The following hypothesis is proposed based on the above narrative:

H1. Strategy significantly impacts the success of automation and robotics in an Industrialised Building System (IBS).

2.1.2 People

Four variables were identified from the people factors. A study by Soetanto et al. (2019) found that many scholars have recognized the importance of people factors on new technology implementation. These factors, in turn, will influence management in terms of leadership, individuals and their aspirations and the usage of appropriate technology to adapt to changing environments. Soetanto et al. (2019) also suggested that people factors influenced the success of new technology and therefore need to be considered and addressed appropriately, especially prior to the implementation. In line with this, Mohammed (2016) also highlighted the people's element which states that necessary skills, knowledge, training, and awareness at all decision-making levels are critical to facilitate change towards automation and robotics in IBS. The industry believes that the government should play an extensive role in establishing training and continuing awareness programmes to support continuous professional development (CPD). Moreover, a study conducted by Nadim & Goulding (2011) found that the respondents considered the "people" element to be one of the most important drivers and inhibitors of an IBS, specifically in the use of new technology. Respondents attributed resistance from the construction industry as arising from the "protectionism and conservatism" inherent within the industry culture. Concerns raised by respondents included fears of a "lost identity" and "changes in role descriptors." However, respondents also acknowledged the necessity to equip the construction industry with the appropriate knowledge and skills. In this respect, respondents noted that the skill problem lies primarily in "the qualification of users" rather than in the "technological aspects of the system" which requires "training" and "discipline". The following hypothesis is proposed based on the above narrative:

H2. People significantly impact the success of automation and robotics in the Industrialised Building System (IBS).

2.1.3 Process

From the Process factors, nineteen variables were identified. Nawi et al. (2016) stated that due to the rapid development of the construction industry, projects have become more complex and require a practical approach, particularly in increasing collaboration among multiple stakeholders. The traditional construction process has been seen as a drawback due to its fragmentation, especially in the design phase (Nawi et al., 2014). Fragmentation in the construction process is a critical issue that negatively affects projects particularly those involving IBS. For example, the absence of the manufacturer and contractor in the design phase can lead to problems in the supply chain (delay and late supply). Nawi et al. (2016) suggested that integrated project delivery (IPD) will solve the problem of fragmentation. On the other hand, Lou & Kamar (2012) suggested partnering and contractual arrangements as a solution to the fragmentation issues as the adopters can work together with clients, manufacturers, and designers from the beginning to delivery. To accelerate change and expedite the learning curve, adopters need to partner with established organisations with sufficient technical know-how. A strategic alliance with other companies is essential to secure contracts in public and private projects. Moreover, Lou & Kamar (2012) suggested that advanced planning and project management are the heartbeats of IBS. From project inception through the design phase, supply chain, delivery coordination, construction, and on-site installation, everything must be planned intelligently. The following hypothesis is proposed based on the above narrative:

H3. The process significantly impacts the success of automation and robotics in an Industrialised Building System (IBS).

2.1.4 Technology

From the Technology factors, nine variables were identified. Lou & Kamar (2012) stated that information technology (IT) provides the enabling support tools for IBS implementation. The use of IBS-enabled CAD software is essential to encapsulate the various existing IBS products and incorporate supply chain management (SCM) into the construction processes. An integrated IT system that can combine construction design, planning, and monitoring is essential. The IT implementation aims to enable more synchronized information management and to help people share it at an earlier stage (Hamid et al., 2011). Kamar & Hamid (2011)stated that through IT, companies could enhance their collaborative activities, keeping all parties up to date regarding the project's progression, and help solve on-site supply chain problems. With IT involvement, the industry can facilitate information dissemination throughout the supply chain allowing the chain itself to move as a coordinating entity to anticipate any problems and contribute to completing the project on time. The utilisation of BIM should be encouraged throughout the design, delivery, and life cycle of a project to manage coordination down to fabrication-level details. BIM enhances the accuracy and effectiveness of cost control, as it links real-time quantity management directly to project design and fabrication information. Fully interconnected collaborative project teams with full-time, real-time access to all information about the project pro-forma, life cycle design, supply chain and mode of delivery, can create an improved supply chain. BIM also enables concurrent collaborative design which improves communication between the project team and supply chain and enables enhanced modes of innovation as well as early clash detection (Li et al., 2017: Tajuddin et al., 2025). The following hypothesis is proposed based on the above narrative:

H4. Technology significantly impacts the success of automation and robotics in an Industrialised Building System (IBS).

The above narratives in the four categories are summarized in Table 2. The relationships between the four hypotheses as well as the overarching conceptual framework for this study are shown in Figure 1. Empirical results will be presented using Partial Least Squared – Structured Equation Modelling (PLS-SEM).

Table 2. CSFs variable for automation and robotics in IBS

CSF Elements	Code	Critical Success Factors (CSFs)	Sources of References
Strategy	ST1	Risk Assessment	Kamar et al., 2010; Ismail, 2012; Yunus et al., 2017
	ST2	Cost Evaluation	Mydin et al., 2015; Nawi et al., 2015; Kumar et al., 2016
	ST3	Economic of Scale (EOS)	Din et al., 2012; Kamar et al., 2014; Tajul Ariffin et al., 2017
	ST4	Partnering	Kamar et al, 2010; Yusof et al, 2015; Nawi et al., 2016
	ST5	Demand	Mydin et al., 2015; Mao et al., 2018
	ST6	Market	Mydin et al., 2015; Mao et al., 2018
	ST7	Government Policies	Din et al., 2012; Mydin et al., 2015; Zhiqiang et al., 2019
	ST8	Government Incentives	Din et al., 2012; Mydin et al., 2015; Zhiqiang et al., 2019
	ST9	Return of Investment (ROI)	Kumar et al., 2016; Ogbehembe et al., 2017; Zhiqiang et al., 2019
	ST10	Vision	Hamid et al., 2012; Yusof et al., 2015; Mydin et al., 2015
	ST11	Mission	Hamid et al., 2012; Yusof et al., 2015; Mydin et al., 2015
	ST12	Top-Down Commitment	Yusof et al., 2015; Nawi et al., 2016; Ariffin et al., 2017
People	PE1	Experienced Work Force	Kamar et al., 2014; Yusof et al., 2015; Silva et al., 2016
	PE2	Technically Capable	Kamar et al., 2014; Yusof et al., 2015; Silva et al., 2016
	PE3	Education	Kamar et al., 2014; Yusof et al., 2015; Silva et al., 2016
	PE4	Training	Kamar et al., 2014; Yusof et al., 2015; Silva et al., 2016
Process	PS1	Good Working Collaboration	Kamar et al., 2014; Meynagh et al., 2014); Yunus et al., 2017
	PS2	Effective Communication Channel	Kamar et al., 2014 ;Čuš-Babič et al., 2014; Yusof et al., 2015
	PS3	Coordination of design, manufacture, transportation and installation	Cus Babic et al., 2014; Nawi et al., 2016; Tajul Ariffin et al., 2017

	PS4	Early Involvement	Kamar et al., 2010; Kamar et al., 2014; Yusof et al., 2015
	PS5	Extensive Planning and Scheduling	Yunus & Yang, 2014; Said, 2015; Andersson & Lessing, 2017
	PS6	Lean Principle	Bock & Linner, 2010b; Mohd Noor et al., 2018; Jin et al., 2018
	PS7	Just in Time (JIT)	Kamar, 2012; Womack; Koskela Bock & Linner, 2010b
	PS8	Just in Sequence (JIS)	Kamar, 2012; Womack; Koskela; Bock & Linner, 2010b
	PS9	Design and Build	Kamar et al., 2010; Meynagh et al., 2014; Yusof et al., 2015
	PS10	Integrated Project Delivery (IPD)	Kamar et al., 2010; Meynagh et al., 2014; Yusof et al., 2015
	PS11	Robot Oriented Design (ROD)	Bock et al.,2010b; Linner, 2013; Saidi et al., 2016; Pan et al., 2018
	PS12	Design for Manufacture & Assembly (DfMA)	Goulding, et al., 2014; Jin et al., 2018
	PS13	Standardization	Kamar et al., 2014; Yusof et al., 2015; Tajul Ariffin et al., 2017
	PS14	Mass Customization	Din et al., 2012; Stojanova et al., 2013; Tajul Ariffin et al., 2017
	PS15	Mass Production	Bock & Linner, 2010a; Din et al., 2012; Tajul Ariffin et al., 2017
	PS16	Modular Design	Bock & Linner, 2010b; Mohd Noor et al., 2018
	PS17	Modular Coordination	Bock & Linner, 2010b; Mohd Noor et al., 2018
	PS18	Supply Chain Support	Meynagh et al., 2014; Yusof et al., 2015; Nawi et al., 2016
	PS19	Continuous Improvements	Kamar et al., 2010; Meiling et al., 2012; Cooke & Davis 2012
Technology	TE1	Information and Communication Technology	Čuš-Babič et al., 2014; Yusof et al, 2015; Saidi et al., 2016
	TE2	Building Information Modelling (BIM)	Cus Babic et al., 2014; Yusof et al., 2015; Yunus et al.,2017
	TE3	Virtual Reality (VR)	Neelamkavil, 2009; Cus Babic et al., 2014
	TE4	Augmented Reality (AR)	Kapliński, 2018; Uddin, 2014; Maier et al., 2017
	TE5	Computer-Aided Drawing (CAD)	Goulding et al., 2014; Nawi et al., 2015; Saidi et al., 2016
	TE6	Computer-Aided Manufacturing (CAM)	Bock & Linner, 2010b; Nawi et al., 2015; Saidi et al., 2016
	TE7	Computer Numerical Control Machine (CNC)	Bock & Linner, 2010b; Saidi et al., 2016
	TE8	Additive Manufacturing/3D Printing	Kapliński, 2018; Zhiqiang et al., 2019; Maier et al., 2017;
	TE9	Internet of Things (IoT)	Kapliński, 2018; Zhiqiang et al., 2019; Maier et al., 2017

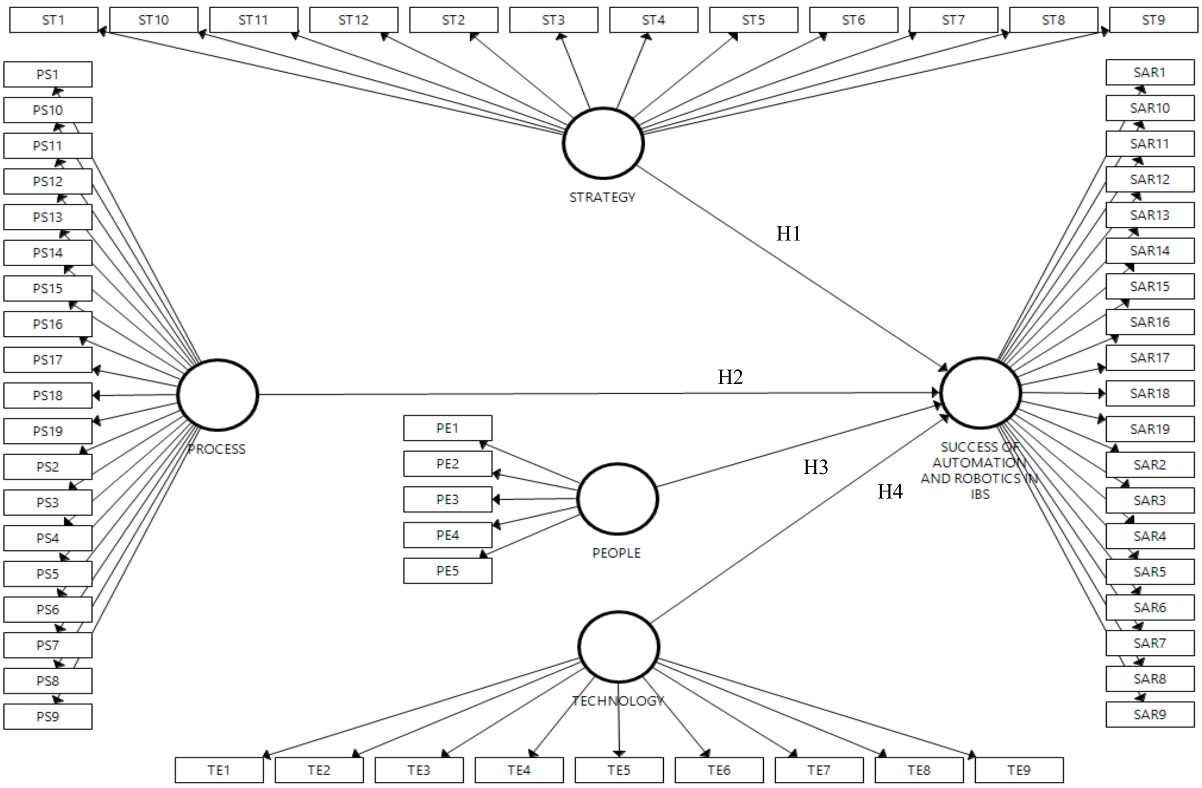

Figure 1. Proposed Conceptual Framework and Hypothesis Relationship (PLS-SEM)

3.0 METHODOLOGY

A quantitative method was adopted in this research, and questionnaires were distributed to companies in Kuala Lumpur and Selangor in Malaysia. Selangor and Kuala Lumpur were chosen as the sampling frame because they are the two leading regions in Malaysia's construction industry. Selangor contributed about 31.3% of the total construction output, while Kuala Lumpur contributed 16.2% (DOSM, 2024). Together, they represent almost half of the national output (47.5%), making them highly relevant for studying industry practices. The high concentration of construction activities in these areas ensures that the data collected is both meaningful and representative of the wider industry. The questionnaires were administered using Google forms which facilitated efficient data collection. Prior to distribution, the questionnaire was pre-tested with 6 experts in the field for comments and suggestions. The questionnaire was then piloted with 30 respondents for its reliability. The questionnaires were sent randomly based on the company's email, addressed to building professionals and managers. A total of 1183 sets of questionnaires were distributed to the respondents consisting of IBS contractors, IBS consultants and IBS manufacturers. A total of 210 questionnaires were returned with 201 usable responses.

The distribution of the respondent's job title is presented in Table 3. Notably, 37.4% of respondents held key decision-making positions either as project/construction manager (23.4% = 47), a director of an organisation (8.5% = 17), and client/project owner (5.5% = 11). In addition, a significant number (59.1%) had a technical background, i.e., Architect, Quantity Surveyor, Civil/Structural Engineer, M&E Engineer, Consultant, and Project coordinator/officer of an organisation, and were therefore key players in an IBS project. These respondents held key positions within an organisation, hence suggesting the appropriate profile and seniority of the respondents in the survey that add weight to the data quality (Alashwal et al., 2017). A five-point Likert scale was used to determine the level of agreement of the critical success factors for implementation of automation and robotics in IBS. The adopted scale was as follows: 1=Strongly Disagree and, 5=Strongly agree. A seven-point Likert scale was then used to determine the level of agreement towards successful implementation of automation and robotics in IBS where 1=Strongly Disagree and, 7=Strongly agree. Subsequently, the data was analysed using PLS-SEM 3.2.7 to test the relationship of CSFs towards the successful implementation of automation and robotics in IBS.

Table 3. Designation of the Respondents

No	Demographic Features	Frequency	Percentage
1	Project/Construction Manager	47	23.4%
2	Architect	13	6.5%
3	Quantity Surveyor	20	10.0%
4	Civil/Structural Engineer	40	19.9%
5	Client/Project Owner	11	5.5%
6	M&E Engineer	8	4.0%
7	Consultant	14	7.0%
8	Project Officer/Coordinator	24	11.9%
9	Director	17	8.5%
10	Others	7	3.5%
	Total	201	100.0%

4.0 ANALYSIS AND RESULT

4.1 Assessment of the Measurement Model

The reliability of each CSF can be assessed through the individual correlation between the CSF and its theoretically associated CSF's elements. A strong correlation between the CSFs and the respective CSFs' elements is important. The reliability of an individual CSF is evaluated based on the extent to which it loads on the CSF elements (Hair et al., 2011). CSFs with outer loadings 0.70 or higher are considered highly satisfactory (Chin et al., 2008; Henseler et al., 2015). Nevertheless, according to Hair et al. (2011), the CSFs with a loading value of 0.40 are regarded as acceptable for an exploratory study, whereas those less than 0.40 should be dropped. The cut-off value taken for outer loading in this study is 0.40 and above. As shown in Table 4, all loading values surpassed the cut-off value suggested by Hair et al. (2011). Additionally, several item loadings from SARs and TEs construct were removed due to high collinearity issues such as the perfect correlation of items involving item TE4, SAR9, and SAR17. The analysis results for all the CSFs have fulfilled the criteria with loading values of more than 0.40 after the second run of the PLS-SEM. In conclusion, all the CSFs have good correlations with their associated CSFs' elements. The second parameter for reliability is evaluated using two metrics: Cronbach's Alpha (CA) and composite reliability (CR) which indicate how well a set of CSFs assesses a single CSF's element. However, even though CA is often used to measure internal consistency reliability, CR is considered a better measure of internal consistency because it uses the standardization of different CSFs when the PLS-SEM is applied (Henseler et al., 2009; Henseler et al., 2015). The recommended cut-off value for establishing internal consistency reliability must not be lower than 0.60 and preferably more than 0.70 (Hair et al., 2012, 2017; Henseler et al., 2009; Henseler et al., 2015). From Table 4, the values for both CA and CR are more than 0.70 in the first and final iteration of the PLS-SEM. Hence, all sets of CSFs provide a reliable assessment of a single CSF's element.

Next, to assess the validity of the variables, one key test is convergent validity which refers to the proportion of variance captured by the CSF's element from its corresponding CSF due to measurement errors (Hair et al., 2014; Henseler et al., 2015). This test measures by assessing the Average Variance Extracted Value (AVE). Hair et al. (2014) and Henseler et al. (2015) argued that a minimum of 50% of the variance from a CSF is explained by the CSF's element to which it is assigned. This implies that the AVE value should be 0.50. Table 4 shows that the initial run of PLS-SEM generated results showing that one construct obtained AVE value less than the threshold value of 0.50. Items with low loadings (SAR11) were removed from the model. The second run of the PLS-SEM revealed an AVE value of more than 0.50. These results show that the study's measurement model has demonstrated adequate convergent validity.

Table 4. Results of Measurement Model

Latent Variable	Indicators	PLS-SEM 1				PLS-SEM 2			
		Loading	AVE	CR	CA	Loading	AVE	CR	CA
Strategy	ST1	0.806	0.563	0.934	0.922	0.806	0.563	0.934	0.922
	ST2	0.691				0.690			
	ST3	0.776				0.774			
	ST4	0.725				0.724			
	ST5	0.756				0.757			
	ST6	0.743				0.745			
	ST7	0.683				0.684			
	ST9	0.736				0.736			
	ST10	0.770				0.769			
	ST11	0.767				0.767			
	ST12	0.792				0.793			
People	PE1	0.830	0.721	0.928	0.903	0.820	0.721	0.928	0.903
	PE2	0.870				0.868			
	PE3	0.886				0.886			
	PE4	0.813				0.820			
	PE5	0.844				0.850			
Process	PS1	0.769	0.581	0.961	0.957	0.768	0.609	0.961	0.957
	PS2	0.745				0.741			
	PS3	0.805				0.815			
	PS4	0.790				0.788			
	PS5	0.786				0.793			
	PS6	0.826				0.824			
	PS7	0.771				0.761			
	PS8	0.787				0.783			
	PS9	~~0.588~~				-			
	PS11	~~0.641~~				-			
	PS12	0.751				0.743			
	PS13	0.778				0.784			
	PS14	0.781				0.788			
	PS15	0.785				0.798			
	PS16	0.743				0.753			
	PS17	0.768				0.774			
	PS18	0.785				0.792			
	PS19	0.780				0.779			
Technology	TE1	0.751	0.636	0.94	0.928	0.764	0.629	0.931	0.916
	TE2	0.828				0.824			
	TE3	0.825				0.795			
	TE4	~~0.838~~				-			
	TE5	0.722				0.751			
	TE6	0.828				0.839			
	TE7	0.816				0.820			
	TE8	0.765				0.754			
	TE9	0.794				0.794			
Success of Automation and Robotics	SAR2	0.713	0.484	0.937	0.929	0.760	0.530	0.935	0.925
	SAR3	0.689				0.735			
	SAR4	0.706				0.752			
	SAR5	0.712				0.755			
	SAR6	0.727				0.778			
	SAR7	0.718				0.758			
	SAR8	0.592				0.533			
	SAR9	~~0.628~~				-			
	SAR10	0.667				0.617			

SAR11	~~0.589~~	-
SAR12	0.601	0.568
SAR13	0.724	0.760
SAR14	0.774	0.801
SAR15	0.777	0.802
SAR16	0.752	0.778
SAR17	~~0.726~~	-

Next is to assess the discriminant validity. This test refers to the extent to which the construct does not correlate with other measures, which are different from it (Chin et al., 2013; Hair et al., 2012). The Fornell-Larcker criterion, cross-loadings, and Heterotrait-Monotrait ratio (HTMT) are the three criteria used to confirm the discriminant validity. Assessing discriminant validity within the structural construct involves evaluating the independence of the latent factors to compare the latent variable's correlations and square root of AVE. As suggested by Fornell & Larcker (1981), the AVE of a latent factor should be greater than the latent factor variance. The comparison of the relationship between the latent construct and the corresponding AVE's square root can be viewed in Table 5. However, this procedure led to the removal of two-measured variables from Table 4 (PS9 and PS11) as they violated the discriminant validity (Lowry & Gaskin, 2014). Nevertheless, this procedure did not compromise the overall research model, provided that most measurements have more than three items. The AVE's square root is highlighted by the diagonal values in the matrix. The values surpass the off-diagonal elements in the parallel rows and columns, indicating good discriminant validity.

Table 5. Discriminants Validity of Constructs

Latent Variable	AVE	Strategy	People	Process	Technology	Success of Automation
Strategy	0.563	**0.750***				
People	0.721	0.584	**0.849***			
Process	0.609	0.680	0.712	**0.781***		
Technology	0.629	0.569	0.608	0.698	**0.793***	
Success of Automation	0.530	0.603	0.562	0.701	0.623	**0.728***

Note: *The diagonal AVE values are greater than the off-diagonal AVE; diagonal values represent the AVE values.

The next assessment for discriminant validity is based on cross-loadings. Cross loadings for all the CSFs have higher values on their relative CSFs element than for other elements either in the same row or the same column. This verifies that the CSFs in each construct represent the assigned CSFs elements, thus affirming the model's discriminant validity. The third approach is to check the Heterotrait-Monotrait ratio of correlation criterion (HTMT) values. The HTMT ratio serves as a better approach for validity assessment than Fornell-Lacker and cross-loading because it can detect the lack of discriminant validity. The HTMT criterion values must be lower than 0.90 to show that the discriminant validity is valid, as illustrated in Table 6. The upper threshold for the current research was 0.765 as suggested for models that share a similar constructs concept (Henseler et al., 2015; Ramayah et al., 2018).

Table 6. HTMT Results

Latent construct	Strategy	People	Process	Technology	Success of Automation and Robotics in IBS
Strategy					
People	0.633				
Process	0.717	0.765			
Technology	0.606	0.660	0.734		
Success of automation and robotics in IBS	0.609	0.581	0.76	0.608	

4.2 Assessment of Structural Model

Table 7 and Figure 2 postulate the findings of the analysis by assessing the path coefficients of all CSFs' elements (paths) by comparing beta (β) values for all the paths. The path coefficient represents hypothesized relationships. The highest β value indicates the strongest relationship of an independent variable (CSF's element) with the dependent variable (Success of Automation and Robotics in IBS) (Urbach & Ahlemann, 2010). Hair et al. (2011) recommended that path coefficients should exceed 0.10 to account for a certain impact within the model. The path coefficient (β) and t-statistics (t-value) for each hypothesis were determined by bootstrapping, a nonparametric approach to gauge the accuracy of PLS estimates (Chin et al., 2008; Hair et al., 2014). To assess the path coefficient (β) and hypotheses, 5000 samples were used to generate the stable estimation as suggested by Henseler et al. (2009). The results showed that Strategy (β=0.151; t-value=1.749), Process (β=0.524; t-value=5.432) and Technology (β=0.175; t-value=2.11) have significant relationships on the success of automation and robotics in IBS.

Conclusively, the findings supported hypotheses H1, H3, and H4. As recommended by Hair et al., (2017), both the coefficient of determination (R^2) and predictive relevance (Q^2) must be considered in assessing the performance of a predictive model. The R^2 measures the predictive power of a structural model. It represents the share of variance explained in a dependent construct. It is perceived that the single R^2 generated in this study resulted in a value of 0.587, indicating that the four constructs can explain 58.7% of the variance in the CSFs' elements which is higher than the cut-off value of 0.50, and hence the model can be classified as moderately strong ((Joe F Hair et al., 2011). The R^2 value ranges from 0 to 1, where higher values indicate greater predictive accuracy. The Q^2 value, generated via a blindfolding procedure, assesses predictive relevance of the model. It is a sample re-use method that systematically removes data points and generates a prediction of their original value (Hair *et al.,* 2017). If the prediction is close to the original value, the model is considered as having a high predictive relevance. The greater the positive value of Q^2, the higher the predictive relevance. The Q^2 value > 0 suggests that the value is well constructed, and the construct demonstrates predictive relevance. For this study, the value of Q^2=0.264, which is greater than zero, indicates that the CSF's element has a good predictive relevance for the success of automation and robotics in IBS.

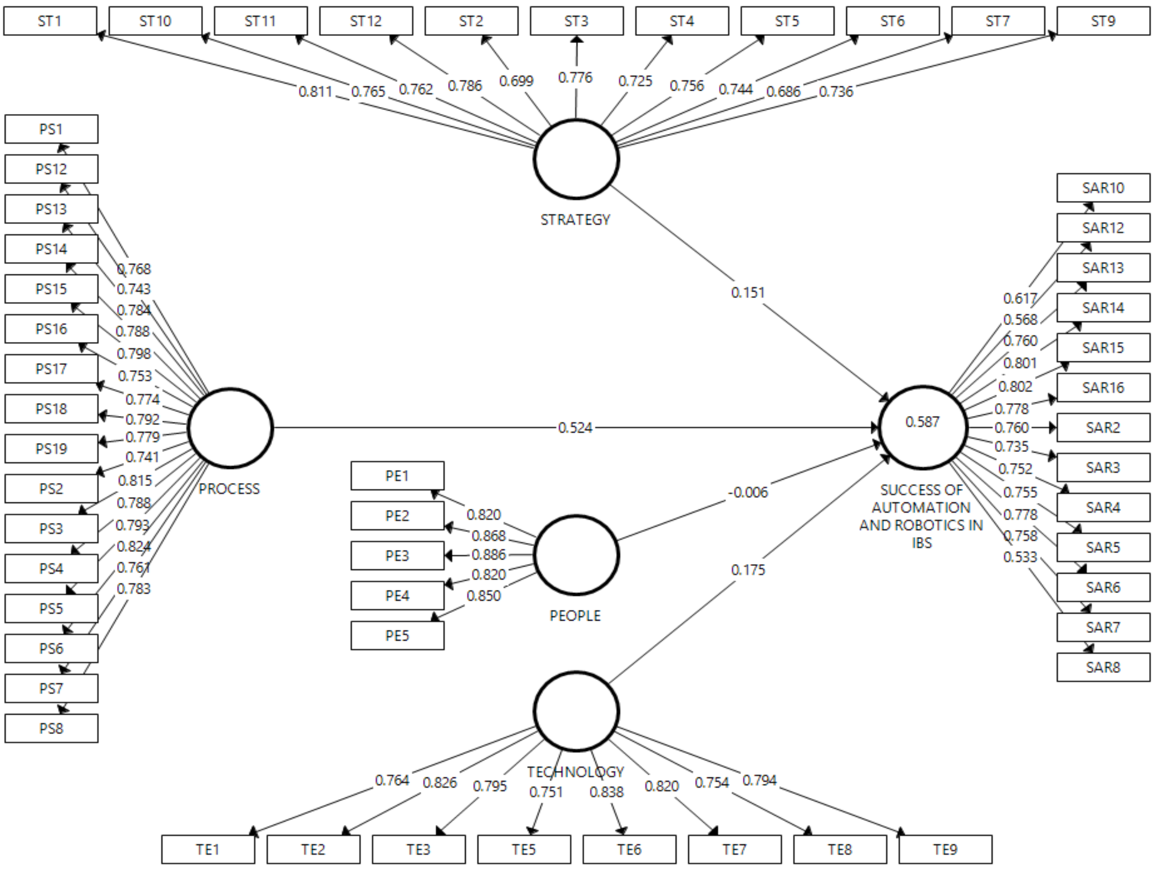

Figure 2. Conceptual Framework and Hypothesis Relationships (PLS-SEM)

Table 7. Results of Hypothesis Tests

Hypothesis	Relationship	Path Coefficient	*t*-value	P-value	Hypothesis
H1	Strategy-> Success of Automation and Robotics	0.151	1.749	0.080	Supported
H2	People-> Success of Automation and Robotics	-0.006	0.078	0.938	**Not Supported**
H3	Process-> Success of Automation and Robotics	0.524	5.432	0.000	Supported
H4	Technology-> Success of Automation and Robotics	0.175	2.111	0.035	Supported

Note: T > 1.64, p-value = 0.10, T > 1.96, p-value = 0.05, T > 2.58, p-value = 0.01

5.0 DISCUSSIONS

Strategy was found to affect the successful implementation of automation and robotics significantly (β coefficient = 0.151; t-value = 1.749; and p-value <0.10). Subsequently, to achieve success in the organisation, all the above results suggest that to achieve the successful implementation of automation and robotics in IBS, an organisation needs to acknowledge the importance of cost evaluation (0.806) and return on investments (0.736) to create a competitive environment when managing automation and robotics in IBS. The organisation that prioritizes the risk assessment (0.691) to evaluate the economies of scale (0.776), demand (0.756), and market factors (0.743) are more likely to succeed in the implementation of automation and robotics in IBS. In addition, the organisation is urged to collaborate through a partnering initiative (0.725) to remain competitive in the industry. The organisation also needs to align its vision (0.770) and mission (0.767). The top-down commitment (0.792) also needs to be implemented to motivate and make sure that the staff aligns with the organisation's vision and mission. It can be seen that the findings of this study are aligned with the previous surveys carried out in this area of research (CIDB, 2016; Els et al., 2012; Goulding et al., 2012; Hamid et al., 2011; Kamar, 2011; Lou & Kamar, 2012; Musa et al., 2017; Nadim & Goulding, 2011; Pan & Goodier, 2012; Sashitharan et al., 2014; Xue et al., 2017) thus confirming the hypothesis.

Process was found to influence the successful implementation of automation and robotics in IBS, (β coefficient = 0.524; t-value = 5.432; and p-value <0.01) since the organisation needs to establish a good working collaboration (0.768) and early involvement (0.7888) for all team members by having a strong relationship with the parties involved. To realize this, the organisation needs to have an effective communication channel (0.741) and advance planning & scheduling (0.793) to ensure the coordination of design, manufacture, transportation, and installation are completed successfully within a realistic schedule. To ensure the successful implementation of automation and robotics in IBS, the organisation is also urged to adopt the design for manufacture & assembly (DfMA) concept (0.743) to ensure the standardisation (0.784) of the design and product to facilitate mass production (0.798) and mass customisation (0.788). This could be achieved through modular design (0.753) and modular coordination (0.774). The organisation also needs to establish its supply chain support (0.792) system through acquiring manufacturing capability. The contractor can control the process, and the profit/loss is more predictable and can be adjusted accordingly across the company's IBS projects (Kamar & Hamid, 2011). On top of that, the organisation needs to consider the lean principle (0.824) through just-in-time (0.761) and just-in-sequence (0.783) to reduce the cost and to maximize the profit efficiently. It is also suggested that the organisation needs to implement continuous improvement (0.779). These factors contribute to the successful implementation of automation and robotics in IBS, thus supporting the hypothesis and the previous studies carried out in this area of research (CIDB, 2016; Els et al., 2012; Goulding et al., 2012; Hamid et al., 2011; Kamar, 2011; Lou & Kamar, 2012; Musa et al., 2017; Nadim & Goulding, 2011; Pan & Goodier, 2012; Sashitharan et al., 2014; Xue et al., 2017).

Technology was found to affect the successful implementation of automation and robotics in IBS, (β coefficient = 0.175; t-value = 2.111; and p-value <0.05). Consequently, all of the above results suggest that to successfully implement automation and robotics in IBS, the organisation needs to consider an appropriate information and communication technology (0.764) infrastructure to support the use of building information modelling (0.824) throughout all stages of construction. The study also reveals that the organisation should explore virtual reality (0.795) and the use of computer-aided drawing (0.751) as well as computer-aided manufacturing (0.839). Further, the organisation is also urged to have computer numerical control machines (0.820), additive manufacturing/3D printing (0.754), and the use of the internet of things (IoT) (0.794). It can be seen that the findings of this study are aligned with the previous surveys carried out in this area of research (CIDB, 2016; Els et al., 2012; Goulding et al., 2012; Hamid et al., 2011; Kamar, 2011; Lou & Kamar, 2012; Musa et al., 2017; Nadim & Goulding, 2011; Pan & Goodier, 2012; Sashitharan et al., 2014; Xue et al., 2017), thus confirming the hypothesis.

However, the hypothesis that ***people*** affect the successful implementation of automation and robotics in IBS was not supported with a statistically insignificant β coefficient (-.006), t-value (0.078), and p-value (>0.10). Nevertheless, although the measurement items have achieved strong results, the construct failed to show a convincing relationship. The factors recognized in this construct are experienced workforce/staff (0.830), technical capability (0.870), highly skilled workforce (0.886), education (0.813), and training (0.844). Although the study design shows that the successful implementation of automation and robotics in IBS is dependent on people as one of the predictors, the data collected does not have sufficient power to detect the dependence in this instance. Thus, the result of this study deviates from the findings of previous researchers in this field (CIDB, 2016; Els et al., 2012; Goulding et al., 2012; Hamid et al., 2011; Kamar, 2011; Lou & Kamar, 2012; Musa et al., 2017; Nadim & Goulding, 2011; Pan & Goodier, 2012; Sashitharan et al., 2014; Xue et al., 2017).

The possible reason for this deviation is that past researchers focused on the people element as an independent variable rather than a moderating variable. Consequently, the people element's moderating roles could play to the successful implementation of automation and robotics in IBS. The respondents found that the people element should be extended so that the organisation will effectively assess and monitor the contribution by people to the successful implementation of automation and robotics in IBS. Since this study is the first attempt to identify the correlation between each CSF's elements in automation and robotics in IBS, the formulation of the conceptual frameworks did not measure these criteria during its development process, thus ignoring the moderating role in which people could play a part. Furthermore, construction organisations and professionals are aware of the benefits and advantages of automation and robotics in IBS (Abanda et al., 2017; Ardiny et al., 2015; Cobb, 2001; Kamaruddin et al., 2016; Kapliński et al., 2002; Lim et al., 2012; Pan et al., 2018; Son et al., 2010; Waris & Khamidi, 2013; Yunus et al., 2015). However, when a new technology or process is introduced in any organisation, it is only natural for the employees to exhibit caution and fear regarding their job security due to potential changes in responsibility and process (Lou & Alshawi, 2009; Hamid et al., 2011). However, these are more related to the organisational soft issues or non-technical issues, which underpin an organization's capacity to absorb new technologies into its work practices successfully (Soetanto et al., 2019). Another factor contributing to this deviation from the previous studies was an unwillingness to change, as it involves changes in people's behaviour to handle new technology (Marcinkowski & Gawin, 2019). People usually resist change as they are already comfortable with the current work practice (Mardhiyah & Salleh, 2012; Strukova & Liska, 2012).

6.0 CONCLUSIONS

The findings of this study contribute significantly to the academic knowledge and new discoveries whilst filling the knowledge gap in terms of strengthening the theoretical research and literature in the field of IBS, automation and robotics, and the social sciences. Up to now, the discussions and literature in past studies on the CSFs for automation and robotics in IBS have been limited, and less extensive than the attention in the relationship of identified CSFs with the successful implementation of automation and robotics in IBS. Although previous studies have explored the area, these were generally broad and lacked focus on specific focus and best practices that can be implemented concerning automation and robotics in IBS. Therefore, this research's uniqueness is in the new knowledge that it contributes. This study has identified four CSFs' elements encompassing 43 CSFs. Only three of these CSFs elements, namely Strategy, Process, and Technology, have a significant relationship with the successful implementation of automation and robotics in IBS specifically, in the Malaysian context. This research supports a previous model (Els et al., 2012; Goulding et al., 2012; Hamid et al., 2011; Kamar, 2011; Lou & Kamar, 2012; Musa et al., 2017; Nadim & Goulding, 2011) as a principal framework for developing the CSFs conceptual model for the successful implementation of automation and robotics in IBS. The CSFs structured model presented in this study was developed by examining the relationships between the CSFs' elements (Strategy, People, Process and, Technology) with the successful implementation of automation and robotics in IBS, using 16 critical criteria. The hypotheses were developed to explain the relevance of these relationships. The conceptual model establishes that implementing these factors can lead to the successful adoption of automation and robotics in IBS. Therefore, the findings are expected to serve as foundational guidelines for future research, enabling other researchers to carry out a comprehensive and in-depth study relating to IBS, automation, robotics, and other related areas.

7.0 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.

Abdullah, M. R., Rashid, M. N. A. & Mohamad, W. N. W. (2024). Challenges In Selecting the Appropriate Type of Industrialised Building Systems (IBS) In Housing Projects: The Role of Intuition and Heuristics Approach. Malaysia Construction Research Journal, 22(2).

Alashwal, A. M., Fareed, N. F., & Al-obaidi, K. M. (2017). Determining Success Criteria and Success Factors for International Construction Projects for Malaysian Contractors. Construction Economics and Building, 17(2), 62.

Andersson, N., & Lessing, J. (2017). The Interface between Industrialized and Project Based Construction. Procedia Engineering, 196(June), 220–227.

Ardiny, H., Witwicki, S., & Mondada, F. (2015). Construction automation with autonomous mobile robots: A review. Proceedings of the 3rd RSI International Conference on Robotics and Mechatronics, ICROM 2015, 418–424.

Bock, T., & Linner, T. (2010a). Enhanced Industrialized Customization Performance by Embedded Microsystems. 27th International Symposium on Automation and Robotics in Construction (ISARC 2010) ENHANCED, Isarc, 2–11.

Bock, T., & Linner, T. (2010b). Individualization of design variation in construction. 2010 - 27th International Symposium on Automation and Robotics in Construction, ISARC 2010, Isarc, 597–606.

Carra, G., Argiolas, A., Bellissima, A., Niccolini, M., Ragaglia, M., Bellissima, A., Argiolas, A., Carra, G., Ragaglia, M., Argiolas, A., Bellissima, A., Niccolini, M., & Ragaglia, M. (2018). Robotics in the Construction Industry: State of the Art and Future Opportunities. Proceedings of the 35th International Symposium on Automation and Robotics in Construction (ISARC), July.

Chin, W. W. Peterson, R. A., Brown, S. P. Chin, W. W. Peterson, R. A., & Structural, S. P. B. (2008). Structural Equation Modeling in Marketing: Some Practical Reminders. Journal of Marketing Theory and Practise, 16(4), 287–298.

Chin, W. W., Thatcher, J. B., Wright, R. T., & Steel, D. (2013). Controlling for Common Method Variance in PLS Analysis: The Measured Latent Marker Variable Approach. 231–239.

CIDB. (2016). Construction Industry Tranformation Program 2016 - 2020.

CIDB. (2020). Construction 4.0 Strategic Plan (2021-2025). In Construction Industry Development Board (CIDB).

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

Čuš-Babič, N., Rebolj, D., Nekrep-Perc, M., & Podbreznik, P. (2014). Supply-chain transparency within industrialized construction projects. Computers in Industry, 65(2), 345–353.

DOSM. (2024). Banci Ekonomi Pembinaan 2023.

Dzulkalnine, N. (2019). IBS Adoption in Malaysian Construction Industry. Proceedings of the International Conference on Industrial Engineering and Operations Management.

Els, M., Van Der Merwe, M. F. &, & Hauptfleisch, A. C. (2012). Critical success criteria and success factors in project management: A quest to enhance generic professional practice. Department of Quantity Surveying and Construction Management, University of the Free State, 2012(1st), 14.

Fornell, C., & Larcker, D. F. (1981). Evaluating Structural Equation Model with Unobservable Variables and Measurement Error. Journal of Marketing Research, 18(1), 39–50.

Goulding, J., Rahimian, F. P., Arif, M., & Sharp, M. (2012). Offsite Construction: Strategic Priorities for Shaping the Future Research Agenda. Architectoni.Ca, 1(1), 62–73.

Goulding, J. S., Pour Rahimian, F., Arif, M., & Sharp, M. D. (2014). New offsite production and business models in construction: priorities for the future research agenda. Architectural Engineering and Design Management, 11(3), 163–184.

Hair, J. F., Hult, G. T. M., Ringle, C. M., Sarstedt, M., Thiele, K. O., & Thiele, K. O. (2017). Mirror, mirror on the wwall:a comparative evaluation of composite-based structural equation modeling methods. Springer.

Hair, J. F. Jr., Hult, G. T. M., Ringle, C., & Sarstedt, M. (2014). A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM). SAGE Publication, Inc.

Hair, J. F., Ringle, C. M., & Sarstedt, M. (2011). PLS-SEM: Indeed, a Silver Bullet. Journal of Marketing Theory and Practice, 19(2), 139–151.

Hair, J. F., Sarstedt, M., Hopkins, L., & Kuppelwieser, V. G. (2014). Partial least squares structural equation modeling (PLS-SEM) An emerging tool in business research. Emerald. https://doi.org/10.1108/EBR-10-2013-0128

Hair, J. F., Sarstedt, M., Pieper, T. M., & Ringle, C. M. (2012). The Use of Partial Least Squares Structural Equation Modeling in Strategic Management Research: A Review of Past Practices and Recommendations for Future Applications. Long Range Planning, 45(5–6), 320–340.

Hamid, Z. A., Kamar, K. A. M., & Alshawi, M. (2011). Industrialised Building System (IBS): Strategy, People and Process. CREAM.

Hamid, Z. Abd., Kamaruzzaman, S. N., Raphael, B., Alias, A., Ghani, M. K., Abdul Razak, M., & Ibrahim, I. (2013). Leveraging ICT Strategy for Malaysian Facilities Management. CREAM.

Hamid, Z., Kamar, K., Ghani, M., Mohd Zain, M., & Abdul Rahim, A. (2011). Business Strategies of Contractors in Industrialised Building Systems (Ibs) Construction. Vertilite.Asia, September 21–22.

Henseler, J., Ringle, C. M., & Sarstedt, M. (2015). A new criterion for assessing discriminant validity in variance-based structural equation modeling. Journal of the Acad. Mark. Sci., 43, 115–135.

Henseler, J., Ringle, C. M., & Sinkovics, R. (2009). The Use of Partial Least Squares Path Modeling in International Marketing. Advances in International Marketing, 20, 277–319.

Jin, R., Gao, S., Cheshmehzangi, A., & Aboagye-nimo, E. (2018). A holistic review of off-site construction literature published between 2008 and 2018. Journal of Cleaner Production, 202, 1202–1219.

Kamar, K. A. M. (2011). Critical Success Factors to Industrialised Building System (IBS) Contractor. PhD Thesis, January.

Kamar, K. A. M., Azman, M. N. A., & Nawi, M. N. M. (2014). IBS survey 2010: Drivers, barriers and critical success factors in adopting industrialised building system (IBS) construction by G7 contractors in Malaysia. Journal of Engineering Science and Technology, 9(4), 490–501.

Kamar, K. A. M., & Hamid, Z. A. (2011). Supply chain strategy for contractors in adopting industrialized building system (IBS). Australian Journal of Basic and Applied., 5(12), 2552–2557.

Kamaruddin, S. S., Mohammad, M. F., & Mahbub, R. (2016). Barriers and Impact of Mechanisation and Automation in Construction to Achieve Better Quality Products. Procedia - Social and Behavioral Sciences, 222, 111–120.

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.

Li, X., Qureshi, A., & Ai-Hussien, M. (2017). Developing a BIM-based integrated model for CAD to CAM building production automation. ISARC 2017 - Proceedings of the 34th International Symposium on Automation and Robotics in Construction, Isarc, 51–58.

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.

Lou, E. C. W., & Alshawi, M. (2009). Critical success factors for e-tendering Implementation in construction collaborative environments: people and process issues. Electronic Journal of Information Technology in Construction, 14(May), 98–109.

Lou, E. C. W., & Kamar, K. A. M. (2012). Industrialized Building Systems: Strategic Outlook for Manufactured Construction in Malaysia. Journal Of Architectural Engineering, 18(June), 69–74.

Lowry, P. B., & Gaskin, J. (2014). Partial Least Squares (PLS) Structural Equation Modeling (SEM) for Building and Testing Behavioral Causal Theory: When to Choose It and How to Use It. IEEE Transactions on Professional Communication, 57(2).

Mangal, M., Wang, Q., & Cheng, J. C. P. (2017). Automated clash resolution of steel rebar in RC beam - Column joints using BIM and GA. ISARC 2017 - Proceedings of the 34th International Symposium on Automation and Robotics in Construction, Isarc.

Marcinkowski, B., & Gawin, B. (2019). A study on the adaptive approach to technology-driven enhancement of multi-scenario business processes. Information Technology and People, 32(1), 118–146.

Mardhiyah, N., & Salleh, H. (2012). The Critical Success Factors (CSFs) in Information Technology / Information System (IT/IS) in Construction: A Case Study of People Issues in. 19(9), 215–235.

Meynagh, M. M., Marsono, A. K., Kamar, K. A. M., & Isaabadi, M. H. Z. (2014). Main Factors of Contractor Reluctancy to Adopt IBS Projects In Malaysia. Australian Journal of Basic and Applied Sceinces, 8(18), 251–254.

Mohamad, D., Ramli, M.Z., Danuri H.N, Sapuan, W. K. (2016). Demand of the industrialized building system (IBS) implementation in Malaysian government projects. Journal of Scientific Research and Development, 3(4), 77–82.

Mohammed, A. M. (2016). Ehancing Skill Worker Requirements in Improving Implementation of IBS In Construction Projects. In PhD Thesis.

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

Musa, M. F., Yusof, M. R., Samsudin, N. S., & Halil, F. M. (2017). The Industrialised Building System Modular System (IBSMS) Framework. Environment-Behaviour Proceedings Journal, 2(5), 105.

Nadim, W., & Goulding, J. S. (2011). Offsite production: a model for building down barriers. Engineering, Construction and Architectural Management, 18(1), 82–101.

Nawi, M., Azman, A., Osman, W. N., Radzuan, K., & Yaakob, M. (2016). Key success factors for team integration practice in Malaysian industrialised building system (IBS) construction industry. Malaysian Journal of Society and Space, 12(3), 88–94.

Nawi, M. N. M., Lee, A., Azman, M. N. A., & Kamar, K. A. M. (2014). Fragmentation issue in Malaysian industrialised building system (IBS) projects. Journal of Engineering Science and Technology, 9(1), 97–106.

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

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(February), 82–95.

Pan, W., & Goodier, C. (2012). House-Building Business Models and Off-Site Construction Take-Up. Journal of Architectural Engineering, 18(2), 84–93.

Ramayah, T., Cheah, J., Ting, F. C. H., & Memon, M. A. (2018). Partial Least Square Structural Equation Modeling (PLS-SEM) Using SmartPLS 3.0: An Updated and Practical Guide to Statistical Analysis (2nd Edition). Pearson.

Rashid, M. N. A (2022). Critical Success Model for Automation and Robotics in Malaysian Industrialised Building System (IBS). PhD Thesis. UNIVERSITI TEKNOLOGI MARA.

Rashid, M. N. A., Abdullah, M. R., Ismail, D., & Saberi, M. H. (2021). Success Criteria for Automation and Robotics in Industrialised Building System (IBS). International Journal of Academic Research in Business & Social Science, 11(2), 1259–1273.

Rockart, B. &. (1981). Critical success factors. Planning Review.

Said, H. (2015). Prefabrication Best Practices and Improvement Opportunities for Electrical Construction. Journal of Construction Engineering and Management, 141(12), 04015045.

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

Sashitharan, S., Jusoh, M. S., Amlus, M. H., Rahimi, A., Ibrahim, A., & Ismail, M. S. (2014). Industrialized Building System (IBS) Performance in Malaysian Construction Industry: Analysing the Cost , Training and Construction Policies. Journal of Applied Science and Agriculture, 9(13), 6–13.

Soetanto, R., Dainty, A. R. J., Price, A. D. F., & Glass, J. (2019). A framework for investigating human factors issues associated with the implementation of new ICT systems in construction organisations. Proceedings of the 2nd International Conference on Innovation in Architecture, Engineering and Construction. Loughborough, UK, June 25-27, 2003, 0–10.

Son, H., Kim, C., Kim, H., Han, S. H., & Kim, M. K. (2010). Trend analysis of research and development on automation and robotics technology in the construction industry. KSCE Journal of Civil Engineering, 14(2), 131–139.

Stojanova, T., Gecevska, V., Bb, K. A., & Kopje, S. (2013). Implementation of Mass Customization. International Journal of Engineering, 227–232.

Strukova, Z., & Liska, M. (2012). Application of automation and robotics in construction work execution. Journal of Interdisciplinary Research, 2(2), 121–125.

Tajuddin, M. A., Rizal Mohamed, M., Najib, M., Rashid, A., Nasir, N., & Mahdzir, M. (2025). Barriers And Solutions of Building Information Modelling (BIM) In Construction Site Safety In Malaysia. In Journal of the Malaysian Institute of Planners (Vol. 23).

Tajul Ariffin, S., Yunus, R., Mohammad, H., & Yaman, S. K. (2017). A Preliminary Review on Economies of Scale (EOS) Towards Industrialized Building System (IBS) Manufacturer. MATEC Web of Conferences, 103(April), 03008.

Urbach, N., & Ahlemann, F. (2010). Structural Equation Modeling in Information Systems Research Using Partial Least Squares. Journal of Information Technology Theory and Application, 11(2), 5–40.

Waris, M., & Khamidi, M. F. (2013). Construction Industry Heavy Equipment Acquisition in Malaysian Construction Industry. 2013 IEEE Symposium on Business, Engineering and Industrial Applications, February 2016.

Xue, H., Zhang, S., Su, Y., & Wu, Z. (2017). Factors Affecting the Capital Cost of Prefabrication — A Case Study of China. MDPI, 1–22.

Yang, Y., Pan, M., & Pan, W. (2019). Automation in Construction 'Co-evolution through interaction' of innovative building technologies: The case of modular integrated construction and robotics. Automation in Construction, 107(May), 102932.

Yunus, R., Masrom, A. N., Abdullah, A. H., & Mustakim, F. (2015). Conceptual Model of Contractor Satisfaction in the Industrialized Building System (IBS) Implementation. Applied Mechanics and Materials, 773–774, 828–833.

Yunus, R., Noor, S. R. M., Abdullah, A. H., Nagapan, S., Hamid, A. R. A., Tajudin, S. A. A., & Jusof, S. R. M. (2017). Critical Success Factors for Lean Thinking in the Application of Industrialised Building System (IBS). IOP Conference Series: Materials Science and Engineering, 226, 012045.

Yunus, R., & Yang, J. (2014). Improving ecological performance of industrialized building systems in Malaysia. Construction Management and Economics, 32(1–2), 183–195.

Yusof, M. R., Nawawi, A. H., Mohammad, M. F., & Musa, M. F. (2015). Key Success Factors in IBS Project Management. IEEE Colloquium on Humanities, Science and Engineering (CHUSER 2014), Chuser 2014, 210–215.

Zhiqiang, C., Balasubramaniam, G., & Edirisinghe, R. (2019). Productivity Improvement in the Construction Industry: A Case Study of Mechanization in Singapore. Advances in Informatics and Computing in Civil and Construction Engineering, 497–503. https://doi.org/10.1007/978-3-030-00220-6