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An Empirical Investigation to Enhancing Construction Site Performance Through Efficient Material Waste Mitigation in the Malaysian Construction Industry

Mahdi Mohammed Abdullah Abkar[1*], Riduan Yunus[1], Ahmed Saleh Ahmed Saif Al-Shameri[2], Ahmed Harouache[2]

[1]Faculty of Civil Engineering and Built Environment,
Universiti Tun Hussein Onn Malaysia, Johor, 86400, MALAYSIA

[1]Faculty of Technology Management and Business,
Universiti Tun Hussein Onn Malaysia, Johor, 86400, MALAYSIA

*Corresponding Author

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Abstract: Automation Technological advancements in construction significantly enhance efficiency by integrating productivity, cost-effectiveness, and innovation throughout the construction life cycle, fostering both economic growth and industry advancement. This study investigates the role of Technology and Management Practices TMP in mitigating material waste to enhance Construction Site Performance (CSP) within Malaysia's construction sector. Five hypotheses were formulated to explore the relationship between TMP and CSP. Data collection involved an online survey targeting construction personnel and experts in Malaysia, resulting in 295 valid responses for hypothesis validation. The analysis utilized Partial Least Squares-Structural Equation Modeling (PLS-SEM) techniques in conjunction with IBM's Statistical Package for the Social Sciences (SPSS), recognized for its robust statistical capabilities in empirical research. The study's findings suggest that adopting TMP, along with their perceived value and applicability in material waste mitigation, can notably elevate the performance of Malaysian construction sites. This emphasizes the significance of technology and management practices in workplace strategies. The results imply that all stakeholders can leverage TMP to advance ongoing efforts in reducing material waste, shaping a more sustainable future.

Keywords: Technology and management practice in construction, Material Waste Mitigation, Malaysian Construction Site, Construction Site Performance

1. Introduction

Over the past two decades, environmental concerns have escalated, urging prompt attention and mitigation efforts in Malaysia. The management of material waste at construction sites significantly impacts project costs and the environment, necessitating innovative waste reduction methods by contractors (Mohammed *et al.*, 2020). This study addresses the scarcity of waste management expertise, emphasizing the risk of improper solid waste handling. Unauthorized dumping practices linked to Malaysia's construction sector highlight the immediate need for effective construction waste management (Amalyn *et al.*, 2023). Malaysia's construction industry has consistently underperformed, facing challenges such as project delays, cost overruns, and subpar quality. Reports from the

*Corresponding author: mahdi.mohammed34@gmail.com

Malaysian Construction Industry Development Board (CIDB) indicate the sector's failure to meet the country's Gross Domestic Product (GDP) expectations (Nawi *et al.*, 2023). The Industrial Building System (IBS) exhibits the potential to improve quality, safety, cost-effectiveness, productivity, and material waste reduction in construction sites (Mohsen *et al*., 2021). However, its limited adoption and reliance on foreign workers lacking the necessary skills hinder its integration into Malaysian construction sites (Nawi *et al*.,2015).

Despite being acknowledged as a means to enhance construction performance, the Industrialized Building System (IBS) faces low adoption rates and challenges in Malaysia's construction industry. Integrating technology with IBS is recognized as a pathway to achieve better project quality and efficient communication among stakeholders (Sio & Ming ., 2021). While Building Information Modelling (BIM) integration with stakeholders offers comprehensive data collection, its application in construction waste management requires deeper exploration (Basheer *et al*., 2021). The incorporation of BIM and other material management technologies can potentially elevate productivity in the construction sector (Rahim, *et al*., 2017). However, resistance, lack of standardization, high costs, and training requirements hinder their adoption in construction sites (Yap, 2022; Hatoum & Nassereddine 2020).

In Malaysia, the construction industry grapples with inefficient construction waste management, resulting in significant environmental and economic impacts. Despite contributing to global energy consumption and emissions, the adoption of green technology in Malaysia remains nascent (Jaffar, 2022). Similarly, the utilization of the Green Building Index (GBI) strategy to address construction waste faces limitations, warranting an investigation into its adoption factors and potential benefits. Material management in developing nations, including Malaysia, lacks clarity, necessitating further research to enhance construction waste management (Rahim *et al.*, 2017). While technology in construction offers connectivity and efficiency, challenges including resistance, lack of standards, and high costs impede its widespread adoption (Yap, 2022; Hatoum & Nassereddine 2020). Efforts to overcome barriers and promote technological adoption in construction sites remain pivotal for the industry's advancement.

2. Literature Review

The existing body of knowledge among the previous researcher's review could be explored and distinguished with such effective implementation in terms of waste reduction by implementing materials in construction sites among the initiatives managing and formulated use in the developed countries. Nurzalikha *et al*. (2015) stated that numerous nations have additionally considered the appropriate site management and location that utilize reusing and recycling for the generated waste produced during construction activities. They add that any condition has to be recycled and reused within any guidelines to secure the material's losses according to the environmental regulations and safety practices. Malaysia needs such a comprehensive waste management system to limit the quantity of waste by upcoming time due to the expansion of lifestyle standards and development, the growth of construction demand, and the increase and the amount of material loss (Alaloul *et al.*, 2021). The population has positively contributed to the increase in generated waste (Mohd Hilmi & Narimah Kasim, 2017).

In the construction industry, such a crucial part plays an essential factor with rapid effect in most countries toward economic growth as well for Malaysian BIM technologies played a new-fangled implementation, playing a foremost part in enlightening the construction management setting. BIM implementation in the construction industry helps to reduce waste and also reliefs in releasing the potential for the process as Rajendran *et al*. (2014) declared that one of the main factors that negatively contribute to the development of construction firms is the piece of material components which spend without consideration as its lead to wasting challenges of materials which cause delay to the project among the estimated time then expenditure exceeding the budget of the project.

As stated by Veerasanai & Alias (2020) mentioned that the development of any nation strongly affects monetary development; aside from the daily lives of citizens' activities that serve the development of any country, business action fills in as a fundamental contribution to the exhibition of different segments in the nation. Manoharan *et al.* (2020) declared that the development of construction projects is hugely in conjunction with the Malaysian Plan 2020 according to the roles that have become vital toward the growth and that roles played increasingly with a crucial enhancement for the status of development that battled to accomplish the target that has been planned initially to be accomplished in the year 2020. The development in the construction industry is imperative to increase with a vital improvement in the side of economic development, which is still expanding with both infrastructure and construction industry demand that are seeking development and improvement with essential to the environments and sustainability as well to the human life concern on the earth (Umar, Shafiq, & Isa, 2018).

Zhang *et al.* (2014) developed in their research to cope with as pressure of environmental change among human change, land use, and economic growth movement, development in construction aspects are in demand for more improvement, which blasting in numerous nation's thought and priority. Hasmori *et al.* (2020) Expressed that the unused components of construction materials that come as a result of the construction activities either during the pre-construction or construction stage, even post-construction, despite such commitments and contributions with rapid development are considered such as a serious issue that faced within the increase of the materials waste in a construction site (Saadi *et al*.,2016).

2.1 Technological Approach in the Construction Sector

Low waste technologies (LWTs) represent a foundational strategy in Construction Waste Management (CWM) within the construction industry. Employing LWTs during construction optimizes resource consumption, substantially curbing waste production, and acknowledges their significant impact on global environmental consequences. The construction sector's utilization of nearly 40% of Earth's extracted raw materials and contribution of close to 50% of global carbon emissions highlight the urgency for waste reduction emissions (Bonoli et al., 2021). Termed 'soft technologies,' these innovations aid project managers in enhancing operational efficiency during construction, thereby minimizing Construction Waste (CW) generation (Martínez-Rojas et al., 2016). LWTs facilitate improved coordination, collaboration, and data exchange among stakeholders involved in construction processes, encompassing data sharing, device performance, and archival practices (Zhang & Ng, 2012; Martínez-Rojas et al., 2016). For instance, Building Information Modeling (BIM), a prevalent information system in construction and engineering, integrates extensive datasets, including geometry and resources. This integration, aligned with project timelines, enables efficient planning, ensuring Just-In-Time delivery of resources and manpower (Won & Cheng, 2017). RFID technology stands as another illustration, streamlining material handling on construction sites, reducing human errors, and minimizing CW generation (Nur Shabudin & Taib, 2021). The incorporation of advanced machinery and tools at construction sites is becoming increasingly common, promoting efficient CWM practices that enhance quality, safety, and performance, and expedite construction timelines (Tam et al., 2015; Pan et al., 2018). An innovative formwork system utilizing prefabricated steel is another frequently employed technique. Offering consistent surfaces and enhanced durability compared to traditional timber-based formwork, it reduces material and labour requirements, mitigating issues related to stepped joints and irregular surfaces (Tam et al., 2015

2.2 Material Waste Mitigation Utilizing the 3R Approach

The increasing incidence of illicit dumping associated with construction endeavours in Malaysia underscores the pressing need for comprehensive management of construction waste in the country (Osman, Nasrun *et al.*, 2017). However, it is noteworthy that there is currently a lack of a well-defined set of criteria for construction waste management, particularly within developing nations. The incorporation of 3R's methodologies, namely Reduction, Reuse, and Recycling, into the domain of materials management. Furthermore, it examines the potential applicability of these 3R principles across various industries, including the construction sector (Osman, Nasrun *et al.*, 2017; Musa Mohammed *et al.*, 2022). Musa *et al*. (2022) state that (the 3R) practice normally specifies the action for each type of waste, while (Azman & Yaacob, 2017) in their finding defined 3R practice in the construction site as responsibilities that all parties involved in the site have to consider as important action to follow during construction workplace. Reusing construction materials can effectively reduce waste generation in construction processes while also improving site management due to waste reduction (Sila, 2021). The recycling of construction waste holds the potential to efficiently reintegrate valuable resources into the production cycle, consequently mitigating waste treatment expenses before disposal (Tan *et al.*, 2017). Furthermore, this practice not only aligns with environmental conservation objectives but also contributes to reducing the strain on land resources designated for material waste disposal. Therefore, the construction industry should focus on the 3R approach to ensure adherence and improve construction site performance.

2.3 Material Waste Mitigation Utilizing BIM

Building Information Modelling (BIM), functioning as a digital technology platform, presents auspicious avenues for enhancing the widespread implementation of waste management strategiess (Erol & Dikmen, 2023). In recent years, BIM has been widely regarded as a game-changing innovation in the building sector. The abbreviation term BIM is the acronym for "building information modelling," which is a set of technologies and related works that are used to define and manage the information needed and created throughout the building design, construction, and operation processes (Hameed *et al*., 2022).

Manzoor *et al.* (2021) mentioned BIM technology positively ensures that project personnel are communicating and working together to speed up the projects and contribute to maximizing the material waste while decreasing the costs and boosting the sustainability of the project. It is evident from the work of past academics and experts in the field that BIM technology can boost project efficiency, reduce mistakes, and save both time and cost (Al-ashmori *et al.*, 2020).

High performance in construction is attainable because of BIM's adaptability to a variety of management procedures and studies, which include both the operational and financial aspects of a project (Doumbouya, Gao, & Guan, 2016). Low productivity, little technical innovation, minimal automation, and computerization are described in the construction business as a study by Aitbayeva, (2020) stated that Advanced technologies like BIM can boost efficiency, cut down on expenses, and speed up the completion of construction projects while similarly research by Tiffany *et al.*, (2019) indicated that, BIM has been gaining some traction in Singapore's construction sector as a way to more effectively coordinate stakeholders in the process, boost site performance, and cut down on rework. The value of building information modelling (BIM) to the construction industry's development and efficiency has been widely acknowledged.

2.4 Material Waste Mitigation Utilizing IBS

The Industrialized Building System (IBS) has gained acknowledgement as a practical approach for enhancing overall construction performance concerning quality, cost-effectiveness, safety and health standards, waste reduction, and productivity. In Malaysia, the construction industry is regarded as a significant contributor to the nation's development (Awag *et al.,* 2023). According to the Construction Industry Development Board Malaysia (CIDB), IBS is described as the method of producing construction components within a controlled environment, then positioning, transporting, and assembling them into a structure with minimal additional on-site activities (Algumaei & Sarpin, 2022).

To enhance the performance of the construction sector, innovative approaches have been introduced to enhance its efficiency. Among the prominent methods being employed and researched are Industrialized Building Systems (IBS) and prefabrication construction techniques (Razak *et al.,* 2022). The utilization of (IBS) technology, which emphasizes off-site prefabrication and modularization, not only leads to a substantial decrease in environmental harm but also results in substantial productivity improvements, reduced labour demands, and enhanced working conditions. IBS technology has now become a widespread and expanding construction method in both developed and developing nations (Rofdzi *et al.*, 2018).

2.5 Material Waste Mitigation Utilizing GBI

Malaysia introduced the Green Building Index (GBI) to support the National Association of Homebuilders (NAHB) in advancing sustainable development through the application of Green Building Guidelines for residential structures (Chin Yee Ha *et al.*, 2023). The technique that has been suggested is much more accurate than an evaluation process that exclusively concentrates on the decrease of energy usage. The GBI rating tool allows land owners and builders to plan and establish environmentally friendly and sustainable buildings that can provide resource productivity, emission reduction, healthy indoor surroundings, maintain high standards for public transportation, and the application resource recovery and green space for their developments, thereby reducing the negative implication that their projects have on the environment (Liew, 2012).

As the green building idea is relatively new to Malaysia and requires innovative materials, it is challenging for developers, contractors, and subcontractors to obtain all of the necessary materials and technologies for the construction of green construction (Chin, Ismail, & Jing, 2020). It has been shown that green practices and techniques in the construction sector significantly benefit the environment. Green building has been characterized as the current trend in environmental protection. However, various advantages and obstacles are drawing and restraining the developers from using and implementing GBI in their projects. There are substantial differences in values produced from the green construction index, which comprise reducing, reusing, and recycling material waste in construction sites (Oyenuga & Bhamidimarri, 2015). This concept appeared to optimize energy conservation, conservation of natural resources, and waste reduction. Considered to be the most conventional method for lowering the amount of construction waste that is diverted to landfills, the value of wastes discovered by decreasing material waste includes strategies, recognition programs, sufficient capital and support for the implementation.

2.6 Material Waste Mitigation Utilizing MMA

The strategy for obtaining the requisite performance in construction projects, known as site management, became more widely accepted. This is due to a realization that appropriate site management is necessary for achieving performance (Tan *et al*., 2017); Sin et al., (2013). One of the most important criteria for improving waste reduction is to increase on-site material reuse (Ajayi *et al.*, 2016).

A study by Mousa & Othman (2019), Particularly where resource management and contact factors methods highlights the significance of cultivating a workforce engaged in environmental concerns, which may enhance performance effectively promoting green culture relies on cooperation, workforce training, assessment and evaluation of environmental objectives, and corporate culture and competitive performance to enhance construction site performance. Minimizing costly materials usually positively enhances construction site performance from quality assurance and economic perspectives (Omeje, Okereke, & Chukwu, 2020). At the same time, site performance is enhanced positively by estimation, budgeting, planning, and monitoring materials in the site workplace (Alaloul, Liew, Amila, & Abdullah, 2016); (Chowdhury *et al*., 2019).

Jusoh & Kasim, (2016) stated that scheduling of materials through material management provides an overview of the time-related work required to finish the project. They add that material management positively affects material handling and transport on the construction site. Besides, quality assurance is one material management that affects the construction site's cost, time, and quality performance. Another study by (Oseghale *et al*., 2021) developed that receiving and inspection are the material management indicators that enable store managers to organize and plan for clearances of materials on site. (Jusoh & Kasim, 2016) ; (Kumar, 2018); and (Rathod, 2019), in their study regard to construction site management, stated that inventory control, storage, and warehousing are essential for construction site performance.

Site communication is one material management indicator that provides sufficient information between all parties. It was shown to impact building site performance significantly (Oseghale *et al*., 2021). Project teams with different values and interests. Effective collaboration and communication between all stakeholders are essential, given the nature of the work (Setiawan, Hansen, & Fujino, 2021). Besides, Abdul Majid *et al*. (2015), Crawford (2017), Gamil (2020) in their finding they mentioned that value engineering is one of the material management aspects with higher specifications and less cost for construction site management.

2.7 Hypotheses and Conceptual Framework

The model illustrating the paper's framework is depicted in Figure 1. To accomplish the paper's objectives, five primary hypotheses have been formulated, outlined below:

H1: There is a significant relationship between Technology and management practice utilising "Reduce, Reuse and Recycle" (3R) as material waste mitigation and Construction Site Performance CSP.

H2: There is a significant relationship between Technology and management practice utilising "Building Information Modelling (BIM) as material waste mitigation and Construction Site Performance CSP.

H3: There is a significant relationship between Technology and management practice utilising "Industrial Building Systems" (IBS) as material waste mitigation and Construction Site Performance CSP.

H4: There is a significant relationship between Technology and management practice utilising the "Green Building Index" (GBI) as material waste mitigation and Construction Site Performance CSP

H5: There is a significant relationship between Technology and management practice utilising Material Management Adoption as material waste mitigation and Construction Site Performance CSP.

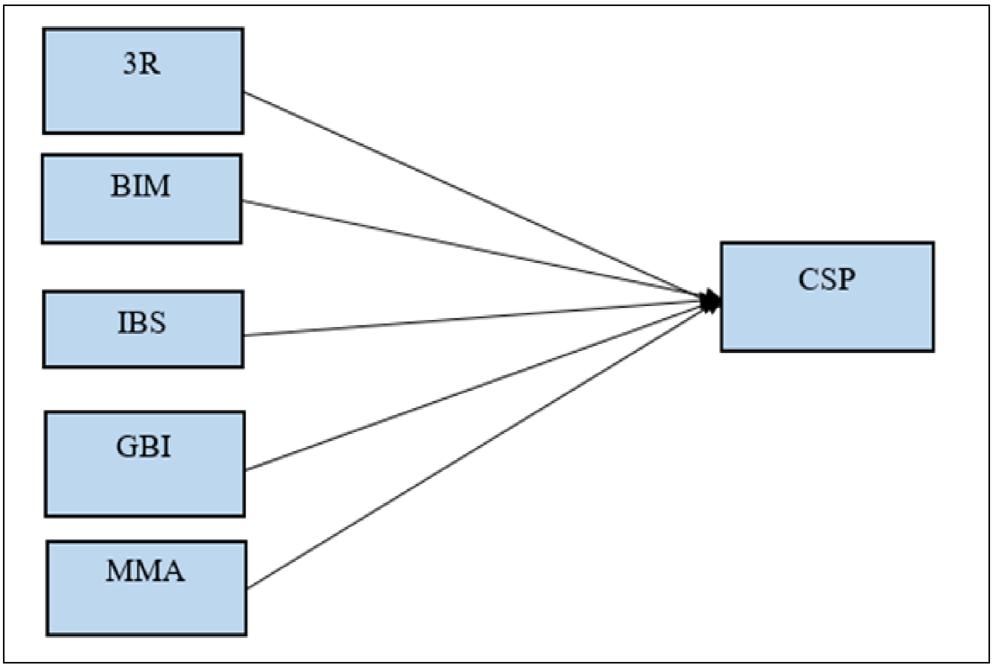

Fig. 1 - Conceptual framework

3. Research Methodology

The research aims to explore the utilization of technology and management practices for material waste mitigation in enhancing site performance within the Malaysian construction industry. Proficiency in technology management, communication, and material implementation is pivotal for successfully integrating the 3R approach, along with BIM, IBS, GBI, and MMA. These methods enable the establishment of on-site waste sorting campaigns and continuous monitoring of waste generation during material commissioning at construction sites. Quantitative data were collected through a questionnaire survey distributed among key industry stakeholders, including project managers, architects, contractors, engineers, and quantity surveyors. This participant selection was derived from comprehensive data provided by the Construction Industry Development Board (CIDB) for 2021. Utilizing a five-point Likert scale (1= Strongly Disagree, 2= Disagree, 3= Neither Agree nor Disagree, 4= Agree, 5= Strongly Agree), respondents evaluated material waste mitigation techniques, drawing insights from previous research (Ajayi & Oyedele, 2018). The survey primarily focused on factors aligned with the 3R approach, emphasizing the reduction of on-site materials to effectively manage construction waste, supported by prior studies (Asadi & Kone, 2018; Mohammed *et al.* 2021; Sila, 2021). Similarly, measurements assessing BIM usage were adapted from previous works, highlighting its potential in managing waste uncertainties in construction projects (Liu *et al.* 2016; Acquah *et al.* 2018; Tam *et al.* 2021; Hosny, Ibrahim, & Nabil, 2023). Moreover, the study incorporated measurements associated with IBS technology adoption for waste mitigation and the improvement of construction performance, sourced from relevant studies showcasing the efficacy of IBS in construction (Algburi & Faieza 2018; Turkyilmaz *et al.* 2019; Azira *et al.* 2020). The questionnaire also addressed GBI's strategy to enhance environmental measures on the construction site. Malaysia introduced the Green Building Index (GBI) to support the National Association of Homebuilders (NAHB) in advancing sustainable development through the application of Green Building Guidelines for residential structures (Chin *et al.*, 2020).

The participants representing various roles within the Malaysian construction sector were identified from CIDB records for 2021, revealing 131,121 registered contractors across different grades and 355,591 individuals engaged as construction personnel. With a targeted sample size of n = 384 from a population of N = 495,609, the study received 327 responses, accounting for 85% of the anticipated sample size. The data collection involved an online survey targeting construction personnel in Malaysia, resulting in 295 valid responses for hypothesis validation. The data analysis utilized Statistical Package for Social Sciences (SPSS) 25.0 and Structural Equation Model/Partial Least Squares (PLS-SEM), notably SmartPLS version 3.7.9 (Stein *et al.* 2017; Sekaran & Bougie, 2016). PLS-SEM facilitated the assessment of the conceptual framework and study hypotheses, enabling the extraction of conclusive findings.

4. Data Analysis

This study explores how technology and management adoption address material waste challenges and improve Construction Site Performance in Malaysia. Investigating five hypotheses, the focus is on discussing test outcomes, drawing from prior research, and highlighting the role of technological and managerial strategies in enhancing Construction Site Performance within the Malaysian construction industry.

Convergent Validity

Convergent Validity (CV) assesses how well items capture underlying components and their correlation with similar constructs (Usakli & Kucukergin, 2018). Evaluating CV involves scrutinizing Average Variance Extracted (AVE), and Composite Reliability (CR) (Hair *et al.*, 2014; Sarstedt & Cheah, 2019). Chin (2010) suggests an AVE threshold of 0.50 or higher and a CR threshold of 0.70 for adequate CV. In this study, Table 1 shows AVE values ranging from 0.643 to 0.761, indicating robust CV for each construct.

Table 1 - Exhibits Reflective Reliability, Loadings, and Average Variance Extracted (AVE)

Items	Loadings	Cronbach's Alpha	Composite Reliability	AVE
CSP1	0.834	0.922	0.924	0.682
CSP2	0.819			
CSP3	0.828			
CSP4	0.810			
CSP5	0.840			
CSP6	0.837			
CSP7	0.833			
CSP8	0.872			
CSP9	0.850			
CSP10	0.814			

CSP11	0.832			
CSP12	0.794			
CSP13	0.805			
CSP14	0.806			
CSP15	0.807			
3R1	0.826	0.948	0.956	0.670
3R2	0.848			
3R3	0.852			
3R4	0.848			
3R5	0.876			
3R6	0.867			
3R7	0.805			
3R8	0.824			
3R9	0.807			
BIM1	0.786	0.923	0.943	0.643
BIM2	0.788			
BIM3	0.809			
BIM4	0.798			
BIM5	0.825			
BIM6	0.807			
BIM7	0.817			
BIM8	0.847			
BIM9	0.836			
BIM10	0.818			
BIM11	0.733			
BIM12	0.747			
GBI1	0.861	0.895	0.927	0.761
GBI2	0.886			
GBI3	0.893			
GBI4	0.848			
IBS1	0.817	0.934	0.946	0.685
IBS2	0.834			
IBS3	0.822			
IBS4	0.798			

IBS5	0.824			
IBS6	0.845			
IBS7	0.832			
IBS8	0.848			
MMA1	0.803	0.943	0.951	0.660
MMA2	0.788			
MMA3	0.793			
MMA4	0.806			
MMA5	0.824			
MMA6	0.806			
MMA7	0.810			
MMA8	0.817			
MMA9	0.836			
MMA10	0.838			

Table 1 illustrates that the Cronbach's alpha for all variables exceeds 0.70, indicating consistency across the study variables (Wan *et al.*, 2013). Additionally, the displays results of AVEs for all variables surpassing the recommended threshold of > 0.5, endorsing the reliability of the measurement model (Bido *et al.* 2019). Consequently, the overall reliability of the latent variables used in this study had internal consistency values ranging from 0.853 to 0.948, all surpassing the minimum threshold of (0.70) of the Cronbach's Alpha indicating satisfactory reliability for the study components. Table 1 unequivocally demonstrates this by showcasing that all indicator loadings surpass the suggested threshold value of 0.5, aligning with the higher levels advised by Wong, (2013) and Sarstedt & Cheah, (2019).

Discriminant Validity

Discriminant validity, according to Hamid *et al.*, (2017), measures the extent of variation between different latent concepts. In this research, Usakli & Kucukergin's (2018), proposed method employs AVE to evaluate discriminant validity. This was achieved by comparing the square roots of AVEs to the correlations between latent variables, as demonstrated in Table 2 below.

Table 2 - Correlation of Average Variance Extracted AVE (Fornell and Larcker outcome)

Latent Variable	3R	BIM	CSP	GBI	IBS	MMA
3R	**0.840**					
BIM	0.195	**0.802**				
CSP	0.558	0.490	**0.826**			
GBI	0.405	0.328	0.593	**0.872**		
IBS	0.438	0.384	0.615	0.249	**0.828**	
MMA	0.427	0.292	0.584	0.471	0.363	**0.812**

In Table 2, it is evident that the significant values of each AVE item along the diagonal lines surpass the corresponding values in both columns and rows, thereby confirming discriminant validity by Fornell and Larcker (1981).

Coefficient of Determination (R^2)

Henseler *et al.* (2016) proposed the criteria of R^2 levels; if the values of R^2 are more than 0.67, the result indicates a high level, while between 0.33-0.67, the justification indicates a moderate level. Besides, if the value of R^2 obtained ranges 0.19 to 0.33, then the level is considered as a small portion, and if the value of R^2 is 0.19 or less, the evaluation is deemed unacceptable. Hence, as indicated in Table 3, and Figure 2, the obtained R^2 values in this study are notably high, totaling 67.4% in explaining the variance attributed to the five exogenous latent constructs (3R, BIM, IBS, GBI, and MMA) concerning the endogenous construct (CSP). This value is deemed substantial, surpassing the critical threshold of 0.67 (Nitzl & Cepeda 2016).

Table 3 - Variance Explained in the Endogenous Construct

Latent Construct	Variance explained (R^2)
Construction Site Performance	0.674%

Predictive Relevancy $Q^2$and Effect size f^2

The interpretation of the effect size (f^2) results aligns with the following criteria: values exceeding 0.35 are deemed significantly high, those falling between 0.15 and 0.35 are considered medium, values within the range of 0.02 to 0.15 indicate a small impact, and lastly, values less than 0.02 are regarded as having no discernible impact (Hair *et al.*, 2019).

$$f^2 = \frac{R^2{}_{in} - R^2{}_{ex}}{1 - R^2{}_{in}} \quad (1)$$

Table 4 depicts the effect sizes (f2) of 3R, BIM, GBI, IBS, and MMA on CSP. Specifically, 3R, BIM, and MMA are categorized as small, whereas GBI and IBS fall into the medium category of effect size (Hair *et al.*, 2019).

Table 4 - Effect size (f^2) for the exogenous construct

Items	R^2-Included	R^2- Excluded	f^2	Decision
3R	0.674	0.652	0.067	Small
BIM	0.674	0.650	0.076	small
GBI	0.674	0.618	0.173	Medium
IBS	0.674	0.601	0.225	Medium
MMA	0.674	0.647	0.086	Small

However, the following analysis focuses on predictive relevance, evaluating the structural model's ability to anticipate heightened relevance across individual indicators of endogenous variables. As emphasized in Table 5, the validation of the PLS-SEM approach hinges on the outcome, particularly the cross-validity redundancy value (Q^2), surpassing zero, aligning with recommendations by Sarstedt *et al.* (2019).

Table 5 - Predictive relevance Q2/Cross Validity redundancy

Total	SSO	SSE	1-SSE/SSO
Construction Site Performance	4425	2440.667	0.448

Hypothesis Testing

The evaluation of the structural model occurs upon its completion, following the guidance of Henseler *et al.* (2016). However, in this study, the t-values stem from bootstrapping, employing 5000 sample rounds across 295 instances or observations, under the recommendation provided by Hair and Sarstedt (2019).

Table 5 - Results of Hypothesis Testing

N	Relationship	Original Sample	Sample Mean	Standard Deviation	T-Values	P-Values	Decisions
H1	3R -> CSP	0.179	0.194	0.063	2.843	0.005	Supported
H2	BIM -> CSP	0.178	0.177	0.066	2.706	0.007	Supported
H3	GBI -> CSP	0.285	0.274	0.073	3.898	0.000	Supported
H4	IBS -> CSP	0.324	0.315	0.076	4.277	0.000	Supported
H5	MMA -> CSP	0.203	0.206	0.081	2.512	0.012	Supported

Significant at P*<0.05; P**<0.01

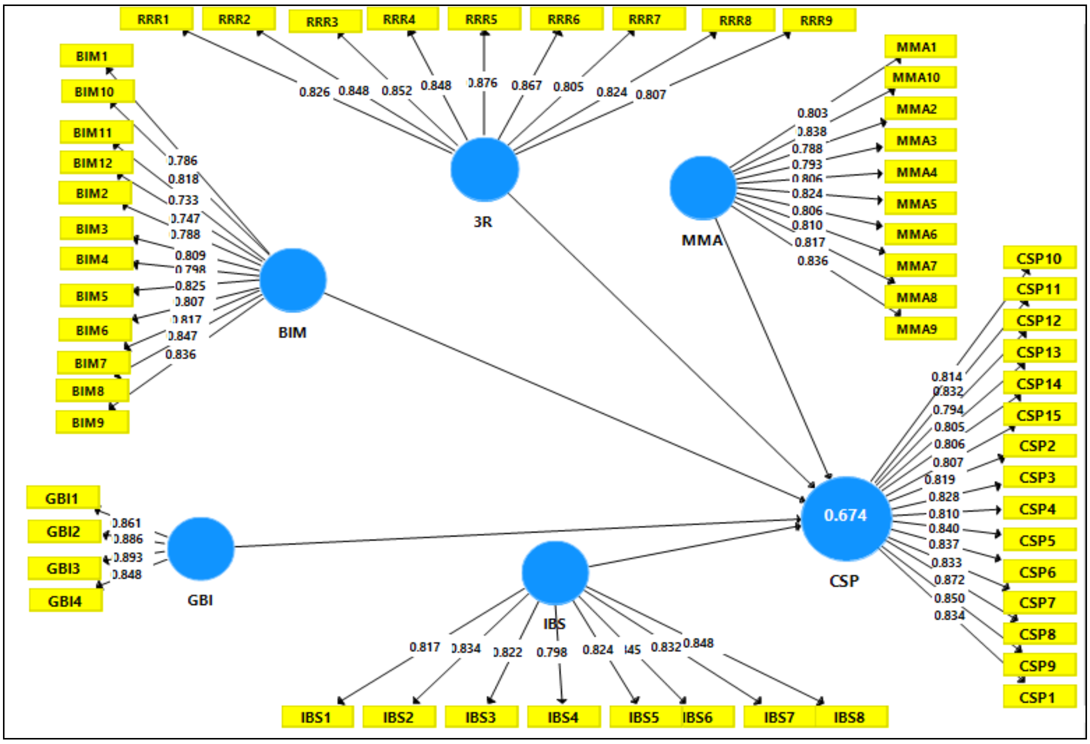

Fig. 2 - Structural model

This study investigates the impact of 3R as an integrated CSP strategy on mitigating material waste within Malaysian construction sites. The findings, presented in Table 5, substantiate significant associations between 3R implementation and CSP enhancement. Mohammed *et al.* (2020) similarly emphasize the substantial influence of material waste on project costs and its positive environmental impact, highlighting the need for contractors to innovate and propose novel waste reduction methods. Additionally, Mundher & Alsamarraie (2021) underscore the significant role of the 3R strategy in managing construction waste, particularly steel waste. Azman, & Yaacob (2017) delineate 3R practices in construction sites as crucial responsibilities for all involved parties, emphasizing their pivotal role in shaping construction workplace actions.

The results affirm a significant correlation between BIM implementation and CSP, as evidenced in Table 5. This aligns with the hypothesis, emphasizing that adopting BIM for material waste mitigation significantly and positively influences approaches to waste reduction on construction sites. Tanko & Zakka (2022) support this by highlighting the substantial presence and output of the Malaysian construction industry, attributing it to factors such as location and administrative advantages, with BIM-based practices notably impacting material waste minimization. Additionally, past studies by Al-ashmori *et al.* (2020) emphasize BIM's capacity to enhance project efficiency, minimize errors, and reduce time and costs, contributing to overall productivity improvements. Doumbouya *et al.* (2016) underline how BIM's adaptability across various management procedures in construction significantly impacts both the operational and financial aspects of projects, facilitating higher performance. Correspondingly, research by Tiffany *et al.* (2019) emphasizes BIM's increasing adoption in Singapore's construction sector for better stakeholder coordination, improved site performance, and reduced rework.

The third hypothesis examines the impact of GBI on CSP. The findings from Table 5 confirm a significant relationship between GBI and CSP, validating the hypothesis that utilizing GBI for material waste mitigation in Malaysian construction sites yields positive effects. This indicates an affirmative link between GBI implementation for waste mitigation in the Malaysian construction industry and enhanced site performance. The Malaysian government actively promotes the use of green building assessment tools to incentivize sustainable building development. Eisa & Rashid, (2022) highlight the adoption of the green building practice across various countries to realize sustainable building principles. Notably, Yusoff & Zahari (2014) emphasize Malaysia's comprehensive assessment system for environmentally sustainable buildings, addressing critical aspects like global warming. Green building involves environmentally conscious and resource-efficient construction practices, spanning planning, design, construction, operation, maintenance, renovation, and deconstruction. Despite Malaysia's strides in adopting global green construction standards, the widespread utilization of green buildings remains at an early stage (Algburi & Faieza, 2018). Initiatives like the Green Building Index (GBI) aim to bolster sustainable development, especially in residential structures, supported by efforts such as the National Association of Homebuilders' Green Building Guidelines (Chin Yee Ha *et al.*, 2023). However, the adoption of green building concepts in Malaysia remains relatively novel, posing challenges for stakeholders in acquiring requisite materials and technologies (Chin, Ismail, & Jing, 2020). Similar Studies have shown that integrating green construction practices significantly benefits the environment (Liew, 2012). The Green Building Index underscores the principles of waste reduction, reuse, and recycling in construction sites, reflecting the current trend in environmental protection (Oyenuga & Bhamidimarri, 2015). However, greener efforts must be recalibrated in terms of new strategies, the supply of essential information, management, and guidelines.

IBS techniques exhibit a strong correlation in this study, significantly enhancing construction site performance through material waste mitigation within the Malaysian construction industry. The study underscores a robust association between IBS, utilized for waste mitigation in the Malaysian construction sector, and the resulting construction site performance (CSP) in Table 5. Similar research by Kamaruddin *et al*. (2018) and Azira *et al*. (2020) emphasizes how IBS practices in material management positively influence project performance in the construction industry. Other findings by Ali *et al.* (2018) and Jaffar & Lee (2020) highlight IBS's role in waste reduction at construction sites, while Algburi & Faieza (2018) note its role in minimizing timber usage. Leveraging ready-made materials in construction represents a modern technology that significantly enhances project efficiency and performance. Additionally, Affendi *et al.* (2017) assert that IBS implementation significantly reduces noise by providing pre-fabricated elements for installation. Studies by Pozin *et al.* (2017) emphasize IBS's benefits in reducing construction waste and lowering total costs, attributing its rising popularity in construction sites to decreased reliance on foreign labor and reduced on-site labor numbers. This suggests that IBS technology and its innovation could potentially emerge as highly efficient strategies for enhancing building site performance.

The findings affirm a significant association between adopting MMA for mitigating material waste and CSP, as demonstrated in Table 5. This confirms the hypothesis, emphasizing that integrating MMA for waste mitigation significantly and positively influences waste reduction strategies on construction sites. The findings are supported by Jusoh & Kasim, (2016) as they highlighted that material scheduling through management offers an overview of time-related tasks necessary for project completion, positively impacting material handling and transportation on construction sites. Additionally, quality assurance, within material management, significantly impacts construction site cost, time, and quality performance. Oseghale *et al.* (2021) identify receiving and inspection as material management indicators enabling effective organization and planning for material clearances on-site. Moreover Kumar, (2018), and Rathod 2019) emphasize the critical role of inventory control, storage, and warehousing in enhancing construction site performance within their studies on construction site management.

5. Conclusion and Future Direction

This research aims to expand knowledge on material waste mitigation in the Malaysian construction industry, focusing on technological and managerial practices like 3R, BIM, IBS, GBI, and MMA concerning construction site performance enhancement. While shedding light on crucial theoretical concepts, the study does have certain limitations. It effectively addresses study questions and fulfils the stated objectives, drawing insights from literature and surveys. The study reveals interconnectedness among 3R, BIM, IBS, GBI, and MMA techniques, establishing strong relationships that positively impact material waste reduction and construction site performance. However, further research avenues emerge from these findings. The construction industry stands to benefit from integrating material waste mitigation and CSP techniques to maintain competitiveness. This study centred on Malaysia's construction industry, aims to enrich existing literature, particularly on material management and construction site performance. The findings could significantly aid construction technology and innovation firms, fostering growth in Malaysia's construction sector. This emphasizes the need for continued exploration into innovative material management and construction site performance aspects in future research endeavours. Such investigations hold the potential to motivate the adoption of technology and management approaches, ultimately elevating various facets of construction performance.

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References

Ab Hamid, M. R., Sami, W., & Mohmad Sidek, M. H. (2017). Discriminant Validity Assessment: Use of Fornell & Larcker criterion versus HTMT Criterion. *Journal of Physics: Conference Series*, *890*(1), 0–5. https://doi.org/10.1088/1742-6596/890/1/012163

Acquah, R., Eyiah, A. K., & Oteng, D. (2018). Acceptance of Building Information Modelling : a survey of professionals in the construction industry in Ghana. *J. Inf. Technol. Constr., 23, 75-91.*, (April).

Affendi, M., Pozin, A., Nasrun, M., Nawi, M., Nor, M., & Azman, A. (2017). *Improving communication in managing industrialised building system (IBS) projects: Virtual environment*. *2*(2), 1–13.

Aitbayeva, D. (2020). *Building Information Model (BIM) Implementation in Perspective of Building Information Model (BIM) Implementation in Perspective of Kazakhstan : Opportunities and Barriers*. (June). https://doi.org/10.9734/JERR/2020/v14i117113

Ajayi, S. O., & Oyedele, L. O. (2018). Critical design factors for minimising waste in construction projects: A structural equation modelling approach. *Resources, Conservation and Recycling*, *137*(May), 302–313. https://doi.org/10.1016/j.resconrec.2018.06.005

Ajayi, S. O., Oyedele, L. O., Bilal, M., Akinade, O. O., Alaka, H. A., & Owolabi, H. A. (2016). Critical management practices influencing on-site waste minimization in construction projects. *Waste Management*. https://doi.org/10.1016/j.wasman.2016.10.040

Al-ashmori, Y. Y., Othman, I., Rahmawati, Y., & Amran, Y. H. M. (2020). *Civil Engineering BIM benefits and its influence on the BIM implementation in Malaysia*. *11*, 1013–1019. https://doi.org/10.1016/j.asej.2020.02.002

Al-Awag, A. M., Alaloul, W. S., Liew, M. S., Baarimah, A. O., & Musarat, M. A. (2023). The potential role of industrialized building systems (IBS) in Malaysian sustainable construction: Awareness and barriers. *In AIP Conference Proceedings (Vol. 2608, No. 1). AIP Publishing.*, *1*.

Alaloul, W. S., Liew, M. S., Amila, N., & Abdullah, W. (2016). Identification of coordination factors affecting building projects performance. *Alexandria Engineering Journal*, *55*(3), 2689–2698. https://doi.org/10.1016/j.aej.2016.06.010

Alaloul, W. S., Musarat, M. A., Rabbani, M. B. A., Iqbal, Q., Maqsoom, A., & Farooq, W. (2021). Construction sector contribution to economic stability: Malaysian gdp distribution. *Sustainability (Switzerland)*, *13*(9), 1–26. https://doi.org/10.3390/su13095012

Algburi, S. M., & Faieza, A. A. (2018). Review of Green Building Index in Malaysia; Existing Work and Challenges. *International Journal of Applied Engineering Research, 11(5), 3160-3167.*

Algumaei, M. S., & Sarpin, N. (2022). Critical Success Factors of Industrialized Building System (IBS) Implementation for Construction Industry in Yemen. *Research in Management of Technology and Business*, *3*(1), 522–536. Retrieved from http://publisher.uthm.edu.my/periodicals/index.php/rmtb

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

Amalyn, A., Rafidi, A., Marhani, M. A., Rafidah, R., Muhammad, R., Akmal, N., … Muhammad, R. (2023). *Challenges of Implementing Effective Solid Waste Management in Construction Projects*. 1–7. https://doi.org/10.55573/JOSSR.061801

Asadi, S., & Kone, V. (2018). Evaluation of reducing waste materials in construction projects using ranking analysis. *Int. J. Civ. Eng. Technol, 9, 831-838.*, (June).

Azira, S., Rahim, A., Amir, M., Hashim, S., & Shen, W. S. (2020). *A Potential Study of Automation System in Industrialised Building System (IBS) i n Enhancing Malaysian Construction Industry ' s Performance*. *2020*(August).

Azman, N., & Yaacob, N. A. (2017). *Construction contractor's perception on effective 3R implementation for solid waste reduction in Perak.*

Basheer, A., Altohami, A., Haron, N. A., Hizami, A., Alias, A., & Law, T. H. (2021). *Investigating Approaches of Integrating BIM , IoT , and Facility Management for Renovating Existing Buildings : A Review*.

Bido, D. de S., & Da Silva, D. (2019). SmartPLS 3: especificação, estimação, avaliação e relato. *Administração: Ensino e Pesquisa*, *20*(2), 488–536. https://doi.org/10.13058/raep.2019.v20n2.1545

Bonoli, A., Zanni, S., & Serrano-Bernardo, F. (2021). Sustainability in building and construction within the framework of circular cities and european new green deal. The contribution of concrete recycling. *Sustainability (Switzerland)*, *13*(4), 1–16. https://doi.org/10.3390/su13042139

Chin, H., Ismail, R., & Jing, K. T. (2020). *The Barriers of Implementing Green Building in Penang Construction Industry*. *12*, 1–10.

Chin, W. W. (2010). How to write up and report PLS analyses. In 'Handbook of Partial Least Squares'. *(Eds VV Esposito, WW Chin, J Henseler and H Wang) Pp. 655–690.*

Chin Yee Ha, Terh Jing Khoo, & Zheng Yik Koo. (2023). Current status of green building development in Malaysia. *Progress in Energy and Environment*, *25*(1), 1–9. https://doi.org/10.37934/progee.25.1.19

Chowdhury, T., Zealand, N., Adafin, J., Albert, M., Zealand, N., Wilkinson, S., & Zealand, N. (2019). *Review of digital technologies to improve productivity of New Zealand construction industry*. *24*, 569–587.

Crawford, R. H., Mathur, D., & Gerritsen, R. (2017). Barriers to Improving the Environmental Performance of Construction Waste Management in Remote Communities. *Procedia Engineering*, *196*(June), 830–837. https://doi.org/10.1016/j.proeng.2017.08.014

Doumbouya, L., Gao, G., & Guan, C. (2016). *Adoption of the Building Information Modeling (BIM) for Construction Project Effectiveness : The Review of BIM Benefits*. *4*(3), 74–79. https://doi.org/10.12691/ajcea-4-3-1

Eisa, A., Al-Hosani, Y., Binti, N., & Rashid, A. (2022). Conceptual Framework for Green Human Resources Management(SGHRM) and its effect on Sustainability in Green Building. *JournalofTianjin UniversityScience And Technology*, *2060*(04), 562–575. https://doi.org/10.17605/OSF.IO/5DRXF

Erol, H., & Dikmen, I. (2023). A BIM-Based Risk Management Model for Construction Waste Reduction and Control. *33rd European Safety and ReliabilityConference (ESREL 2023)*, (September), 2503–2510. https://doi.org/10.3850/978-981-18-8071-1

Fornell, C., & Larcker, D. F. (1981). *Evaluating structural equation models with unobservable variables and measurement error. Journal of marketing research, 18(1), pp. 39-50.*

Gamil. (2020). Internet of things in construction industry revolution 4.0: Recent trends and challenges in the Malaysian context. *Journal of Engineering, Design and Technology*, *18*(5), 1091–1102. https://doi.org/10.1108/JEDT-06-2019-0164

Hair J, F., Sarstedt, M., Hopkins, L., & G. Kuppelwieser, V. (2014). *Partial least squares structural equation modeling (PLS-SEM) An emerging tool in business research. European Business Review, 26(2), pp. 106-121.*

Hair, J. F., & Sarstedt, M. (2019). Factors versus Composites: Guidelines for Choosing the Right Structural Equation Modeling Method. *Project Management Journal*, *50*(6), 619–624. https://doi.org/10.1177/8756972819882132

Hameed, K., Barika, M., Garg, S., Bilal, M., & Kang, B. (2022). *Journal of Industrial Information Integration Review article A taxonomy study on securing Blockchain-based Industrial applications : An overview , application perspectives , requirements , attacks , countermeasures , and open issues*. *26*(September 2020).

Hasmori, M. F., Zin, A. F., Nagapan, S., Deraman, R., Abas, N., Yunus, R., & Klufallah, M. (2020). The on-site waste minimization practices for construction waste. *In IOP Conference Series: Materials Science and Engineering (Vol. 713, No. 1, p. 012038).*

Hatoum, M. B., & Nassereddine, H. (2020). Developing a framework for the implementation of robotics in construction enterprises. *EG-ICE 2020 Workshop on Intelligent Computing in Engineering, Proceedings*, (June), 453–462.

Henseler, J., Hubona, G., & Ray, P. A. (2016). Using PLS path modeling in new technology research: Updated guidelines. *Industrial Management and Data Systems*, *116*(1), 2–20. https://doi.org/10.1108/IMDS-09-2015-0382

Hosny, S., Ibrahim, A. H., & Nabil, Y. (2023). Reducing Reinforced Concrete Materials Waste in Construction Projects Using Building Information Modeling in Egypt. *Journal of Information Technology in Construction*, *28*(June 2022), 332–345. https://doi.org/10.36680/j.itcon.2023.017

Hwang, B., Asce, M., Zhao, X., Asce, A. M., & Yang, K. W. (2019). *Effect of BIM on Rework in Construction Projects in Singapore : Status Quo , Magnitude , Impact , and Strategies*. *145*(2), 1–16. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001600.

Jaffar, N., Affendi, N. I. N., Mohammad Ali, I., Ishak, N., & Jaafar, A. S. (2022). Barriers of Green Building Technology Adoption in Malaysia: Contractors' Perspective. *International Journal of Academic Research in Business and Social Sciences*, *12*(8), 1552–1560. https://doi.org/10.6007/ijarbss/v12-i8/14490

Jaffar, Y., & Lee, C. K. (2020). *Factors Influencing Industrialized Building System (IBS) Project Performance : A Systematic Review*. *3*(2), 64–81.

Jusoh, Z. M., & Kasim, N. (2016). A Review on Implication of Material Management to Project Performance. *MATEC Web of Conferences*, *87*. https://doi.org/10.1051/matecconf/20178701012

Kamaruddin, S. S., Mohammad, M. F., Mahbub, R., & Ahmad, K. (2018). The Mechanisation and Automation of the IBS Construction Approach in Malaysia. *Asian Journal of Environment-Behaviour Studies*, *3*(10), 167–177. https://doi.org/10.21834/aje-bs.v3i10.324

Kumar, U. N. (2018). Construction Material Management on Project Sites. *International Journal for Research in Applied Science and Engineering Technology*, *6*(1), 1371–1378. https://doi.org/10.22214/ijraset.2018.1207

Liew, P. Y. (2012). *Achievability of Green Building Index Malaysia . Universiti Tunku Abdul Rahman.*

Liu, S., Xie, B., Tivendal, L., & Liu, C. (2016). *Critical Barriers to BIM Implementation in the AEC Industry Critical Barriers to BIM Implementation in the AEC Industry*. (June). https://doi.org/10.5539/ijms.v7n6p162

Manoharan, E., Othman, N., Mohammad, R., Chelliapan, S., & Tobi, S. U. M. (2020). Integrated approach as sustainable environmental technique for managing construction waste: A review. *Journal of Environmental Treatment Techniques*, *8*(2), 560–566.

Manzoor, B., Othman, I., Gardezi, S. S. S., & Harirchian, E. (2021). *Strategies for Adopting Building Information Modeling (BIM)*. 1–14.

Martínez-Rojas, M., Marín, N., & Vila, M. A. (2016). The Role of Information Technologies to Address Data Handling in Construction Project Management. *Journal of Computing in Civil Engineering*, *30*(4), 1–20. https://doi.org/10.1061/(asce)cp.1943-5487.0000538

Mohammed, M., Shafiq, N., Abdallah, N. A. W., Ayoub, M., & Haruna, A. (2020). A review on achieving sustainable construction waste management through application of 3R (reduction, reuse, recycling): A lifecycle approach. *IOP Conference Series: Earth and Environmental Science*, *476*(1).

Mohammed, Musa, Shafiq, N., Elmansoury, A., Al-Mekhlafi, A. B. A., Rached, E. F., Zawawi, N. A., … Ibrahim, M. B. (2021). Modeling of 3r (Reduce, reuse and recycle) for sustainable construction waste reduction: A partial least squares structural equation modeling (pls-sem). *Sustainability (Switzerland)*, *13*(19). https://doi.org/10.3390/su131910660

Mohd Hilmi & Narimah Kasim. (2017). *Conceptual Model for Systematic Construction Waste Management*. *01008*(2017), 1–7.

Mohsen, A., Alawag, M., Alaloul, W. S., Liew, M. S., Al-bared, M. A. M., Amila, N., … Ammad, S. (2021). *The Implementation of the Industrialized Building System in the Malaysian Construction Industry a Comprehensive Review*. Springer Singapore.

Mousa, S. K., & Othman, M. (2019). The impact of green human resource management practices on sustainable performance in healthcare organisations : a. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2019.118595

Mundher M. Alsamarraie , Ali Tighnavard Balasbaneh b, F. G. (2022). Evaluation Of 3rs Concept For Sustainable Steel Waste Disposal: Control Strategy. *Malaysian Journal of Civil Engineering, 34(1), 11-17.*, *32*, 21–24.

Nawi, M. N. M., Azman, M. N. A., Baluch, N., Kamar, K. A. M., & Abd Hamid, D. Z. (2015). Study on the use of industrialised building system in Malaysian private construction projects. *ARPN Journal of Engineering and Applied Sciences*, *10*(17), 7368–7374.

Nawi, M. N. M., Riazi, S. R. M., Deraman, R., Hanafi, A. G., & Hussin, K. C. (2023). Expert Perspective on the Barriers and Enablers of Joint Effort and Technological Collaboration Among Malaysian Industrialized Building System (IBS) Housing Project Supply Chains. *Journal of Advanced Research in Applied Sciences and Engineering Technology*, *30*(3), 383–393. https://doi.org/10.37934/araset.30.3.383393

Ng, L. S., Tan, L. W., & Seow, T. W. (2017). Current practices of construction waste reduction through 3R practice among contractors in malaysia: Case study in penang. *IOP Conf. Ser.: Mater. Sci. Eng. 271 012039*.

Nitzl, C., Roldan, J. L., & Cepeda, G. (2016). Mediation analysis in partial least squares path modelling, Helping researchers discuss more sophisticated models. *Industrial Management and Data Systems*, *116*(9), 1849–1864. https://doi.org/10.1108/IMDS-07-2015-0302

Nur, S., Binti Shabudin, A., Yazid, M., & Taib, M. (2021). *Mjit 2021 a Study of Smart Warehouse Efficiency in Shorubber (M) Sdn. Bhd*. *5*(5), 26–36. Retrieved from www.mitec.unikl.edu.my/mjit

Nurzalikha, & Ismail, Z. (2015). Government Initiatives Pertaining to Construction Waste Minimization in Malaysia. *International Journal of Energy and Environment, 9, 165-170.*

Omeje, H. O., Okereke, G. K., & Chukwu, D. U. (2020). Construction Waste Reduction Awareness: Action Research. *Journal of Teacher Education for Sustainability*, *22*(1), 66–83. https://doi.org/10.2478/jtes-2020-0006

Oseghale, Godwin Ehis, Johnson Damilola Adetooto, and B. O. (2021). Evaluation of Material Management Methods in Selected Building Construction Sites in Abuja and Lagos State, Nigeria. *American Journal of Mechanical and Materials Engineering*, *5*(1), 11.

Osman, W. N., Nasrun, M., Nawi, M., Saad, R., & Ismail, R. (2017). *Factors Affecting Systematic Implementation of Reduce and Recycle in Construction Industry*. *6*(1), 270–278.

Oyenuga, A., & Bhamidimarri. (2015). Sustainable approach to managing construction and demolition waste: An opportunity or a new challenge. *International Journal of Innovative Research in Science, Engineering and Technology, 4(11), 10368-10378.*

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. https://doi.org/10.1016/j.jclepro.2018.02.053

Pozin, M. A. A., Nawi, M. N. M., Lee, A., & Azman, M. N. A. (2017). Improving communication in managing industrialised building system (IBS) projects: Virtual environment. *Malaysian Construction Research Journal*, *2*(Special Issue 2), 1–13.

Rahim, M. H. I. A., Kasim, N., Mohamed, I., Zainal, R., Sarpin, N., & Saikah, M. (2017). Construction waste generation in Malaysia construction industry: illegal dumping activities. *In IOP Conference Series: Materials Science and Engineering (Vol. 271, No. 1, p. 012040). IOP Publishing*.

Rajendran, P., Seow, T., & Goh, K. (2014). (2014). *bulding information modeling (bim) in design stage to assist in* *time, cost and quality in construction innovation*. (2), 1–7.

Rathod, J. M. (2019). *A Framework For Rfid Enabled Material Management for International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)*. (May).

Razak, M. I. A., Khoiry, M. A., Badaruzzaman, W. H. W., & Hussain, A. H. (2022). DfMA for a Better Industrialised Building System. *Buildings*, *12*(6). https://doi.org/10.3390/buildings12060794

Rofdzi, M. N. A. R. M., & Ismail, A. D. (2018). *Key Elements Towards Automation and Robotics in Industrialised Building System (IBS)*. (January 2019).

Saadi, N., Ismail, Z., & Alias, Z. (2016). A review of construction waste management and initiatives in malaysia. *Journal of Sustainability Science and Management*, *11*(2), 101–114. Retrieved from http://soe.umt.edu.my/wp-content/uploads/sites/51/2016/12/10-web.pdf

Sarstedt, M., & Cheah, J. H. (2019). Partial least squares structural equation modeling using SmartPLS: a software review. *Journal of Marketing Analytics*, *7*(3), 196–202. https://doi.org/10.1057/s41270-019-00058-3

Sekaran, U., & Bougie, R. (2016). *Research methods for business: A skill building approach*. John Wiley & Sons.

Setiawan, A. F., Hansen, S., & Fujiono, A. (2021). Measuring the influence of communication planning towards construction project performance. *Civil and Environmental Engineering, 17(1), 58-65.*

Sila, J. N. (2021). Material management and project performance of construction companies in Nairobi city county, Kenya. *International Academic Journal of Information Sciences and Project Management, 3(6), 368-391.*, *3*(6), 368–391.

Sin, T. J., Chen, G. K., Long, K. S., Goh, I., & Hwang, H. (2013). Current practice of waste management system in Malaysia: Towards sustainable waste management. *1st FPTP Postgrad. Semin." Towards Sustain. Manag, 1106, 1-19.*

Sio Kah, K., & Ming Qin, H. (2021). *Barriers of Applying Building Information Modelling (BIM) According to BIM ISO*. *2022*(September 2021), 2600–7320. Retrieved from https://intijournal.intimal.edu.my

Solanke, B. H. (2015). Effective strategy for construction materials procurement during construction towards the enhancement of sustainable building production in Western Cape, South Africa (Vol. 16).

Stein, C. M., Morris, N. J., Hall, N. B., & Nock, N. L. (2017). Structural equation modeling. *Methods in Molecular Biology*, *1666*, 557–580. https://doi.org/10.1007/978-1-4939-7274-6_28

Tam, V. W. Y., Fung, I. W. H., Sing, M. C. P., & Ogunlana, S. O. (2015). Best practice of prefabrication implementation in the Hong Kong public and private sectors. *Journal of Cleaner Production*, *109*, 216–231. https://doi.org/10.1016/j.jclepro.2014.09.045

Tam, N. Van, Diep, T. N., Toan, N. Q., Le, N., & Quy, D. (2021). Factors affecting adoption of building information modeling in construction projects: A case of Vietnam. *Cogent Business & Management, 8(1), 1918848.*, *8*(1).

Tan, F., Lim, H. S., Ng, L. S., Tan, L. W., Seow, T. W., & Kesauliya, O. M. C. (2017). Current practices of construction waste reduction through 3R practice among contractors in malaysia: Case study in penang. *Conf. Ser.: Mater. Sci. Eng. 271 012039*.

Tanko, B. L., & Zakka, W. P. (2022). *BIM in the Malaysian construction industry : a scientometric review and case study industry*. https://doi.org/10.1108/ECAM-04-2021-0324

Turkyilmaz, A., Guney, M., Karaca, F., Bagdatkyzy, Z., Sandybayeva, A., & Sirenova, G. (2019). A comprehensive construction and demolition waste management model using PESTEL and 3R for construction companies operating in central Asia. *Sustainability (Switzerland)*, *11*(6). https://doi.org/10.3390/su11061593

Umar, U. A., Shafiq, N., & Isa, M. H. (2018). Investigation of construction wastes generated in the Malaysian residential sector. *Waste Management and Research*, *36*(12), 1157–1165. https://doi.org/10.1177/0734242X18790359

Usakli, A., & Kucukergin, K. G. (2018). Using partial least squares structural equation modeling in hospitality and tourism: Do researchers follow practical guidelines? In *International Journal of Contemporary Hospitality Management* (Vol. 30). https://doi.org/10.1108/IJCHM-11-2017-0753

Veerasanai, R., & Alias, A. (2020). A review of foreign construction firm presence in the Malaysian construction industry. *International Journal of Construction Management, 1-14.*, 1–14.

Wan, M. gtmmad A. B. W. A. (2013). A Comparison Of Partial Least Square Structural Equation Modeling (PLS-SEM) and Covariance Based Structural Equation Modeling (CB-SEM) for Confirmatory Factor Analysis. *International Journal of Engineering Science and Innovative Technology (IJESIT)*, *2*(5), 198–205.

Won, J., & Cheng, J. C. P. (2017). Identifying potential opportunities of building information modeling for construction and demolition waste management and minimization. *Automation in Construction*, *79*, 3–18. https://doi.org/10.1016/j.autcon.2017.02.002

Wong, K. K. K.-K. (2013). Partial Least Squares Structural Equation Modeling (PLS-SEM) Techniques Using SmartPLS. *Marketing Bulletin, 24*.

Yap, J. B. H. (2022). *Barriers To The Adoption Of New Safety Technologies In Construction: A Developing Country Context, Volume 28*(2), 120_130.

Yusoff, W., & Zahari, W. (2014). Analysis of the international sustainable building rating systems (SBRSS) for sustainable development with special focused on green building index (GBI) Malaysia. *Journal of Environmental*

Conservation Research, *11*, *11-26*.

Zhang, P., & Ng, F. F. (2012). Attitude toward knowledge sharing in construction teams Peihua. *Industrial Management & Data Systems.*

Zhang, X., Wu, Y., Shen, L., & Skitmore, M. (2014). A prototype system dynamic model for assessing the sustainability of construction projects. *International Journal of Project Management*, *32*(1), 66–76. https://doi.org/10.1016/j.ijproman.2013.01.009