

RESEARCH ARTICLE

Examining the role of drone technology in building site safety compliance

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ABSTRACT - Managing safety on construction sites is often regarded as a crucial element in the building industry. In recent years, construction companies have utilised drone technology to monitor the safety of construction sites. Unmanned aerial vehicles (UAVs), commonly known as drones, are aircraft without a pilot that can be controlled remotely or operate independently, using GPS data and software. Construction companies frequently utilise drones to enhance their security measures and effectively reduce risks by capturing and observing high-resolution images with real-time information. This research aimed to investigate the factors that may influence the use of drone technology for construction site safety management in Malaysia. The quantitative study approach using a nonprobability sampling technique was employed in this study. A total of 300 questionnaires were distributed via email to construction sector workers, and 108 replies were obtained. Data were analysed using the SmartPLS 4.0 software. Four independent variables— technological capabilities, safety requirements, operational efficiency, and drone compatibility —were assessed in relation to the use of drone technology on the construction site. The findings indicated that the compatibility of drone (COD) and operational efficiency (OE) were the two key elements driving the construction industry to adopt drone technology. At the same time, safety requirements (SR) and technological capabilities (TC) did not significantly influence the adoption of drone technology in the construction industry. This research offered a clearer insight into the requirements essential for improving the use of drone technology in the Malaysian construction industry.

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1. INTRODUCTION

The need for efficiency, sustainability, and creativity is driving a digital change in Malaysia's construction sector. New technology adoption in the construction sector is expected to be accelerated by the digital transformation, commonly referred to as the Fourth Industrial Revolution (IR4.0), that is taking place in manufacturing and industrial processes. The Construction 4.0 (C4.0) Strategic Plan 2021-2025, introduced by CIDB in 2021, served as a roadmap for Malaysian construction companies to expedite the adoption of IR 4.0 technologies. The goal of this strategic plan is to promote the Shared Prosperity Vision 2030 (SPV 2030) and the National Policy on IR 4.0 (Industry4WRD) by embracing digital transformations and developing an innovative construction ecosystem in Malaysia's construction industry. Unmanned aerial vehicles (UAVs), or drones, are one of the digital technologies associated with Industry 4.0 (Albeaino, 2021). These drones are used for mapping, data collection, monitoring, transportation, and entertainment, and they are designed to fly autonomously. A human can use controls to launch a drone into the air, or a machine can use map coordinates to send a drone into the air. Drones can be utilised for various purposes, including aerial photography, mapping, surveillance, monitoring, and product delivery. Some professions in the construction sector involve high-risk behaviour that can make it difficult to maintain safety while balancing the need to save time and money. Thus, the use of drones in the construction industry is especially crucial.

Drones are utilised in the construction industry for four primary purposes, according to Tatum and Liu (2017): surveying, inspecting, conducting safety inspections, and capturing images and videos. In addition to providing geotagged images and real-time project progress insights, drones can be used to collect data from the air. In building security management, they can also be utilised for security and monitoring purposes. Improved safety, lower costs, and enhanced data collection and utilisation are just a few advantages that drones offer in construction. Drones are equipped with cameras and a network of sensors to collect data and perform tasks such as visual inspection and quality control. On building sites, drones are employed for routine safety surveillance. The drone features a camera that takes excellent pictures. Moreover, drones enable more accurate and efficient mapping of construction sites and progress tracking by capturing aerial photos. Such capability can help improve safety on building sites by utilising drone capabilities to execute high-risk working activities on construction sites.

Based on the discussion above, the use of drones in the construction industry can improve job performance, enhance safety at construction sites, and increase productivity. Despite all these benefits, Ab Rahman (2019) stated that the usage

of drone technology in the Malaysian construction sector was found to be very limited. The use of drone technology in Malaysia's construction industry is hindered by several reasons, necessitating quick fixes. The restricted flight duration, length, and operations, due to battery life limitations, are some of the challenges the construction company faces when implementing drone technology in its projects. A variety of factors related to battery life constraints must be considered, such as take-off weight and battery quality, which in turn affect the type of cameras and sensors that can be used (Outay, 2020). Environmental factors, such as severe weather and rough terrain, including hills, mountains, or underground tunnels, may disrupt signals and connectivity.

There are also security concerns, including privacy violations for victims and the potential for criminals to exploit the system for illicit purposes. Operating a drone carries the risk of colliding with other objects or persons, which can cause the drone to malfunction and crash into the on-site personnel area or structure, potentially resulting in bodily injuries or property damage. Another issue with drone use in Malaysia is obtaining a license. The Civil Aviation Regulation and its Civil Aviation Directive govern all Unmanned Aerial Systems (UAS)/drone flying operations in Malaysia. This implies that before using the drone, the pilot must have the appropriate authorisation from the relevant authorities. Obtaining this approval to fly requires a private pilot's license, which could take some time. The issue of exact drone use or the absence of a positioning framework to ensure precise system positioning can pose significant challenges for construction management (Yahya, 2021).

Given the numerous barriers to drone adoption in the construction sector, these limitations might render construction companies hesitant to adopt drone technology. Similarly, the Malaysian government's determination to modernise the construction industry's technologies may have been hindered by this. Hence, it is critical to analyse the challenges faced by the construction industry in adopting drone technology. Thus, the purpose of this study was to investigate the factors that might influence the use of drone technology for construction site safety management in Malaysia. The application of drone technology in Malaysia's construction site safety industry, with a primary emphasis on improving worker productivity, safety, and collaboration, was the focus of this study. This report provided insightful information from academics and experts in the field of building site safety management. The construction management team can lower construction costs and boost project efficiency by successfully implementing drones (Sadiku, 2024). Through such an initiative, construction firms can investigate more effective ways to enhance safety aspects at construction sites using drone technology. In fact, it also enhances the advancement of the construction industry, particularly in the area of safety management.

2. LITERATURE REVIEW

2.1 Origin and Concept of Construction Safety Management in Malaysia

The construction industry in Malaysia is growing as the demand for residential, commercial, and infrastructure projects continues to expand. The construction industry is prone to several health risks due to its dynamic nature. Therefore, protection is crucial in the construction business to ensure a healthy working environment (Patel, 2021). One of the cornerstones of effective accident prevention and maintaining a low accident rate on construction sites is eliminating risky behaviours, which account for most worker injuries (Wong, 2023). Safety issues are far more important in the construction industry. The strategy addresses issues such as identifying safety concerns, developing action plans, and implementing recommendations and strategies to mitigate safety hazards and enhance industry standards.

In construction projects, safety management encompasses the core responsibilities and tasks of safety and health staff, as well as their supervisory management, aimed at preventing accidents and fatalities during construction. It highlights the crucial role of integrating safety practices in all construction activities to ensure a safe working environment. In the construction sector, safety is the primary prerequisite for the entire complex of measures and protocols, which includes protecting workers, equipment, and the audience from potential accidents and injuries. Safety encompasses the following components: risk assessment, safety training, personal protective equipment (PPE), and emergency preparedness. The prevention policy of construction site injuries consists of the engagement of safety costs and human resource costs, the directness of safety supervision, and the good results of safety performance, for example, accident rates and costs, organisational structure, and safety audit ratings.

The Malaysian construction sector has witnessed significant technological advancements, with drones emerging as a powerful tool to enhance productivity, safety, and cost efficiency (Yahya et al., 2021). These UAVs offer unique capabilities that traditional methods cannot match, enabling companies to enhance project performance and achieve higher levels of precision throughout various phases of construction projects. However, the use of drones in construction is still in its infancy due to several factors (Choi et al., 2023; York et al., 2020). This section delves deeper into the factors that can influence the adoption of drone technology in the Malaysian construction industry.

2.2 Drone Technology Capability

A drone is a vehicle without a driver, equipped with several onboard sensors, which can fly autonomously or be guided remotely by a distance-based operator, sometimes known as UASs (Hatoum, 2022). Drones include devices that can fly independently along set routes using an onboard computer or follow commands transmitted remotely by a pilot on the ground. The size of drones can range from large military drones to smaller drones. Initially used for military purposes, drones have recently undergone significant advancements in both hardware and software technology, resulting in

substantial growth in their civilian applications over the past few years. Since then, as part of the military Internet of Things (IoT), drones have been utilised for offensive missions, intelligence gathering, aerial surveillance, search and rescue operations, and reconnaissance. The use of drone technology helps save resources, minimise power consumption, reduce pollution, and better prepare for emergencies. Within the construction sector, UASs have been utilised in various stages, including pre-construction applications, construction applications, and post-construction applications (Albeaino, 2021). Using drones in construction was thought to have several advantages, including time savings, increased accessibility to previously inaccessible areas, and cost savings during job completion. Indoor UAVs hold promise as a worthy alternative to conventional methods of inventory management that require labour and pose human safety issues (Companik et al., 2018).

2.3 Safety Requirements

Although various initiatives have been implemented to address safety and health issues in the construction sector, several health issues persist. Drone safety monitoring is a promising technology in improving safety practices and reducing potential hazards in work operations. For instance, the use of drone technology provides an expanding aerial view of the construction site, allowing safety managers to monitor worker activities, identify potential hazards, and ensure compliance with safety protocols. These measures help prevent accidents and injuries at the job site. Drones are also equipped with high-tech equipment such as cameras, sensors, and data processing capabilities, which positively serve safety monitoring in construction. Through the capture of images and videos, drones can identify unsafe conditions such as twisted structures, debris, damaged equipment, or improper use of protective gear (Namian et al., 2021). In addition, drone usage at construction sites may cause workers in ways that would lead to safety performance improvement (Namian et al., 2021). Lower costs and increased efficiency for aerial security surveillance, compared to the traditional methods such as manual inspections or the use of cranes and helicopters, are among the benefits drones can bring to the construction industry. Drones can cover larger areas in less time, while less specialised equipment or personnel are used; this also works so beneficially for a wide variety of application industries, including oil and gas companies, utilities, agriculture, and infrastructure.

2.4 Operational Efficiency

The operational and maintenance expenses associated with construction site safety management are among the obstacles to the widespread adoption of drone technology. This addresses the issue of increasing project efficiency while considering worker safety. In view of the time required to conduct inspections manually, which significantly reduces labour costs, makes helipads unnecessary, and enables the easy detection of potential problems as they arise during construction, helping to avoid costly errors and delays, drone estimates appear to be on the higher side. For this specific drone technology, operational efficiency demands are associated with maintenance, repairs, inspections, and other related tasks (Hatoum, 2022). The operating costs of drone technology include fuel and energy, depreciation, maintenance, and repairs, all of which can occasionally be expensive. This is because construction drones are of higher quality than those used in other industries. As such, working with drone manufacturers on getting discounts through bulk orders or long-term agreements is required. This may reduce the initial purchase price of drones. Additionally, there may be a requirement for skilled professionals to operate these drones or undergo specialised skills training (Yahya, 2021). In order to encourage the numerous uses of drone technology in safety management on construction sites, policies to reduce the price of professional drones and skills training expenses can be developed.

2.5 Compatibility Drone

Drones are capable of surveying structures efficiently to detect cracks, degradation, and other issues. By doing this, worker safety concerns can be reduced, and the need for labour-intensive manual inspections can be eliminated. Drones equipped with more features will assist in construction work (Choi, 2023). Frequent site surveys and inspections provide the necessary data to monitor progress and identify hazards in real-time. Efficient inspections and repairs, enabled by drone technology, reduce worker risk and improve structural maintenance. Safety oversight and material monitoring prevent theft and ensure proper resource utilisation. The Malaysia Digital Economy Corporation (MDEC) also plays a role in creating digital skills training courses for site managers and project managers to support the upskilling and reskilling of Malaysian talent, contributing to the country's economic recovery in the construction industry (MDEC, 2020). Effective drone flight operations require workers who possess skills and experience in this technology (Opfer & Shields, 2014). Therefore, having expertise and training in drone technology is crucial for every employee, as meteorological factors and pilot training significantly impact the use of drones in security inspections (Nguyen, 2023). Drone operators are expected to understand the flight objectives to ensure the drone operates safely and flies to the designated location according to surveillance or activity requirements (Zhang, 2022). Therefore, the lack of trained drone operators is one of the problems with applying drone technology to the safety management of construction sites. Furthermore, drone operators also need to be knowledgeable about the use of drones and the skills to navigate construction areas, since the primary function of drones is to take pictures and videos, as well as monitor and map activities in a relatively large area.

2.6 The Underpinning Theory/Theories

The core theory of this work is based on the socio-technical systems (STS) theory and the concept of human-technology cooperation. According to the paradigm known as socio-technical systems (STS) theory, organisations are

systems made up of interrelated social and technical elements. It highlights that when social and technological factors are considered jointly and viewed as interrelated, the design and functionality of any organisational structure are maximised. STS principles are employed to design work systems that consider both the technical requirements and the social needs of employees, resulting in increased productivity and job satisfaction. Thus, any organisation employs people with capabilities who work towards goals, follow processes, use technology, operate within a physical infrastructure, and share certain cultural assumptions and norms. The theory was developed in the 1950s at the Tavistock Institute in London, resulting from industry-based action research that focused on coal mining and labour studies in Britain (Abbas et al., 2025).

According to Emery (1980), socio-technical study focuses on the reciprocal advantages that arise when social and technical components come together. The process of dual structuring, which occurs at this intersection, highlights the reciprocity between humans and machines (Ropohl, 1999). As a result, the socio-technical method identifies the technical and social components—referred to as subsystems that make up a suprasystem, which is a larger system of interest. According to the theory, the interactions between these subsystems contributed to the success of the socio-technical system. Dominant technocratic paradigms that ignored human aspects and were technologically deterministic gave rise to socio-technical theory (Trist, 1981). Drawing on this theoretical framework, the research aimed to identify the key factors that impact this partnership and devise strategies to enhance human-technology interaction within the construction industry in Malaysia.

2.7 Hypothesis Development

The relationship between each factor and the application of drone technology in the project will then be further explained in this section.

2.7.1 The relationship between technological capabilities and the application of drone technology

The capabilities of drone technology have found their operational application in the construction industry, particularly in enhancing efficiency and safety. With its various state-of-the-art features, such as high-resolution imaging and the capability to collect live data, drones are enabling detailed and consistent site monitoring. Flying drones is legal in Malaysia, according to the Civil Aeronautics Authority of Malaysia (CAAM), provided that one complies with drone regulations at the time of flight (Malaysian Drone Law, 2022). However, considering that its developments and new technological innovations will likely continue to increase the adoption of drones in the construction industry (Tatum & Liu, 2017). Together with digital mapping systems and construction management software, drone technology enhances the accurate management of resources through effective labour utilisation.

H1: TC has a positive effect on the application of drone technology

2.7.2 The relationship between safety requirements and applications of drone technology

The need for safety on construction sites is growing more crucial due to the rising risks faced by workers. In such situations, drone technology serves as a powerful tool for enhancing safety. Drones can perform inspections in hazardous and hard-to-access locations, thereby effectively reducing workers' exposure to risks (Choi, 2023). Through continuous and strict observation of construction site conditions, drones can detect potential dangers well in advance, preventing them from escalating into major issues. This enables a project manager to devise prompt preventive actions to maintain safety and ensure adherence to established safety protocols (Patel, 2021). By capturing video and images through the air using the drone, an organisation can assess the situation, identify problems, and plan operations. Additionally, the application of drone technology in managing construction site safety also provides real-time data collection. The inclusion of advanced features, such as thermal imaging and live video streaming, enables real-time monitoring of activities on-site. The detection of real-time environmental conditions and the degree of work progress helps managers make swifter and more relevant interventions regarding safety (Sadiku, 2024). This helps to propel operational efficiency and safety, cementing the viability of drones within safety considerations in the construction field.

H2: SR has a positive effect on the application of drone technology

2.7.3 The relationship between operational efficiency and applications of drone technology

New digital technologies shorten the overall time and expense of construction projects while simultaneously increasing output (Sawant, 2021). Despite being widely used in other industries (such as agriculture, public safety, military applications, science and research, security monitoring, mining, and so on), drones have only lately entered the construction business. However, the cost of using drone technology in the construction industry is high. Drones of a more professional nature are employed in the construction industry, as opposed to ordinary drone models, and replacement parts are also costly. Operational efficiency in the construction industry is enhanced significantly through the application of drone technology, with numerous advantages prevailing. They provide real-time data collection, offering an overhead view of project progress that enables managers to quickly identify deviations from the original plan (Choi, 2023). The data collected by drones can later be integrated with the software for digital mapping and construction management systems. In this regard, drones not only enhance efficiency in monitoring but also significantly reduce the risks and costs associated with project management. Besides enhancing efficiency and ensuring worker safety, drones offer a valuable tool for ensuring project effectiveness through their application.

H3: OE has a positive effect on the application of drone technology.

2.7.4 The relationship between the compatibility of drones and the applications of drone technology

The relationship between drone compatibility and drone technology applications is crucial to ensure effective and safe use across various industries, including construction. This compatibility refers to the ability of drones to function well with the software and monitoring tools used in project management. The MDEC also plays a role in creating digital skills training courses for site managers and project managers to support the upskilling and reskilling of Malaysian talent, contributing to the country's economic recovery in the construction industry. (MDEC, 2020). When drones are designed to integrate with digital mapping systems and management software, they can provide accurate and real-time data, which is crucial for assessing project progress and quickly identifying any deviations. With this compatibility, project managers can make more informed and responsive decisions, improve operational efficiency, and comply with established safety guidelines. Therefore, the compatibility between drones and technology applications not only enhances productivity but also supports compliance with the necessary safety regulations in the construction industry.

H4: COD has a positive effect on the application of drone technology

2.8 Conceptual Framework

To fulfil the objective of this study, which was to investigate the factors that may influence the use of drone technology for construction site safety management in Malaysia, the following conceptual framework was proposed. The development of this framework was adapted from the socio-technical systems theory and the concept of human-technology cooperation. These theories emphasised the dynamic interaction between technology and human labourers in the construction industry, highlighting how they can work together to achieve common goals. Figure 1 illustrates the conceptual framework for the study.

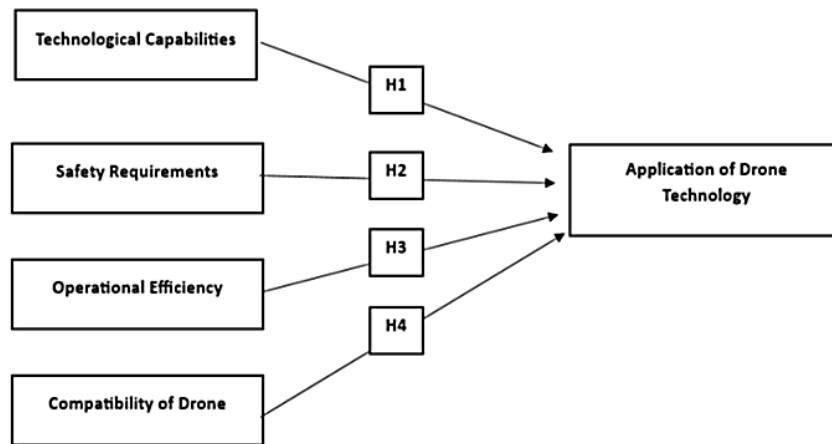


Figure 1. Conceptual framework

3. METHODOLOGY

This study employed a quantitative technique, utilising survey questionnaires for data collection. The unit of analysis in this study was the individual who has or currently works in the construction industry. They were people aged 18 years and above who worked with a developer, consultant, or contractor company on construction projects. A non-probability sampling method, utilising the snowball technique, was employed in this study to identify the respondents. The snowball sampling technique begins with one or more initial study participants. It then continues based on referrals from those respondents to their acquaintances. This process continues until it reaches the desired sample point.

Questionnaires were distributed through electronic mail (email) to three hundred (300) individuals who have worked in the construction sector, preferably with some exposure to drone utilisation within Malaysia. The questionnaires were divided into six sections. The demographic data of the respondent were presented in Part A, along with the company profile and personal information of the respondent's background, such as age, department, years of employment, and position. A 5-point Likert scale ordered-choice question, where 1 signifies "strongly disagree" and five indicates "strongly agree," was used in sections B, C, D, E, and F for respondents to provide their answers. All measurements were adapted from several sources from past research studies. Questions on the current state of drone technology use in construction site safety management can be found in Part B. Then, in Section C, inquiries were made about safety requirements for Industry 4.0 drones. Part D discussed the industrial elements of operational efficiency. Following that, the compatibility of drone technology was covered in section E. Lastly, Part F allowed the respondent to provide any additional comments on the evolution of drone technology in construction site safety management.

One academic and one industry professional conducted a pre-test to evaluate content validity and minimise potential biases. Content validation was employed to verify whether the drafted questions functioned as planned and to assess if there were weaknesses that needed improvement to minimise the possibility of measurement error. This pre-test took

place before the distribution of the survey questionnaires to the larger sample involved in this study. According to the calculations from G-Power software, the minimum sample size required was determined to be 103. Data gathered from the survey were then analysed using the Partial Least Squares Structural Equation Modelling (SmartPLS 4.0) to derive conclusions. This analysis aimed to assess and predict an objective approach for obtaining a more accurate numerical measurement based on the successfully gathered data. Numerous statistical methods are available for social researchers to determine which is the most appropriate technique. For this study, the author utilised SmartPLS 4.0 software to test all the hypotheses. Reasons for this choice were that PLS-SEM is suitable for prediction-oriented studies. In addition, PLS-SEM makes it possible to conduct analysis regardless of the quantity of samples available, which is more appropriate because it may permit a small to moderate number of samples.

An essential component of data analysis is descriptive statistics, which give an overview of a dataset's key characteristics. Descriptive statistics, such as the mean, median, mode, standard deviation, and range, are used in research to characterise the features of a population or sample (Tomaszewski et.al., 2020). Descriptive statistics help describe and understand the characteristics of a particular data set by providing a summary of the data sample and measures. It is used to summarise and explain the variable or variables for a sample of data. Descriptive statistics serve as an essential tool for summarising and characterising the main components of a data set, allowing researchers to understand the characteristics of a population or sample.

4. RESULTS AND DISCUSSION

It is appropriate to combine the Results and Discussion sections into a single section. Clear and concise results were required. The significance of the work's findings should be thoroughly discussed throughout the discussion section. Extensive citations and discussion of already published material should be avoided.

4.1 The Respondent's Demographic

The study's response rate is displayed in Table 1. Three hundred workers who work in Malaysia's construction sector had received the survey via email. Based on the G-Power calculation, the study's minimum sample size was 108. Since 110 responses were received (a response rate of 36.67%), the minimum sample requirements were met. Table 1 displays the outcome.

Table 1. Response rate

Data Collection Method	Total of Distribution	Total Respond	Minimum Sample Size	Response Rate
Email	300	110	108	36.67

Table 2 reveals the demographics of the respondents in this study. The majority of respondents were employed in Frontline Management (22.7%) and Senior Management (26.4%), while middle management accounted for 50.9% of the respondents.

Table 2. Respondents' demographics

Demographic Items	Categories	Frequency	Percentage (%)
Current Position	Senior Management	29	26.4
	Middle Management	56	50.9
	First Line Management	25	22.7
Working Experience	Under 5 years	39	35.5
	6 to 10 years	52	47.3
	More than 10 Years	19	17.3
Level of Implementation Use of Drone Technology Initiatives	Very small Extent	2	1.8
	Small Extent	9	8.2
	Certain Extent	34	30.9
	Good Extent	30	27.3
Company age group	Great Extent	35	31.8
	3 – 5 years	27	24.5
	6 – 10 years	49	44.5
	More than 10 years	34	30.9
	Total	110	100

Table 2 indicates that the largest group of respondents, 47.3%, had job experience of between 6 and 10 years combined. Next, there were individuals with fewer than five years of experience (35.5%) and those with more than ten years of work experience (17.3%). This result suggested that the majority of the respondents were experienced workers with more than 5 years of working experience in the construction industry. Thirty-five persons (31.8%) of the respondents reported that

the use of drone technology implementation was "great extent", 34 persons (30.9%) reported as "certain extent", 30 persons (27.3%) reported as "good extent". While a minority of them, nine persons (8.2%), as "small extent" and two persons (1.8%) as minimal extent". This result suggested that many companies implemented drone technology in their operations. In terms of the duration of work service, the majority of respondents have worked with the same company for more than five years. Forty-nine persons (44.5%) have been with the company between six and ten years. Thirty-four persons (30.9%) have been with the company for more than 10 years, and 27 persons (24.5%) have been with the company between three and five years.

4.2 Measurement Model

Validity and reliability are crucial to ensure that the sample obtained is valid and reliable. To effectively test the validity of the sample, factor analysis, Composite Reliability (CR), and Average Variance Extracted (AVE) were employed. Additionally, the structural model evaluation discussed hypothesis testing for positive results. Figure 2 shows the PLS-Path model after considering the factor loading threshold. Factor loadings represented the strength of the relationship between observed variables (indicators) and their corresponding latent constructs (factors). Stronger relationships were indicated by higher factor loadings, implying that the indicator effectively measured the underlying construct. The threshold is considered a standard value for factor loading, with 0.50 still considered an acceptable value (Hair et al., 2011). In this study, all the factor loadings had values exceeding 0.50.

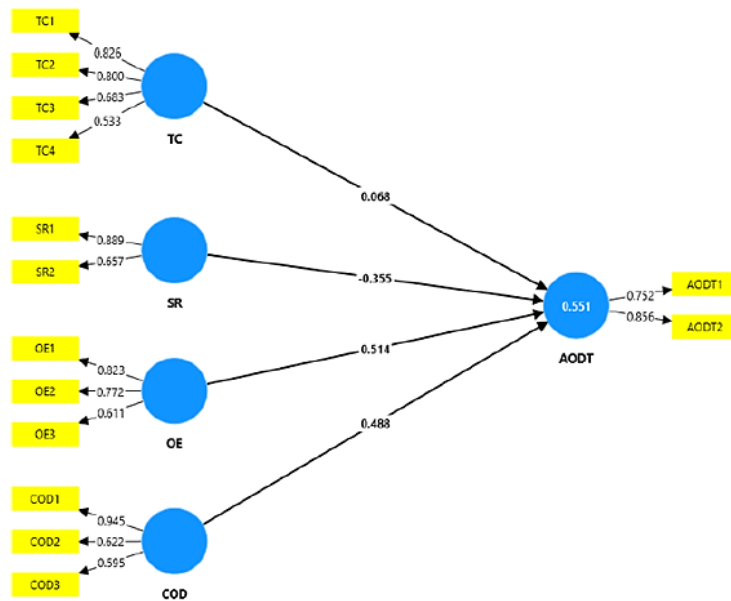


Figure 2. Measurement model

4.3 Internal Consistency & Convergent Validity

A standard method for checking internal consistency is Cronbach's Alpha, a statistic that measures the inter-item relationship using SmartPLS. The range of this value goes from negative infinity to one. Convergent validity occurs when the items of the measurement instrument satisfactorily converge as a representation of the intended construct. The AVE was computed as the average of the squared loadings for all the indicators related to a particular construct. An AVE value above 0.50 is considered an indication of good convergent validity (Hair et al., 2011). AVE is calculated as the mean of the squared loadings of each indicator associated with a construct. Detailed results are shown in Table 3. This study yielded AVE values ranging from 0.518 to 0.649, which exceeded the minimum value of 0.50.

Table 3. Internal consistency & convergent validity

	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)
AODT	0.465	0.483	0.787	0.649
COD	0.651	1.143	0.774	0.545
OE	0.580	0.599	0.783	0.549
SR	0.385	0.443	0.754	0.611
TC	0.747	0.804	0.807	0.518

CR is a measure of internal consistency that assesses how well a set of items consistently measures a single underlying construct. In this study, the CRs of all the latent variables ranged from 0.754 to 0.807. These CR values exceeded the benchmark of 0.600 as recommended by Bagozzi et al. (1991). Therefore, the reliability of all the latent constructs was acceptable and satisfactory.

4.4 Discriminant Validity

Discriminant validity refers to the extent to which factors are distinct and uncorrelated. It is a measure to assess whether the constructs are proven to have no relationship. This enables the clear distinction between measurements of different constructions. Furthermore, discriminant validity makes sure that reflective constructs logically and pertinently demonstrate the strongest association with their own indicators. Three primary techniques are available for testing discriminant validity in SMART-PLS: the Monotrait-Heterotrait Ratio (HTMT), Cross-Loading, and the Fornell-Larcker Criterion. The Fornell-Larcker Criterion was explicitly applied in this stage of the investigation. The Fornell-Larcker criterion compares the square root of the AVE values with the latent variable correlations. The Fornell-Larcker test suggested that to achieve discriminant validity, the square root of the AVE for each construct should be greater than its correlations with other constructs. Based on the results, all the requirements were met; thus, the discriminant validity test was achieved. At this point, researchers concluded that both the convergent validity and discriminant validity tests have passed the construct validity requirement for this study. The Fornell-Larcker Criterion summary result is shown in Table 4.

Table 4. Fornell-Lacker Criterion

	AODT	COD	OE	SR	TC
AODT	0.806				
COD	0.677	0.738			
OE	0.611	0.668	0.741		
SR	0.372	0.563	0.795	0.782	
TC	0.570	0.670	0.788	0.647	0.720

4.5 Structural Model

Hypothesis testing was performed using the structural model in PLS-SEM. Structural equation modelling (SEM) was used to achieve this, providing researchers with both direct and indirect means of examining complex correlations between different variables (Authors, 2020). Typically, this process begins by evaluating how well the model explains the data, and subsequently, the importance and relevance of the path coefficients are examined (Hair et al., 2012). This analysis aimed to scrutinise the proposed hypotheses regarding the relationships between variables established in the initial phase of the study. Regardless of whether the relationships were supported or not, the analysis incorporated a bootstrapping phase, revealing the level of support for each proposed hypothesis. The hypothesis testing results are summarised in Table 5.

Table 5. Summary of hypothesis testing results

Hypotheses	Path	β	Sample MEAN (M)	Standard deviation (STDEV)	T statistics (O/STDEV)	P values	Decision
H4	COD ->AODT	0.488	0.532	0.154	3.179	0.001	Supported
H3	OE ->AODT	0.514	0.433	0.244	2.106	0.035	Supported
H2	SR ->AODT	-0.355	-0.341	0.251	1.412	0.158	Not Supported
H1	TC ->AODT	0.068	0.146	0.233	0.292	0.771	Not Supported

According to Henseler et al. (2009), the bootstrapping technique can be used to assess the significance of the path coefficient, which provides t-values and p-values. The p-value should be less than 0.05 and the t-value greater than 1.645 for a one-tailed test (Hair et al., 2013). Table 5 in this study reveals that the COD had a positive effect on the application of drone technology, as indicated by a t-value (p-value = 0.001; t = 3.179; β = 0.488). Then, OE also positively influenced the application of drone technology, as supported by a t-value (p-value = 0.035; t = 2.106; β = 0.514). On the other hand, the following hypothesis, namely SR, was not supported because the t-value was 1.412 (the limit was greater than 1.645), and the p-value was 0.158 (the limit should be no more than 0.05), while the β value was -0.355. While the last hypothesis, TC, was not supported because the p-value was 0.771 (limit was greater than 1.645), the t-value was 0.292 (limit should be no more than 0.05), and the β value was 0.068. Thus, only two hypotheses were supported, which were H3: OE had a positive effect on the application of drone technology, and H4: COD had a positive impact on the application of drone technology.

5. CONCLUSIONS

The function and integration of drone technology in the safety sector at Malaysian building sites was the main topic of this study paper. With a focus on the effects on productivity and safety, the goal was to examine how the efficient use of drones may work alongside the human workers on construction sites. Data were gathered through surveys using a quantitative technique and a suggested sample size of 108 construction experts. The demographic profiles of the participants were also included in this study, and the results were summarised using descriptive analysis. Furthermore, this study employed measurement models to evaluate the reliability and validity of the data gathered, considering key elements such as discriminant validity, convergent validity, and internal consistency. The structural model and variance inflation factor (VIF) were also examined in this research to investigate the relationships and predictions between the

various variables involved. This paper addressed essential topics in the building industry, particularly the challenges of integrating technology into conventional methods. While considering how new technology may impact employment positions in the business, it highlighted the potential advantages in terms of safety and increased efficiency. According to the study's findings, two factors that favoured the deployment of drone technology were compatibility and OE. However, there was no discernible benefit to the requirement for safety and TC. This result addressed the study's objective, which was to investigate the factors that may influence the use of drone technology for construction site safety management in Malaysia.

Research focused on the interaction of drone technologies and their application in construction site safety within Malaysia has various limitations. The first was legal and regulatory uncertainty, which hinders the wide acceptance of drones, as many authorities have not yet provided clear guidelines for their use in the industry. The second was the defence against expenses and associated high investments that range from the purchase of professional drones to their operational and maintenance training. Additionally, reliance on atmospheric conditions also hinders drone operations, as adverse weather can disrupt monitoring and safety functions at construction sites. All the above come to show that although drone technology has quite a lot of promise for better safety and overall efficiency, there are huge considerations to take into account to allow effective adoption within the construction industry.

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AUTHORS CONTRIBUTION

Mohd Ghazali Maarof (Conceptualization; Visualisation; Writing, Supervision)

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Shaharin Hamid (Conceptualization; Methodology, Visualisation; Writing)

AVAILABILITY OF DATA AND MATERIALS

The data supporting this study's findings are available on request from the corresponding author.

ETHICAL STATEMENT

Not applicable.

CONFLICT OF INTEREST

The author(s), as noted, certify that they have NO affiliations with or involvement in any organisation or agency with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, jobs, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, expertise or beliefs) in the subject matter or materials addressed in this manuscript.

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