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BARRIERS TO THE ADOPTION OF NEW SAFETY TECHNOLOGIES IN CONSTRUCTION: A DEVELOPING COUNTRY CONTEXT

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Abstract. The adoption rate of new technologies is still relatively low in the construction industry, particularly for mitigating occupational safety and health (OSH) risks, which is traditionally a largely labor-intensive activity in developing countries, occupying ill-afforded non-productive management resources. However, understanding why this is the case is a relatively unresearched area in developing countries such as Malaysia. In aiming to help redress this situation, this study explored the major barriers involved, firstly by a detailed literature review to identify the main barriers hampering the adoption of new technologies for safety science and management in construction. Then, a questionnaire survey of Malaysian construction practitioners was used to prioritize these barriers. A factor analysis further identified six major dimensions underlying the barriers, relating to the lack of OSH regulations and legislation, technological limitations, lack of genuine organizational commitment, prohibitive costs, poor safety culture within the construction industry, and privacy and data security concerns. Taken together, the findings provide a valuable reference to assist industry practitioners and researchers regarding the critical barriers to the adoption of new technologies for construction safety management in Malaysia and other similar developing countries, and bridge the identified knowledge gap concerning the dimensionality of the barriers.

Keywords: construction industry, safety management, technology adoption, barriers, factor analysis, developing countries.

Introduction

The construction industry is inherently reluctant to innovate, especially in developing countries (Yap et al., 2019). For example, in investigating industrial revolution (IR) 4.0 in the current Egyptian situation, Alaloul et al. (2020, p. 229) concluded that “the implementation of IR 4.0 within the construction industry is still lacking tremendously despite having the accessibility of these technologies.” As Wang et al. (2020, p. 651) highlight, “the implementation of building information modelling (BIM) in many projects has failed to achieve expected benefits due to user resistance.” Likewise, in Malaysia, there is a limited utilization of automation and robotics for such on-site construction as structural steelwork and the assembly of prefabricated components (Rohana, 2012). Previous studies found the construction industry in developing countries having a similar pattern of problems despite different geographical, social, political and economic backgrounds (Kang et al., 2018; Yap et al., 2019).

Recently, Forcina and Falcones’ (2021) systematic review collected and analyzed 68 articles from 2010 to 2020 to conclude that *IR 4.0 enabling technologies* can benefit safety management. These enable the smart factory (e.g., cyber-physical system (CPS), radio-frequency identification (RFID), internet of things (IoT), automation, modularization, robotics), simulation and modelling (e.g., building information modelling (BIM), augmented reality (AR), virtual reality (VR), mixed reality (MR)), and digitization and virtualization (e.g., cloud computing, big data, mobile computing) across the entire construction value chain (Oesterreich & Teuteberg, 2016). However, despite the technological advancements and academic attention in this area, the rate of integrating new technologies into construction safety science and management is still limited (Karakhan et al., 2019). Furthermore, the applications of new technologies for construction safety are mainly a

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matter for academic research, with a limited transition into practice (Zhou et al., 2013).

In response, the present study examined the barriers that construction practitioners attribute to inhibiting the application of new technologies to increase construction safety in the context of the developing world; using Malaysia as a base of the study. Notably, little attempt has been made to explore the underlying dimensions of these barriers in the construction domain. As a corollary, therefore, the aim of the study was to contribute towards bridging these gaps in knowledge by providing answers to the research questions:

1. What are the barriers to the adoption of new safety technologies in construction?
2. What are the fundamental underlying dimensions involved?

1. Literature review

1.1. Safety issues in construction

Construction is also notorious for its poor *safety performance* when comparing its accident statistics to other industries. Construction sites are famous for their hazardous working conditions and being one of the world's most dangerous working environments in the world (Kang & Wu, 2020). In Malaysia, the Occupational Safety and Health Department's (DOSH) statistics recorded 169 deaths and 3,911 accidents in 2018, with a fatality rate of 13.44 per 100,000 workers (Babulal, 2020). This is ten times worse than that of the United Kingdom, for instance, and consistent with Hämäläinen et al. (2006) concerning the disparity of construction safety and health performance between developing and developed countries.

This is partly due to construction sites being dynamic, fast-paced, and risky. The high rate of accidents is also attributed to conventional work processes: these are very labor-intensive with few technological advances, involving unsafe behaviors, use of heavy machinery, and dangerous working conditions (Xu & Wang, 2020; Zhou et al., 2015). Furthermore, the construction also reported a considerably high incidences of work-related musculoskeletal disorders (WMSDs) among the workers (Rwamamara et al., 2010). For these reasons, construction safety has remained a major issue in both academic research and practice.

1.2. Advancing safety science with new technologies

According to Demirkesen and Tezel (2021), the industry's complex and highly dynamic nature demands an *acceleration in new technologies* to transform the current state of construction safety management. From this perspective, Edirisinghe (2019, p. 184) has emphasized that "the future construction site will be pervasive, context-aware and embedded with intelligence", reinforcing the concept of digital skin for safety objectives.

Indeed, recent years have seen a growing interest in value-creating disruptive *innovations* to overcome safety problems in the industry and deliver a new competitive

advantage. Previous studies investigating a proactive safety management perspective conclude that the utilization of innovative solutions can significantly reduce the workers' exposure to physical safety hazards, which in turn creates a safer work environment (Nnaji & Karakhan, 2020; Yap et al., 2021; Zhou et al., 2013).

In this regard, innovative solutions can provide safety and operational value on construction sites: safer work-sites to better safeguard workers (Oesterreich & Teuteberg, 2016). For example, safety *simulation* using information from surveillance cameras is capable of analyzing integrated human-machine-environment risk to provide dynamic safety prewarnings to allow timely corrective actions (Xu & Wang, 2020). True *automation* of safety, security, and operational tasks can save time and reduce errors – making worksites run faster, safer, and smarter (Edirisinghe, 2019; Oesterreich & Teuteberg, 2016; Pan & Zhang, 2021).

Although there is optimism about the potential for new technologies to help manage project risks, few studies have addressed construction safety problems through the use of new technologies: with the exception of China, this is particularly the case in the context of developing countries (Zhou et al., 2013). Also, the lack of automation and smart systems is linked to poor safety performance (Kamaruddin et al., 2016; Okpala et al., 2020). Zhou's et al. (2015) comprehensive literature review of 439 peer-reviewed papers (from 1978 to 2013) published in 10 leading construction management and safety academic journals highlighted six research gaps, one of which concerns the lack of new technology applications in construction safety practice. They further emphasized that most new technology applications remain in the stage of academic research but with limited industrial applications. Furthermore, the potential barriers that could affect the adoption and use of innovative solutions to overcome safety risks still need to be adequately studied and explained (Nnaji & Karakhan, 2020).

1.3. Barriers to the adoption of new safety technologies for construction work

Previous studies make various contributions to the utilization of new technologies for construction safety risk management and the technologies applicable, but studies of the barriers hampering their safety of adoption are quite limited. Given this situation, the review of the literature was extended more broadly to include studies appraising the challenges in adopting such new technologies as IR 4.0, automation, and robotics. This yielded 18 variables/indicators representing the barriers as summarized in Table 1.

Nnaji and Karakhan (2020) have identified 13 key barriers to the adoption of new technologies for *OSH management*. By prioritizing the survey data collected from 102 construction professionals in several states across the US, the five most critical barriers were found to be "extensive upfront investment required", "need for extensive training before achieving optimum performance", "con-

Table 1. Summary of barriers to safety technology adoption in construction

No.	Barriers	References
A	<i>Economic-related</i>	
A1	Costly investment associated with new technology	Aripin et al. (2019), Bademosi and Issa (2021), Delgado et al. (2019), Kamaruddin et al. (2016), Nnaji and Karakhan (2020), Yahya et al. (2019)
A2	Required worker training may not be cost effective	Delgado et al. (2019), Kamaruddin et al. (2016), Nnaji and Karakhan (2020), Yahya et al. (2019)
A3	Slim profit margins in the industry	Loushine et al. (2006), Nnaji and Karakhan (2020)
B	<i>Regulatory-related</i>	
B1	Lack or no government regulation for use	Amirah et al. (2013), Nnaji and Karakhan (2020), Pradhananga et al. (2021)
B2	Lack of government commitment	Abdul-Rashid and Abdul-Aziz (2003), Delgado et al. (2019)
B3	Lack of legislation	Abdul-Rashid and Abdul-Aziz (2003), Bademosi and Issa (2021)
C	<i>Management/leadership-related</i>	
C1	Lack of top management and leadership support	Cortellazzo et al. (2019), Tam et al. (2001)
C2	Lack of decision support tools	Nnaji and Karakhan (2020), Pradhananga et al. (2021)
C3	Creates liability concerns	Bademosi and Issa (2021), Nnaji and Karakhan (2020)
D	<i>Technical-related</i>	
D1	Incompatibility of technology with current practices and current construction operations	Bademosi and Issa (2021), Delgado et al. (2019), Yahya et al. (2019)
D2	Unavailability of technological assistance for technology use in the management of OSH	Aripin et al. (2019), Kamaruddin et al. (2016)
D3	Technology performance concerns	Delgado et al. (2019), Nnaji et al. (2018), Pradhananga et al. (2021)
E	<i>Knowledge-related</i>	
E1	Lack of professional knowledge	Aripin et al. (2019), Kamaruddin et al. (2016), Osunsanmi et al. (2020)
F	<i>Socio-cultural-related</i>	
F1	Culture of the construction industry	Delgado et al. (2019), Rohana (2012)
F2	Decision to use differs from client requirements	Nnaji et al. (2020b), Shen and Marks (2016)
F3	Ageing workforce resistant to change	Aripin et al. (2019), Bademosi and Issa (2021), Delgado et al. (2019), Pradhananga et al. (2021)
G	<i>Security-related</i>	
G1	No assurance of data security	Bademosi and Issa (2021), Gou et al. (2013), Nnaji and Karakhan (2020), Osunsanmi et al. (2020)
G2	Privacy of workers personal data is not guaranteed	Bademosi and Issa (2021), Gou et al. (2013)

cerns regarding the technical support availability”, “doubts regarding the reliability of these technologies”, and “client rarely demands for their use”. In South Africa, Osunsanmi et al. (2020) reported the use of RFID with mobile technologies for *monitoring construction professionals* on site is hindered by their cost and low technical ability.

In another U.S.-based study, the critical factors hindering the broad adoption of *robotics* in construction were found to include immature technologies, the nature of the industry, complex technical processes involved, economic feasibility, and a weak culture of innovation. In the UK, Delgado et al. (2019) combined the findings from a literature review and qualitative analysis from focus group discussions to reveal a list of 11 limiting factors to robotic adoption in construction. Later, they employed a questionnaire survey for ranking the factors. The three top concerns were high start-up capital, no strong need to increase work

efficiency, and low R&D budgets for innovation capacity. Finally, a factor analysis revealed a 4-factor solution of relating to contractor-side financial limitations, client-side financial limitations, technical and work culture limitations, and a weak business case. In Malaysia, the main challenges to the adoption of construction robotics are the high cost to acquire, maintain, and update the new technologies (Yahya et al., 2019). In another Malaysian study, Kamaruddin et al. (2016) used a brainstorming workshop to solicit views from experts and experienced practitioners to observe four major barriers of *mechanization and automation*, which are capital cost, skill resources, maintenance, and availability of the new technologies. According to Rohana (2012), the extent of readiness of the construction industry to utilize construction automation and robotics is related to financial commitments, availability of technical knowledge and equipment, compatibility with

existing construction practices and operations, situation of the workforce, and characteristics/culture of the industry.

In investigating the common challenges for IR 4.0 adoption among U.S.-based construction companies, Demirkesen and Tezel (2021) have reported problems arising from lack of standardization, legal and contractual issues, and cost of implementation. A systematic review by Edirisinghe (2019) noted that the challenges to achieving *digital skin* at the construction site are primarily associated with technical limitations, problems associated with standardization, haphazard technology design, development, and implementation, with limited studies of the factors that affect the acceptance of new technologies and a lack of understanding of human aspects of technological change.

2. Methodology

The quantitative methodology was used, involving a cross-sectional structured questionnaire survey adopted to access the barriers to the adoption of new safety technologies in Malaysia's construction industry. Malaysia's Gross National Income (GNI) per capita is at US\$11,200 according to the latest estimates, is classified as a developing nation. The survey method is an effective and economic way of collecting feedback from a relatively large sample in a short time for statistical analysis, as well as being a widely used technique to prioritize relevant variables in construction safety management studies (e.g., Delgado et al., 2019; Nnaji & Karakhan, 2020; Yap et al., 2020).

Descriptive statistics were obtained, whereby the relative ranking of the barriers was assigned based on the mean scores, considering the views of clients, contractors, and consultants. The Kruskal-Wallis nonparametric analysis of variance (ANOVA) test was used to determine if there were any statistically significant differences between the three respondent groups. A data reduction technique

using exploratory factor analysis was then applied to explore the possible underlying factor structure of the identified list of barriers.

2.1. Questionnaire design

After identifying the barriers to the adoption of new safety technologies, a questionnaire was developed containing two parts (see Appendix). In Part 1, the participants were asked to provide demographic information about their project role, job position held, years of experience, and academic background. Part 2 provided a list of barriers identified through an integrative literature review (Table 1). For each barrier, the participants were requested to indicate their level of agreement on a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree).

2.2. Survey participants and demographics

The sampling frame consisted of construction professionals familiar with current construction practices in Malaysia, with a tertiary education, and representing the primary parties (client, contractor, and consultant) to obtain industry-wide information. The participants were sampled using convenience and snowball techniques. A total of 600 e-survey forms were distributed by email and the LinkedIn platform. Participation in the survey was voluntary but reminders were made using follow-up emails to increase the response rate. In total, 150 participants responded to the survey. To ascertain the quality of the responses, the researchers checked if there were responses with straightlining and participants not meeting the sampling criteria. Table 2 summarizes the participants' demographic profile with 50 clients, 50 contractors, and 50 consultants. Nearly 70% are in executive positions, while approximately half have over 5 years of working experience in the construction industry. The participants were regarded as sufficient to exercise sound judgement – establishing the validity of the responses.

Table 2. Demographic profile of respondents

Description	Demography	Role in Project			N	% response
		Client	Contractor	Consultant		
Job position	Executive	35	38	34	107	71.3
	Manager	6	4	11	21	14.0
	Senior manager	8	8	4	20	13.3
	Director/top management	1	0	1	2	13.3
Experience working in construction (years)	5 years or less	20	31	27	78	52.0
	6–10 years	17	12	12	41	27.3
	11–15 years	5	4	6	15	10.0
	16–20 years	5	1	2	8	5.3
	More than 20 years	3	2	3	8	5.3
Highest academic qualification	Diploma	2	1	0	3	2.0
	Bachelor' degree	38	41	36	115	76.7
	Master's degree	10	5	11	26	17.3
	Doctorate/PhD	0	3	3	6	4

3. Analysis and ranking of barriers

Cronbach's coefficient α value was 0.895, which is higher than the threshold of 0.70 needed to establish the internal reliability of the scale used (Hair et al., 2019). Ranked in ascending order based on the overall results, Table 3 presents the means and standard deviations of each barrier according to client, contractor, and consultant type. Overall, all the barriers had a mean score importance rating greater than 3.0, with the five most significant barriers of:

1. Costly investment associated with new technologies (mean = 4.17);
2. Culture of the construction industry (mean = 4.01);
3. Decision to use differs from the client requirements (mean = 3.79);
4. An ageing workforce resistant to change (mean = 3.70);
5. Lack of top management and leadership support (mean = 3.67).

For the *clients*, these are:

1. Costly investment associated with new technologies (mean = 4.04);
2. Culture of the construction industry (mean = 4.02);
3. An ageing workforce resistant to change (mean = 3.68);
4. Technology performance concerns (mean = 3.60);
5. Decision to use differs from the client requirements (mean = 3.56).

For the *contractors*:

1. Costly investment associated with new technologies (mean = 4.04);
2. Lack of top management and leadership support (mean = 3.80);
3. Decision to use differs from the client requirements (mean = 3.74, $\sigma = 0.853$);
4. Culture of the construction industry (mean = 3.74, $\sigma = 1.051$);
5. Availability of technological assistance for the use of new technologies in OSH management (mean = 3.72, $\sigma = 0.904$).

For the *consultants*:

1. Costly investment associated with new technologies (mean = 4.42);
2. Culture of the construction industry (mean = 4.26);
3. Decision to use differs from the client requirements (mean = 4.06);
4. Lack of decision support tools (mean = 3.82, $\sigma = 0.873$);
5. Creation of liability concerns (mean = 3.82, $\sigma = 1.082$).

The highest-ranked barrier of *costly investment associated with new technologies* is associated with economic feasibility. Adopting new technologies for mechanization and automation means there is a need for a substantial and sustained budget – the capital cost of new technologies and maintenance costs, whereby the equipment is expensive to operate and maintain (Kamaruddin et al.,

2016; Oesterreich & Teuteberg, 2016). In investigating the readiness of the Malaysian construction industry in utilizing automation and robotics, Rohana (2012) has observed that price sensitivity negatively influences the intention to adopt new technologies. As Aripin et al. (2019) have highlighted, the construction industry is risk-averse to costly investment in new technologies. According to Dodge Data & Analytics (2019, p. 1), “most contractors don't have a dedicated innovation budget, and tend to pay for new technologies by absorbing the costs in anticipation of long-term gains or by passing on the costs”, indicating a half-heartedness in utilizing new technologies to help improve construction safety management. Moreover, the cost of employing new technologies to study human safety can be prohibitive, which poses significant challenges for researchers in this area (You et al., 2018), particularly for prototype building in developing countries. For example, the harsh construction site environment (outdoors, dust, and moisture) involves higher requirements for computing equipment and mobile devices that can withstand the impact from strong vibrations, large falls, and humidity (Oesterreich & Teuteberg, 2016). In the US, the operation and maintenance costs of new technologies is a major concern among practitioners (Nnaji & Karakhan, 2020; Dodge Data & Analytics, 2017). According to Delgado et al. (2019), it is still unclear whether the existing construction market structure and dynamics justifies large capital investments in utilizing new technologies for construction safety risk mitigation.

The persistent fragmentation within the construction industry arises from its multistakeholder and discipline-oriented nature, with the many layers of responsibilities and control within the different phases of construction having a negative influence on project performance, productivity, and the adoption of innovative solutions (Yap et al., 2019). Hence, fragmentation and the project-based nature of activities inhibit technology innovation and adoption across the specialized trades involved (Bademosi & Issa, 2021; Rohana, 2012) – as a result of confrontational behavior restricting alternative thinking. The unduly fragmented and complex industry dynamics with manual processes across the supply chain creates significant challenges in communication and collaboration, resulting in a strained and adversarial working culture, and inefficiencies related to knowledge hoarding and a lack of coordination (Demirkesen & Tezel, 2021). Moreover, the extensive use of subcontractors causes many problems in coordination, safety planning, allocating safety responsibility, and communication (Kartam et al., 2000). These characteristics have caused a huge challenge to safety management at construction sites, as well as retarding the diffusion of new safety technologies. The lack of commitment to innovation and inefficient coordination between designers and contractors in terms of promoting new technologies is more likely to make their integration to safety applications more difficult. Against this background, enhancing safety management on smart construction sites will involve future

construction procurement and project management being more robust and productive, with real-time information retrieval and dissemination, structured and efficient communication, and embedded intelligence (Edirisinghe, 2019).

Clients expect a contractor to finish the work with minimal costs of production (Tam et al., 2001). As Kartam

et al. (2000, p. 181) have elucidated, “competitive bidding and owners’ negligence in including the cost of safety in tenders all adversely affect the safety performance of many contractors.” The current tendering practice that prioritizes “lowest price” is a crucial limitation to innovation (Delgado et al., 2019). Client involvement can significantly influence psychological safety climate (Shen et al., 2015).

Table 3. Mean score and ranking of barriers

Ref.	Barriers	Overall (N = 150)			Clients (N = 50)			Contractors (N = 50)			Consultants (N = 50)			KW p-value
		Mean	SD	Rank	Mean	SD	Rank	Mean	SD	Rank	Mean	SD	Rank	
A1	Costly investment associated with new technology	4.17	0.908	1	4.04	1.009	1	4.04	1.009	1	4.42	0.609	1	0.132
F1	Culture of the construction industry	4.01	0.952	2	4.02	0.937	2	3.74	0.899	4	4.26	0.965	2	0.004**
F2	Decision to use differs from client requirements	3.79	0.966	3	3.56	1.181	5	3.74	0.853	3	4.06	0.767	3	0.087
F3	Aging workforce resistant to change	3.70	1.116	4	3.68	1.168	3	3.72	1.051	6	3.70	1.147	8	0.998
C1	Lack of top management and leadership support	3.67	1.046	5	3.46	1.182	7	3.80	0.808	2	3.76	1.098	7	0.306
C2	Lack of decision support tools	3.65	0.969	6	3.46	1.129	6	3.68	0.868	7	3.82	0.873	4	0.265
C3	Creates liability concerns	3.62	1.014	7	3.40	1.088	8	3.64	0.827	9	3.82	1.082	5	0.068
D3	Technology performance concerns	3.61	0.995	8	3.60	1.069	4	3.58	0.906	11	3.66	1.022	11	0.806
D2	Availability of technological assistance for technology use in the management of OSH	3.58	1.025	9	3.40	1.178	9	3.72	0.904	5	3.62	0.967	12	0.517
A2	Required worker training may not be cost effective	3.56	1.126	10	3.24	1.271	12	3.64	1.025	10	3.80	1.010	6	0.058
E1	Lack of professional knowledge	3.51	1.219	11	3.28	1.278	10	3.66	1.062	8	3.60	1.294	13	0.291
D1	Incompatibility of technology with current practices and current construction operations	3.42	1.101	12	3.26	1.242	11	3.58	0.906	11	3.42	1.126	15	0.569
A3	Slim profit margins in the industry	3.41	1.050	13	3.06	1.096	15	3.48	0.995	12	3.68	0.978	9	0.012*
G1	No assurance of data security	3.37	1.040	14	3.20	1.030	13	3.46	0.930	14	3.46	1.147	14	0.257
G2	Privacy of workers personal data is not guaranteed	3.33	1.065	15	3.14	0.990	14	3.44	1.033	15	3.40	1.161	16	0.304
B2	Lack of government commitment	3.24	1.163	16	2.76	1.135	18	3.28	1.031	17	3.68	1.151	10	0.001**
B3	Lack of legislation	3.23	1.205	17	2.86	1.278	17	3.48	1.054	13	3.34	1.206	18	0.039*
B1	Lack or no government regulation for use	3.19	1.151	18	2.90	1.165	16	3.32	1.019	16	3.36	1.225	17	0.136

Notes: SD denotes standard deviation. KW denotes Kruskal-Wallis. * and ** denote the mean is significant at the 0.05 and 0.01 level of significance, respectively.

In this light, the lack of client demand also results in the unwillingness of designers to utilize BIM for safety planning efforts during the design stage (Nnaji & Karakhan, 2020). As such, client advocacy for the practice of prevention through design (PtD) will drive designers due to the need for improved client relationships and ability to attract new business (Dodge Data & Analytics, 2017). Given that the client will need to absorb the cost of adopting new technologies for OSH management, limited development budgets and short-term decision making prevent the adoption of new approaches.

Although innovative solutions have great potential for improving productivity, efficiency, and safety through all stages of projects, previous studies highlight the conservative nature of the construction industry, which in turn creates resistance to change (Demirkesen & Tezel, 2021; Okpala et al., 2019), especially when the change involves a variation in pre-existing methods and re-engineering of basic work processes (Long & Spurlock, 2008). Technology change resistance may affect the individuals' willingness to accept new technologies and motivation to their use due to uncertainty surrounding the new processes and fear of unknown consequences (Cinite & Duxbury, 2018). Technology-driven change, such as the use of robotics and automation, may minimize manpower with the possibility of eliminating some construction work (Oesterreich & Teuteberg, 2016; Okpala et al., 2020). According to Zou (2002, p. 29), "cultural issues involving human behavior, attitudes, thoughts and relationships can lead to resistance to changes in their working environment." New working methods imply that workers have to leave their comfort zone, while many lack the ability to understand their potential increased benefits over traditional work practices (Zou, 2002).

As Yi and Chan (2014, p. 219) have highlighted, "the construction industry has encountered a serious shortage of construction workers, while confronting an ageing workforce and fewer young people entering the construction field". Although some older experienced workers are technophobic (Long & Spurlock, 2008), safety management in construction is still generally very much reactive. Even the use of simple personal protective equipment (PPE) for safety purposes is still meeting with some resistance by the workers (Teizer et al., 2013). Thus, it is unsurprising that there is a high degree of skepticism in the workforce over the use of such new safety technologies as smart personal wearables (Dodge Data & Analytics, 2017).

Safety-specific leadership refers to the leaders' endeavors toward safety – leaders creating the organizational climate (Zohar, 2010). The level of safety climate represents the shared perceptions of the safety prioritization compared to other competing priorities (Zohar, 2010). Safety stimuli include policies, procedures, and practices for guiding and directing appropriate and adaptive safety behavior in carrying out task activities (Shen et al., 2015). In this vein, strong safety leadership is a key to improving construction safety, especially for countries where safety is facing significant challenges and requires transformational

development (Wu & Fang, 2017). Thus, top management commitment is needed to support a safety climate to mitigate and prevent hazards and risks in the construction environment (Shen et al., 2015). However, the industry is undermined by several managerial challenges, namely: lack of research and development (R&D), insufficient safety budgets, insufficient OSH rules, poor safety documentation and procedures, lack of attention from leaders, lack of respect for workers, and inadequate PPE at work (Delgado et al., 2019; Maliha et al., 2021; Yap & Lee, 2020). Against this background, unsupportive managerial attitudes of the adoption of innovative solutions and a lack of managerial competence in risk assessment have hindered the adoption of new technologies to improve construction safety performance.

The Kruskal-Wallis ANOVA test suggests that only the *culture of construction industry* (ranked *less* important by contractors), *lack of legislation* (ranked *more* important by contractors), and *slim profit margins in the industry* and *lack of government commitment* (both ranked *more* important by consultants) have statistically significant differences between the three respondent types (Table 3).

4. Exploratory factor analysis

Exploratory factor analysis is used for analyzing patterns of correlations to uncover underlying factors in the data, and has been widely used as a data reduction technique to group a large number of variables into fewer numbers of factors in previous safety studies in the construction context (e.g., Delgado et al., 2019; Yap & Lee, 2020). The Kaiser–Meyer–Olkin (KMO) index ($KMO \geq 0.50$) and Bartlett's test ($p\text{-value} < 0.05$) are used to ascertain the factor reliability, whereas the latent root criterion (eigenvalues > 1.0) is applied to determine the optimal number of groupings (Hair et al., 2019). The KMO value of 0.895 and Bartlett's test result ($p\text{-value} = 0.000$) here indicated the suitability of the data set for factor analysis (see Table 4).

By applying varimax orthogonal rotation, six components were extracted with a cumulative variance of 76.68%, which is greater than the recommended value of 60% for establishing construct validity (Hair et al., 2019). Each of the variables weighed heavily on only one of the factors, and the loading on each factor exceeded 0.40. The Cronbach's α ranged from 0.710 to 0.906, indicating that each extracted factor was internally consistent. The label of the underlying factor was assigned according to the variables with higher factor loadings or a whole set of variables (Hair et al., 2019).

5. Discussion of factor analysis results

5.1. Factor 1: Lack of OSH regulations and legislation

Factor 1 accounted for 15.12% of the total variance explained, explaining the three most significant barriers concerning government policy and safety-related legislation on OSH to ensure that construction is safe and well-planned.

Table 4. Factor analysis results

Details of the factors and barriers	Factor loading	Variance explained (%)	Cronbach α	Average mean
<i>Factor 1: Lack of OSH regulations and legislation</i>	–	15.119	0.905	3.22
Lack of legislation (B3)	0.874			
Lack or no government regulation for use (B1)	0.842			
Lack of government commitment (B2)	0.800			
<i>Factor 2: Technological limitations</i>	–	14.439	0.821	3.53
Unavailability of technological assistance for technology use in the management of OSH (D2)	0.823			
Incompatibility of technology with current practices and current construction operations (D1)	0.819			
Technology performance concerns (D3)	0.800			
Lack of professional knowledge (E1)	0.485			
<i>Factor 3: Lack of genuine organisational commitment</i>	–	14.131	0.878	3.65
Creates liability concerns (C3)	0.823			
Lack of decision support tools (C2)	0.800			
Lack of top management and leadership support (C1)	0.773			
<i>Factor 4: Prohibitive costs</i>	–	11.136	0.710	3.87
Required worker training may not be cost effective (A2)	0.848			
Slim profit margins in the industry (A3)	0.741			
Costly investment associated with new technology (A1)	0.622			
<i>Factor 5: Safety culture within the construction industry</i>	–	11.049	0.714	3.83
Culture of the construction industry (F1)	0.780			
Ageing workforce resistant to change (F3)	0.712			
Decision to use differs from client requirements (F2)	0.704			
<i>Factor 6: Privacy and data security concerns</i>	–	10.810	0.906	3.35
Privacy of workers personal data is not guaranteed (G2)	0.919			
No assurance of data security (G1)	0.899			
Cumulative variance explained		76.684	0.895	
Kaiser-Meyer-Olkin measure of sampling adequacy		0.801		
Bartlett's test of sphericity approx. χ^2		1551.620		
df		153		
Sig.		0.000		

Note: Extraction method = Principal component analysis; rotation method = Varimax with Kaiser normalization. Rotation converged in 6 iterations.

Nonetheless, the average mean was the lowest at 3.22, indicating this factor has the least impact on the adoption of new safety technologies for construction. Obsolete safety rules and regulations and their lack of enforcement contributed to high accident rates. For example, the oil and gas industry is engaging “performance-based” safety regulation that is outcome based – requiring a defined outcome but leaving the means of achievement to the regulated entity (McKinsey Global Institute, 2017). However, non-compliance with OSH regulations are commonplace in construction. Regarding new safety technologies, there is no information relating to standards and government regulations for use, even in the US (Nnaji & Karakhan, 2020; Okpala et al., 2019). The development of suitable guidelines is needed for their effective adoption for a wide range of construction activities (Pradhananga et al., 2021). Moreover, the lack of government incentives and tariffs to promote the application of new safety technologies has also contributed to their limited use (Delgado et al., 2019).

5.2. Factor 2: Technological limitations

This factor encompassed four barriers of technical constraints, accounting for the second-largest variation of 14.44%. Immature technologies and the complex implementation of new technologies are major technical challenges behind their uncertain adoption in construction (Pradhananga et al., 2021). Given that the use of new information and communication technologies (ICT) requires a fast and reliable internet access at construction sites, unreliable broadband connectivity is a significant obstacle to overcome (Oesterreich & Teuteberg, 2016). Unproved effectiveness highlights the concerns from the industry of the readiness to test new technologies. Additionally, automation is delimited by the highly complicated and interconnected work tasks involved in using robotic and automated systems (Delgado et al., 2019). According to Nnaji et al. (2020a), the application of new safety technologies is influenced by the level of complexity, required features,

required support, available support, training required, durability, technology effectiveness, reliability, and versatility involved. For example, such issues as interoperability and limitations with sensor devices are common constraints related to BIM and the integration of IoT devices (Tang et al., 2019). Other issues limiting the application of BIM technology include the lack of a standard regulation for the data storage format, lack of a component database, and lack of a standard that can be applied in the process of construction (Li et al., 2021). There is a need for strategic technology alliances with high-tech industry for the greater adoption of new technologies (Yahya et al., 2019) to provide safety and operational value.

5.3. Factor 3: Lack of genuine organizational commitment

Factor 3 contained three barriers relating to the role of management commitment to safety intervention practices using new technologies. The construction industry has a prevalent weak innovation culture (Pradhananga et al., 2021). The poor safety awareness of firms' top leaders and lack of organizational commitment are major safety risk factors (Jitwasinkul & Hadikusumo, 2011; Zou & Zhang, 2009). In transforming the current landscape, all stakeholders need to search for forward-looking solutions when potentially 'game-changing' technologies become available (McKinsey Global Institute, 2017). In this vein, strong organizational support for change is required (Liu et al., 2016; Wang et al., 2020). Other associated organizational issues include cost savings, peer influence, top management, organizational culture, competitive advantage, and compatibility (Nnaji et al., 2020a).

5.4. Factor 4: Prohibitive costs

Factor 4 contains three barriers with a total variance of 11.14%, emphasizing the high costs involved in adopting new construction safety technologies. This factor has the highest average mean of 3.87, indicating the significance of the financial implications of adopting new technologies to streamline construction processes and improve safety performance. In the US, Nnaji and Karakhan (2020) reported that the turnkey cost to adopt new technologies is the top-most barrier to the adoption of new construction safety technologies. Other aspects related to economic feasibility are the true cost of running new technologies, the maintenance required, and immersive training needed to educate and develop skills among workers for a more automated workplace. The cost factors are associated with an initial investment, operating cost, and maintenance cost, which can affect the economic and financial risks borne by organizations (Bademosi & Issa, 2021). Thus, an extensive cost-benefit analysis is needed before the decision to integrate new technologies into construction safety can be made.

5.5. Factor 5: Construction industry safety culture

This factor has the second-highest average mean of 3.83. The industry's poor safety record is highly attributable

to a poor safety culture both industry-wide and within most organizations (Jitwasinkul & Hadikusumo, 2011; Zou, 2011); thus, it is unsurprising that the majority of contractors do not earmark a budget for mitigating project risk with predictive analytics (Dodge Data & Analytics, 2019). The slow adoption of new technologies and an ageing workforce can create inefficiencies and hinder productivity growth (Yap et al., 2019; Yi & Chan, 2014). A heavy reliance on traditional labor-intensive methods encourages high accident risks, particularly in developing countries. The current work culture of aversion to change highlights the effects of the industry's weak innovation culture (Delgado et al., 2019). For example, the majority of the contractors do not budget for risk mitigation technologies (Dodge Data & Analytics, 2019). The workforce challenges to the adoption of new technologies are associated with unskilled workers, job security, access to blue-collar workers, and the technology-human interface (Pradhananga et al., 2021), while client demand, competitive advantage, and desire to improve productivity have a low influence on contractors' desire to improve their current safety management practices (Dodge Data & Analytics, 2017).

5.6. Factor 6: Privacy and data security concerns

"Privacy of workers personal data is not guaranteed" (factor loading = 0.919) and "no assurance of data security" (factor loading = 0.899) create this sixth factor, with a total variance of 10.81%, explaining the significance of privacy and security in adopting new technologies to improve work processes and construction safety. Data security and privacy are major issues in IoT (Goyal et al., 2019), where data integrity is not guaranteed (Tang et al., 2019). The automated capture and record of personal data pose some ethical and legal concerns over the tracking and monitoring of workers and handling of the recorded information, which is regulated by the data protection law (Oesterreich & Teuteberg, 2016). Some privacy policies restrict workers being tagged to track their location and movements, but provide anonymous access location information to restricted or hazardous areas by automatically triggering an alarm (Edirisinghe, 2019). One of the biggest risks associated with the application of unmanned aircraft technology for construction work is regarding privacy concerns (Tatum & Liu, 2017): sensor-based localization equipment and wearable systems are expensive but can provoke such social issues as privacy, security, legal, and health concerns.

Conclusions

In recent years, there has been a major upsurge of innovation across various industries, bringing many opportunities for improvements in operational flexibility, efficiency, and safety. However, the construction industry has been lackadaisical in the adoption of technological advancements in comparison with other industries. As reported in previous studies, new technologies certainly have the potential to address some of the inherent challenges of

conventional construction safety management practices. As Zhou et al. (2013, p. 606) have highlighted, the application of new technologies “is deemed an effective way to further construction safety management.” Therefore, the slow uptake of new technologies tends to delay the transformation needed to optimize workplace safety, reduce risks, and improve productivity in the hazardous environments of construction sites. Only limited studies have appraised the challenges to adopting new technologies for safety science and management in construction. To bridge the existing knowledge gap, the present study investigated the barriers to adopting new safety technologies and reveals the underlying dimensionality of the barriers in the Malaysian construction industry.

An extensive review of the literature identified 18 potential major barriers listed in Table 1. This was followed by a questionnaire survey designed and administered to construction practitioners to observe how critical these barriers are perceived according to 50 developers, 50 contractors, and 50 consultants. Overall, the five most significant barriers were found to be the *costly investment associated with new technologies, culture of construction industry, decision to use differs from client requirements, ageing workforce is resistant to change, and lack of top management and leadership support*. To uncover the underlying barriers, an exploratory factor analysis was conducted, in which six principal factors were manifested, namely: *lack of OSH regulations and legislation, technological limitations, lack of genuine organizational commitment, prohibitive costs, safety culture within the construction industry, and privacy and data security concerns*.

Implications

Theoretical implications

This study provides the theoretical base for the critical barriers to the adoption of new technologies for construction safety according to the cognizance of clients, consultants and contractors; highlighting the several issues in need of immediate attention before effective measures can be devised to better integrate them into construction operations to improve safety performance. The findings from the study suggest a conventionally accepted top-down adoption process and the diffusion of new technologies may not be effective. Of the five most significant barriers, four are related to the social-cultural aspect while one is associated with the economical aspect. Accordingly, building a positive safety culture in construction requires a bottom-up approach, where the people on the ground play a pivotal role in the successful adoption of new safety technologies. Nonetheless, organizations need to increase capital allocation for investing in new technologies that underpin improved safety performance. The identified underlying factors in the context of a developing country are new to construction management literature.

Practical implications

The adoption of new safety technologies within the construction industry is expected to significantly improve safety performance to be on a par with such counterparts as the manufacturing and automotive industries; at the same time, circumventing the social stigma of being a “dangerous, dirty, and difficult” (3D) industry. However, these barriers identified herewith need to be systematically addressed across the diverse stakeholders involved to ensure successful implementation. The underlying factors largely explain the barriers involved and serve as indicators to guide industry practitioners and policymakers in evaluating the feasibility and state of readiness of adoption technologies for safety management. A shift towards a high-technology and high-skilled construction industry is needed to boost this vital industry for national development in terms of both economy and welfare, and transition a developing economy for growth and higher income.

Limitations and future studies

A limitation of the study is that the data collected solely using a self-completion questionnaire does not allow further probing to generate further explanation from construction practitioners such as in qualitative interviews. Furthermore, the use of a five-point Likert scale for rating the barriers may not be completely reliable, as different respondents may attach different values to different points of the scale. Although the empirical data were collected in Malaysia, the results might also be relevant for other developing countries where the construction industries share similar characteristics. Future studies investigating other developing countries in Asia and Africa regions will be useful to validate this supposition. Future research opportunities exist to investigate the process-need areas and the enabling factors influencing the adoption of new safety technologies to better align the construction industry toward adopting technology-based safety management systems.

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Author contributions

All authors have contributions to this article. Conceptualization and supervision, J. B. H. Yap; methodology and formal analysis, C. G. Y. Lam; recourses and data curation, N. Talebian; original draf preparation, M. Skitmore.

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APPENDIX

Questionnaire Form

This survey will take approximately 5 to 10 minutes to complete. Please be assured that there will be no attempts to disclose your identity throughout this study. All the data will be used purely for academic purpose and will be strictly anonymous. Nevertheless, you may choose to withdraw from this survey at any time if it has made you uncomfortable.

Part I: General Information

Please tick “√” in the checkbox.

- | | |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>1. Type of Organization (Please select current type):</p> <p><input type="checkbox"/> Client</p> <p><input type="checkbox"/> Contractor</p> <p><input type="checkbox"/> Consultant</p> | <p>2. Type of Organization (Please select current type):</p> <p><input type="checkbox"/> Client</p> <p><input type="checkbox"/> Contractor</p> <p><input type="checkbox"/> Consultant</p> |
| <p>3. Position in the company (Please select one only):</p> <p><input type="checkbox"/> Executive</p> <p><input type="checkbox"/> Manager</p> <p><input type="checkbox"/> Senior manager</p> <p><input type="checkbox"/> Director/top management</p> | <p>4. Position in the company (Please select one only):</p> <p><input type="checkbox"/> Executive</p> <p><input type="checkbox"/> Manager</p> <p><input type="checkbox"/> Senior manager</p> <p><input type="checkbox"/> Director/top management</p> |
| <p>5. Working experience in construction (Please select one only):</p> <p><input type="checkbox"/> 5 years or less</p> <p><input type="checkbox"/> 6–10 years</p> <p><input type="checkbox"/> 11–15 years</p> <p><input type="checkbox"/> 16–20 years</p> <p><input type="checkbox"/> More than 20 years</p> | <p>6. Highest academic qualification (Please select one only):</p> <p><input type="checkbox"/> High School</p> <p><input type="checkbox"/> Diploma</p> <p><input type="checkbox"/> Bachelor's Degree</p> <p><input type="checkbox"/> Master's Degree</p> <p><input type="checkbox"/> Doctorate/PhD</p> |

Part II: Barriers to the adoption of safety technology in construction project

Please indicate one level of agreement on the following barriers that hinder the adoption of safety technology in construction projects:

	Barriers	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
A	Economic-related					
A1	Costly investment associated with new technology	1	2	3	4	5
A2	Required workers training may not be cost effective	1	2	3	4	5
A3	Slim profit margins in the industry	1	2	3	4	5
B	Regulatory-related					
B1	Lack or no government regulation for use	1	2	3	4	5
B2	Lack if government commitment	1	2	3	4	5
B3	Lack of legislation	1	2	3	4	5
C	Management/leadership-related					
C1	Lack of top management and leadership support	1	2	3	4	5
C2	Lack of decision support tools	1	2	3	4	5
C3	Creates liability concerns	1	2	3	4	5
D	Technical-related					
D1	Incompatibility of technology with current practices and current construction operation	1	2	3	4	5
D2	Availability of technological assistance for technology use in the management of OSH	1	2	3	4	5
D3	Technology performance concern	1	2	3	4	5
E	Knowledge-related					
E1	Lack of professional knowledge	1	2	3	4	5
F	Socio-cultural-related					
F1	Culture of construction industry	1	2	3	4	5
F2	Decision to use differs from client requirements	1	2	3	4	5
F3	Aging workforce is resistant to change	1	2	3	4	5
G	Security-related					
G1	No assurance of data security	1	2	3	4	5
G2	Privacy of workers personal data is not guaranteed	1	2	3	4	5

Thank you for your participation. Your response is of high importance for this study and is much appreciated.