Embracing Emerging Technologies for Safety Management: What is Needed to Raise the Adoption Level for Urban Construction?

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Abstract. Urban construction tasks are considered 3D (dirty, dangerous and difficult), requiring the use of power tools, heavy machines, and dangerous equipment, working at heights, having to walk around debris, and many other hazardous working environments. As such, this high-risk sector often recorded a high number of injuries and fatalities rates. Recently, there has been increasing attention on reinforcing safe work practices at construction sites to mitigate risks and reduce workplace injuries, especially by enabling safety using emerging technologies. However, the industry-wide adoption rate is still low. This paper appraised the viable strategies for improving innovative technology adoption to enhance safety performance and accelerate constructor excellence. A total of ten (10) viable strategies were identified from the comprehensive review of previous studies. A structured survey questionnaire containing these 10 strategies was used to collect data from 133 industry professionals in Malaysia. The topmost three strategies in order of importance are: r*einforcing education and on-the-job training, providing government incentives* and *establishing government mandates*. The ranking of the strategies has practical implications as it provides the basis for refining the most significant strategies that industry stakeholders should focus attention on for the successful adoption of emerging technologies in managing safety for urban construction projects.

Keywords: Urban construction, site safety, management engineering, latest technology, adoption strategies

1 Introduction

The construction sector and its associated activities exert an exceptional impact on long-term economic and social growth. Intrinsically, thriving construction is a driving force behind most economies, contributing immensely to the gross domestic product (GDP) and improving people's quality of life. Despite its important role, construction work in urban developments is inherently dangerous and puts lives at risk of serious injury on the job. Construction accidents and safety disasters have huge repercussions

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– loss of human lives, serious injuries, increased workmen's compensation, demotivation of workers, conflict with workers, property damage, delayed schedules, and increased costs. A report by the International Labour Organization (ILO) underscores alarming statistics whereby the rate of productivity losses from accidents and work-related illnesses is estimated at over 4% of annual GDP globally [1].

Construction has often been stigmatized as a 3D industry, referring to being dirty, dangerous and difficult due to the harsh working environments in construction sites that are mostly dynamic, fast-paced, and risky with poor safety performance. In 2022, construction is one of the most dangerous industries in the US with construction labourers experienced the most workplace deaths [2]. Likewise in Malaysia, the fatality rate per 10,000 construction workers is 13.44 which is 10 times worse than that of the UK. In Sub-Saharan Africa, the fatality and injury rates are 21 and 16,012 per 100,000 workers, respectively [3]. India, however, reported the world's highest accident rates among construction workers [4]. In China, nearly 2 daily deaths are attributed to construction activities [5]. The high accident rates can be inextricably linked to conventional work processes and labour-intensive tasks with limited technological advances.

With relentless urbanisation set to continue, construction safety remained a primary concern and attracted a plethora of studies, particularly on how to significantly improve safety performance in urban construction sites and achieve the goal of zero accidents. A review of the most recent publications on construction safety reveals an increasing trend in embracing emerging technological solutions of Industry 4.0 for construction safety management. Several researchers believe that improving technology adoption for safety applications would improve workplace conditions and reduce the number of fatal and nonfatal injuries throughout the sector [6, 7]. A recent study in Malaysia on the enablers of using emerging technologies for safety agenda observed that the primary advancements are directly linked to improving hazard identification, reinforcing safety planning, enhancing safety inspection, enhancing safety monitoring and supervision and raising safety awareness [8]. Comparable findings are also reported in the US where the highly rated benefits are: improved workers' awareness of workplace hazards, support warning workers of workplace hazards, eliminating hazards during the design phase and facilitating visualizing hazards [9]. The most common technologies used for safety management include building information modelling (BIM), wearable sensing devices (WSDs), mobile devices on-site and radio frequency identification (RFID) [6]. As for the inhibitors that undermine the usage of innovative technological safety measures in construction, Yap et al. conducted a factor analysis on 18 barriers and found 6 underlying factors comprising paucity of safety regulations and legislation, boundaries with technology use, absence of organizational commitment, high investment capitals, inherently poor occupational health and safety culture, and data protection and security risks [10]. The majority of previous studies focused on the types of technologies applicable to construction safety context, benefits and challenges. Only limited studies have investigated the potential strategies to improve the adoption rate of embracing innovative solutions for safety science and management in the urban construction context. Urban construction and multi-story buildings certainly present additional, multi-faceted challenges. As the trend for urbanization shows no sign of decline, a forward-thinking approach to safety science and management is needed for future urban construction sites.

Despite the academic attention and positive impacts of safety technologies, the rate of technology adoption is still lackadaisical. For this reason, these new technologies are not applied broadly in urban construction projects beyond academic research; a lack-lustre transition into practice. Against this backdrop, the present study appraised the viable strategies to achieve higher adoption of utilising emerging technologies for enhanced safety management; using the Malaysian urban construction projects as the base of the study.

2 Viable Strategies to Raise the Adoption Level of Safety Technology in Urban Construction Projects

Table 1 presents a list of viable strategies for the construction industry identified from the literature to provide the theoretical underpinning.

Table 1. Summary of viable strategies from the literature

Ref	[11]	[12]	[25]	[14]	[15]	[16]	[17]	[18]	[19]	[20]	[9]	[21]	[22]	[23]	[24]
S1		✓	✓												✓
S2			✓		✓	✓						✓			
S3			✓	✓											✓
S4		✓	✓						✓						✓
S5								✓		✓	✓				
S6													✓	✓	
S7	✓						✓		✓						
S8					✓										✓
S9							✓				✓				
S10			✓							✓					

Legend:

S1: Providing government incentives; S2: Establishing government mandates; S3: Piloting emerging technologies or safety applications; S4: Recruiting and onboarding recent graduates; S5: Introducing safety incentive programme for construction companies; S6: Organising technological trade exhibitions and conferences; S7: Reinforcing education and on-the-job training; S8: Promoting research with university-industry collaboration; S9: Integrating technological requirements into construction process; and S10: Revamping organisational culture and safety attitude.

3 Research Design and Methodology

This study adopted the positivist paradigm, using deductive reasoning to observe phenomena empirically and then drawing realistic conclusions using the quantitative data. A cross-sectional survey design is employed as it is the most practical and economical data collection technique from a large sample for statistical analyses. It is worth noting that such surveys are widely utilised in construction and safety management domains to prioritise variables [10, 25].

The survey data was analysed using Statistical Package for the Social Sciences (SPSS) programme version 23. Descriptive statistics using mean scores were used to gauge the relative ranking of the viable strategies as perceived by the construction professionals from developers', consultants' and contractors' organisations. The Kruskal-Wallis test (also known as one-way ANOVA on ranks for nonparametric data) was employed to determine if there were any statistically significant differences between the three respondent groups.

3.1 Questionnaire Design

Following a detailed literature review, ten (10) viable strategies were identified and included in the questionnaire comprised of two parts. The first part was used to collect the demographic background information about the respondents and their organisational role in the urban construction projects. In the second part, the respondents were requested to rate statements concerning the viable strategies to enhance the adoption level of safety technology in urban construction projects (10 items) on a five-point Likert scale ranging from 1 (ineffective) to 5 (extremely effective).

3.2 Survey Respondents and Demographics

The sampling frame consisted of professionals currently working on urban construction projects and are familiar with current safety management practices in Malaysia and from the three key stakeholders namely developer, consultant and contractor. This diversity of respondents was chosen to maximise the quality of information in which diverse perspectives in urban construction settings are represented. Non-probability sampling approach with convenience and snowball techniques was used to select the respondents. Following a successful pilot study with 30 returned responses, another 385 survey forms were distributed online via email and other social media such as LinkedIn and WhatsApp in which 103 valid responses were returned and after combining the pilot responses, a total of 133 valid responses were collected. This sample size is adequate for reliable statistical analyses.

The respondents' demographic profiles with 41 developers, 44 consultants, and 48 contractors are summarized in Table 2. About half of the respondents have more than 10 years of working experience in the construction industry while 40% are in managerial and above positions. Additionally, 90% hold Bachelor's or higher degrees. These are considered sufficient to obtain sound judgment from qualified respondents in a perception study of this nature.

Table 2. Demographic profile of respondents.

Parameter	Category	Respondents group			Total	Frequency (%)
		Developer	Consultant	Contractor		
	Executive	21	27	32	80	60.2

Position in company	Manager	9	10	9	28	21.1
	Senior manager	9	3	3	15	11.3
	Director / Top management	2	4	4	10	7.5
Working experience (in years)	Less than 5	7	15	17	39	29.3
	Between 5 to 10	7	10	11	28	21.1
	Between 11 to 15	17	12	11	40	30.1
	Between 15 to 20	6	3	3	12	9.0
	More than 20	4	4	6	14	10.5
Academic qualification	Postgraduate (PhD, Master)	15	10	6	31	23.3
	Bachelor	24	32	32	88	66.2
	Diploma, Certificate	2	2	9	13	9.8
	High school	0	0	1	1	0.8

4 Results and Discussions

4.1 Analysis and Ranking of Viable Strategies

Cronbach's coefficient α value is 0.853, which is which is greater than the threshold of 0.70 needed to establish internal consistency [10]. Ranked in ascending order based on the overall results, Table 3 depicts the means and standard deviations of each strategy according to developer', consultant' and contractor's ratings. All 10 strategies have attained a mean score higher than 3.0, which is regarded as important in the rating scale. The following discussion deliberates on the three most effective strategies to raise safety technology adoption for urban construction projects.

Table 3. Mean scores and ranking of viable strategies surveyed

	Overall (N = 133)			Developer (N = 41)			Consultant (N = 44)			Contractor (N = 48)				
Ref	Mean	SD	Rank	Mean	SD	Rank	Mean	SD	Rank	Mean	SD	Rank	X^2	p-value
S7	4.233	0.937	1	4.244	0.860	1	4.250	0.991	3	4.208	0.967	1	0.206	0.902
S1	4.173	1.011	2	4.195	1.054	3	4.409	0.871	1	3.938	1.060	4	5.471	0.065
S2	4.143	0.986	3	4.220	0.881	2	4.205	1.069	5	4.021	1.000	2	1.616	0.446
S5	4.128	0.916	4	4.098	0.944	4	4.295	0.823	2	4.000	0.968	3	2.207	0.332
S9	3.947	1.025	5	3.951	1.094	5	4.159	0.939	6	3.750	1.021	7	4.256	0.119
S10	3.917	0.954	6	3.829	0.972	6	4.068	0.900	7	3.854	0.989	5	1.891	0.389

S8	3.835	1.095	7	3.463	1.227	8	4.227	0.961	4	3.792	0.988	6	10.669	0.005**
S3	3.789	1.087	8	3.659	1.039	7	4.045	1.140	8	3.667	1.059	8	5.222	0.073
S6	3.541	1.190	9	3.341	1.196	9	3.727	1.227	9	3.542	1.148	9	2.774	0.250
S4	3.451	1.196	10	3.293	1.209	10	3.636	1.241	10	3.417	1.145	10	2.015	0.365

Note: **. The mean difference is significant at the 0.01 level of significance.

Based on the overall rating, "S7: Reinforcing education and on-the-job training" was ranked first, with a mean score of 4.233. The construction professionals opined this being the most effective and pragmatic strategy for the successful adoption of safety technologies for urban construction projects. A major underlying reason for the discouraging innovation diffusion in construction projects is poor training and skills development among project personnel across the industry [26]. In this connection, Nnaji et el. accentuated that high-quality personnel training and capacity building are necessities to engender a positive culture and safety stewardship that supports the commitment to technology implementation and adoption [27]. To keep pace with technological advancements, ongoing training and education are paramount. Construction safety professionals must engage in continuous learning. In addition, educational programmes, online courses, technical workshops and trade events are some avenues to raise the practitioners' knowledge and awareness about new technology trends and explore cutting-edge innovations for construction safety applications. Along the same lines, Nnaji and Karakhan avowed that a qualified and well-trained workforce is an important prerequisite for safety technology's adoption, acceptance and use [9]. They further pointed out that training courses should inform personnel about the "must-knows" and potential benefits of technological advancements for construction safety science and management. The training programme should encompass sufficient information and real-life examples that demonstrate the effectiveness of the technologies on workplace safety. Written assessments can be used to appraise the personnel's competence and awareness of technology applications to foster a continuous learning culture, ultimately stimulating the diffusion of safety technologies into their work processes.

"S1: Providing government incentives" is in second place. The finding echoes previous studies underscoring the role of governments in driving technological innovation and the need to incentivize technology adoption [28–30]. Governments offer various subsidies and grants for investment costs, research and development (R&D) and tax reduction to promote the adoption of new technology [31]. With the government's backing in the form of finance or supportive policies, there is an increased propensity to use enabling technologies in construction projects. In a Chinese study examining the BIM adoption behaviours from the perspectives of the technology-organisation-environment (TOE) framework and the theory of technology acceptance model (TAM), Yuan, Yang and Xue elucidated that external incentives from the government in the form of tax exemption and/or R&D subsidies are effective measures to stimulate R&D and technology diffusion activities [32]. In a Malaysian survey, it was reported that

60% of the respondents failed to allocate any financial incentives or support to invest in new technology [33]. In this light, the Malaysian government have been formulating strategies to promote construction digitalisation towards technological advancement and improved industry safety performance. Financial aid from the government is vital for fueling construction innovations.

"S2: Establishing government mandates" is rated the third most viable strategy. Both developed and developing countries have been leveraging government mandates to generate paradigm shifts and facilitate the diffusion of innovations. The US and UK are successful examples in this respect, where satisfactory results arising from the mandates have been reported over the years [34]. In the case of Malaysia, all public projects with a budget of over RM100 million (USD 21.11 million) are required to adopt and implement building information modelling (BIM) in the building process [35]. The majority of the Malaysian construction professionals surveyed by the Construction Industry Development Board (CIDB) are supportive of the government's initiative to mandate the use of BIM in the construction industry [33]. BIM can support design for safety, safety planning and safety training [8]. BIM can also be integrated with other digital technologies such as augmented/virtual reality for 3D safety inductions to the construction workers. From this perspective, this study suggests that the Malaysian government mandates pro-innovation regulations for using transformative technologies for safety science and management in both public and private projects. Such regulatory pressure could ease the industry's resistance to safety technologies adoption, ultimately improving performance construction safety [17]. The government via the relevant agencies such as the Ministry of Works and CIDB play a vital role in revolutionising the country's construction landscape.

4.2 Differences in Perceptions Between Parties

A close examination of the Kruskal-Wallis tests in Table 3 revealed that all groups have similar perceptions on the strategies that are viable in raising the adoption of safety technologies, except for "S8: Promoting research with university-industry collaboration". Based on overall, this strategy is ranked at the eighth place (Mean = 3.835). It is worth noting that the respondents from the consultant group rated this strategy (Mean = 4.227) much higher than the developers (Mean = 3.463) and contractors (Mean = 3.792). The finding is unsurprising as there is increased attention to designers' role in construction safety (design for safety) and the use of technology-driven applications.

In urban construction projects, there is a big pool of specialist talents in the consultants' team, which includes architects, civil, electrical and mechanical engineers as well as quantity surveyors. Their tasks encompass front-to-end planning, as designers for the project, project management, contract administration and quality control. Most importantly, their core duty is to ensure the project is delivered according to the client's needs. In the context of this study, the consultants have to ensure that the contractors implement the required health and safety measures to create and maintain a safe workplace, all safety risks are well controlled and that the projects are meeting the safety standards.

In the UK, the level of satisfaction among the clients about the performance of the appointed project consultants and observed that the majority of the clients put a high weightage on technical accuracy and innovation in working methods which contribute significantly to the consultants' key performance attributes [36]. In this vein, the consultants must be at the forefront of their niches and industries. They have to continuously develop their knowledge and skills as well as be engaged with academia-industry linkages to exchange knowledge, skills, resources and capabilities as well as promote technology transfer, identify the barriers and opportunities. Effective collaboration between academic and industrial partners is a significant enabler to drive technology innovation and adoption into practice [24]. Academic institutions are knowledge providers, offering consultants the latest solutions in the industry and market. With this up-to-date and sophisticated knowledge, they can guide the clients on the most appropriate technologies and safety processes, thereby effectively achieving the best safety results for the construction project.

5 Concluding Remarks

The global construction sector is still lackadaisical in embracing new technologies to address the existing safety problems that undermine its productivity and reputation. Previous studies suggest that introducing innovative solutions into safety management practices can significantly improve construction safety performance. Despite the increasing academic attention, current statistics indicate that safety in construction remains a major issue and lags considerably behind other major economic sectors. Nonetheless, there is a scarcity of studies examining urban construction-specific strategies to accelerate safety technology adoption. Considering the current relatively low adoption rate of embracing emerging technologies for safety science and management, this study explored some of the most effective measures to raise the adoption rate to enhance safety performance and accelerate constructor excellence.

An extensive literature review from 15 previous studies has successfully shortlisted ten viable strategies as listed in Table 1. This was followed by a questionnaire survey designed and administered to professionals in the three key stakeholders in construction, comprising those from developers', consultants' and contractors' organisations to observe how effective these strategies are perceived in influencing the technological adoption rate for enhanced safety management in urban construction projects. Overall, the three most pragmatic strategies were found to be: S7: reinforcing education and on-the-job training, S1: providing government incentives, and S2: establishing government mandates.

The advent of new technologies and the global drive for urban expansion call for more transformative measures to meet future construction needs with fewer safety risks. This study provides the theoretical base for the viable strategies for the adoption of emerging technologies for construction safety according to the cognizance of developers, consultants and contractors; emphasising the several issues in need of immediate attention before urban construction sites can resolutely integrate new methods, tools and innovative solutions to improve overall safety performance and enhances productivity.

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