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# PREDICTORS TO INCREASE SAFETY TECHNOLOGY ADOPTION IN CONSTRUCTION: AN EXPLORATORY FACTOR ANALYSIS FOR MALAYSIA

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**Abstract.** Accidents and injuries continue to be major problems in the construction industry despite persistent endeavours over the years to improve health and safety management. Novel approaches using emerging technologies can enhance construction safety performance. Given their limited adoption and lack of empirical evidence in the context of developing countries, this paper examines the predictors influencing the successful adoption of safety technologies in the construction industry. Using a survey questionnaire involving 133 Malaysian construction professionals, the significance of the predictors is prioritised. A factor analysis is used to reduce the predictors involved into a fewer number of dimensions. The most influential predictors are presented. Four underlying dimensions of the surveyed predictors are uncovered, comprising organisational commitment/technology orientation, supporting technological attributes, personal perception/performance expectancy and government support. The rate of technology implementation to improve safety risk mitigation in construction is still limited. By taking cognisance of the critical influential predictors involved, the adoption level of safety technology could be raised. This paper bridges the identified knowledge gap regarding the dimensionality of safety technology adoption predictors in construction, with findings that shed new light on the factors influencing technology adoption in a developing country to stimulate technological innovations to streamline construction safety.

**Keywords:** construction safety, technology adoption, success predictors, safety technologies, developing countries, factor analysis.

## Introduction

Construction work is physically demanding worldwide, and the risky and unhealthy operations involved constantly expose workers to a variety of workplace hazards (Tang et al., 2022; Yap & Lee, 2020). Accidents have a huge adverse impact on construction projects, such as loss of human lives, increased medical expenses, worker's mental illness, loss of time, productivity loss, reduce morale and conflict with workers (Chong & Low, 2014; Shao et al., 2019). The occupational health and safety (OSH) of construction workers therefore remains a primary global concern.

However, as Jiang et al. (2021, p. 788) highlight, "construction safety has been a long-term problem in the development of the construction industry". Despite constant efforts to promote safety, construction continues to be one of the most dangerous industries in most countries (Mohammadi et al., 2018). For example, the industry is beleaguered with a disproportionately high number of injuries and fatalities (Raheem & Hinze, 2014) compared to other major industries. The construction industries in countries such as Australia, Sweden and UK have more fatalities than any other industry (Priyadarshani et al., 2013). Accident rates are even more alarming in developing countries (Hämäläinen et al., 2006). India, for example, has the world's highest accident rate of 16.4% of fatal global occupational accidents (Kanchana et al., 2015). In Sub-Saharan Africa, the fatality and injury rates are 21 and 16,012 per 100,000 workers, respectively (Irumba, 2014). In Malaysia, 169 deaths and 3,911 accidents were recorded in 2018 (Babulal, 2020), with a fatality rate of 13.44 per 100,000 – 10 times worse than that of the UK.

The common causes of construction accidents are attributable to faulty equipment, unsafe acts of workers and unsafe working conditions (Akinlolu et al., 2020). There is also a close relationship between safety and productivity – their disparate trade-off usually demanding the latter to be

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prioritised ahead of the former (Neale & Gurmu, 2021). Underinvestment in skills development, R&D and innovation have contributed to the slow labour-productivity growth in construction, which has averaged only 1% per annum over the past two decades (Mckinsey Global Institute, 2017). In most countries, the construction industry growth lags behind the total economy. The construction industry is still very comfortable using labour-intensive techniques and methods of production (Yap et al., 2019). The rate of technology implementation is still limited (Alaloul et al., 2020; Karakhan et al., 2019).

Modern technology and innovations have fuelled the evolution of Industry 4.0 to optimise productivity, quality, safety and improve agility in project management (Calabrese et al., 2020). The trend of digitalisation, automation and the more extensive use of IoT-enabled production are driving changes in the industry, and the increased use of innovative solutions is believed to be able to prevent construction workplace accidents and injuries. The emergence of advanced technologies, for instance, such as cloud computing, building information modelling (BIM), virtual reality (VR), geographic information systems (GIS), unmanned aerial vehicle (UAV), camera network systems, radio frequency identification (RFID), wearable sensing devices, robotics and automation, laser scanning, photogrammetry and digital signage have substantial potential for improving construction safety science and management (Akinlolu et al., 2020; Alaloul et al., 2020; Edirisinghe, 2019; Nnaji et al., 2019).

The industry has a low consciousness with regard to integrating Industry 4.0 into OSH management. Nnaji et al. (2019, p. 2656) highlight that "current literature focuses primarily on evaluating the effectiveness of safety technologies and assessing the return-on-investment of implementing safety technologies". Against such a background, there is a scarcity of studies that have quantitatively examined the factors influencing successful technology adoption in construction and the catalysts needed to raise the adoption level, particularly in the context of a developing country like Malaysia (Gamil et al., 2020; Mariam et al., 2021). In response, to bridge these substantial knowledge gaps, the present study aims to appraise the predictors of safety technologies adoption for construction projects. Notably, little attempt has been made to explore the underlying dimensions of the predictors. The study expands the findings from prior work by Nnaji et al. (2019) in the USA and responding to calls for embracing advanced technologies to improve safety risk mitigation in construction (Karakhan et al., 2019; Mckinsey Global Institute, 2017; Zhou et al., 2015).

## 1. Literature review

### 1.1. Application of technology for OSH management in construction

Previous studies suggest that construction safety science and management could be optimised using emerging technologies (Awolusi et al., 2018; Calabrese et al., 2020; Nnaji & Karakhan, 2020). According to Akinlolu et al. (2020), the use of technological innovations to streamline OSH management in construction has fast gained academic attention. Nnaji et al. (2019, p. 2656) refer to safety technology as "the application of information technology, digitalization, and sensing devices to monitor and improve safety management and/or performance." These include advanced automation, robotics, BIM, GIS, RFID, VR, UAV, data mining, sensing technology and wireless networks and robotics (Akinlolu et al., 2020; Zhou et al., 2013). In recent times, various reality capture technologies, robotics and the internet of things (IoT) have been reported as having the capability to enhance construction operations (Bademosi & Issa, 2021; Delgado et al., 2019).

The technology diffusion rate is slow, however, as the construction industry as a whole remains very reluctant to adopt new technology (Alaloul et al., 2020; Yap et al., 2019). According to Mitropoulos and Tatum (2000), the drivers of innovation in construction are related to acquiring competitive advantage, alleviating process-related problems, technological opportunities and institutional requirements. On the other hand, they also assert the barriers impeding technology diffusion to be uncertainties connected with the uses of new technologies and lack of available information regarding the technologies and benefits of technological advances. In the USA, the major barriers impeding technology adoption for OSH management are large initial investment costs, that new technologies are complicated and require extensive reskilling of the workforce and lack of technical support (Nnaji & Karakhan, 2020). In Malaysia, Gamil et al. (2020) reported that the challenges of implementing Industry 4.0 technologies are associated with technology, administrative and legislative issues and knowledge predicaments. Nevertheless, research into the trends of safety management technologies in the context of the developing world outside China is under-represented, with the U.K., U.S. and China taking leading roles (Akinlolu et al., 2020). Despite the increasing number of studies, however, most innovative applications for construction safety remain in the stage of academic research, with limited transitions into practice (Zhou et al., 2013, 2015). Without any large-scale applications, improvements in construction safety, efficiency and productivity are likely to be limited.

### 1.2. Technology adoption predictors

The widely used innovation adoption framework comprises technology-organisation-environment (TOE) factors (Cai et al., 2020). Wang et al. (2018) employ a resource-based view (RBV) to propose a research model of innovation for construction organisations, concluding that commitment to innovation is needed to improve and secure performance. According to Yusof et al. (2017, p. 436), "an organisation's performance tends to be associated with its innovativeness", and that innovation orientations (e.g., creation and adoption) will determine the state of innovation in an organisation. They further explain that innovation creation is R&D-oriented, which involves being a market explorer and reflects a pioneer's efforts. On the other hand, innovation adoption involves being a creative imitator, a market follower and a safe player. This approach involves replication (reverse engineering) of foreign technologies. Yusof et al. (2017) highlight that construction organisations in Malaysia are mostly innovation-adoption-oriented and the same can be deduced of other developing countries with similar characteristics. The influential predictors that should be deliberated when making decisions have yet to be adequately studied and explained (Nnaji et al., 2019).

Nnaji et al. (2019) identify 26 factors influencing safety technology adoption in construction and categorise them as being individual-, organisational-, technology- and external-related. Their survey in the U.S. found the main three factors to be related to technological aspects, which are associated with reliability, effectiveness and durability. The applications of robotics and automated systems in the U.S. are significantly undermined by the high initial cost of investment, lack of desire to improve productivity and low R&D budgets (Delgado et al., 2019). In a separate study, Bademosi and Issa (2021) evaluated robotics and automation technologies (RAT) against cost and benefit factors, concluding that the use of RAT is enticed by long-term cost savings but undermined mainly by the high capital investment involved.

As Nnaji et al. (2019, p. 2659) highlight, "despite the increasing trend in the number of studies on technology in construction, the predictors of safety technology adoption have not been adequately studied and identified". Given the scarcity of previous studies specific to the safety context in construction, an analytical study of the existing literature related to technology adoption in general (not specific to safety and construction industry) resulted in recognising 20 predictors (factors affecting adoption and implementation of new technology), which are summarised in Table 1. Nonetheless, these identified predictors will guide the present investigation on the adoption of safety technology in construction.

## 2. Research methodology

### 2.1. Research design and method

A positivist research philosophy using a deductive approach is adopted to examine the adoption of safety technologies in construction objectively. A quantitative research design using a cross-sectional questionnaire

Table 1. Summary of predictors of safety technologies adoption in construction projects

| Ref | Predictors | References |
|---|---|---|
| F1 | Technology complexity | Ahuja et al. (2020), Chen et al. (2019), Choi et al. (2017), Delgado et al. (2019), Nnaji et al. (2020), Okpala et al. (2020) |
| F2 | Top management support | Ahuja et al. (2020), Chen et al. (2019), Fernandes et al. (2006), Nnaji et al. (2020), Tsai et al. (2014) |
| F3 | Capital cost of technology | Ahuja et al. (2020), Delgado et al. (2019), Nnaji et al. (2020), Tsai et al. (2014), Zhang et al. (2020) |
| F4 | Perceived usefulness | Choi et al. (2017), Fernandes et al. (2006), Hong et al. (2019), Tsai et al. (2014), Zhang et al. (2020) |
| F5 | Government regulations | Ahuja et al. (2020), Chen et al. (2019), Hong et al. (2019), Nnaji et al. (2020) |
| F6 | Government promotion and initiative | Chen et al. (2019), Tsai et al. (2014) |
| F7 | Level of training required | Delgado et al. (2019), Tsai et al. (2014) |
| F8 | Personal motivation | Choi et al. (2017), Hong et al. (2019), Okpala et al. (2020), Tsai et al. (2014) |
| F9 | Expertise and skill of the project team | Ahuja et al. (2020), Fernandes et al. (2006), Hong et al. (2019), Tsai et al. (2014) |
| F10 | Proven technology effectiveness | Delgado et al. (2019), Hong et al. (2019) |
| F11 | Organisation culture | Delgado et al. (2019), Hong et al. (2019) |
| F12 | Technology brand and reputation in industry | Nnaji et al. (2020), Zhang et al. (2020) |
| F13 | Technology compatibility | Ahuja et al. (2020), Chen et al. (2019) |
| F14 | Personal privacy | Choi et al. (2017), Seo et al. (2015) |
| F15 | Perceived vulnerability | Choi et al. (2017), Okpala et al. (2020) |
| F16 | Social influence | Choi et al. (2017), Tsai et al. (2014), Zhang et al. (2020) |
| F17 | Organisation data security | Hong et al. (2019), Osunsanmi et al. (2020) |
| F18 | Organisation technology readiness | Chen et al. (2019), Mom et al. (2014) |
| F19 | Technology reliability | Ahuja et al. (2020), Nnaji et al. (2020) |
| F20 | Size of organisation | Fernandes et al. (2006), Kamal et al. (2016) |

was employed, as it provides an efficient and economical means of obtaining the perceptions of a large number of practitioners with experience in construction-based settings. The sampling frame comprised professionals from the three main participants in construction projects, viz. clients, consultants and contractors in Malaysia. Sampling was undertaken by convenience and snowball techniques. The methodological flowchart for the study is presented in Figure 1.

The Statistical Package for Social Sciences (SPSS), version 23, was used to analyse the data collected. Cronbach's alpha test was employed to measure the internal consistency of the questionnaire. The analyses were done to prioritise the predictors according to their descriptive statistics (mean scores and standard deviations). The perceptions of the different respondent groups (viz. client, consultant and contractor) affecting the rankings of variables are then appraised using the Kruskal-Wallis (KW) nonparametric analysis of variance test. Factor analysis is primarily used to examine the relationships between a large number of significantly correlated variables and reduce them to a manageable level for appropriate interpretation. In recent years, the exploratory factor analysis (EFA) technique has been used in a variety of construction management areas such as delay and cost overruns (Kim et al., 2016; Le-Hoai et al., 2008), safety performance (Ajayi et al., 2021; Li et al., 2018) and innovation orientation (Yap et al., 2022; Yusof et al., 2017) factors. In the present study, the primary objective was to obtain coherent and meaningful underlying dimensions (principal factors) of the surveyed predictors (subfactors); thereby assisting in understanding the latent factor structure.

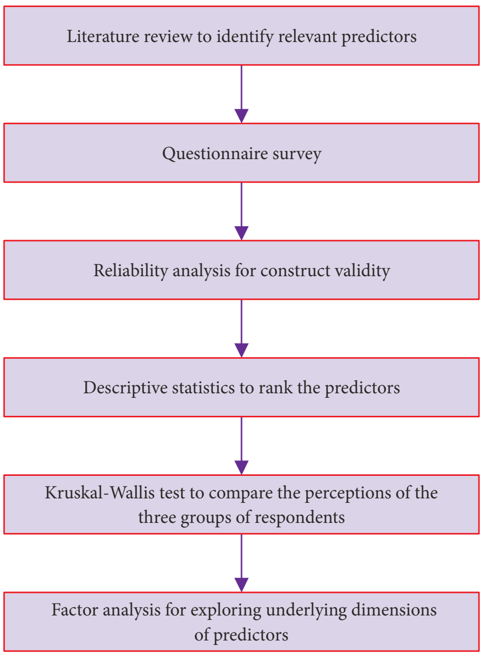


Figure 1. Methodological flowchart for the study

## 2.2. Questionnaire design

The questionnaire was designed based on the literature review and consultation with industry experts. The questions were drafted clearly and concisely for creating easy-to-understand materials and limited to a 15-minute completion time to prevent survey fatigue. The questionnaire contains three parts. Part I concerns the respondents' demographic information, in terms of their role in the project, designation, years of industry experience and educational background. Part II contains the questions (i) *Are you satisfied with the current safety practices in your construction projects?* on a five-point Likert scale ranging from 1 (not at all satisfied) to 5 (extremely satisfied), and (ii) *In your opinion, how important is the adoption of safety technologies in improving construction safety?* on a five-point Likert scale ranging from 1 (not at all important) to 5 (extremely important). Part III involves rating the extent of agreement with the 20 predictors (Table 1) based on a five-point Likert scale from 1 (strongly disagree) to 5 (strongly agree).

The questionnaire pilot involved 35 targeted industry practitioners to ascertain the clarity, readability and appropriateness of the questionnaire. Cronbach's coefficient $\alpha$ value is 0.921, which is greater than the threshold of 0.70 needed for acceptable scale reliability (Hair et al., 2019). This is an important step to ensure the success of the main study. With the reliability of the research instrument established, the questionnaire remained unaltered for the main survey.

## 2.3. Survey participants and background

A total of 350 questionnaires were distributed via email and 103 (29.43%) responses were returned. Combined with the pilot responses, 133 responses were therefore collected, with a consolidated response rate of 34.55% (see Table 2 for details). This sample size is adequate for reliable statistical analysis (Hair et al., 2019). Furthermore, the sample size-to-parameters ratio of 6.65:1 is considered adequate for factor analysis (Yap et al., 2020). The scale reliability is established with Cronbach's coefficient $\alpha$ value of 0.920 (Hair et al., 2019).

Table 3 provides detailed information concerning the respondents' demographics. A majority of 94 (70.7%) have over 5 years of industry experience in construction, with nearly 40% holding managerial positions or above. Additionally, approximately 90% hold a Bachelor or higher degree.

Table 2. Summary of response rates

| Survey methods | Distributed questionnaires | Returned questionnaires | Response rate (%) |
|---|---|---|---|
| Pilot study | 35 | 30 | 85.71 |
| Main study | 350 | 103 | 29.43 |
| Overall | 385 | 133 | 34.55 |

Table 3. Demographic profile of respondents

| Parameter | Category | Respondents group (N = 133) | | | Total | Frequency (%) |
|---|---|---|---|---|---|---|
| | | Client | Consultant | Contractor | | |
| Designation | Executive | 21 | 27 | 32 | 80 | 60.2 |
| | Manager | 9 | 10 | 9 | 28 | 21.1 |
| | Senior manager | 9 | 3 | 3 | 15 | 11.3 |
| | Director/top management | 2 | 4 | 4 | 10 | 7.5 |
| Industry experience | <5 years | 7 | 15 | 17 | 39 | 29.3 |
| | 5–10 years | 7 | 10 | 11 | 28 | 21.1 |
| | 11–15 years | 17 | 12 | 11 | 40 | 30.1 |
| | 15–20 years | 6 | 3 | 3 | 12 | 9.0 |
| | >20 years | 4 | 4 | 6 | 14 | 10.5 |
| Highest education level | Postgraduate degree (PhD, Master's degree) | 15 | 10 | 6 | 31 | 23.3 |
| | Bachelor's degree | 24 | 32 | 32 | 88 | 66.2 |
| | Diploma, certificate | 2 | 2 | 9 | 13 | 9.8 |
| | High school | 0 | 0 | 1 | 1 | 0.8 |

## 3. Survey results and analysis

### 3.1. Respondents' satisfaction regarding current safety practices in construction

Figure 2 depicts the respondents' level of satisfaction with the current safety practices at the construction projects in which they are involved. The majority of the clients and consultants perceive that the implementation of safety measures is inadequate.

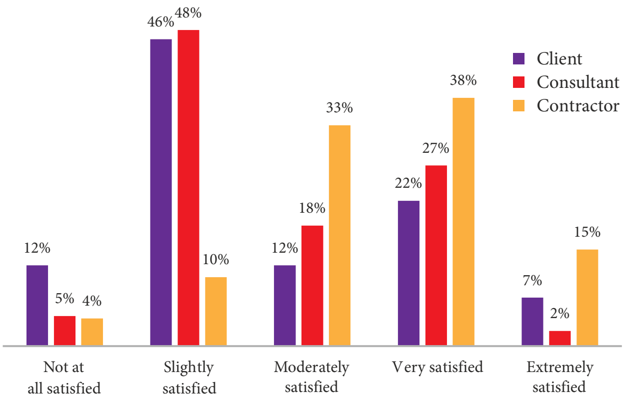


Figure 2. The degree of the respondents' satisfaction about the current safety practices in construction projects

### 3.2. Respondents' perceptions on the significance of the adoption of safety technologies in improving construction safety

Figure 3 depicts the perceived importance of improving construction safety using emerging technologies, with approximately 80% of the clients, 73% of the consultants and 58% of the contractors indicating the criticality of embracing technological solutions to mitigate construction safety risks and enhance safety performance. This result corresponds with SmartMarket Insight (2019) and Construction Industry Development Board [CIDB] (2020) in the need to capitalise on cutting-edge technologies to transform construction productivity, safety and competitiveness.

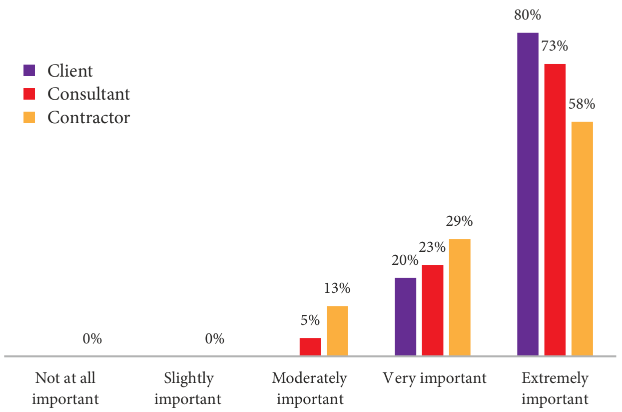


Figure 3. The degree of importance about the adoption of safety technologies in improving construction safety

### 3.3. Ranking of predictors

Table 4 shows the mean and standard deviation of the importance ratings for each predictor. For predictors having a similar mean score, the one with the smaller standard deviation is considered more significant.

All the predictors have a mean value above 3.00 and are therefore considered relevant. The five most influential are, *overall*:

1) Expertise and skill of the project team (mean = 4.451);
2) Proven technology effectiveness (mean = 4.406);
3) Top management support (mean = 4.383);
4) Government promotion and initiative (mean = 4.338);
5) Technology reliability (mean = 4.331).

Table 4. Mean and ranking of predictors of safety technologies adoption in construction projects

| Ref | Predictors | Overall (N = 133) | | | Client (n = 41) | | | Consultant (n = 44) | | | Contractor (n = 48) | | | KW asymptotic significance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | SD | Rank | Mean | SD | Rank | Mean | SD | Rank | Mean | SD | Rank | |
| F9 | Expertise and skill of the project team | 4.451 | 0.821 | 1 | 4.366 | 1.019 | 1 | 4.568 | 0.661 | 1 | 4.417 | 0.767 | 4 | 0.549 |
| F10 | Proven technology effectiveness | 4.406 | 0.739 | 2 | 4.317 | 0.934 | 2 | 4.523 | 0.590 | 3 | 4.375 | 0.672 | 5 | 0.579 |
| F2 | Top management support | 4.383 | 0.785 | 3 | 4.293 | 0.844 | 3 | 4.364 | 0.780 | 8 | 4.479 | 0.743 | 3 | 0.455 |
| F6 | Government promotion and initiative | 4.338 | 0.887 | 4 | 4.195 | 1.100 | 6 | 4.273 | 0.758 | 10 | 4.521 | 0.772 | 1 | 0.175 |
| F19 | Technology reliability | 4.331 | 0.785 | 5 | 4.220 | 1.013 | 4 | 4.545 | 0.589 | 2 | 4.229 | 0.692 | 8 | 0.100 |
| F3 | Capital cost of technology | 4.316 | 0.856 | 6 | 4.220 | 1.061 | 5 | 4.409 | 0.787 | 7 | 4.313 | 0.719 | 6 | 0.724 |
| F5 | Government regulations | 4.293 | 0.886 | 7 | 4.049 | 1.094 | 9 | 4.295 | 0.795 | 9 | 4.500 | 0.715 | 2 | 0.116 |
| F17 | Organisation data security | 4.233 | 0.806 | 8 | 4.098 | 0.970 | 8 | 4.432 | 0.695 | 5 | 4.167 | 0.724 | 11 | 0.134 |
| F1 | Technology complexity | 4.203 | 0.877 | 9 | 4.122 | 1.053 | 7 | 4.409 | 0.726 | 6 | 4.083 | 0.821 | 13 | 0.135 |
| F13 | Technology compatibility | 4.203 | 0.952 | 10 | 3.902 | 1.261 | 12 | 4.500 | 0.665 | 4 | 4.188 | 0.790 | 10 | 0.040* |
| F18 | Organisation technology readiness | 4.135 | 0.824 | 11 | 4.000 | 0.949 | 10 | 4.250 | 0.781 | 11 | 4.146 | 0.743 | 12 | 0.449 |
| F7 | Level of training required | 4.038 | 0.941 | 12 | 3.927 | 0.959 | 11 | 3.864 | 1.133 | 14 | 4.292 | 0.651 | 7 | 0.172 |
| F12 | Technology brand and reputation in the industry | 3.992 | 0.933 | 13 | 3.805 | 1.030 | 13 | 4.091 | 1.030 | 12 | 4.063 | 0.727 | 14 | 0.246 |
| F11 | Organisation culture | 3.962 | 1.025 | 14 | 3.683 | 1.059 | 14 | 3.977 | 1.131 | 13 | 4.188 | 0.842 | 9 | 0.050 |
| F20 | Size of organisation | 3.820 | 1.036 | 15 | 3.561 | 1.305 | 15 | 3.818 | 0.947 | 15 | 4.042 | 0.798 | 15 | 0.293 |
| F4 | Perceived usefulness | 3.699 | 1.161 | 16 | 3.390 | 1.243 | 16 | 3.773 | 1.198 | 16 | 3.896 | 1.016 | 17 | 0.138 |
| F15 | Perceived vulnerability | 3.602 | 1.134 | 17 | 3.317 | 1.192 | 17 | 3.659 | 1.200 | 18 | 3.792 | 0.988 | 19 | 0.166 |
| F16 | Social influence | 3.579 | 1.123 | 18 | 3.317 | 1.171 | 18 | 3.659 | 1.293 | 17 | 3.729 | 0.869 | 20 | 0.184 |
| F8 | Personal motivation | 3.496 | 1.172 | 19 | 2.878 | 1.249 | 20 | 3.636 | 1.163 | 20 | 3.896 | 0.881 | 16 | 0.000** |
| F14 | Personal privacy | 3.489 | 1.152 | 20 | 2.902 | 1.136 | 19 | 3.636 | 1.123 | 19 | 3.854 | 1.010 | 18 | 0.000** |

*Notes*: SD denotes standard deviation; KW denotes Kruskal-Wallis; *The mean is significant at the 0.05 level of significance; **The mean is significant at the 0.01 level of significance.

*Expertise and skill of the project team* is associated with the human capital's capability, knowledge and technological skills. In a fast-changing and innovative business environment, the competence of project team members is a crucial success factor for innovation (Oh & Choi, 2020; Sony & Naik, 2020). In contrast, the key prohibitive challenges to the integration of such new technologies as wearable sensing applications in construction OSH practice are related to a lack of experience and expertise (Ahn et al., 2019). In investigating the use of BIM for construction safety in the Gaza Strip, for example, Enshassi et al. (2016) observed that a high percentage of practitioners from contracting organisations are unfamiliar with BIM technology, which reflects the limited educational knowledge and their low commitment to using BIM. For the successful implementation of safety technologies, construction practitioners with adequate skills and expertise would have to be nurtured. Within this framework, formal education provides the literary knowledge required for workers to use technologies to carry out high-order tasks. Considering that the use of new technologies could be significantly different from existing practices or ageing technologies, companies embracing new technology have to reskill and upskill the existing workforce. In this vein, Ayinla and Adamu (2018) highlight that addressing the digital skills gap is a prerequisite to any technological adaptation and adoption. Notably, different technologies may have varied skill requirements, which suggests the need for training to be technology specific.

Construction firms tend to adopt technologies that have already been proven competent and comply with a range of strict requirements. Unproved effectiveness indicates poor readiness of the technology as the technology is still immature. Construction organisations are usually unwilling to adopt a new technology if they are unsure about its effectiveness. In this light, uncertainty over the usefulness of new technologies is a critical impediment to adoption. There must be documented evidence that the technical attributes of the technology fulfil the desired performance requirements, thereby affirming that the technology is effective (Nnaji & Karakhan, 2020). For safety technologies to be accepted by construction practitioners, their effectiveness, applicability to the work process and value-adding impact must be evaluated and established.

Technology adoption is closely linked to positive support from top management. This is echoed by several past studies that reveal the most significant factor influencing the adoption decision is the commitment and support from top management (Son et al., 2015; Sony & Naik, 2020). This implies that top management play a key role because they always decide how much it is financially wise to invest in innovations. The support from top management may range from organisational strategy to day-to-day activities (Xu et al., 2014). Their endorsement is vital to secure such resources as capital to facilitate the diffusion process (Aksorn & Hadikusumo, 2008). Moreover, proactive management will provide training to the workers to upgrade their skills and expertise.

The government plays a vital role in technology diffusion by assembling an enabling environment that is conducive for firms to adopt safety technologies through a wide array of government measures. This is because the government can take the initiative to encourage the development and application of technologies for safety purposes. Government promotion will create and provoke awareness, knowledge and interest among the construction practitioners to adopt new technology. This can be done by providing incentives to captivate more investment in new technologies. Having an incentive can be immensely beneficial, especially for those small and medium-sized construction organisations that have limited resources and have to rely on government funding to ensure successful technology adoption (Zakaria et al., 2018). Furthermore, government-supported academic research and utilisation of automation and robotics in construction projects are contributors to the adoption of these technologies (Cai et al., 2020).

Safety technologies must be sufficiently reliable to meet the required safety performance consistently. For instance, tracking technology is reliable if it is capable of recording and monitoring activities accurately and precisely (Cheng et al., 2011). This finding corresponds with Nnaji et al.'s (2019) finding that technology reliability is the most influential safety technology adoption predictor in the U.S. construction industry. In another study, AlHogail (2018) observed that technology reliability has positive effects on trust towards its adoption, while Seo et al. (2015) also highlight that reliability is hindering the practical application of technologies. They posit that the essential requirement for successful safety and health control is the reliability and accuracy of data collected by the technology, which is a challenging task due to the unique nature of construction characterised by such dynamics as job sites involving different workers, various types of equipment and building materials and continuously changing working environments. These dynamic attributes at the sites may result in technical issues for safety technology applications.

The Kruskal-Wallis ANOVA test reveals that the opinions of the respondents concerning the predictors are generally homogenous except for *technology compatibility*, *personal privacy* and *personal motivation*. "Technology compatibility" is ranked higher by the consultants, which implies that consultants are more aware of the compatibility of the safety technology with current work practices and future systems. This may be due to their concerns on interoperability issues within the software and technologies used by their organisations. This finding coincides with previous studies investigating architects' perceptions in adopting new technology. According to Son et al. (2015), for instance, compatibility plays a facilitating role in influencing the designer's perception of the technology as being useful and easy to use. Ding et al. (2015) also have a comparable finding in appraising the factors affecting BIM adoption by architects in China.

In contrast, "personal privacy" is rated higher by contractors. Such safety technologies as UAV and wearable safety devices would require continuous monitoring at construction sites to gather context-aware data about what, when and where the workers do their jobs. These devices could debase the workers' morale as they might perceive the organisation is spying on them. They tend to be sensitive towards sharing their personal information such as their location during idle periods and physiological status, especially if exposing this personal information to the management will pose a potential threat to them in a social sense (Choi et al., 2017; Okpala et al., 2020). As such, this critical privacy concern will lead to the workers' reluctance to adopt safety technology at the workplace.

"Personal motivation" is also rated higher by contractors. As Adriaanse et al. (2010) assert, personal motivation is influenced by the perceived benefits and disadvantages of the technologies. Sexton et al. (2006), on the other hand, highlight that the motivation to adopt new technology is very much shaped by the project environment. The industry's disproportionately high rate of accidents means that, while OSH is the responsibility of every party involved in construction projects, contractors have to be extra aware that they are accountable for OSH at construction sites.

### 3.4. Exploratory factor analysis of predictors

The Kaiser-Meyer-Olkin (KMO) is 0.858, which is better than the 0.50 value needed to establish sampling adequacy for factor analysis (Table 5). The Bartlett's test of sphericity is 1692.6 ($\rho = 0.000$), which indicates there is the needed significant difference in the variances (Hair et al., 2019).

Table 5. Factor loading and variance explained

| Factor profile | Factor loading | Variance explained (%) | Cronbach α | Average mean |
|---|---|---|---|---|
| ***Dimension 1: Organisation's commitment and technology orientation*** | – | 19.468 | 0.874 | 4.102 |
| Organisation culture (F11) | 0.795 | – | | |
| Top management support (F2) | 0.741 | – | | |
| Organisation technology readiness (F18) | 0.662 | – | | |
| Social influence (F16) | 0.659 | – | | |
| Size of organisation (F20) | 0.615 | – | | |
| Capital cost of technology (F3) | 0.567 | – | | |
| Level of training required (F7) | 0.527 | – | | |
| Organisation data security (F17) | 0.470 | – | | |
| Expertise and skill of the project team (F9) | 0.420 | – | | |
| ***Dimension 2: Supporting technological attributes*** | | 19.279 | 0.871 | 4.227 |
| Proven technology effectiveness (F10) | 0.832 | – | | |
| Technology complexity (F1) | 0.828 | – | | |
| Technology reliability (F19) | 0.821 | – | | |
| Technology compatibility (F13) | 0.697 | – | | |
| Technology brand and reputation in the industry (F12) | 0.665 | – | | |
| ***Dimension 3: Personal perception and performance expectancy*** | | 17.010 | 0.898 | 3.571 |
| Perceived vulnerability (F15) | 0.875 | – | | |
| Personal privacy (F14) | 0.854 | – | | |
| Perceived usefulness (F4) | 0.822 | – | | |
| Personal motivation (F8) | 0.764 | – | | |
| ***Dimension 4: Government support*** | | 11.213 | 0.900 | 4.316 |
| Government promotion and initiative (F6) | 0.868 | – | | |
| Government regulations (F5) | 0.793 | – | | |
| Cumulative variance explained | | 66.969 | 0.920 | |
| Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy | | 0.858 | | |
| Bartlett's test of sphericity Approx. $\chi 2$ | | 1692.649 | | |
| df | | 190 | | |
| Sig. | | 0.000 | | |

*Notes*: Extraction method = Principal component analysis; rotation method = Varimax with Kaiser normalization. Rotation converged in 7 iterations.

With the factorability of the 20 predictors surveyed established and using the varimax orthogonal rotation latent root criterion, the principal component analysis generates 4 underlying dimensions (latent construct) that account for 66.97% of the total variance explained. As all 20 variables attain factor loadings exceeding 0.40, all the variables are retained. Table 5 presents the final rotated component matrix, in which all the dimensions have high reliability with Cronbach's α values greater than 0.70 (Hair et al., 2019). Each dimension can be interpreted and named according to characteristic/construct the factor represents, as discussed below.

## 4. Discussion of the underlying dimensions

*Dimension 1: The organisation's commitment and technology orientation*

The first–dimension accounts for 19.47% of the total variance explained. The variables with the highest loadings are organisation culture, top management support and organisation technology readiness. This implies that an organisation's commitment and technology orientation have a significant influence on its adoption of technology. Despite the variety of safety benefits that technologies offer, their applications in construction projects have not yet been fully realised. A critical ground for this can be the difficulties of adoption at the organisational level. Previous studies have highlighted that organisation culture is instigated at the top and employees tend to emulate the manner of top management in decision making (Yap & Chow, 2020). Therefore, top management needs to take the lead by actively supporting safety efforts at all levels. Hence, organisations should strengthen their organisation safety culture and commit to the implementation of new innovative technology to enhance safety.

To raise the adoption rate, it is necessary for organisations to have a proactive inclination toward the application of new technology. Previous studies show that being a more technology–oriented organisation is likely to benefit business performance (e.g., Al-Ansari et al., 2013; Halac, 2015). As Yousaf et al. (2021) assert, technology orientation is made up of several dimensions, which entail management capability, technological capability, commitment to learning and commitment to change. This corresponds with Abbasnejad et al.'s (2020) literature review of the enablers of BIM adoption in AEC firms, which emphasises the significance of management's technological knowledge, leadership skills and commitment to change in technology diffusion.

Essentially, the successful implementation of technology necessitates considerable attention and commitment from senior management. In the context of the present research, organisational commitment refers to top management valuing the prominence of safety technologies and being involved in the adoption and implementation process. In doing this, top management may perform a facilitating role to empower and encourage employees to embrace new technologies (Abbasnejad et al., 2020). A technology–oriented organisation tends to devote its resources to acquiring technologies, such as to employee training or investment in areas that could promote adoption. Cultivating construction professionals with technological competence can greatly help in the effective implementation of technologies. This stresses the need for an organisation to provide the necessary resources for new skills development and upgrading the existing workforce's skills. Against this backdrop, Son et al. (2015) highlights that construction organisations that create an enabling environment for their employees are more likely to adopt new technology.

*Dimension 2: Supporting technological attributes*

This dimension accounts for the second–largest variation of 19.28% and contains five factors that explain the criticality of supporting technological attributes in influencing technology adoption. This is a technology–based factor, which constitutes proven technology effectiveness, technology complexity, technology reliability and technology compatibility, as well as technology brand and reputation in the industry, with factor loadings ranging from 0.665 to 0.832. Technological attributes include complexity, durability, effectiveness, reliability, versatility, maturity, technical support and other relevant technical features (Nnaji et al., 2019). As Sepasgozar and Davis (2019) underscore, technology attributes play a prominent role in influencing user decisions in adopting a construction technology. This assertion coincides with a study conducted in the U.S., which reveals that technology–related factors such as technology reliability, effectiveness and durability are the most influential factors in safety technology adoption (Nnaji et al., 2019). In a recent study, Nnaji et al. (2020) employ factor analysis to categorise safety technology adoption predictors according to technology-, organisational- and external- aspects. Technology predictors have the largest total variance explained at 25.63% and the variables with the highest factor loadings are related to reliability, effectiveness of the proven technology and availability of technical support. Peansupap and Walker (2005) also report comparable findings, whereby such technology characteristics as compatibility, relative advantage and complexity have more than a moderate impact on information and communication technology diffusion and adoption within the Australian construction organisations. It is worth noting that an organisation is more driven to adopt the new technology when it offers more advantages than current technologies or working practices.

*Dimension 3: Personal perception and performance expectancy*

Perceived vulnerability, personal privacy, perceived usefulness and personal motivation create the third factor. This is a people–concerned dimension, and accounts for 17.01% of the total variance explained. Individual–level factors also influence decisions to implement new technology. As Howard et al. (2017) point out, the acceptance of technology is an individual act based on personal perceptions; thus, the user's perceptions and expectations of the technology play a crucial role in its adoption rate. For instance, some construction workers may feel reluctant to adopt new technology due to the perceptions and concerns that the technology may endanger their personal privacy (Gheisari & Esmaeili, 2019; Son et al., 2015). On another note, the acceptance of safety technologies may be positively elevated when they perceive that the working environment and activities are hazardous and may pose critical health threats (Choi et al., 2017; Okpala et al., 2020).

The worker's belief and evaluation of the usefulness of the technology is also essential. This aspect has received considerable attention in several studies, which reveal that performance expectancy significantly influences an individual's behavioural intention to accept and use a technology (Choi et al., 2017; Son et al., 2015). Generally, performance expectancy relates to how much individuals believe they can acquire benefits in work performance by using a system. Performance expectancy relates to the perceived enhancement of safety performance acquired through adopting safety technologies. Moreover, construction practitioners are unlikely to adopt a technology unless convinced that it can provide answers to their questions. Therefore, they may accept the use of the technology if they perceive that the technology may enhance on–site safety performance. Hence, personal perceptions and performance expectancy represents a crucial factor in accelerating or hampering the adoption of safety technologies by construction practitioners.

*Dimension 4: Government support*

This fourth dimension accounts for 11.21% of the total variance explained, emphasising the two most significant factors with regard to the government's support. Government promotion and initiative attained the highest loading, followed by government regulations, all with factor loadings exceeding 0.700. Safety can be ameliorated at different hierarchical levels of a construction project – from the government to the individual. Being stationed at the top of the hierarchy, the government level constitutes the occupational health and safety departments that formulate rules and regulations together with managing their implementation. The existing trend in stimulating adoption is the top–down approach, thus stressing the crucial role of government in diffusing adoption. As Delgado et al. (2019) observe, the government is usually the biggest construction client and the amount of public spending on infrastructure has a massive impact on technology adoption. This essentially signifies that the government is the key driver to enforce the use of technologies in health and safety practice. In Asia, the Singaporean government has been the leader in the BIM adoption process and has enforced BIM in many public projects (Enshassi et al., 2016), while the Korean government has also been the prime mover for the rapid adoption of BIM through establishing legislative actions (Son et al., 2015).

Intrinsically, the government has many tools to support the adoption of new technologies in the construction industry, such as promoting collaboration with universities and research institutes, financial incentives, supplementary requirements in contracts and mandates. All these tools have different degrees of effectiveness. Several previous studies have accentuated the role of government in realising the adoption process. For instance, Ding et al.'s (2015) China study suggests that the government may launch demonstration projects to manifest the economic benefits and effectiveness attained from safety technology adoption. In Nigeria, Abubakar et al. (2014) emphasise that government agencies should conduct awareness enhancing programs to extinguish firms' resistance to change and encourage construction stakeholders to uphold safety technologies in practice.

Furthermore, the government may provide such financial support as incentives and subsidies to motivate stakeholders, as such economic support directly offsets the cost of technology adoption. This has been discussed in a Malaysian study, where Kamal et al. (2016) explain that the government should provide financial and tax support to construction firms to enhance their innovation activity. Through the provision of tax incentives, the Malaysian government can stimulate firms to be involved in R&D activities and bolster their collaboration with such knowledge providers as universities and research institutes to breed more innovations to have a significant impact on construction safety. Other than financial support, the provision of knowledge support by the government is also essential in diffusing adoption. As Hong et al. (2019) highlight, such knowledge–supporting activities as training and consultation provided to small to medium organisations can offer a solid practical foundation for technology implementation. Such knowledge support can equip employees with competent professional skills.

## Concluding remarks

Industry 4.0 is creating a change in the current paradigm and shaping industrial sectors towards digital transformation in order to be highly productive and competitive. Despite recent advancements in new technologies, the construction industry has been hesitant to embrace emerging technological opportunities. Previous studies suggest the introduction of proactive innovative solutions into safety management practices can substantially improve construction safety performance. Given the construction industry's relatively poor safety record, it is believed that increased safety technology adoption could increase productivity, improve jobsite safety and reduce risks. However, the utilisation rate of such emerging technologies as BIM, wearable sensing devices and drones for safety management in construction is still low. The lack of a theoretical framework prevents a systemic understanding of the factors influencing technology adoption in construction, particularly in the context of such developing countries as Malaysia. Moreover, there is limited scholarly consensus over the underlying dimensions of the predictors of safety technology adoption. In response, this paper addresses the identified knowledge gaps by appraising the predictors involved.

Based on a survey of 133 Malaysian construction practitioners, the study reveals that conventional safety management practices are insufficiently adequate to prevent construction workplace accidents and injuries. The majority of the practitioners acknowledge that technology applications can provide an effective means of improving safety performance. Prioritised by mean scores, the five most influential predictors are identified as *expertise and skill of project team*, *proven technology effectiveness*, *top management support*, *government promotion and initiative* and *technology reliability.* Using an exploratory factor analysis, four underlying dimensions of the surveyed predictors are uncovered, comprising organisational commitment/technology orientation, supporting technological attributes, personal perception/performance expectancy and government support. These largely explain the predictors and are new to the adoption of new technologies for safety and health management in construction.

The findings of this study also have several practical implications that are expected to be of great value and utility for construction organisations and governments interested in adopting innovative safety practices to capitalise on the various sophisticated capabilities available, and which are not possible with typically reactive traditional approaches. An increased understanding of the influential predictors is needed to guide sound and informed decision making to prepare for modern technological solutions to improve the management of jobsite risks. Given the current low technology diffusion rate for construction safety, focusing on these 20 predictors and the 4 underlying dimensions will raise the readiness of the construction industry towards integrating innovative methods for the detection and correction of workplace hazards to benefit the industry's safety in the future. Moreover, the underlying dimensions and the corresponding predictors can be used to develop a comprehensive indicator or index system to evaluate the organisation's or industry's readiness to adopt new safety technologies. The results can also be utilised to develop predictive analysis models to drive better decisions for technology adoption to reduce the theory–practice gap.

The study is limited to the Malaysian construction industry and other similar contexts: future work can be expanded to other countries for comparative analysis and to draw generalisable findings. Similarly, while describing an observable pattern, the correlation between variables does not necessarily represent causation: such a relationship could be evaluated using structural equation modelling (SEM) or comparable methods. The focus is also primarily on the role of technology to streamline construction safety, efficiency and productivity: future research would benefit from exploring the unprecedented health and safety challenges in construction sites during and after the Covid-19 pandemic and how the increased use of technologies can reduce or eliminate the risk of exposure.

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## Author contributions

All authors have contributions to this article. Conceptualization and supervision, JBH, Yap; data collection and statistical analysis, KPH, Lee; writing of the manuscript, M, Skitmore; interpretation of the results, YL, Lew and WP,Lee; review and editing of manuscript, D, Lester.

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No potential conflict of interest was reported by the authors.

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