ENHANCING DIGITAL TRANSFORMATION IN CONSTRUCTION HEALTH AND SAFETY: A SYSTEMATIC REVIEW OF THE CURRENT STATE OF THE ART

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Previous studies have emphasized the need to improve the state of knowledge regarding the benefits of incorporating safety technologies to improve safety of workers. Despite the benefits that could be gained from incorporating safety technologies, its potential has not been fully realised. This paper therefore filled the gap by examining critical success factors required for implementing safety technologies in the management of construction H&S from the organisational point of view and then develop a framework for its adoption. A systematic literature review was conducted on selected articles from 2012-2022 to allow a thorough synthesis on recent literature on digital innovations and construction H&S. The success factors are attributed to strategic initiatives, organisational culture, learning capability and knowledge sharing and financial and statutory drivers. The findings from this study will be valuable to industry practitioners, policy makers, regarding strategies to enhance its successful implementation in the construction industry.

Keywords: safety technologies; industry 4.0; digital transformation; health and safety

INTRODUCTION

Numerous scholars are constantly searching for new tactics and procedures that could boost H&S efficacy in construction. An overview of current publications shows a definite trend toward the use of new inventions for H&S management (Yap *et al.,* 2021; Zhou *et al.,* 2013). These innovations can be used to suppress occupational dangers in a variety of construction activities (Nnaji and Karakhan, 2020). Research on utilising technological innovations for construction H&S has increased because of the advantages that can be derived from its adoption (Karakhan *et al.,* 2018; Zhang *et al.,* 2022). However, despite the opportunities and benefits posed by technological innovations in managing H&S hazards, its adoption and implementation is still very low.

This could partly be attributed to difficulties associated with its implementation at the organisation level (Lokuge *et al.,* 2019). Although, most research is focused on using technological inventions to mitigate health hazards in construction sites, they are unable to establish a complete approach for measuring the importance of integrating

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smart technologies (Nnaji and Awolusi, 2021). Incorporating safety technologies for construction H&S management is a continuing phenomenon with a variety of impacting parameters that may influence its implementation (Malomane *et al.,* 2022). As more technologies are developed or adapted for safety purposes, it is essential to determine ways to improve the integration of technologies within H&S management. In most cases, a technological change goes through three phases prior to becoming a standard practice in an organisation.

These phases are the adoption of the technology, its implementation and the acceptance or utilisation of the technology (Nnaji and Awolusi, 2021). Given the level of fragmentation within the construction industry and the different construction means and methods adopted among construction firms, it is necessary to determine the success factors of adopting innovative technologies and examine their level of importance on influencing overall adoption of H&S technologies in construction. Previous literature focuses primarily on evaluating the effectiveness of and assessing the return-on-investment of implementing H&S technologies (Yap *et al.,* 2021; Gao *et al.,* 2019; Khakurel *et al.,* 2018) rather than investigating critical success factors of implementing H&S technologies.

Therefore, this study will examine critical success factors for implementing digital innovations within corporate contexts. Furthermore, there is an absence of a clear integrated model, further complicating the deployment of digitalisation in construction H&S. In view of this, an implementation framework will be created to give a stronger conceptual foundation for the overall implementation process. This will allow construction firms to better embrace and implement more effective processes and change management methods because of this. A review of the existing literature on construction H&S, and digital innovations will identify the primary critical success criteria that must be evaluated for effective and efficient integration of safety technologies for construction H&S.

Safety Technologies Adoption as a Process Change

The adoption of safety technologies in construction is one of the paramount ways to reduce H&S hazards in order to protect workers and ensure the successful delivery of construction projects (Yap *et al.,* 2020). Nnaji and Awolusi (2021) mentioned that the implementation of safety technologies creates unique opportunities for construction to change from existing corporate procedures or for creating new ones. This is why it is termed as a process change enabler or process change management (Kraus *et al.,* 2022). Implementing safety technologies in construction H&S is not just about modifying software packages, but it's all about restructuring the firm in its response to matters of H&S of their workers and transforming construction processes and practices (Martínez-Rojas *et al.,* 2020).

An organisation's efforts and activities should be evaluated and improved on a regular basis. Successful implementation of safety technologies in H&S requires different approaches which involves team management, cultural change, and significant changes in the construction operations and methods (Golisadeh *et al.,* 2018). Any business process change requires a strategic initiatives where top managers define and communicate a vision of change. An organisational structure with an effective culture, a willingness to exchange ideas, teamwork, and a capacity to learn should allow the deployment of certain process management and change management method (Lines and Reddy Vardireddy, 2017) for the implementation of digital innovations in construction H&S.

METHOD

This study was carried out as a systematic literature review using the method suggested by Abbasnejad *et al.,* (2021). Qualitative research approach was used to obtain the primary data. Based on this method, the literature-based findings were extracted, analyzed, and reported using a three-stage procedure. A desktop study was undertaken in the first round to collect literature using several search databases such as Google Scholar, Web of Science, ScienceDirect (Elsevier), and Scopus. Also, English-language journals and peer-reviewed publications, conference papers on the research focus make up the literature dataset covering periods from 2012-2022. For compiling the literature, keywords such as "construction H&S" or "digital technologies" or "safety management" or "safety technologies" or "Industry 4.0" and "critical success factors or drivers or implementation or adoption or change management" were used as a basis for retrieval.

This research resulted in the collection of 225 papers which were acquired from different construction and safety management literature and related journals as listed by Wing (1997), Nasirian *et al.,* (2019), and Zhou *et al.,* (2013). The number of relevant papers and their corresponding source tiled is outlined as "Initial Number of Papers". These articles were exported to Endnote support platform to manage the bibliography. Afterwards, the papers were considered for eligibility based on; inclusion and exclusion criteria which allows redundant publications to be discarded based on the focus of the research, incomplete articles, language used, and year of publication.

This resulted in the selection of 78 papers for further investigation. Further filtering was performed on the 78 manuscripts to test for eligibility based on quality assessment which focused on the type of journal articles (peer-reviewed and of high quality with the exclusion of non-peer-reviewed papers), duplicate papers where the same author/s published in more than two conference proceedings. Also, in cases where a journal article is an extended version of a conference paper, the journal article was prioritised because journals represent more rigorous and in-depth analysis. A total number of 34 papers were recognised as meeting the requirement of this study, thus providing a suitable basis for the analysis of literature and for developing strategies to enhance the implementation of safety technologies. Content analysis was used for analysed the collected publications. The data were managed and analysed using Microsoft Excel and the synthesis of the findings is presented in the following sections. Each of the publications, with its corresponding journal, and authors are listed in Table 1.

FINDINGS

The results of this study are presented in two parts. The first part provides a summary of the journals publishing papers on safety technologies and the topics being considered. In the second part, a conceptual framework for enhancing safety technologies in the construction industry is developed and details regarding different elements of enhancing safety technologies is presented (Figure 1). This review revealed seven sources that have published more than one paper around the enhancement of safety technologies (Table 1). Some of these journals belongs to the list of top construction journals by Zhou *et al.,* (2013), including Journal of Construction Engineering and Management, Automation in construction, Construction Management and Economics, Engineering, Construction and Architectural Management, and Journal of Management in Engineering which contains 15 different

papers. Famous safety management journal such as Safety Science was also included. Other journals focus on Construction Innovation, Journal of Information Technology in Construction, Technological Forecasting and Social Change.

Table 1: Search results for relevant publications

Source title	Initial number of publications	Final number of publications	References
Journal of Construction Engineering and Management	35	3	Ahn *et al.,* (2019), Karakhan *et al.,* (2018), Nasirian *et al.,* (2019)
Automation in Construction	42	4	Golizadeh *et al.,* (2018), Martinez-Rojas *et al.,* (2020), Zhang *et al.,* (2022), Li *et al.,* (2018)
Construction Management and Economics	24	4	Lingard (2013), Wing (1997), Zhou *et al.,* (2013), Shibeika and Harty (2015)
Engineering, Construction and Architectural Management	12	2	Aghimien *et al.,* (2020), Nnaji *et al.,* (2019)
Construction Innovation	8	1	Farghaly *et al.,* (2021)
Architectural Engineering and Design Management	2	1	Abbasnejad *et al.,* (2021)
International Journal of Construction Management	9	1	Akinlolu *et al.,* (2020)
Journal of Building Engineering	1	1	Nnaji and Karakhan (2020)
Journal of Management in Engineering	7	2	Lee *et al.,* (2015), Lines *et al.,* (2017)
Journal of Engineering, Design and Technology	7	1	Yap *et al.,* (2021)
Organization, Technology and Management in Construction-An International Journal	4	1	Mihic *et al.,* (2019)
Frontiers from Architectural Research	10	1	Ramilo and Embi (2014)
Frontiers in Built Environment	5	1	Swallow and Zulu (2019)
Safety Science	16	2	Badri *et al.,* (2018), Martinez-Aires and Martinez-Rojas (2018)
International Journal of Environmental Research and Public Health	2	1	Malomane *et al.,* (2022)
Computers and Education	6	1	Gao *et al.,* (2019)
Journal of Information Technology in Construction	12	2	Hare *et al.,* (2020), Miller *et al.,* (2014)
International Journal of Information Management	9	1	Kraus *et al.,* (2022)
Information Technology and People	6	1	Khakurel *et al.* (2018)
Information and Management	1	1	Lokuge *et al.,* (2019)
Technological Forecasting and Social Change	6	1	Martinez-$_{Caro}$ *et al.,* (2020)
Technology in Society	1	1	Nnaji and Awolusi (2021)

Framework for Enhancing the Implementation of Safety Technologies

To better understand safety technologies, a framework has been devised that incorporates the key elements that need to be considered when devising appropriate strategies (Figure 1). The four main elements of the framework are strategic initiatives, organisational readiness, financial and statutory drivers, and learning capability and knowledge sharing. Each element includes several sub-elements discussed. Each element includes several sub-elements:

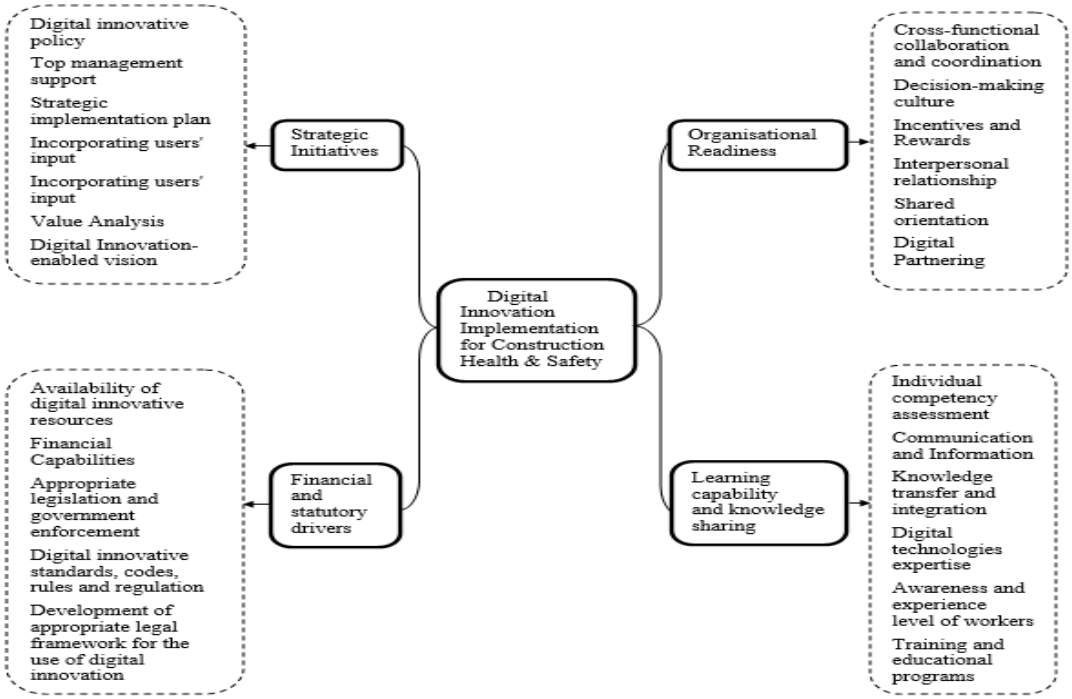

Figure 1: Framework showing drivers for successful implementation of safety technologies

Strategic Initiative

According to Table 1, one of the critical success factors for the implementation of safety technologies for construction H&S is strategic initiatives. Nnaji and Awolusi (2021) mentioned that the buy-in of key stakeholders is crucial for digital innovations to successfully penetrate the construction sector. Given the increased desire and gradual shift towards a more collaborative project delivery approach, this buy-in is becoming increasingly vital. In this process, the support of top management is crucial for the successful adoption of safety technologies for H&S management (Lingard, 2013).

The willingness and commitment of top management to provide essential resources and their involvement is vital to implementation (Nnaji and Awolusi, 2021). Digital innovative managers will need to assume tasks such as regular communication to suppliers of software, training, supervision, and developing digital policies and plans (Yap *et al.,* 2021). In addition, effective innovative policies (guidelines, standards, etc.) should be established to guide practices, and compliance should be highly established to ensure the achievement of construction H&S (Hare *et al.,* 2020). Goals and objectives, roles and duties, adoption scope, process flows, duration of the project, and supporting organisational and technical infrastructures, as well as the evaluation process, should all be included in the implementation plan (Mihic *et al.,* 2019). During the evaluation process, construction workers should be involved because they are crucial to the effective adoption of safety technologies (Yap *et al.,* 2021). Yap *et al.,* (2020) also mentioned that a detailed training program that incorporates predicted training requirements and includes generating a cost-effectiveness rationale should be produced.

Although, the cost of purchasing and operating safety technologies should not be the main driver of their adoption (Nnaji *et al.,* 2019), the influence of a technology on an organisation's bottom line is crucial to ensuring senior management's continued support. Furthermore, an enabled vision for understanding the role that safety

technologies will play in the mitigating health hazards will help firms in determining performance goals and fulfilling key objectives (Nnaji and Awolusi, 2021). This idea must be compelling enough to inspire collaboration and commitment of the employees (Lee *et al.,* 2015).

Organisational Culture

Digital innovative initiatives will advance in an open and safe environment if mistakes are allowed to be perceived as improvement opportunities (Abbasnejad *et al.,* 2021). Changes resulting from the introduction of safety technologies may cause resistance (Martínez-Caro *et al.,* 2020). In this vein, efficient communication is essential, as it enables individuals to feel more involved in the implementation process while also keeping them informed about organisational practices, standards, and aspirations (Ahn *et al.,* 2019). Finally, impediments to implementation are most likely to be addressed by an organisational culture that is open to change and consists of shared common values and goals (Ahn *et al.,* 2019).

Workers and employees should also be involved as quickly as possible by management (Abbasnejad *et al.,* 2021). Organisational change agents (leaders) with the required skills, expertise, and leadership capabilities are required to effectively explain the advantages of safety technologies in minimizing or suppressing health risks (Khakurel *et al.,* 2018). Leaders must identify and analyse the sources of resistance and provide strategies to deal with them effectively to drive consensus throughout the implementation process (Nnaji and Awolusi, 2021). Digital adoption should not begin unless potential users (construction workers) develop and maintain a positive mind-set (Ahn *et al.,* 2019).

As a result, managing change initiatives is a vital enabler for implementing digital innovations. To effectively deal with exchange of information, integration, IT systems, and software difficulties, there must be collaboration among external vendors, consultants, and supply chain partners (Yap *et al.,* 2021). This will help maintain tight and trusting relationships with other entities who have valuable information about advanced technologies by providing opportunities to learn and gain expertise about the concept. Therefore, project stakeholders, organisations, professional bodies, and local governments are encouraged to collaborate to improve project organisational-related issues, such as the adoption of safety technologies to prevent potential health risks of workers.

Learning Capability and Knowledge Sharing

Successfully implementing digital innovations for construction H&S can also be achieved through learning capability and knowledge sharing (Swallow and Zulu, 2019). It is important for construction firms to develop informal learning networks for knowledge acquisition to take place. Construction employees' skills are improved, and their awareness of digital concepts and tools is expanded through effective and well-designed training and continuous educational programs (Gao *et al.,* 2019). Personal attributes, training intervention design and delivery, and training performance evaluation are some of the major categories that training, and education might follow (Miller *et al.,* 2014). Candidate competences must be identified, measured, and recorded to improve learning performance. Training performance evaluation should incorporate assessments of learning outcomes, behavioural reactions, and expectations on whether training programmes have enhanced trainee values and to what degree new knowledge and skills have resulted in improved job performance (Martínez-Aires *et al.,* 2018). Thorough training and education are

critical for attaining end-user expectations, as well as supporting a long-term focus on continuous development.

Furthermore, information exchange and communication are critical in minimizing resistance to change as well as the risk and uncertainty that come with new systems, processes, and technology (Zhang *et al.,* 2022). The development of a knowledge management (KM) system for safety innovations facilitates the codification of internal routines, employee learning experiences, builds on knowledge, coordinates complex change activities, disseminates knowledge, and ultimately increases the dynamic capability of the organisation (Ahn *et al.,* 2019). Firms' ability to capture and re-use gained information and experience is hampered if they do not build an effective learning capability and knowledge management system. This means that top management of construction firms and professional bodies must place a greater emphasis on employees' training, as well as increasing their knowledge and awareness of the use of safety technologies to mitigate health hazards in construction by organising seminars, workshops, and conferences.

Financial and Statutory Drivers

These underlying factors are related to the ease of securing funding for the acquisition of digital software and its associated licenses, support from government in the form of start-up funds for construction firms, development of an effective regulatory basis to guide its implementation in projects, among others. Malomane *et al.,* (2022) recognized the challenges faced by the relatively high cost of digital software acquisition. As a result, to improve the implementation of safety technologies for reducing potential health risks in building projects, stakeholders involved must make a concerted effort and commitment to make the required funds available to help the efficient adoption of safety technologies (Nnaji and Karakhan, 2020). Also, top executives in the construction sector should be eager to make long-term investments and commitments in the execution of safety technologies that will have long-term effects (Nnaji and Karakhan, 2020). It is also critical that the government work to support small and medium-sized construction enterprises with funds and incentives to encourage them to utilize safety technologies to reduce health risks in their projects (Li *et al.,* 2018).

Considering the possible impact these innovations could have on construction workers' H&S, establishing a comprehensive strategy for facilitating the adoption and use of safety technologies has become imperative. As a result, this research contributes to a better understanding in a variety of ways. To begin with, the industry is ripe for the adoption and diffusion of safety technologies that will play a significant role in revolutionizing H&S in the construction industry, given the alarming state of safety performance in the industry and the current push to leverage innovative and effective methods to improve workers' H&S. The current research revealed the most important aspects to consider when using safety technologies on a construction project or inside an organisation.

Once digital innovations have been effectively embraced and deployed on a larger scale in organisations, practitioners can use artificial intelligence to create predictive models that can provide significant insights to designers and planners, thus enhancing the design for safety objectives. In addition, the results showed that the most significant factors for implementing safety technologies are having a knowledgeable and well-trained workforce, as well as ensuring that the technologies give relevant and usable information to end-users in a timely manner. This means that effective training

and information campaigns could help to alleviate some severe worries about these technologies, such as privacy risks and data security. After identifying the crucial success elements for the successful implementation of safety technologies for construction H&S management, the main fundamental precepts for the strategic integration of these technological innovations in all aspects of the construction activity must be established.

CONCLUSIONS

Organisations' inability to realize the value of safety technologies in avoiding construction hazards is primarily due to the difficulties involved with successful implementation. The effective adoption of digital innovations for reducing health hazards on construction projects necessitates a considerable systemic reform in the construction industry's business operations. When an organisation experiences a major transformation, detailed planning and management are essential during the implementation process. This research found that organisational readiness, strategic initiative, learning capability and knowledge sharing, as well as financial and legislative factors in a collaborative network relationship, can help construction firms to successfully implement safety technologies for reducing health hazards and realizing the associated outcomes and benefits.

A greater knowledge of the observed success factors should help construction firms improve the adoption of safety technologies for construction H&S management. As a result, there is a critical need for key project stakeholders to give the safety of construction workers a greater priority, as well as equip and retrain them to keep up with the industry's current trend of innovation. The development and implementation of a suitable working strategy or model to implement digital innovations should be prioritized by top management of construction companies. It is critical for government agencies and professional organisations to work together to give necessary and appropriate subsidies or financial incentives to small and medium-sized construction enterprises to encourage them to utilize safety technologies in their workplace.

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