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Proactive prevention: embedding safety into South African construction design

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Abstract

Purpose – Prevention through Design (PtD) has continued to gain traction as a viable method for achieving safety in construction due to its ability to address safety issues right from the project's design phase. However, despite the existing discourse on the potential of PtD, evidence of its application in the delivery of safe construction projects in South Africa is still limited. Therefore, this study explored PtD as a proactive approach toward ensuring safety on construction sites in South Africa.

Design/methodology/approach – The study adopted a post-positivist philosophical stance using a quantitative research design and a structured questionnaire as the instrument for data collection. Built environment professionals involved in the design and delivery of construction projects were surveyed, and the data analysis was done using frequency, mean score, the Kruskal–Wallis *H*-Test and confirmatory factor analysis in EQS 6.4.

Findings – The study found a high awareness of PtD practices, albeit a moderate level of implementation. All 14 PtD practices assessed were considered significant to achieving safety within the South African construction industry. However, their implementation is challenged by the poor safety culture, budget constraints to implement safety practices, lack of PtD education and training, absence of supporting policies and standards and deficiency in designers' skills and understanding of PtD, among others.

Originality/value – By strategically integrating the identified PtD practices in the design phase of construction projects in South Africa, safety risks can be mitigated and a culture of accident prevention can be achieved. The study also provides a foundation for future studies in South Africa seeking to explore proactive prevention of accidents in construction projects through PtD – an aspect that has gained less attention in the South African construction safety discourse.

Keywords Design for safety, Occupational health and safety, Prevention through design, Proactive prevention, Site accidents

Paper type Research paper

1. Introduction

The construction industry in South Africa, like its counterpart in other countries, is crucial to socio-economic development. The industry is a catalyst for the creation of employment, development of infrastructure and economic growth. Contributing about 3.4% to the country's gross domestic product and 11% to the country's total employment (Department of Trade, Industry and Competition, 2023; Zingoni, 2020), the construction industry has become crucial to the South Africa's prosperity. This significant contribution of construction to total employment is indicative of the industry's high dependence on people to deliver its projects (Ngwenya and Aigbavboa, 2017). The complexity of construction projects, coupled with its high dependence on human input makes construction sites susceptible to safety issues. Therefore, over the years, ensuring safety on construction sites has been a topical issue, particularly because of the dire consequences of site accidents.

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Studies worldwide have continued to explore construction safety to eliminate unsafe practices or reduce their possibility of occurrence. A significant body of work exists on occupational health and safety (OHS) management of construction projects and the unsafe practices of construction workers in countries worldwide. In South Africa, the need for improvement in the OHS management of construction projects as workers continue to get exposed to site hazards and risks has been noted (Smallwood and Deacon, 2020). This improvement becomes necessary as construction workers will likely be permanently disabled when site accidents occur (Agumba and Musonda, 2019). Moreover, the Federated Employers Mutual Assurance Company (2022) reported over six thousand accident cases in 2022 alone and over fifty thousand site accidents that required urgent medical attention between 2015 and 2021. Allen (2024) reported the death of four construction workers following the collapse of a sand embarkment at a construction site in Ballito, South Africa. This collapse follows another recent apartment building collapse that led to the loss of lives in George, South Africa. These statistics of construction site accidents in the country have continued to increase despite the enactment of the Construction Regulations of 2014, which is part of the Occupational Health and Safety Act 85 of 1993 in South Africa designed to improve health and safety standards within the country's construction industry (Tealio, 2024).

The importance of attaining a safe working environment has necessitated diverse proposed approaches, including the management at the different phases of construction, the development of safety models and practices, safety training, and the use of technological innovations (Chan and Aghimien, 2022; Ibrahim *et al.*, 2025; Ikuabe *et al.*, 2021). One crucial practice toward ensuring improved safety that has continued to garner research attention is Prevention through Design (PtD). Also known as Design for Safety (Abueisheh *et al.*, 2020; Manu *et al.*, 2021), Designing for Construction Safety (Öney-Yazıcı and Dulaimi, 2015), or Safety in Design (Guo *et al.*, 2021), PtD involves designing out hazards and hazardous activities in the workplace (Schulte *et al.*, 2008). PtD is rooted in Lorent's (1987) report, which identified that most accidents on construction sites are linked to facility design issues, and Szymberski's (1997) Time-Safety Influence Curve, which observed that safety decreases as construction progresses (Tymvios *et al.*, 2020). Since its introduction, the concept of PtD has gained increasing attention in the construction industry (Che Ibrahim *et al.*, 2022). The National Institute for Occupational Safety and Health (2023) described PtD as reducing or preventing injuries, illness and fatalities by inculcating preventative measures in designs that impact workers. In construction, careful attention to how projects are designed to ensure safety has emanated from past studies that have noted a correlation between design decisions and safety on construction sites (Gibb *et al.*, 2006). Over time, PtD practices have become viable approaches to tackling work-related illnesses and injuries in construction (Abueisheh *et al.*, 2020; Che Ibrahim *et al.*, 2022; Schulte *et al.*, 2008).

The benefits of PtD have led to studies exploring its usage within the construction industry of developing countries such as Ghana (Manu *et al.*, 2021), Indonesia (Machfudiyanto *et al.*, 2023), Kuwait (Sharar *et al.*, 2022), Malaysia (Che Ibrahim *et al.*, 2022; Christermeller *et al.*, 2022), Nigeria (Che Ibrahim *et al.*, 2022; Manu *et al.*, 2019; Umeokafor *et al.*, 2023), Palestine (Abueisheh *et al.*, 2020), Saudi Arabia (Hassanain *et al.*, 2022) and Vietnam (Phan and Zhou, 2023). These studies noted varying levels of awareness, knowledge and desire to implement this concept of designing for safety among key construction professionals. They further noted the importance of PtD in achieving a safe and healthy construction environment in developing countries. However, in the context of the South African construction industry, the exploration of PtD is still scant, particularly in how experts perceive the significance of PtD practices in attaining safety in the country. A quick literature search using the Scopus database revealed that out of all articles that have referenced the concept of PtD in construction, only one (i.e. Che Ibrahim *et al.*, 2022) has explored South Africa as a study area. Che Ibrahim *et al.* (2022) focused on the competencies designers need to implement PtD in Malaysia, Nigeria and South Africa. The study further noted that one of the earliest studies around achieving safety from the design perspective was the work of Goldswain and Smallwood, published in 2015. Goldswain and Smallwood (2015) proposed a working model that architectural designers can use to improve OHS and ergonomics in South Africa. Several suggestions were proposed for improving OHS, including using training and education among designers. Judging from the emerging trends of increased awareness of PtD in developing countries, as noted in existing studies, there is a possibility that this safety approach is already being used within the South African construction industry. However, the extent of this usage is unclear and might not be adequately documented, creating a knowledge gap worth exploring.

To this end, this study explored the use of PtD and the significance attributed to PtD practices in the quest for a safe construction environment in South Africa. It further delineates the major challenges facing the use of PtD in the country. The findings offer practical direction for using PtD to deliver safe construction projects. By strategically integrating the identified PtD practices in the design phase of construction projects in South Africa, safety risks can be mitigated, and a culture of accident prevention can be achieved. The study also provides a basis for a wider discussion on addressing critical issues hindering the use of safety practices in the country.

2. Prevention through design in construction

PtD has continued gaining prominence among construction professionals and researchers who are concerned about the safe working conditions on construction sites (Poghosyan *et al.*, 2018). This is because PtD offers the ability to "design out" hazards in construction projects right from the design phase, thus reducing their probability of occurrence and their attributed injuries and fatalities (Abueisheh *et al.*, 2020; Schulte *et al.*, 2008). Manu *et al.* (2019) averred that adopting PtD is a collaborative effort among designers and other project stakeholders to design a project that prioritizes safety while ensuring other project objectives are achieved. This collaborative effort becomes crucial as it ensures that safety considerations do not compromise the project's function, aesthetics, and budget. Ultimately, while achieving safety on projects, PtD also aims to balance safety and other project criteria.

According to Dong *et al.* (2017), the implementation of PtD encompasses a wide range of methodologies and procedures. These include hazard identification, risk assessment, selecting safer materials and processes, and integrating safety measures into the design. The primary objective of PtD is to restrict or eliminate potential hazards, decrease the likelihood of accidents, and ensure the protection of workers. Dong *et al.* (2017) also noted that PtD may involve the construction of buildings with fall prevention systems, providing appropriate lighting and signage, or establishing ergonomic workspaces to minimize the risk of musculoskeletal injuries. Although the specific PtD practices employed may vary depending on the nature of the construction project, the underlying principle remains consistent: prioritizing safety from the initial stages of planning and design. In agreement, Pu *et al.* (2023) emphasized that PtD focuses on prevention, aiming to address safety concerns at their source during the design phase. This approach significantly reduces the probability of accidents, injuries, and unfavorable outcomes.

The myriads of studies on designing to ensure safety in construction has unearthed certain practices. For instance, in exploring strategies required for safety design, Wang *et al.* (2013) noted that four stages are common in designing for safety within engineering projects. These are feasibility studies, construction technological design, construction design, and basic design. Carefully considering these stages can prove highly beneficial to achieving safety. The Health and Safety Authority (2023) noted that designing out hazards entails several practices. These practices include specifying less hazardous materials; avoiding processes that generate harmful and hazardous substances such as fumes, dust, noise or vibration, among others; specifying easy-to-handle materials for construction projects; and carefully considering work at height equipment and activities during design. Care must also be taken to avoid buried services and accidents caused by obstructed traffic movement on site. In exploring the concept of designing for safety in developing countries, Manu *et al.* (2019)

assessed the frequency of adopting practices relating to work-at-height, work done in confined spaces, site congestion, and manual handling of materials and hazardous substances. Drawing from existing works, Manu *et al.* (2019) proposed 15 practices that have been validated and explored within diverse studies in different developing countries. To this end, the studies of Abueisheh *et al.* (2020), Christermeller *et al.* (2022), and Manu *et al.* (2021) have all explored practices such as designing to avoid hazards, specification of low maintenance; none hazardous and easy-to-handle materials ensuring design allows safe movement of workers on site and promote safety of the public; elimination of risky materials and methods; promote offsite construction; eliminate working in confined spaces and from heights; ensuring risk assessment are carried out while preparing hazard identification drawings on projects. This current study explored fourteen PtD practices adapted from these existing submissions to assess the use of PtD and the priority placed on these practices by construction practitioners in South Africa.

3. Implementation and challenges facing prevention through design in construction

The benefits of implementing PtD practices for better health and safety construction sites have been explored in existing studies. It has been noted that many potential risks in construction projects can be eliminated by "designing out risks" (Behm, 2005; Haslam *et al.*, 2005). To this end, studies have explored the implementation and challenges of using this beneficial safety approach. For instance, in the United Arab Emirates, Öney-Yazıcı and Dulaimi (2015) explored designing for construction safety by assessing the interface between confidence and attitudes of designers and safety culture. It was observed that certain demographic characteristics such as nationality, age, and experience play significant roles in the attitude of designers toward embracing PtD.

Furthermore, the safety culture within an organization is significantly related to the attitude of designers toward using this safety in the design process. It was concluded that if designers are to improve their knowledge and understanding of PtD, then hands-on experience must be promoted within the country's construction industry. In Nigeria, Manu *et al.* (2019) explored PtD from architects' perspective and noted a low use of this practice in preventing injuries and fatalities on construction projects. The study found that awareness, training and education, and membership in a design professional body are some of the factors limiting the widespread adoption of PtD in the country. In a similar study, Umeokafor *et al.* (2023) explored PtD in Nigeria and concluded that resistance to using this approach could come from construction clients who might not be familiar with the safety concept.

Abueisheh *et al.* (2020) explored PtD implementation among construction design professionals in Palestine and discovered that despite having a high level of awareness, the actual implementation of PtD is low due to certain implementation challenges. These challenges could be the inadequacy of training programs, lack of organizational commitment, or lack of support for training on PtD. In Malaysia, Abas *et al.* (2020) noted that in the quest to reduce accidents in construction sites, emphasis is now being placed on the safety responsibility of diverse parties involved in the design stage of construction works. While assessing the confidence and attitudes of designers toward the use of PtD, Abas *et al.* (2020) observed that designers were confident in their ability to design for safety but required more convincing to employ the concept. Substantial effort is required to promote this beneficial safety tool among these professionals. In a similar study in Malaysia, Christermeller *et al.* (2022) discovered high awareness and implementation of PtD practices, which have also increased training opportunities in the country. It was further noted that issues relating to the delivery of design for safety lessons in formal education, influence from clients, legislation and industry guidelines were key challenges to implementing safety concepts in the Malaysian construction industry.

In Ghana, Manu *et al.* (2021) noted a high awareness level but low use of safety design practices. It was further noted that for the implementation of safety design concepts to improve, construction clients, educational institutions and design professional bodies must be ready to drive and support this implementation. Also, Acheampong *et al.* (2024) assessed the challenges facing using design for safety in Ghana and noticed four major clusters of issues. These are design process and communication, regulation and expertise limitations, planning and education constraints, and attitude and perception. Che Ibrahim *et al.* (2022) explored PtD implementation from the perspective of designers' competencies in Malaysia, Nigeria, and South Africa. It was observed that while a considerable number of the participants sampled in Malaysia are aware of PtD, a low awareness and implementation level was noted in Nigeria and South Africa. The study further noted issues around inadequate guidance to implementation, poor knowledge and education, and inadequate use of collaborative approaches to procuring construction projects as principal culprits of this poor implementation.

Similarly, in Kuwait, Sharar *et al.* (2022) assessed design professionals' perspective of PtD and noticed, albeit its moderate adoption level, there is a high awareness of the concept among these sets of professionals. It was further noted that appropriate regulations, industry guidance, and formal education and training will go a long way in improving the implementation of these safety design practices. Likewise, in Saudi Arabia, Hassanain *et al.* (2022) observed issues relating to the fear of cost overruns by construction clients when PtD concepts are initiated, lack of awareness and supporting policies as critical barriers to their implementation. This fear can be attributed to the lack of adequate understanding of the overall benefit of ensuring safety from the design stage, which can drastically cut down the overall cost of achieving safety on construction projects in the long run (Wang *et al.*, 2013). In Vietnam, Phan and Zhou (2023) assessed architects' PtD awareness, attitude and practices and noticed that while there was high awareness of the concept and positive attitude toward using it, the actual adoption was low. It was suggested that training and education on PtD is required to promote improved adoption in the country. In Indonesia, Machfudiyanto *et al.* (2023) explored the different factors to consider in successfully implementing PtD within the construction industry. The study concluded that factors relating to contract documentation, designers, clients, regulations, knowledge, and available tools are crucial to successfully implementing safety considerations in construction design.

These studies point to the growth in awareness of PtD, albeit with slow adoption in many developing countries due to several implementation challenges. Exploring these concepts in the context of South Africa, where such a study is scarce, became crucial to contributing to the existing construction safety discourse.

4. Research methodology

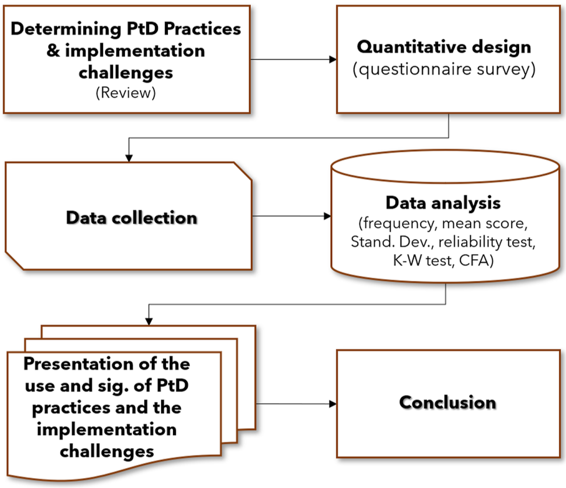
The study adopted a post-positivism approach through a quantitative research design using a questionnaire as an instrument for data collection. The questionnaire was adopted because it can reach a wide range of professionals and gather empirical data (Tan, 2011). The questionnaire was designed in three sections which assessed the respondents background, the use of the identified PtD practices and the challenges facing PtD usage in the country. A cover letter describing the research, informing the respondents of their voluntary participation, and assuring them of anonymity accompanied the questionnaire. The questionnaire was distributed electronically among selected construction professionals involved in the design and construction of projects. These include architects, engineers, and construction managers actively involved in the design and construction of projects in Gauteng province, South Africa, and have at least five years of continuous work experience. While architects and engineers play active role in designing of construction projects, the input of construction managers can be sought during the design stage in some peculiar projects especially when the procurement option allows. The threshold of active involvement in a project and years of experience was considered necessary to ensure that the study's respondents understood the country's construction industry safety dynamics. Also, Gauteng was selected as the study area as the province houses many construction activities and organizations (Construction Industry Development Board, 2020). Based on this set threshold, it was difficult to determine the target population's exact number, making calculating the study's sample size impossible. Hence, snowball sampling was employed, and a small group of professionals were first identified and invited to participate in the survey. These groups then referred others to participate in the survey. In the end, responses were gathered from 67 professionals, which were considered adequate for data analysis and drawing logical conclusions.

The data gathered on the respondents' backgrounds were analyzed using frequency (*f*), while mean score (M) was used to rank the different PtD practices and challenges. The respondents were grouped based on the type of organization they work for, and Kruskal–Wallis *H*-Test (K–W) was used to determine the significant difference in the ranking of these PtD practices and challenges by the respondents from consulting, contracting and government organizations. This categorization of respondents became relevant as most past studies have placed emphasis on other demographic data like age, experience and professional body (Abueisheh *et al.*, 2020; Christermeller *et al.*, 2022; Manu *et al.*, 2021). The type of organization a professional works for can shape how they perceive the significance of certain phenomena. The K–W test was considered suitable as it is a non-parametric test used to identify the significant difference in the rating of variables by three or more groups (Pallant, 2020). The reliability of the questionnaire was also tested using the Cronbach alpha (α) test with a set threshold of 0.7 and above, as noted in previous studies (Bagozzi and Yi, 2012). The data gathered on the respondent's perception of the significant PtD practices that can improve safety was further confirmed using confirmatory factor analysis (CFA) in EQation (EQS) software version 6.4. Figure 1 gives an overview of the research method adopted.

5. Findings and discussion

5.1 Background information

Table 1 gives the respondents background information. The professionals in the study include architects ($f = 25$), construction managers ($f = 15$), and engineers ($f = 27$). Most of these professionals have a bachelor's degree ($f = 46$), with 18 having a master's degree and only 3



Source(s): Figure by author (2024)

Figure 1. Overview of the research method

Table 1. Background information characteristics

Category	Classification	*f*	%
Profession	Architect	25	37.3
	Engineer	27	40.3
	Construction Manager	15	22.4
	Total	67	100.0
Highest academic qualification	Diploma	3	4.5
	Bachelor's/Honours Degree	46	32.8
	Master's Degree	18	35.8
	Total	67	26.9
Type of organization	Government	14	20.9
	Consultancy	35	52.2
	Contracting	18	26.9
	Total	67	100.0
Years of experience	5 years	32	47.8
	6–10 years	18	26.9
	11–15 years	17	25.4
	Total	67	100.0
	Average	7.8 years	
Awareness of PtD concept	Yes	63	94.0
	Unsure	4	6.0
	Total	67	100.0
Use of PtD concept	Yes	31	46.3
	No	24	35.8
	Unsure	12	17.9
	Total	67	100.0

Source(s): Author's compilation (2024)

with a Diploma. Many of these professionals ($f = 35$) were from consulting firms, with 18 and 14 from contracting and government organizations, respectively. Regarding the years of experience, 32 have the minimum set threshold of five years while the remaining 35 have above five years, with an average year of experience of 7.8 years calculated for the study participants. The background analysis also revealed that while 63 professionals are aware of the concept of PtD, only four indicated that they were unsure. However, in terms of actual use of PtD practices, only 31 noted that they use them in their projects, while 24 did not, and 12 were unsure. The result of the background information implies that the professionals who participated in this study are well-equipped academically to understand the research questions and have adequate experience in the industry. They are also well aware of the concept of PtD and can contribute meaningfully to the subject.

5.2 Use of prevention through design practices

The use of the PtD practices was assessed across the different groups of respondents, and the result is presented in Table 2. The reliability of adopting these PtD practices was tested using the α test, and an α-value of 0.808 was derived, confirming that these variables are reliable. The relationship in the rating of these variables was tested using the K-W test, and the result revealed no significant difference in the view of these professionals as a *p*-value of above 0.05 was derived. On an individual basis, the result revealed that professionals in consulting firms mostly use PtD practices that consider the safety of the public, design to eliminate working in confined spaces and undertake risk assessment at the design stage. For those in contracting organizations, avoiding overhead cables in design, considering the public's safety, and undertaking risk assessment at the design stage were most common. Those in government organizations mostly use specifying easy-to-handle and less maintenance materials.

Table 2. Use of prevention through design practices

Prevention through design	Consulting M	R	Contracting M	R	Government M	R	Overall M	R	K-W Chi-sq.	*p*-value
Design considers safety of the general public	3.31	1	3.56	2	3.14	8.00	3.34	1	0.915	0.633
Design eliminates working in confined space	3.29	2	3.33	7	3.21	6.00	3.28	2	0.077	0.962
Design safety risk assessment is undertaken	3.23	3	3.56	2	3.00	9.00	3.27	3	2.155	0.340
Designing to avoid risk from overhead cables	2.97	10	3.72	1	3.36	4.00	3.25	4	5.626	0.060
Design specifies less maintenance materials	3.11	5	3.17	9	3.57	1.00	3.22	5	1.657	0.437
Design eliminates working at heights	3.09	6	3.50	4	3.00	9.00	3.18	6	2.034	0.362
Design considers safe movement of workers on site	3.03	8	3.06	11	3.50	3.00	3.13	7	1.716	0.424
Design to avoid hazards during construction	3.23	3	3.33	7	2.57	14.00	3.12	8	3.790	0.150
Design specifies easy to handle materials	2.97	10	3.00	14	3.57	1.00	3.10	9	2.628	0.269
Design considers ease of construction	2.74	13	3.50	4	3.29	5.00	3.06	10	1.148	0.317
Designing of structure to avoid risk from buried services	3.03	8	3.06	11	3.07	7.00	3.04	11	0.006	0.997
Design specifies non-hazardous materials	3.09	6	3.06	11	2.79	12.00	3.01	12	0.839	0.657
Design includes clear safety notes	2.94	12	3.39	6	2.64	13.00	3.00	13	3.107	0.212
Design considers offsite prefabrication of elements	2.74	13	3.17	9	2.86	11.00	2.88	14	1.340	0.512
Group M	3.06		3.31		3.11		3.14			

Note(s): R = Rank, M = Mean score, SD = Standard deviation
Source(s): Author’s compilation (2024)

Overall, the group *M*-value revealed 3.14, implying an average adoption of the identified practices. This further confirms the level of usage earlier observed in the background information. Further assessment shows that design considers safety of the general public ($M = 3.34$, $p = 0.633$), eliminates working in confined spaces ($M = 3.28$, $p = 0.962$), design safety risk assessment is undertaken ($M = 3.27$, $p = 0.340$), designing to avoid risk from overhead cables ($M = 3.25$, $p = 0.060$), and design specifies less maintenance materials ($M = 3.22$, $p = 0.437$) are the top used practices. However, the design includes clear safety notes ($M = 3.00$, $p = 0.214$), and the design considers offsite prefabrication of elements ($M = 2.88$, $p = 0.512$), ranked as the least used practices within the South African construction industry.

5.3 Confirming the significance attributed to the prevention through design practices for safety in construction

The data gathered on the significance of the identified fourteen PtD practices in attaining safety in the South African construction industry was analyzed, and the result is presented in Table 3. The result from the K-W test shows a significant *p*-value below 0.05, which was derived for the design practice that considers offsite prefabrication of elements, and the design includes clear safety notes. This implies that the professionals across the different groups rated these variables differently. However, there is considerable agreement in rating all other practices, as the K-W test revealed a *p*-value of above 0.05 for the remaining twelve practices.

From the individual perspective, the result shows that professionals in consulting organizations prioritize design that considers the safe movement of workers on site, undertaking design safety risk assessment, and designing to avoid hazards during construction as the most critical to achieving safety in construction projects. Those in contracting view designing to avoid risk from buried services, designing to avoid hazards during construction, designing that considers the safe movement of workers on site, and designing to eliminate working in confined spaces as most crucial. All these practices relate more to onsite construction, which these contracting organizations mostly handle. For those in government organizations, designs to eliminate working in confined spaces designs that consider offsite prefabrication of elements, designs that include clear safety notes, and designs that consider ease of construction were ranked top.

Overall, the result shows that the professionals considered all the identified practices as crucial to attaining a safe working environment as an *M*-value of above average of 3.0 was achieved for all assessed PtD practices. Topmost among these practices are design considers safe movement of workers on site ($M = 4.48$, $p = 0.442$), design eliminates working in confined space ($M = 4.46$, $p = 0.102$), design considers offsite prefabrication of elements ($M = 4.45$, $p = 0.030$), and design health and safety risk assessment is undertaken ($M = 4.43$, $p = 0.140$).

5.3.1 Confirmatory factor analysis. Following the ranking of the identified PtD practices, a CFA of these factors was conducted to confirm the significance of these practices and determine their level of predictive accuracy toward achieving safety in construction sites. In conducting CFA, the Robust Maximum Likelihood (RML) estimation was employed, and the standardized coefficient (λ) derived was assessed to determine their validity. The result in Table 4 revealed that all the PtD practices had a λ-value ranging from 0.762 to 0.895. These results are higher than the expected 0.7 threshold for a valid variable (Hulland, 1999; Oke and Ogunsemi, 2016), thus confirming that they are all valid to achieve safety in the South African construction industry. Also, the internal consistency of these practices was assessed using the Cronbach alpha (α) and Rho alpha (ρA) tests. Past studies have noted a threshold of above 0.7 for internal consistency to be achieved (Bagozzi and Yi, 2012; Hair *et al.*, 2019). The result revealed an α-value of 0.867 and ρA-value of 0.870, which are higher than the set cut-off, thus confirming internal consistency. Table 4 further shows the significance of each PtD practice. The result revealed that all fourteen practices were significant at a *Z*-value of above 1.96

Table 3. Rating of the significance attributed to PtD practices

Prevention through design	Consulting M	Consulting R	Contracting M	Contracting R	Government M	Government R	Overall M	Overall R	K-W Chi-sq.	*p*-value
Design considers safe movement of workers on site	4.54	1	4.33	2	4.50	8	4.48	1	1.632	0.442
Design eliminates working in confined space	4.40	5	4.33	2	4.79	1	4.46	2	4.563	0.102
Design considers offsite prefabrication of elements	4.43	4	4.22	8	4.79	1	4.45	3	7.027	0.030**
Design safety risk assessment is undertaken	4.46	2	4.22	8	4.64	5	4.43	4	3.931	0.140
Designing of structure to avoid risk from buried services	4.37	7	4.39	1	4.50	8	4.40	5	0.616	0.735
Design to avoid hazards during construction	4.46	2	4.33	2	4.36	12	4.40	5	1.196	0.550
Design includes clear safety notes	4.37	7	4.11	12	4.79	1	4.39	7	7.329	0.026**
Design considers safety of the general public	4.37	7	4.22	8	4.64	5	4.39	7	5.591	0.061
Design considers ease of construction	4.31	12	4.22	8	4.79	1	4.39	7	5.855	0.054
Design eliminates working at heights	4.40	5	4.11	12	4.64	5	4.37	10	2.849	0.241
Design specifies less maintenance materials	4.31	12	4.33	2	4.43	11	4.34	11	0.634	0.728
Designing to avoid risk from overhead cables	4.29	14	4.33	2	4.50	8	4.34	11	0.964	0.618
Design specifies non-hazardous materials	4.34	10	4.28	7	4.29	13	4.31	13	0.208	0.901
Design specifies easy to handle materials	4.34	10	4.00	14	4.29	13	4.24	14	1.874	0.392

Note(s): ** *p*-value sig. @95% confidence level, R = Rank, M = Mean score, SD = Standard deviation
Source(s): Author's compilation (2024)

Table 4. Confirmatory factor analysis of PtD practices

Prevention through design	λ	*Z*-value	Sig.	R^2
Design includes clear safety notes	0.895	8.785	**	0.802
Design eliminates working in confined space	0.882	8.590	**	0.778
Design considers safe movement of workers on site	0.878	8.530	**	0.771
Design specifies less maintenance materials	0.858	8.252	**	0.736
Design considers safety of the general public	0.849	8.126	**	0.721
Design considers offsite prefabrication of elements	0.845	8.076	**	0.715
Designing of structure to avoid risk from underground services	0.824	7.795	**	0.679
Design safety risk assessment is undertaken	0.821	7.751	**	0.674
Designing to avoid risk from overhead cables	0.809	7.598	**	0.655
Design to avoid hazards during construction	0.796	7.410	**	0.634
Design considers ease of construction	0.795	7.418	**	0.632
Design specifies easy to handle materials	0.787	7.312	**	0.619
Design eliminates working at heights	0.765	7.042	**	0.585
Design specifies non-hazardous materials	0.762	7.002	**	0.580

Note(s): ** *p*-value sig. @95% confidence level, λ = standardized coefficient, R^2 = coefficient of determination
Source(s): Author's compilation (2024)

($p < 0.05$). In confirming the predictive accuracy of these practices to achieve safety, each practice's coefficient of determination (R^2) was assessed. Past studies have noted a threshold of 0.25, 0.50 and 0.75 for weak, moderate and strong predictive accuracy (Hair *et al.*, 2019). The result in Table 4 shows that most of the assessed practices have between moderate and strong predictive accuracy and can sustainably lead to a safe working environment in the country. Top practices on this list are "design includes clear safety notes" ($R^2 = 0.802$), "design eliminates working in confined space" ($R^2 = 0.778$), and "design considers safe movement of workers on site" ($R^2 = 0.771$).

The fitness of these PtD practices was assessed by exploring the standardized root mean squared (SRMR) along with other fit indices, as suggested by Hu and Bentler (1999). Table 5 shows that the SRMR value of 0.072, which is within the threshold of ≤0.08 for an acceptable fit (Hu and Bentler, 1999). Although the derived root mean squared error of approximation (RMSEA) revealed a value of 0.149, which is above the expected threshold of between 0.05 and 0.10 (Singh, 2009), other fit analyses revealed acceptable fits. For instance, the Bentler–Bonnet Non-Normed Fit Index (NNFI) of 0.847, within the expected threshold of 0.60–1.00 for an acceptable fit, was achieved. Also, the Comparative Fit Index (CFI) and Bollen's incremental fit index (IFI) both had values of 0.796 and 0.801, respectively. These values were also within the expected thresholds (Doloi *et al.*, 2011; Oke and Ogunsemi, 2016).

Table 5. Summary of fit indices

Fit indices	Cut-offs	Value	Remarks
S-Bχ^2	–	189.95	–
Df	–	77	–
S-Bχ^2/Df	<3	2.46	Acceptable
SRMR	≤0.08	0.072	Acceptable
RMSEA	0.05 to 0.10	0.149	Not acceptable
CFI	0 to 1	0.796	Acceptable
NNFI	0.60 to 1.00	0.847	Acceptable
IFI	0.90 to 1.00	0.801	Acceptable
GFI	0 to 1	0.667	Acceptable

Source(s): Author's compilation (2024)

The derived SRMR, along with results from the NNFI, CFI, and IFI, all affirmed that these PtD practices are suitable for achieving safety in the South African construction industry.

5.4 Challenges facing the use of prevention through design

In understanding the challenges facing the use of PtD practices among construction professionals in South Africa, 12 challenges were assessed, and the result is presented in Table 6. The reliability of these challenges was tested using the α test, and an α-value of 0.874 was derived, confirming that these variables are reliable for measuring the challenges facing the use of PtD in the study area. Overall, the K-W test revealed a convergent view among survey participants as a *p*-value of above 0.05 was derived for all the challenges assessed.

From the perspective of professionals within consulting organizations, the poor safety culture, absence of supporting policies and standards, and budget constraints in construction projects are the major hindrances to implementing PtD practices. However, those in contracting organizations noted that the poor safety culture, resistance to change among design professionals, and budget constraints are the most crucial challenges. Those in government organizations rated a lack of PtD education and training and an over-dependence on subcontracting in project delivery as the two major challenges.

Overall, the respondents considered these challenges critical as they all had an above-average *M*-value of above average of 3.0. Top on the list is the poor safety culture of the construction industry with an *M*-value of 4.51. This indicates that if a safe working environment is to be achieved through PtD, then the South African construction industry must be ready to jettison its old approach of neglecting safety and encourage a better safety culture. Budget constraints to implement safety practices (M = 4.43, $p = 0.873$), lack of PtD education and training (M = 4.42, $p = 0.090$), absence of supporting policies and standards (M = 4.39,

Table 6. Challenges facing the use of PtD

	Consult.		Contr.		Govt.		Overall		K-W Chi-sq.	
Challenges facing the use of PtD	M	R	M	R	M	R	M	R		*p*-value
Poor safety culture of the construction industry	4.49	1	4.44	1	4.64	3	4.51	1	0.764	0.682
Budget constraints in construction project	4.43	2	4.39	3	4.50	8	4.43	2	0.271	0.873
Lack of PtD education and training	4.33	4	4.28	5	4.79	1	4.42	3	4.825	0.090
Absence of supporting policies and standards	4.43	2	4.11	8	4.64	3	4.39	4	1.469	0.480
Deficiency in designers' skills and understanding of PtD	4.31	5	4.29	4	4.50	8	4.35	5	0.137	0.934
Overdependence on subcontracting in project delivery	4.26	7	4.11	8	4.79	1	4.33	6	3.871	0.144
Resistance to change among design professionals	4.23	9	4.44	1	4.36	12	4.31	7	1.779	0.411
Poor health and safety management programs, procedures and policies	4.26	7	4.06	11	4.64	3	4.28	8	4.854	0.088
Uncertainty of the required capabilities	4.29	6	3.94	12	4.64	3	4.27	9	3.776	0.151
Clients' fear of additional cost of safety design practices	4.23	9	4.17	7	4.50	8	4.27	9	1.027	0.598
Design uncertainty	4.17	11	4.11	8	4.50	8	4.22	11	1.656	0.437
Non-inclusion of safety officers at the project design phase	4.00	12	4.22	6	4.64	3	4.19	12	2.525	0.283

Note(s): R = Rank, M = Mean score, SD = Standard deviation
Source(s): Author's compilation (2024)

$p = 0.480$) and deficiency in designers understanding of PtD (M = 4.35, $p = 0.934$) were also considered to be part of the topmost issues facing the implementation of PtD practices within the country. Although design uncertainty and non-inclusion of safety officers at the project design phase ranked the lowest on the table, they cannot be ignored as they exhibit high *M*-values of 4.22 and 4.19, respectively. This implies that they tend to deter the implementation of PtD if not adequately addressed.

5.5 Discussion of findings

The findings of this study revealed an overall high level of awareness of the concept of PtD, albeit the average implementation of this practice. This finding contrasts with the earlier submission of Che Ibrahim *et al.* (2022), which observed a low awareness level among 59 professionals in South Africa. This disparity in the findings indicates an improvement in the awareness level of PtD among professionals in the country over the years. However, the findings further imply that more needs to be done to improve the use of these practices. It is imperative to note that this slow implementation of PtD is a common phenomenon among developed and developing nations across the world (Soh *et al.*, 2020) and, as such, requires a concerted effort to improve its adoption globally.

Furthermore, the findings of the study revealed that while PtD practices such as considering the safety of the general public, eliminating working in confined spaces, overhead cables and heights, undertaking safety risk assessment, as well as specifying less maintenance materials are currently being used by some of the professionals, other practices must also be considered for a holistic attainment of safety on construction sites in South Africa. These include considering ease of construction, designing a structure to avoid risk from buried services, specifying non-hazardous materials, providing clear safety notes in designs, and considering offsite prefabrication of elements. These practices were ranked the least in terms of usage. These findings are in tandem with similar studies conducted in other developing countries (Christamaller *et al.*, 2022; Manu *et al.*, 2021). However, they deviate from the submission of Abueisheh *et al.* (2020) that the use of designs that enable ease of constructing, avoiding construction operations that create hazardous fumes, vapor and dust and Christamaller *et al.* (2022) submission that design minimize risks from buried services and overhead cables were part of the most used practices in Palestine and Malaysia respectively. This disparity in result can be attributed to the unique context of the construction industry of these different countries. For instance, a high level of awareness and implementation has been observed in Malaysia (Che Ibrahim *et al.*, 2022; Christamaller *et al.*, 2022). This significantly impacts the extent of adoption of certain PtD practices. The emergent implication of these findings is that for construction practitioners seeking to improve safety on construction sites in South Africa, there is a need to give adequate attention to all PtD practices. This is essential as the findings from the CFA conducted further revealed that all these practices were deemed significant, and acceptable fit indices were achieved.

Also, the findings revealed that some of the root causes of the slow-paced implementation of PtD practices in the South African construction industry are poor safety culture, budget constraints to implement safety practices, lack of PtD education and training, absence of supporting policies and standards, deficiency in designers' skills and understanding of PtD, overdependence on subcontracting in project delivery, and resistance to change among design professionals. This finding is in tandem with past observations in the United Arab Emirates (Öney-Yazıcı and Dulaimi, 2015), Nigeria (Manu *et al.*, 2019; Umeokafor *et al.*, 2023), Kuwait (Sharar *et al.*, 2022) and Vietnam (Phan and Zhou, 2023). The poor safety culture of the construction industry globally has been reiterated in past studies. The South African construction industry is no exception, with poor attention to safety being prominent within the country (Aghimien *et al.*, 2018; Smallwood, 2004). Evidently, this has a significant impact on the implementation of safety initiatives like PtD, as noted in the results of this study. Thus, if PtD implementation is to improve, the issue of safety culture among project participants needs to be addressed through continuous safety enlightenment programs, workshops and seminars. Also, construction organizations in South Africa can further promote a safety culture within the industry by ensuring proactiveness through safety plans, effective communication, undertaking competence training, employing emerging technologies to work smarter, and putting accident reduction programs in place (Bray, 2023).

Chellappa and Gunasekaran (2022) have noted that there are pointers in existing studies indicating that clients' legislation, influence and motivation are crucial to implementing PtD in construction. This is understandable as Aghimien *et al.* (2021) have noted that construction clients are critical drivers in adopting innovative concepts, and their buy-in is essential for successfully implementing these ideas. With the South African Government being one of the major clients of the construction industry, ensuring adequate financial incentives, legislations and policies that promote PtD in public project delivery will go a long way in promoting this safety strategy. Manu *et al.* (2021) also noted that for the implementation of safety design concepts to improve, construction clients, educational institutions and design professional bodies must be ready to drive and support this implementation by creating platforms designed to alienate the fear of building designers and overcome their resistance to change. Educational and industry professional bodies can revisit the curriculum of accredited construction-related courses to ensure the inclusion of safety design elements. Likewise, learning approaches promoting hands-on experience among young construction professionals within South African higher education institutions will promote the required training and education. Öney-Yazıcı and Dulaimi (2015) also noted the need for hands-on experience with PtD among construction professionals.

6. Conclusion

The continuous occurrence of site accidents on construction sites has led to a shift from striving to attain safety during the construction phase of projects to a more proactive approach of entrenching safety concepts at the design phase of projects. Owning its ability to eliminate site accidents, injuries, and fatalities right from the early stages of construction projects, PtD has continued to gain traction as a viable method for achieving safety in the construction industry of many countries. In the quest to achieve proactive prevention on construction sites, this study assessed the awareness, use, and challenges facing implementing PtD practices in the South African construction industry. Based on the findings, the study concludes that the level of awareness of PtD among the sample professionals is high. Also, the level of implementation of PtD practices is moderate. The study further concludes that the most used PtD practices are designs that consider the general public's safety, eliminate working in confined spaces, use overhead cables and heights, undertake a safety risk assessment, and specify fewer maintenance materials.

Similarly, there is a need to improve the use of other practices such as ensuring ease of construction, designing structures to avoid risk from buried services, specifying non-hazardous materials, providing clear safety notes in designs, and considering offsite prefabrication of elements. These practices have received less attention. Overall, all the fourteen assessed PtD practices were deemed highly significant to attaining a safe construction environment in South Africa. Therefore, construction stakeholders seeking proactive prevention of site accidents and unsafe activities must consider these practices at the design stage. Finally, the study concludes that the implementation of PtD within the South African construction industry is challenged by the poor safety culture of the construction industry, budget constraints to implement safety practices, lack of PtD education and training, absence of supporting policies and standards, deficiency in designers' skills and understanding of PtD, overdependence on subcontracting in project delivery, and resistance to change among design professionals.

Based on the aforementioned conclusion, the study recommends that in order to improve the level of usage of PtD within the South African built environment, a concerted effort is needed among all parties to the delivery of construction projects. Moreover, professional bodies such as the South African Council for the Architectural Profession, the Engineering

Council of South Africa, the South African Council for Project and Construction Management Profession, the Construction Industry Development Board, as well as the Council for Built Environment must create regulations that promote PtD among their members and also provide means of enforcing the adoption of these regulations. Although significant awareness exists, it is important for these professional bodies and other stakeholders to continuously promote the understanding of PtD among construction professionals. This understanding can be improved through workshops, seminars and conferences.

Practically, the study's findings offer viable direction for the use of PtD to deliver safe construction projects. By implementing these practices, the South African construction industry can improve its risk management capabilities while improving its reputation for poor safety delivery. More so, through strategically integrating the identified PtD practices in the design phase of construction projects in South Africa, safety risks can be mitigated, and a culture of accident prevention can be achieved. Theoretically, the study also provides a foundation for future studies in South Africa seeking to explore proactive prevention of accidents in construction projects through PtD - an aspect that has gained less attention in the South African construction safety discourse.

Despite these contributions, the findings of these studies are limited by several factors. Firstly, the study adopted an exploratory approach using a quantitative research design due to the absence of existing studies in the South African context. Future studies can adopt a qualitative or mixed-method approach to get different perspectives. More so, the study draws its conclusions from the responses of 67 selected professionals who are actively involved in the design and construction of projects in Gauteng, South Africa. While this sample was adequate for the selected data analysis, there is the possibility of having a different perspective if more professionals from other provinces participated in the study. As such, further studies can be conducted using a larger sample drawn from other provinces to generalize the results for the entire country.

References

Abas, N.H., Abd Rahman, R., Mohammad, H. and Rahmat, M.H. (2020), "Designer's confidence and attitude towards designing-for-construction-safety (DfCS) implementation", *IOP Conference Series: Materials Science and Engineering*, Vol. 713 No. 1, doi: doi: 10.1088/1757-899X/713/1/012045.

Abueisheh, Q., Manu, P., Mahamadu, A.M. and Cheung, C. (2020), "Design for safety implementation among design professionals in construction: the context of Palestine", *Safety Science*, Vol. 128, pp. 1-14, doi: 10.1016/j.ssci.2020.104742.

Acheampong, A., Adjei, E.K., Atibila, D.W., Adade-Boateng, A.O., Kissi, E. and Manu, P. (2024), "Exploring the multidimensional challenges in integrating design for safety (DfS) in the Ghanaian construction industry", *Journal of Engineering, Design and Technology*. doi: 10.1108/JEDT-11-2023-0481.

Aghimien, D.O., Oke, A.E., Aigbavboa, C.O. and Ontlametse, K. (2018), "Factors contributing to disabling injuries and fatalities in the South African construction industry", *Joint CIB W099 and TG59 International Safety, Health, and People in Construction Conference held in Salvador, in Brazil in 1st -3rd of August 2018*, pp. 337-345.

Aghimien, D.O., Aigbavboa, C.O., Oke, A.E. and Thwala, W.D. (2021), *Construction Digitalisation – A Capability Maturity Model for Construction Organisations*, 1st ed., Routledge, New York.

Agumba, J.N. and Musonda, I. (2019), *Occupational Accidents Predicting Early Retirement of Construction Workers in South Africa*, 1st ed., Routledge Publisher, Abingdon.

Allen, A. (2024), "Four workers die in South Africa construction site collapse", available at: https://www.healthandsafetyinternational.com/article/1873668/four-workers-die-south-africa-construction-site-collapse (accessed 3 June 2024).

Bagozzi, R.P. and Yi, Y. (2012), "Specification, evaluation, and interpretation of structural equation models", *Journal of the Academy of Marketing Science*, Vol. 40 No. 1, pp. 8-34, doi: 10.1007/s11747-011-0278-x.

Behm, M. (2005), “Linking construction fatalities to the design for construction safety concept”, *Safety Science*, Vol. 43 No. 8, pp. 589-611, doi: 10.1016/j.ssci.2005.04.002.

Bray, C. (2023), “How to create a positive safety culture in the construction industry?”, available at: https://www.notifytechnology.com/how-to-create-a-positive-safety-culture-in-the-construction-industry/#:~:text=It%20also%20involves%20capturing%20and,it%20as%20a%20shared%20journey (accessed 3 June 2024).

Chan, D.W.M. and Aghimien, D.O. (2022), “Safe working cycle: is it a Panacea to combat construction site safety accidents in Hong Kong?”, *Sustainability*, Vol. 14 No. 2, pp. 1-17, doi: 10.3390/su14020894.

Che Ibrahim, C.K.I., Belayutham, S., Awuzie, B.O. and Oke, A.E. (2022), “Analysis of designers’ prevention through design (PtD) competence in the construction industry: a study of Malaysia, Nigeria, and South Africa”, *Safety Science*, Vol. 150, pp. 1-17, doi: 10.1016/j.ssci.2022.105710.

Chellappa, V. and Gunasekaran, A.L. (2022), “Drivers for implementing design for safety in construction: a review”, *Proceedings – Institution of Civil Engineers: Management, Procurement and Law*, Vol. 177 No. 1, pp. 39-49, doi: 10.1680/jmapl.22.00029.

Christermaller, F., Che Ibrahim, C.K.I., Manu, P., Belayutham, S., Mahamadu, A.-M. and Yunusa-Kaltungo, A. (2022), “Implementation of design for safety (DfS) in construction in developing countries: a study of designers in Malaysia”, *Construction Economics and Building*, Vol. 22 No. 2, pp. 1-26, doi: 10.5130/AJCEB.v22i2.8105.

Construction Industry Development Board (2020), “Construction monitor –transformation, Q4”, available at: http://www.cidb.org.za/publications/Documents/Construction%20Monitor,%20Transformation%202020.pdf (accessed 22 December 2020).

Department of Trade, Industry and Competition (2023), “Construction industry plays critical role in creating an enabling environment in South Africa”, available at: http://www.thedtic.gov.za/construction-industry-plays-critical-role-in-creating-an-enabling-environment-in-south-africa/ (accessed 15 June 2024).

Doloi, H., Iyer, K.C. and Sawhney, A. (2011), “Structural equation model for assessing impacts of contractor’s performance on project success”, *International Journal of Project Management*, Vol. 29 No. 6, pp. 687-695, doi: 10.1016/j.ijproman.2010.05.007.

Dong, S., Zhang, S., Li, H. and Wu, C. (2017), “Integration of safety design and construction planning for building construction”, *Journal of Construction Engineering and Management*, Vol. 143 No. 12, 04017102, doi: 10.1061/(ASCE)CO.1943-7862.0001397.

Federated Employers Mutual Assurance Company (2022), “FEM registers alarming number of injuries in local construction industry”, available at: https://www.fem.co.za/fem-2022-construction-industry-workplace-accident-statistics/ (accessed 3 May 2024).

Gibb, A., Haslam, R., Gyi, D., Hide, S. and Duff, R. (2006), “What causes accidents?”, in *Proceedings of the Institution of Civil Engineers– Civil Engineering*, Thomas Telford, pp. 46-50, doi: 10.1680/cien.2006.159.6.46.

Goldswain, C.C. and Smallwood, J.J. (2015), “Toward improved construction health, safety, and ergonomics in South Africa: a working model for use by architectural designers”, *Acta Structilia*, Vol. 22 No. 1, pp. 1-32.

Guo, B.H.W., Weston, R., Jianphinitnan, P., Liu, W., Scheepbouwer, E., van der Walt, D. and Goh, Y. M. (2021), “A regulatory perspective on safety in design practices in New Zealand”, *Safety Science*, Vol. 141, pp. 1-12, doi: 10.1016/j.ssci.2021.105352.

Hair, J.F., Risher, J.J., Sarstedt, M. and Ringle, C.M. (2019), “When to use and how to report the results of PLS-SEM”, *European Business Review*, Vol. 31 No. 1, pp. 2-24, doi: 10.1108/EBR-11-2018-0203.

Haslam, R.A., Hide, S.A., Gibb, A.G.F., Giyi, D.E., Pavitt, T., Atkinson, S. and Duff, A.R. (2005), “Contributing factors in construction accidents”, *Applied Ergonomics*, Vol. 36 No. 4, pp. 401-415, doi: 10.1016/j.apergo.2004.12.002.

Hassanain, M.A., Al-Harogi, M. and Sanni-Anibire, M.O. (2022), “Design for safety in the construction industry: a study of architecture and engineering firms in Saudi Arabia”, *Facilities*, Vol. 40 Nos 13/14, pp. 895-911, doi: 10.1108/F-04-2022-0056.

Health and Safety Authority (2023), "Designing for safety", available at: https://www.hsa.ie/eng/your_industry/construction/designing_for_safety/ (accessed 15 June 2024).

Hu, L.T. and Bentler, P.M. (1999), "Cut-off criteria for fit indexes in covariance structure analysis: conventional criteria versus new alternatives", *Structural Equation Modeling: A Multidisciplinary Journal*, Vol. 6 No. 1, pp. 1-55, doi: 10.1080/10705519909540118.

Hulland, J. (1999), "Use of partial least squares (PLS) in strategic management research: a review of four recent studies", *Strategic Management Journal*, Vol. 20 No. 2, pp. 195-204, doi: 10.1002/(SICI)1097-0266(199902)20:2<195::AID-SMJ13>3.0.CO;2-7.

Ibrahim, K., Simpeh, F. and Adebowale, O.J. (2025), "Benefits and challenges of wearable safety devices in the construction sector", *Smart and Sustainable Built Environment*, Vol. 14 No. 1, pp. 50-71, doi: 10.1108/SASBE-12-2022-0266.

Ikuabe, M., Aghimien, D., Aigbavboa, C., Oke, A. and Thwala, W. (2021), "Site accidents in the South African construction industry: cleaning the augean stables", in Kantola, J.I., Nazir, S. and Salminen, V. (Eds), *Advances in Human Factors, Business Management and Leadership. AHFE 2021. Lecture Notes in Networks and Systems*, Springer, Cham, Vol. 267, pp. 92-99, doi: 10.1007/978-3-030-80876-1_14.

Lorent, P. (1987), "Les conditions de travail dans l'industrie de la construction Productivité, conditions de travail, qualité concertée et totale", Comité National d'Action pour la Sécurité et l'Hygiène dans la Construction, Brussels.

Machfudiyanto, R.A., Kim, S., Latief, Y., Rachmawati, T.S.N. and Laksono, N.B. (2023), "Analysis of design-for-safety implementation factors in the Indonesian construction industry: a two-staged SEM-artificial neural network approach", *Heliyon*, Vol. 9 No. 11, pp. 1-15, doi: 10.1016/j.heliyon.2023.e21273.

Manu, P., Poghosyan, A., Mshelia, I.M., Iwo, S.T., Mahamadu, A. and Dziekonski, K. (2019), "Design for occupational safety and health of workers in construction in developing countries: a study of architects in Nigeria", *International Journal of Occupational Safety and Ergonomics*, Vol. 25 No. 1, pp. 99-109, doi: 10.1080/10803548.2018.1485992.

Manu, P., Poghosyan, A., Agyei, G., Mahamadu, A.M. and Dziekonski, K. (2021), "Design for safety in construction in sub-Saharan Africa: a study of architects in Ghana", *International Journal of Construction Management*, Vol. 21 No. 4, pp. 382-394, doi: 10.1080/15623599.2018.1541704.

National Institute for Occupational Safety and Health (2023), "Prevention through design program", available at: https://www.cdc.gov/niosh/programs/ptdesign/default.html#:~:text=The%20Prevention%20through%20Design%20(PtD,effective%20way%20to%20protect%20workers (accessed 3 May 2024).

Ngwenya, L.M. and Aigbavboa, C. (2017), "Improvement of productivity and employee performance through an efficient human resource management practice", in Kantola, J., Barath, T., Nazir, S. and Andre, T. (Eds), *Advances in Human Factors, Business Management, Training and Education. Advances in Intelligent Systems and Computing*, Springer, Cham, Vol. 498, pp. 727-737, doi: 10.1007/978-3-319-42070-7_67.

Oke, A.E. and Ogunsemi, D.R. (2016), "Structural equation modelling of construction bond administration", *Journal of Financial Management of Property and Construction*, Vol. 21 No. 3, pp. 192-211, doi: 10.1108/JFMPC-02-2016-0008.

Öney-Yazıcı, E. and Dulaimi, M.F. (2015), "Understanding designing for construction safety: the interaction between confidence and attitude of designers and safety culture", *Architectural Engineering and Design Management*, Vol. 11 No. 5, pp. 325-337, doi: 10.1080/17452007.2014.895697.

Pallant, J. (2020), *SPSS Survival Manual. A Step-by-step Guide to Data Analysis Using IBM SPSS*, McGraw-Hill Education, London.

Phan, P.T.C. and Zhou, Z. (2023), "Implementation of design for construction safety (DfS) in the Vietnam context: awareness, attitude and practices", *Journal of Engineering, Design and Technology*, Vol. 22 No. 6, pp. 1958-1979, doi: 10.1108/JEDT-11-2022-0558.

Poghosyan, A., Manu, P., Mahdjoubi, L., Gibb, A.G.F., Behm, M. and Mahamadu, A.M. (2018), "Design for safety implementation factors: a literature review", *Journal of Engineering, Design and Technology*, Vol. 16 No. 5, pp. 783-797, doi: 10.1108/JEDT-09-2017-0088.

Pu, W., Raman, A.A.A., Hamid, M.D., Gao, X. and Buthiyappan, A. (2023), "Inherent safety concept based proactive risk reduction strategies: a review", *Journal of Loss Prevention in the Process Industries*, Vol. 84, pp. 1-21, doi: 10.1016/j.jlp.2023.105133.

Schulte, P.A., Rinehart, R., Okun, A., Geraci, C.L. and Heidel, D.S. (2008), "National prevention through design (PtD) initiative", *Journal of Safety Research*, Vol. 39 No. 2, pp. 115-121, doi: 10.1016/j.jsr.2008.02.021.

Sharar, M., Agyekum, K., Manu, P., Che Ibrahim, C.K.I., Mahamadu, A.-M., Antwi-Afari, M.F. and Danso, F.O. (2022), "Design for safety in construction: a study of design professionals in Kuwait", *International Journal of Building Pathology and Adaptation*, Vol. 42 No. 4, pp. 596-617, doi: 10.1108/IJBPA-01-2022-0015.

Singh, R. (2009), "Does my structural model represent the real phenomenon? A review of the appropriate use of structural equation modelling model fit indices", *The Marketing Review*, Vol. 9 No. 3, pp. 199-212, doi: 10.1362/146934709X467767.

Smallwood, J.J. (2004), "Optimum cost: the role of health and safety", in Verster, J.J.P. (Ed.), *International Cost Engineering Council 4th World Congress*, Cape Town, 17-21 April.

Smallwood, J. and Deacon, C. (2020), "Occupational health (OH) practices in South African construction", *MATEC Web of Conferences*, Vol. 312, pp. 1-9, doi: 10.1051/matecconf/202031203003.

Soh, J., Jeong, J. and Jeong, J. (2020), "Improvements of design for safety in construction through multi-participants perception analysis", *Applied Sciences*, Vol. 10 No. 13, pp. 1-22, doi: 10.3390/app10134550.

Szymberski, R. (1997), "Construction project safety planning", *Tappi Journal*, Vol. 80 No. 11, pp. 69-74.

Tan, W.C.K. (2011), *Practical Research Methods*, Pearson Custom, Singapore.

Tealio (2024), "Construction regulations and annexure 3 in South Africa", available at: https://tealio.ai/blog/construction-regulations-and-annexure-3-in-south-africa (accessed 15 June 2024).

Tymvios, N., Hardison, D., Behm, M., Hallowell, M. and Gambatese, J. (2020), "Revisiting Lorent and Szymberski: evaluating how research in prevention through design is interpreted and cited", *Safety Science*, Vol. 131, pp. 1-9, doi: 10.1016/j.ssci.2020.104927.

Umeokafor, N., Okoro, C., Diugwu, I. and Umar, T. (2023), "Design for safety in construction in Nigeria: a qualitative inquiry of the critical opportunities", *International Journal of Building Pathology and Adaptation*, Vol. 41 No. 2, pp. 476-494, doi: 10.1108/IJBPA-05-2021-0066.

Wang, X., Zhang, L.J. and Liu, X.Y. (2013), "Strategies for inherent safety design during engineering construction", *Applied Mechanics and Materials*, Vols 357-360, pp. 2510-2514, doi: 10.4028/www.scientific.net/AMM.357-360.2510.

Zingoni, T. (2020), *Deconstructing South Africa's Construction Industry Performance*, Mail and Guardian, available at: https://mg.co.za/opinion/2020-10-19-deconstructingsouth-africas-construction-industry-performance/#:~:text=The%20South%20African%20construction%20sector,for%20construction%20in%20the%20country (accessed 15 June 2024).

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