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Determining the significant contributing factors to the occurrence of human errors in the urban construction projects: A Delphi-SWARA study approach

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ABSTRACT

The construction industry is believed to be more susceptible to human errors than other industries because of its unique characteristics, particularly when it comes to urban construction projects (UCP). Despite the considerable attention given to human errors in construction sector, there has been a lack of emphasis on analysing these errors in specific projects like construction in urban environments with distinct complexities. Hence, this paper seeks to determine and assess the critical factors influencing human errors associated with the UCP. In this vein, Three rounds of Delphi surveys were done with 17 specialists in safety and construction management. According to the Delphi survey results, 35 substantial factors that contribute to the incidence of human errors in the UCP were discovered. Then, an empirical questionnaire based on the 5-point Likert scale of measurement was developed and distributed among 37 construction experts to assess the level of impact that each factor on occurring human error in the UCP. The questionnaire had 35 influential factors related to human errors, categorised into five primary divisions (environmental, technological/information systems, individual (permanently related), individual (temporarily related), and organisational). Before the distribution, the reliability and validity of the questionnaire were evaluated and confirmed. The factors were ranked using the Step-wise Weight Assessment Ratio Analysis (SWARA) technique at this point. The research findings indicated that the criterion of "technological factors/information systems" is the most crucial, with the criterion of "individual factors (permanently related)" coming in second and the criterion of "environmental factors" coming in third. The sub-criterion "weak maintenance management systems" scores first in the general ranking of sub-criteria, indicating traditional network systems, the absence of appropriate tools and equipment, and a lack of understanding of required resources. The sub-criterion "defects in details and information and lack of design dynamism" is placed second, while the sub-criterion "violation of safety regulations (use of drugs, etc.)" is ranked third. The study results can help industry practitioners make more educated judgements to minimise and manage human errors in the UCP.

1. Introduction

Empirical data indicates that human resources are crucial for the success of any construction project, but they often receive less attention than materials and machines due to their lower prices (Sarvari et al., 2021a). Studying how the changed work environment affects flexible workforces involves exploring methods to influence human behaviour based on their understanding and experience with the system and its characteristics (Lowe, 2008). When faced with a novel system, setting, or complex machine, every human displays a set of attributes and

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characteristics known as human factors. When encountering novel situations devoid of applicable past experiences or established guidelines, individuals must engage in heightened cognitive effort, information analysis, solution identification, and technique selection. Crowl (2007) asserts that in this cognitive process, theoretical hypotheses about the conditions should be formulated and then compared with the desired outcome through a process of trial and error.

Researchers have discovered that hidden costs can influence the ultimate project cost, in addition to the primary project expenditures that have direct effects. Accidents caused by human errors throughout work processes contribute significantly to hidden costs. Neglecting these errors and mishandling human errors might jeopardise project performance in the long term (Kyriakidis et al., 2019). Workers in industrial settings frequently encounter a range of hazards and accidents due to the many machineries and tools present. The utilisation of technology and machines in manufacturing leads to a higher likelihood of dangers and accidents in these contexts (Zhang et al., 2019). Construction projects encounter various risks during the project life cycle, particularly in the construction phase, such as staff not following safety guidelines, machinery hazards, geographical location, and workload (Chan et al., 2021). Human errors can occur at all levels of an organization, whether managerial, conceptual, or technological, according to Porathe et al. (2018). Construction project faults can stem from a variety of sources such as investors, consumers, and suppliers. Various factors such as education level, work experience, stress, exhaustion, workplace ergonomics, hours worked, and social environment can influence and potentially distort individual judgements. An error is comprised of a sequence of events, such as causes, human error, shortcomings, outcomes, and other factors (Aydin et al., 2021).

Construction workers may experience human errors in high-pressure situations. Khaleghi et al. (2022) found that over 80 % of accidents are attributed to human errors. The financial burden resulting from health, safety, and environmental risks in sectors like construction can be substantial for corporations (Martin et al., 2019). Identifying human errors in every phase of project building is crucial for the success of the project and the organization's sustainability (Tripathi and Jha, 2018). Accidents of any kind and severity bring up various economic, social, and health issues for society. Preventive actions are necessary to avoid repeat accidents by learning from past experiences and lessons, as the consequences can extend beyond the project's scope. (Holen et al., 2019). Research suggests that an effective way to prevent and decrease human errors is by utilising techniques to predict and identify potential errors, analyse the underlying causes, and implement suitable control solutions (Akyuz et al., 2016). Recently, there have been numerous endeavours to pinpoint the causes of accidents in different industries. Most accidents are considered to be caused by human mistake resulting from negligence or incompetence in performing jobs. Researchers studying accidents have discovered that it is feasible to avert accidents by pinpointing their causes (Rolison et al., 2018).

Urbanisation and the growing need for welfare and secure living environments have led to an increased demand for housing and construction projects over the last twenty years (Sarvari et al., 2021a). Urban development success is closely linked to the successful completion of essential projects and infrastructure, emphasising the need for increased reliability in projects that frequently encounter crises. Uncertainty has a substantial impact on the project environment, especially for large projects. Establishing and monitoring safety is crucial for initiating, carrying out, completing, and running projects throughout their life cycle. Despite the significant impact of this aspect on the project's success, it receives less attention, particularly in developing nations, because of many cultural, social, economic, and technical influences. This lack of attention can lead to various mishaps and significant human and financial losses (Boussabaine and Kirkham, 2008). Urban projects are subject to uncertainty because of their unique circumstances. Identifying human errors in urban project development can greatly decrease expenses resulting from subpar building quality (Gilchrist and Allouche, 2005). This study seeks to determine and evaluate the factors influencing human errors in urban construction projects (UCP) in the developing country of Iran, to enhance the success rate of these projects by better understanding and effective management of essential factors by decision-makers. Therefore, an extensive literature review was done to identified influential factors contributing to human errors. This was followed by three rounds of the Delphi technique that were used to identify factors, which were then analysed by the Step-wise Weight Assessment Ratio Analysis (SWARA) technique. The study results can serve as a decision-making tool for important stakeholders in UCP.

2. Research background

Incidents like Bhopal-India demonstrate that even with technological advancements, automation in various industries, and decreased human involvement in the workplace, human error can still result in significant human and financial catastrophes (Meshkati, 1991; Gupta, 2002; Labib and Champaneri, 2012; Chan et al., 2022). It is because human responsibilities in the workplace lead to a rise in the psychological burden and complexity of work, increasing the chances of errors. Additionally, as the level of responsibility grows, the impact of human errors also escalates (Liu et al., 2004). Human error is a significant component of human factors, as individuals often make mistakes while interacting with a system or a machine (Ramiro and Aisa, 2012). Human decisions and behaviour determine the system's trajectory. Errors stem from causes like lack of awareness, limited human skills, improper attitude, inappropriate processes, instruments, and working environment conditions (Volk et al., 2014).

An error is an unintended failure to complete an intended action, whether independently or as part of a sequence of planned actions, to achieve the expected result within the permissible parameters of the activity or its result (Whittingham, 2004). Errors can be viewed as a sequence of events involving causes, human mistakes, flaws, outcomes, and so forth. Many corrective activities in these systems consist of recurring cycles, indicating that multiple human errors and flaws occur prior to detection (Rafieyan et al., 2022). Kohn et al. (2000) defines human mistake as every instance where the intended sequence of mental or physical actions fails to produce the desired outcome, and these failures are not due to random occurrences. An error might arise from inaccurate planning or implementation, as per this definition. Crowl (2007) defined an error as an unauthorised activity that occurs when the system's set performance limits are exceeded. Errors are inadvertent activities such as slips, carelessness, and mistakes. Violations are categorised as a collection of deliberate actions (Shanmugam and Robert, 2015). Boal and Meckler (2010) state that errors and misconduct can occur in all operational areas, leading to negative impacts on individual or group performance. OSHA suggests that doing a thorough occupational safety analysis can help prevent numerous injuries and illnesses. This analysis includes determining administrative and technical control mechanisms, training needs, and detailed instructions for each task. It is recommended to apply this method in all industries and at any point in the system's life (Bentley et al., 2005). In the last two decades, urbanisation in emerging nations has surged, leading to a higher demand for urban housing and infrastructure. This has resulted in an increase in accidents in the construction sector. Multiple experts have investigated this matter to determine the cause. Gürcanlı et al. (2015) found a positive correlation between the increase in the number of building projects and the rise in worker fatalities in Turkey. Project hazards and accidents were decreased when staff and workers were more informed about the project's status. People who got safety training also had a lower risk. They also emphasised that training, tools, and working circumstances were crucial elements. Kumar et al. (2016) demonstrated the significance of human factors in causing accidents on construction sites in a separate study. Technology, automation, mechanisation, and improved safety measures are key factors that enhance productivity in construction projects. Hameed et al. (2016) developed a method to determine the optimal interval for maintenance and shutdown of machinery by assessing the risk associated with human factors. Their proposed approach consisted of three steps: selecting equipment based on its sensitivity to operational problems, simulating system failures considering human error, and conducting inspections to minimise errors due to human intervention by reducing maintenance period.

Rafieyan et al. (2022, 2024) conducted a study to identify key elements contributing to accidents in Industrial Parks Construction Projects (IPCPs) in Iran resulting from human error. 41 reasons for errors in implementing IPCPs were identified and categorised into nine primary types through the Delphi survey results. The study revealed that specific factors significantly influence the frequency of building accidents resulting from human errors. Rafiyan et al. (2022) conducted a study to identify and evaluate the significant elements contributing to accidents on industrial park building projects (IPCPs) resulting from human error. The study identified time, delayed interpretation, and incorrect diagnosis or prognosis as the top three critical human errors occurring during IPCPs in Iran. This research study has provided project stakeholders with a valuable tool to improve decision-making about accident management and prevention on construction sites, particularly those resulting from errors by individuals with IPCPs. Chan et al. (2022) aim to identify the primary causes of errors in the construction industry. The statistics indicate that all parameters examined are above average and can be identified as significant contributors to construction site accidents resulting from human errors. Five crucial issues are inappropriate work and safety culture, inadequate technology for equipment and safety protection, violation of safety standards, working at a fast pace, and a deficient education system inside the firm. The study results can assist individuals in large corporations and safety managers on construction sites in making more informed decisions.

Construction research institutes have conducted thorough investigations into the origins of building and construction faults (Kletz, 2018; Chen et al., 2019). In Bentley's (1981) study, 27 construction projects were analysed to determine the causes of construction defects, which were classified into 7 categories: lack of skill, maintenance failure, executive workshop knowledge and awareness deficiency, poor design quality, structural complexity and difficulty, project information, project weakness and ambiguity, and certain aspects of project/design information. Investigations found that insufficient and confusing project information was the primary cause of the shortcomings. Scientific investigations suggest that human errors play a dominating and major part in causing various structural abnormalities. These inaccuracies may result in job duplication, increased costs, schedule delays, and environmental uncertainty, impacting project performance. Design flaws pose a hazard to the success of building projects, primarily originating from human error (Love and Sohal, 2003).

Several studies have established a clear correlation between safety climate and safety performance in building construction projects (Barbaranelli et al., 2015). Studies indicate that people who feel insecure at work are less motivated to follow safety requirements, resulting in increased levels of human error, injuries, and losses (Zou and Sunindijo, 2013). Griffin and Neal (2000) state that safety researchers are focused on identifying mediators in safety research investigations. Prior research has recognised personal traits, viewpoints, and organisational factors as mediators. Upon reviewing the literature, numerous studies have been conducted to pinpoint the factors contributing to accidents in construction projects. Various factors have been found and categorised, with one category specifically focusing on human-related issues. These characteristics can vary across different contexts and initiatives, leading to diverse impacts. There has been a lot of previous research on human error in many other kinds of projects, such as power plant construction, industrial, road, and dam development. Nevertheless, urban construction projects and other types of projects have not been as widely acknowledged. This research seeks to determine and emaluate the influential factors contributing to human errors in the UCP to address the existing research gap.

3. Research methodology

This study aims to identify and analyse the factors that influence human errors in UCP. To do it, an extensive analysis of existing literature was carried out. Three rounds of the Delphi technique were employed to monitor the significant factors outlined in the literature. Seventeen experts in the area rated the existence of known human error factors in three rounds of the Delphi technique using a 5-point Likert scale, focusing on the construction industry in Iran. Only factors with a significance level of 3 or above were considered at this point. Fink et al. (1984) developed this strategy to facilitate consensus among group members on decisions on additions or removals. There are no strict guidelines for selecting Delphi panel experts, but the expertise of the experts is more crucial than their quantity (Khosravi et al., 2020). The individuals on the Delphi panel are knowledgeable professionals and evaluators within the same sector, possess strong communication abilities, and are available to engage in the research (Lee et al., 2018). Sarvari et al. (2021b) state that the typical number of specialists falls within the range of 10 to 20. The required number of specialists is contingent upon factors such as the complexity level, decision quality, team abilities, data collection duration, and accessible resources. Experts were provided with a questionnaire that utilised a 5-point Likert scale. The Delphi group participants in this study were selected using purposive sampling. Sarvari et al. (2020) employed this strategy for comparable research inquiries. The questionnaire was given to 37 individuals in the target population to evaluate the accuracy, consistency, quality, and suitability of the created model about accidents caused by human errors in the urban construction sector. 37 individuals' perspectives were assessed by confirmatory factor analysis. The SWARA technique was applied to prioritise the identified factors in the last phase. Table 1 displays the demographic characteristics of 17 experts involved in the Delphi survey rounds and 37 persons assessed during the confirmatory factor analysis stage to verify model adequacy and rank the found components. Fig. 1 depicts the research procedure of the project.

Table 1
Demographics of survey participants and Delphi experts.

Characteristic	Code	Number (%)	
		Survey participants (n = 37)	Dephi Rounds (n = 17)
Educational level	Bachelor's degree	15 (40.54)	4 (23.5)
	Master's degree	16 (43.24)	11 (64.7)
	PhD degree	6 (16.22)	2 (11.8)
Experience in urban construction projects	<10 years	10 (27.03)	4 (23.5)
	10–20 years	22 (59.46)	9 (53.0)
	>20 years	5 (13.51)	4 (23.5)
Tenure in safety management	<10 years	16 (43.24)	9 (53.0)
	10–20 years	14 (37.83)	6 (35.3)
	>20 years	7 (18.92)	2 (11.7)
Role	Client	7 (18.91)	2 (11.7)
	Consultant	21 (56.76)	10 (58.8)
	Contractor	9 (24.33)	5 (29.5)
Career position	Architect	3 (8.19)	1 (5.95)
	Engineer – Civil, Electrical and Mechanical	5 (13.5)	3 (17.6)
	Safety Manager	8 (21.6)	4 (23.5)
	General Manager – Procurement and Contracts	5 (13.5)	3 (17.6)
	Project Manager	5 (13.5)	2 (11.8)
	Senior Project Manager	7 (18.9)	3 (17.6)
	University Professor	4 (10.81)	1 (5.95)

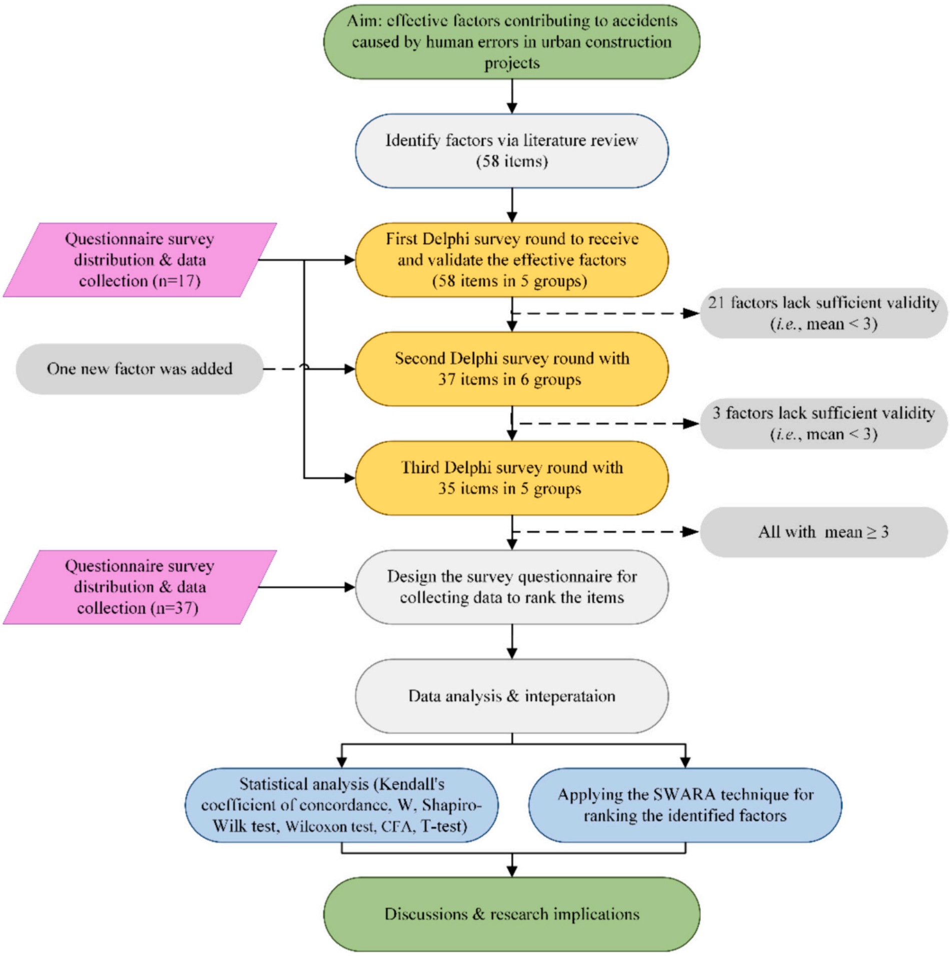

Fig. 1. Overall research design for the study.

3.1. Delphi survey method

The Delphi survey approach was utilised to monitor and evaluate the factors identified in the study literature. The questionnaire for the initial Delphi round was created using information from previous studies and initial surveys conducted by researchers. It included 58 significant factors related to human error occurrence, categorised into five groups: environmental (E), information systems/technological and equipment and machinery (IS/EM), Individual (permanently related) (IP), Individual (temporarily related) (IT), and organisational (O)factors. 17 experts were consulted to assess if the discovered criteria might be accurately deemed as contributing to accidents caused by human error at the UCP in Iran. The Delphi survey study included managers and senior specialists with experience in UCP and as members of project management teams. They possessed ample expertise in safety and risk management. The major criteria for selecting individuals are managers with over 5 years of experience and senior specialists and university lecturers with over 10 years of work experience.

Based on the first round results, 58 factors were either merged, removed, or revised in terms of their expression. The Delphi panel suggested that the IS group is better categorised into two distinct groups. Therefore, in the second phase, an updated questionnaire with 37 items categorised into six groups, was distributed to the Delphi panels, resulting in the incorporation or removal of some factors. The review of the second round indicated that all items related to the suggested group by the panel (i.e., equipment and machinery) were eliminated due to the mean below 3. In this round, before evaluating the data, it was recommended to reclassify the factor of operational barriers resulting from construction machines as part of the E group. Thus, despite receiving a score of <3, the item was attributed to the E group; it might be because of the unsuitability of the selected group for the item. Furthermore, a new it (i.e., Poor maintenance management systems (traditional net systems, lack of necessary tools and equipment, and lack of knowledge of required resources)) was proposed to be included in the IS group. Additionally, some modifications were required for grammar and writing in this round. With the completion of the second round, an updated questionnaire with 35 factors divided into 5 groups was presented to the Delphi panel members in the third round. In this round, the Delphi panel members determined that all 35 items and 5 groups were influential in causing accidents due to human error in the UCP (Table 2). The questionnaire's face validity was evaluated using feedback from certain participants. Three rounds of Delphi were conducted with 17 experts to assess the content validity using Lawshe content validity, and Kendall's coefficient of concordance (Onwuegbuzie and Combs, 2010). Schmidt (1997) states that Kendall's coefficient of concordance indicates that individuals who rank many categories based on their importance tend to employ comparable criteria to assess the importance of each category and reach a consensus on this. The Cronbach's alpha coefficient was calculated using SPSS software to assess the reliability of the survey. The questionnaire demonstrated high reliability, with an overall dependability score of 0.978.

During Delphi surveys, participants with different backgrounds, expertise, and interpretations of the questions may provide different responses. In this study, to reduce subjectivity and prejudice, clear criteria and definitions for the factors were set. It helped standardised responses and minimised individual interpretations. Furthermore, the

Table 2
The findings from the third round of the Delphi survey were used to monitor and evaluate the factors indicated in the study literature.

Code	Group	Effective factors contributing to the occurrence of human errors in the UCP	Mean	Result	Sources
E1	Environmental (E)	Poor ergonomics and geometry of the project workplace	3.47	✓	Falck and Rosenqvist (2012); Chan et al. (2022)
E2		Adverse environmental conditions (dust, horizontal visibility, noise, odor, ambient temperature, altitude, weather, snow)	3.58	✓	Needham et al. (2006); Chan et al. (2022)
E3		Social pressures	3.23	✓	Klein (2018); Chan et al. (2022)
E4		Accessibility problems (improper workplace arrangement, etc.)	3.41	✓	Knight and Oswal (2018); Chan et al. (2022)
E5		Improper work and safety culture	4.05	✓	Barbaranelli et al. (2015); Chan et al. (2022);
E6		Operational barriers because of construction machinery	3.47	✓	Volk et al. (2014); Rafieyan et al. (2024)
IS1	Information systems/ Technological (IS)	The complexity of work activities due to new technologies (for example, performance diversity, high information volume, etc.)	3.17	✓	Soualhi et al. (2020); Rafieyan et al. (2024)
IS2		Defects in details and information and lack of design dynamics	3.41	✓	Deacon (2008); Chan et al. (2022)
IS3		Errors in instructions (incorrect information, incomplete information, insufficient requirements, etc.)	3.58	✓	Love and Sohal (2003); Rafieyan et al. (2024)
IS4		Software defects	3.35	✓	Needham et al. (2006); Chan et al. (2022)
IS5		Excessive trust in technology	3.17	✓	Needham et al. (2006); Chan et al. (2022)
IS6		Unfamiliarity with new technologies (difference between the operator and designer mindset)	3.29	✓	Ramiro and Aisa (2012); Chan et al. (2022)
IS7		Poor information management (information collection, identification, and evaluation).	3.35	✓	Dong et al. (2019); Rafieyan et al. (2024)
IS8		Poor maintenance management systems (traditional net systems, lack of necessary tools and equipment, and lack of knowledge of required resources)	3.76	✓	Interview
IP1	Individual (permanently related) (IP)	Individual-job physical and mental incompatibility	3.52	✓	Storey (1994); Rafieyan et al. (2024)
IP2		Violation of safety regulations (drug use, etc.)	4.17	✓	Kumar et al. (2016); Rafieyan et al. (2022)
IP3		Job dissatisfaction	3.52	✓	Atkinson (1998); Morais et al. (2022);
IP4		Job habits and dailyness	3.41	✓	Morais et al. (2022); Rafieyan et al. (2024)
IT1	Individual (temporarily related) (IT)	Physical conditions (fatigue, illness, weight)	3.64	✓	Morais et al. (2022); Rafieyan et al. (2022)
IT2		Poor psychological conditions (stress, repetitive jobs, poor memory, personal life problems, allergies, constant alertness, etc.)	3.94	✓	Morais et al. (2022); Rafieyan et al. (2024)
IT3		Poor awareness and understanding of the situation in error detection	3.94	✓	Volk et al. (2014); Chan et al. (2022)
IT4		Inadequate understanding of information and plan recognition in error detection.	3.64	✓	Love and Sohal (2003); Rafieyan et al. (2022)
IT5		Intentional and unintentional unsafe acts (omission of an act or unfinished activities in the project, etc.)	3.82	✓	Kumar et al. (2016); Rafieyan et al. (2024)
IT6		False beliefs and attitudes towards the effects of error	3.76	✓	Volk et al. (2014); Chan et al. (2022)
IT7		Misunderstanding due to simultaneous working with several software systems and different areas (misunderstanding of some general aspects of system performance)	3.58	✓	Volk et al. (2014); Rafieyan et al. (2022)

(*continued on next page*)

Table 2 (*continued*)

Code	Group	Effective factors contributing to the occurrence of human errors in the UCP	Mean	Result	Sources
IT8		Haste in doing work (due to lack of time or irregular working hours)	4.05	✓	Dong et al. (2019); Chan et al. (2022)
O1	Organisational (O)	Failure to address the error-causing problem	3.64	✓	Klein (2018); Chan et al. (2022)
O2		Failure to manage changes during project implementation	3.41	✓	Volk et al. (2014); Chan et al. (2022)
O3		Lack of a proper communication among project stakeholders	3.29	✓	Klein (2018); Rafieyan et al. (2024)
O4		Unavailability of proper educational system in the organization	4	✓	Morais et al. (2022); Rafieyan et al. (2024)
O5		Failure to accurately predict work risks by the project management department	3.76	✓	Bentley, 1981; Rafieyan et al. (2024)
O6		Poor project planning	3.47	✓	Klein (2018); Chan et al. (2022)
O7		Lack of organization and improper task assignment	3.58	✓	Klein (2018); Rafieyan et al. (2024)
O8		Poor supervisory inspection	3.88	✓	Dong et al. (2019); Chan et al. (2022)
O9		Improper quality control	3.58	✓	Dong et al. (2019); Rafieyan et al. (2024)

careful selection of a varied panel of experts for the survey was another method used to tackle subjectivity and bias in Delphi surveys. By incorporating individuals with diverse viewpoints, histories, and knowledge, the likelihood of bias was minimised, leading to a more thorough and equitable evaluation of the subject matter. The survey process encouraged convergence towards more objective and informed answers by enabling participants to examine and update their responses based on group feedback. The anonymity and confidentiality in Delphi polls reduced social pressures and influence, resulting in more candid and impartial responses.

3.2. *SWARA technique*

The SWARA technique is one of the multi-criteria decision-making methods used to extract the uncertainties in the process of evaluating the linguistic expressions of criteria and options. The main advantage of the SWARA technique based on decision-making problems is that it does not need to be evaluated to solve decision-making problems and set criteria, and it is a scale to find the weight of the priorities of the criteria based on the strategies or plans of the organization (Kebede et al., 2017; Majeed and Breesam, 2021). The basic principles of SWARA and the method of determining the relative weight of the criteria can be explained in detail through the next steps as follows (Mou et al., 2015):

3.2.1. *First step*

The criteria requirements should be sorted according to their importance. At this stage, experts rank the defined criteria according to their importance. For example, the most important criteria are in the first place, the least important are in the last place (Majeed and Breesam, 2021).

3.2.2. *Second step*

determination of scientific criteria (S_j); It evaluates the comparative importance of the average value. Starting from the second-ranked criteria, one must find their importance, that is, how much more important is criterion (C_j) than criterion (C_{j+1}).

$$S_j \leftrightarrow j+1 = \sum_{k=1}^{r} C_j \leftrightarrow j+1 \Big/ r \tag{1}$$

3.2.3. *Third step*

the coefficient (K_j) is calculated as follows:

$$K_j = \begin{cases} 1, & j = 1 \\ S_{j+1}, j > 1 \end{cases} \tag{2}$$

3.2.4. *Fourth step*

Determine the recalculated weight q_j as follows:

$$q_j = \begin{cases} 1, & j = 1 \\ q_j - 1 \Big/ K_j, j > 1 \end{cases} \tag{3}$$

3.2.5. *Fifth step*

The weight values of the criteria are calculated with the sum of one:

$$W_j = q_j \sum_{k=1}^{m} q_j \tag{4}$$

where W_j represents the relative weighted value of the criteria (Majeed and Breesam, 2021).

4. Presentation of survey results

The analysis of this study was performed using SPSS statistical software at two levels of descriptive and inferential statistics. Prior to conducting the confirmatory factor analysis, a randomness test was carried out on the data. The effectiveness of each of the 35 factors was then determined, and the 5 groups (i.e., environmental factors, technological factors/information systems, individual factors (permanent related), individual factors (temporary related), and organisational factors) were analysed using the Wilcoxon test.

4.1. *Analysing statistical data and assessing the normality of data distribution*

The generalisation of sample findings to the broader population relies on the concept of data randomness. Hence, to generalise the results of the data randomness test, the findings are presented in Table 3. The table results indicate that the principle of data randomness is statistically significant ($p < 0.05$) (Arcuri and Briand, 2014).

Table 4 displays the average and standard deviation of 35 discovered factors influencing accidents caused by human errors in the urban construction business, as well as the results of the Wilcoxon test assessing their effectiveness. It is visible. The study found that the average rating of the 5 factors contributing to accidents caused by human errors in the UCP was above the midpoint of the 5-point Likert scale, specifically 3. The p-value of the Wilcoxon test is $<$0.05. The efficiency of the found factor in causing accidents due to human errors has been proven (Schefzik et al., 2023).

The Shapiro-Wilk test was utilised to assess the normality of the data

Table 3
Data randomness test.

Groups	Factors	Test Value	Cases < test value	Cases ≥ test value	Number of runs	Z value	*P* value
E	E1	4	16	21	18	−0.225	0.822
	E2	4	16	21	19	0.000	1.000
	E3	4	10	27	15	−0.040	0.968
	E4	4	10	27	19	1.238	0.216
	E5	4	11	26	16	0.000	1.000
	E6	4	14	23	24	1.809	0.070
IS	IS1	4	13	24	18	0.000	1.000
	IS2	4	18	19	23	1.006	0.315
	IS3	4	12	25	16	−0.274	0.784
	IS4	4	12	25	21	1.254	0.210
	IS5	4	16	21	20	0.115	0.909
	IS6	4	14	23	19	0.034	0.973
	IS7	4	15	22	18	−0.117	0.907
	IS8	4	10	27	15	−0.040	0.968
IP	IP1	4	11	26	14	−0.786	0.432
	IP2	4	14	23	17	−0.321	0.748
	IP3	4	15	22	12	−1.195	0.054
	IP4	4	12	25	17	0.000	1.000
IT	IT1	4	17	20	20	0.041	0.967
	IT2	4	14	23	24	1.809	0.070
	IT3	4	11	26	15	−0.385	0.700
	IT4	3	2	35	5	0.000	1.000
	IT5	4	17	20	19	0.000	1.000
	IT6	3	3	34	7	0.000	1.000
	IT7	4	18	19	20	0.005	0.996
	IT8	4	14	23	17	−0.321	0.748
O	O1	4	14	23	11	−1.952	0.056
	O2	4	12	25	15	−0.656	0.512
	O3	4	11	26	13	−1.188	0.235
	O4	4	14	23	17	−0.321	0.748
	O5	3	3	34	5	−1.219	0.223
	O6	4	13	24	17	−0.134	0.894
	O7	4	16	21	17	−0.565	0.572
	O8	4	10	27	11	−1.744	0.081
	O9	4	9	28	13	−0.513	0.608

distribution in the 5 extracted groups, and the findings are presented in Table 5. Table 5 results indicated that the data from E, IS, and IP groups were not normally distributed ($P < 0.05$), whereas the data from IT and O groups were normally distributed ($P > 0.05$). The reference is from Tian et al., 2023. The non-parametric Wilcoxon method was utilised to assess the impact of the E, IS, and IP groups, while the *t*-test was employed to evaluate the influence of the IT and O groups. The findings are displayed in Table 6. Table 6 shows that the average scores for Groups E, IS, IP, IT, and O are 3.847, 3.740, 3.770, 3.666, and 3.748, respectively. The *P*-Values of the Wilcoxon and *t*-tests are <0.05, indicating that all five groups are significantly associated with human error factors in the UCP.

4.2. Confirmatory factor analysis

Structural equation modelling using the PLS (partial least squares) method was employed to assess the validity of a model identifying key factors contributing to accidents resulting from human errors in the urban construction sector. Fig. 2 depicts the measuring model of influential factors in accidents caused by human errors in the urban construction sector.

Fig. 1 displays a measuring model that pertains to all 5 groups: E, IS, IP, IT, and O. The numbers displayed on the lines are the factor loadings of each latent variable. The measurement model's fit criteria were assessed by examining reliability criteria (Cronbach's alpha, composite reliability), confirmatory validity criteria (factor loading coefficients), convergent validity (AVE coefficient), and divergent validity (Heterotrait-Monotrait (HTMT) Ratio).

When fitting measurement models, the aim is to assess the confirmatory validity of constructs by examining the appropriateness of factor loadings. Factor loadings with standardised estimation values exceeding 0.5 significantly impact the measurement of the respective variable. It has. The factor loading values for all factors in Table 7 are over 0.5, and their T statistic absolute values exceed 1.96, indicating significant impact on the measurement in the model. Saputra and Andajani (2024) are associated with this group. Fig. 3 illustrates the T statistic values of the variables.

The measurement models' reliability was assessed using Cronbach's alpha and composite reliability criteria. Table 7 shows that the Cronbach's alpha coefficient and CR coefficient for all 5 groups above 0.8, indicating high reliability. The constructs are assessed as suitable (Nie et al., 2023). Table 7 shows that the convergent validity coefficient of 5 constructs exceeds 0.5 and their rho_A value is over 0.7, indicating that all 5 constructs in the model are valid in terms of validity (Cáceres-Matos et al., 2023).

The model's capability to predict observable variables based on their corresponding hidden variable values is assessed using the cv com index. A positive index value signifies the adequacy of the structure's quality (Adhiatma and Fachrunnisa, 2021). The model structures have a strong capability to predict visible variables based on their corresponding hidden variable values, as shown in Table 7.

Divergent validity is a crucial requirement for model structures, assessing the link between a structure and its indicators in comparison to its interaction with other structures. The acceptable divergent validity of a model suggests that a construct in the model has stronger relationships with its indicators than with other constructs. Acceptable divergent validity is shown by an HTMT ratio below 0.9, as shown in Table 8. The HTMT ratio indicates that the model constructs have diverging validity (Barati et al., 2024).

The findings from the measurement model fitting section indicate that all criteria met adequate values, confirming the reliability, validity, and quality of the measurement models for the 5 groups. The research instrument demonstrates validity in terms of content, divergent, and convergent aspects, as well as reliability through Cronbach's alpha coefficient, composite reliability, and factorial coefficients, indicating good quality.

Table 9 also displays the evaluation findings of the collinearity and importance of the external weights of the variables. The indices' weights are statistically significant at the 0.001 level, indicating that they explain a substantial percentage of the variance in the endogenous variables. The collinearity test results indicate that the variance inflation factor (VIF) for all 35 components is below 5, demonstrating the absence of collinearity among them (Yang et al., 2024).

Once the measurement models have been validated using the data analysis method in SMART PLS software, the next step is to fit the structural model and assess its criteria. In the structural model portion, just the endogenous hidden variables (groups) are investigated, unlike the measurement model section where the extracted factors are considered. Table 10 displays the R2 and Q2 indices of endogenous variables from 5 groups: environmental influences, technical factors/information systems, individual factors (permanent related), individual factors (temporary related), and organisational factors.

The Q2 criteria, also known as the validity check index or redundancy, was established by Stone and Gears in 1975. It assesses the predictive capability of the model, with a Q2 value over zero for a construct indicating its strength. It accurately predicts the external structure associated with it. The Q2 index for all three variables in the model is greater than zero, indicating a strong predictive link between the exogenous and endogenous structures of the model (Zhu et al., 2023).

The R2 index quantifies the influence of an external variable on an internal variable. The R2 value is computed exclusively for the dependent or endogenous variables in the model, and it is 0 for all other variables. Put simply, R2 indicates the capacity of independent variables to forecast the dependent variable. Chin (1998) defines R2 values of 0.19, 0.33, and 0.67 as thresholds for weak, medium, and strong values

Table 4
The descriptive statistics results and the significance test of the identified factor's impact on accidents caused by human errors.

Groups	Factors	Mean	Standard deviation	Excess Kurtosis	Skewness	Wilcoxon test (test value = 3)			
						Negative ranks	Positive ranks	Z value	P value
E	E1	3.73	0.859	−0.826	0.038	12.38	8.00	−3.857	0.000
	E2	3.73	0.794	−0.798	0.204	11.67	8.00	−4.013	0.000
	E3	3.946	0.868	1.92	−0.925	14.19	23.00	−4.244	0.000
	E4	3.865	0.875	1.887	−0.986	14.80	17.75	−4.114	0.000
	E5	3.946	0.899	1.346	−0.821	13.71	21.50	−4.153	0.000
	E6	3.865	0.905	−0.993	−0.175	13.48	7.50	−4.096	0.000
IS	IS1	3.676	0.988	0.197	−0.69	15.23	13.90	−3.364	0.001
	IS2	3.649	0.992	−0.165	−0.259	11.71	10.17	−3.214	0.001
	IS3	3.757	0.819	−0.094	−0.429	14.86	11.50	−4.083	0.000
	IS4	3.784	0.874	1.486	−0.814	13.78	16.75	−3.913	0.000
	IS5	3.622	0.968	0.1	−0.453	13.17	12.13	−3.2	0.001
	IS6	3.784	0.843	−0.659	−0.122	13.35	9.00	−4.057	0.000
	IS7	3.811	0.982	0.102	−0.491	12.50	12.50	−3.68	0.000
	IS8	3.838	0.916	1.404	−0.982	15.44	16.00	−3.973	0.000
IP	IP1	3.892	0.763	−0.414	−0.187	14.15	10.00	−4.504	0.000
	IP2	3.784	0.843	−0.659	−0.122	13.35	9.00	−4.057	0.000
	IP3	3.622	0.94	0.376	−0.572	13.55	13.25	−3.273	0.001
	IP4	3.784	0.874	1.486	−0.814	13.78	16.75	−3.913	0.000
IT	IT1	3.649	0.813	−0.584	0.124	11.80	8.50	−3.735	0.000
	IT2	3.757	0.97	0.312	−0.589	13.59	12.83	−3.604	0.000
	IT3	3.892	0.763	−0.414	−0.187	14.15	10.00	−4.504	0.000
	IT4	3.514	0.826	1.182	−0.345	10.22	13.00	−3.111	0.002
	IT5	3.541	0.757	−0.192	−0.143	12.23	10.50	−3.522	0.000
	IT6	3.595	0.884	−0.775	0.189	11.58	7.50	−3.365	0.001
	IT7	3.595	0.884	0.677	−0.3	10.82	12.75	−3.256	0.001
	IT8	3.784	0.904	−0.749	−0.228	14.09	9.00	−3.923	0.000
O	O1	3.514	0.948	1.042	−1.033	13.83	17.60	−2.812	0.005
	O2	3.838	0.822	−0.391	−0.287	14.32	10.00	−4.252	0.000
	O3	3.757	0.882	1.541	−0.962	14.85	16.33	−3.855	0.000
	O4	3.784	0.904	−0.749	−0.228	14.09	9.00	−3.923	0.000
	O5	3.514	0.826	−0.463	0.255	10.94	8.00	−3.189	0.001
	O6	3.811	0.865	1.377	−0.655	12.67	21.00	−3.953	0.000
	O7	3.73	0.859	−0.826	0.038	12.38	8.00	−3.857	0.000
	O8	3.892	0.727	−0.039	−0.264	14.63	11.00	−4.617	0.000
	O9	3.892	0.863	2.287	−1.096	15.29	18.50	−4.21	0.000

Table 5
Evaluating the normality of the data in the groups through the Shapiro-Wilk test.

Factors	Shapiro-Wilk		Hypothesis confirmation	Normal distribution	Test
	Statistic	P value			
E	0.934	0.030	H1	No	Wilcoxon test
IS	0.917	0.009	H1	No	Wilcoxon test
IP	0.936	0.034	H1	No	Wilcoxon test
IT	0.962	0.240	H0	Yes	t-test
O	0.948	0.084	H0	Yes	t-test

H_0: The data of the research questionnaire has a normal distribution.
H_1: The data of the research questionnaire do not have a normal distribution.

Table 6
One-sample t-test results for human errors in urban construction projects.

Factors	Mean	Std. Deviation	Wilcoxon test (Test value = 3)			
			Z value	P value	Negative ranks	Positive ranks
E	3.847	0.728	−4.774	0.000	18.721	14.750
IS	3.740	0.730	−4.365	0.000	16.567	15.500
IP	3.770	0.708	−4.650	0.000	18.121	16.000

Factors	Mean	Std. deviation	t-test (Test value = 3)		95 % confidence interval of the difference	
			t	P-value	Lower	Upper
IT	3.666	0.681	5.946	0.000	0.439	0.893
O	3.748	0.701	6.488	0.000	0.514	0.982

(Mohd Khalil et al., 2024). The data from able 10 shows that the R2 values for group E and IP are weak, while the values for the other three groups are average.

Cohen's effect size index quantifies the strength of the association between the latent variables and is displayed in Table 10. The numbers 0.02, 0.15, and 0.35 have been designated as thresholds for weak, medium, and significant effect sizes according to Hakawati et al. (2024). The effect size was substantial for all 5 groups.

The GOF criterion is utilised to assess the model's overall quality. This criterion pertains to the overall section of structural equation models, allowing the researcher to adjust the fit of the general section once the fit of the measurement and structural parts of the general model have been assessed. A GOF index value of 0.01 or higher suggests a weak measurement model quality, while a GOF index of 0.25 or higher indicates an average quality model. A GOF index of 0.35 or higher signifies a strong quality model (Amerian, 2024). The GOF index value for the research model is 0.505, indicating strong quality.

The quality of the measurement model will be confirmed and assured before examining the structural model and the general model for the significance of the coefficients in the paths. The results of the significance test for path coefficients are presented in Table 10. The results in Table 10 show that the standard coefficient for all 5 groups is statistically significant ($P < 0.05$) and positive, indicating that the model is appropriate and does not require modification.

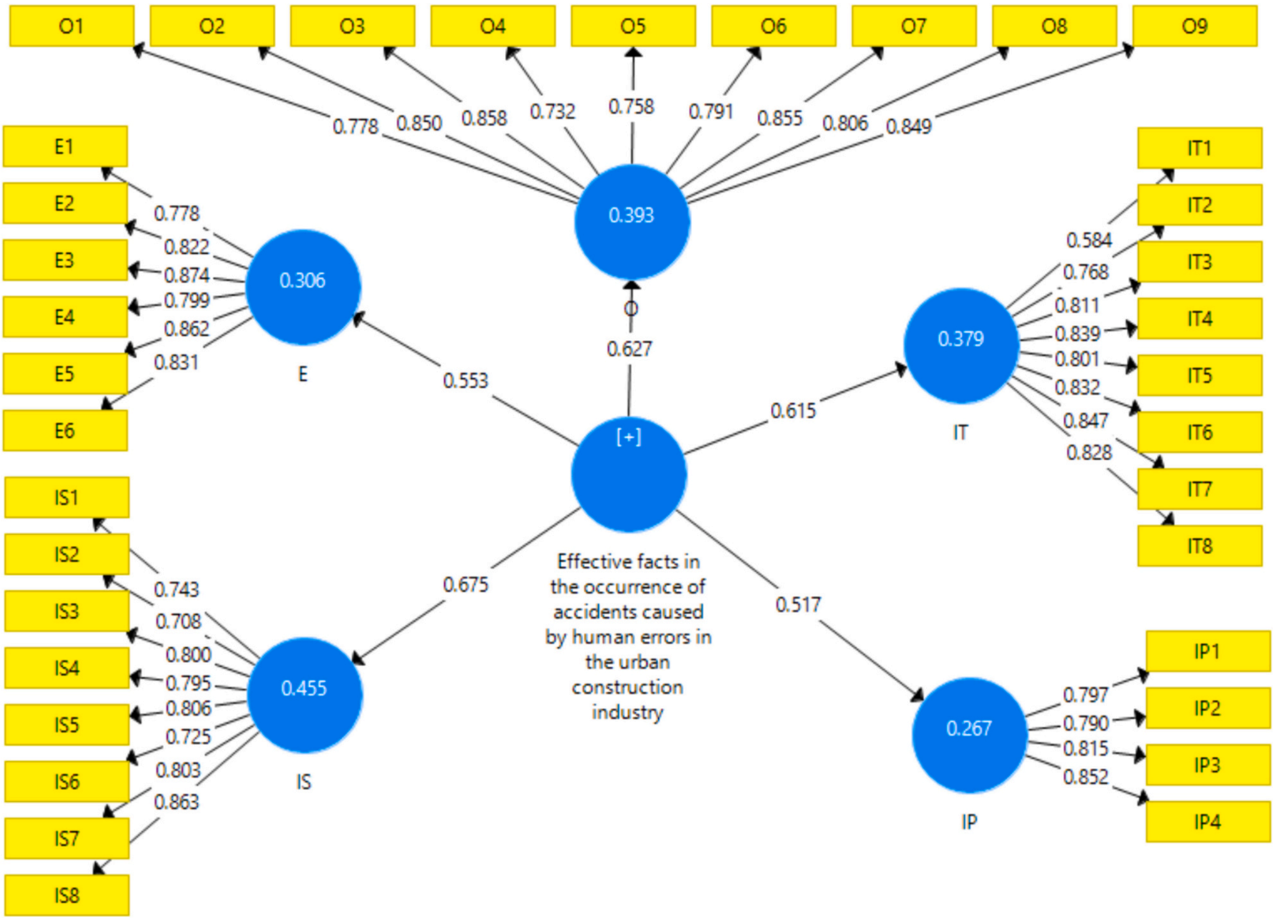

Fig. 2. The measurement model of effective factors leading to the occurrence of accidents caused by human errors in the urban construction projects in the standard mode.

4.3. Assessing human factors using the SWARA technique

Table 11 displays the ranking results of criteria and sub-criteria using the SWARA technique. The SWARA method ranked “technological factors/information systems” as the most important criterion with a weight of 0.433, and “individual factors (permanently related)” as the second most important with a weight of 0.244. The criterion “environmental factors” with a weight of 0.157 is ranked third. The sub-criterion “weak maintenance management systems” ranks first in the general ranking of sub-criteria due to traditional network systems, lack of appropriate tools and equipment, and lack of understanding of required resources. The sub-criterion “defects in details and information and lack of design dynamism” is placed second, while the sub-criterion “violation of safety regulations (use of drugs, etc.)” is ranked third.

5. Discussion of survey results

The findings of this study closely resemble those of prior studies. Kumar et al. (2016) shown the significance of human factors in causing construction site accidents. Mechanisation, technology, machine automation, and improved safety measures have significantly enhanced the efficiency of building projects. In 2015, Gürcanlı et al. conducted a study on the hazards associated with construction projects in Turkey. Experience, safety training, tools, work environment, and other project-related elements were identified as crucial for minimising human error. The study’s findings highlighted the significance of safety training and supervision in the workplace. Workers who received safety training had a lower likelihood of sustaining injuries. Two studies conducted by Barbaranelli et al. (2015) and Zou and Sunindijo (2013) revealed that individuals experiencing feelings of insecurity in the workplace had decreased adherence to safety protocols and lower accuracy in task performance. As a result, there were increased incidents of accidents and financial losses in the workplace. The project’s safety condition is evaluated based on a measure known as “safety performance.” Multiple studies have demonstrated that construction projects that prioritise safety and efficiency are more likely to achieve successful completion. He et al. (2020) emphasised the significance of avoiding operational forecasts that rely on operational risks in designing project systems.

Soualhi et al. conducted a 2020 study on the impact of low intelligence on complex scenarios in the construction industry. Dong et al. (2019) discussed the impact of inadequate real-time tracking and precise predictions of machine breakdowns on maintenance decisions. Zhang et al. highlighted in their 2017 study that there is no centralised method to locate satisfactory solutions in construction projects. Adamson et al. (2017) discussed the impact of cognitive processes, judgement, selection, segregation, and routine maintenance and repair operations on projects in the construction sector. Kumar et al. (2016) discussed the impacts of deliberate and unintentional dangerous behaviours, safety rule violations, sensory and memory impairments, errors in job accuracy, and non-compliance with safety regulations in construction projects. Morais et al. (2022) discussed the consequences of not making pre-work predictions in the construction industry.

Researchers have diligently utilised findings from recent and earlier studies to enhance understanding and identify the primary reasons for errors in the construction sector. Employers, contractors, and other key individuals in construction projects encounter numerous uncertainties and challenges when identifying, anticipating, and managing human errors in the field. Identifying, forecasting, and managing human errors

Table 7
Evaluating the validity (confirmatory and convergent) and reliability of the constructs.

Factors	Loadings	SE	T Statistics	P-value	∝	rho_A	CR	AVE	CV.COM
E1 < - E	0.778	0.095	8.184	0.000	0.908	0.912	0.929	0.686	0.520
E2 < - E	0.822	0.069	11.984	0.000					
E3 < - E	0.874	0.045	19.222	0.000					
E4 < - E	0.799	0.097	8.206	0.000					
E5 < - E	0.862	0.048	17.968	0.000					
E6 < - E	0.831	0.065	12.757	0.000					
IS1 < - IS	0.743	0.104	7.118	0.000	0.908	0.912	0.926	0.611	0.461
IS2 < - IS	0.708	0.113	6.257	0.000					
IS3 < - IS	0.800	0.057	14.000	0.000					
IS4 < - IS	0.795	0.086	9.293	0.000					
IS5 < - IS	0.806	0.065	12.400	0.000					
IS6 < - IS	0.725	0.090	8.051	0.000					
IS7 < - IS	0.803	0.076	10.598	0.000					
IS8 < - IS	0.863	0.057	15.243	0.000					
IP1 < - IP	0.797	0.105	7.624	0.000	0.833	0.847	0.887	0.663	0.411
IP2 < - IP	0.790	0.112	7.049	0.000					
IP3 < - IP	0.815	0.091	8.916	0.000					
IP4 < - IP	0.852	0.076	11.263	0.000					
IT1 < - IT	0.584	0.143	4.100	0.000	0.914	0.922	0.931	0.629	0.489
IT2 < - IT	0.768	0.069	11.163	0.000					
IT3 < - IT	0.811	0.072	11.227	0.000					
IT4 < - IT	0.839	0.059	14.318	0.000					
IT5 < - IT	0.801	0.062	13.001	0.000					
IT6 < - IT	0.832	0.061	13.654	0.000					
IT7 < - IT	0.847	0.054	15.596	0.000					
IT8 < - IT	0.828	0.057	14.558	0.000					
O1 < - O	0.778	0.074	10.556	0.000	0.934	0.939	0.945	0.656	0.524
O2 < - O	0.850	0.047	18.218	0.000					
O3 < - O	0.858	0.056	15.230	0.000					
O4 < - O	0.732	0.079	9.233	0.000					
O5 < - O	0.758	0.093	8.150	0.000					
O6 < - O	0.791	0.098	8.041	0.000					
O7 < - O	0.855	0.066	13.013	0.000					
O8 < - O	0.806	0.088	9.146	0.000					
O9 < - O	0.849	0.072	11.828	0.000					

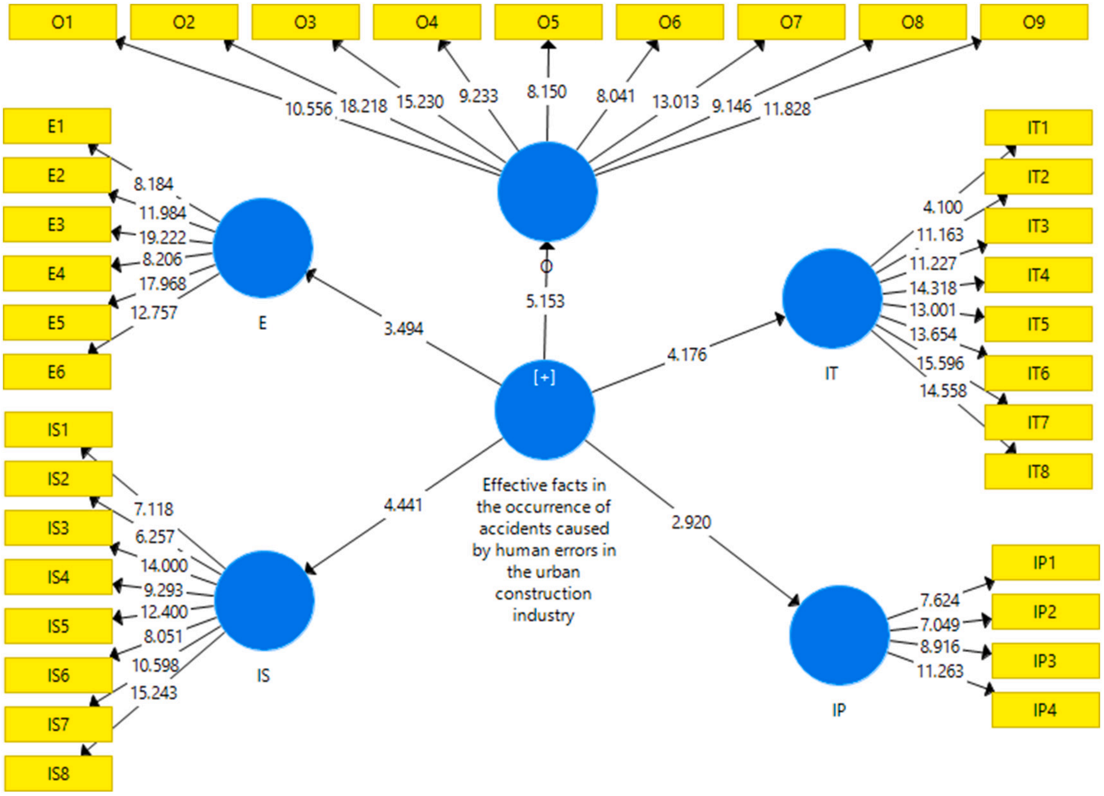

Fig. 3. The measurement model of effective factors in the occurrence of accidents caused by human errors in the urban construction projects in the significant mode.

Table 8
HTMT ratio for evaluating the diverging validity.

	E	IP	IS	IT	O
E					
IP	0.278				
IS	0.295	0.296			
IT	0.198	0.225	0.300		
O	0.195	0.258	0.199	0.200	

Table 9
Verification of collinearity and inclusion of external weight.

Factors	Outer weights	SE	T statistics	*P* values	VIF
E1 < - E	0.165	0.054	3.026	0.003	2.164
E2 < - E	0.221	0.056	3.929	0.000	2.452
E3 < - E	0.196	0.049	3.974	0.000	3.367
E4 < - E	0.201	0.050	4.015	0.000	2.264
E5 < - E	0.204	0.042	4.844	0.000	3.407
E6 < - E	0.219	0.053	4.142	0.000	2.443
IP1 < - IP	0.241	0.083	2.920	0.004	1.904
IP2 < - IP	0.385	0.121	3.167	0.002	1.518
IP3 < - IP	0.295	0.097	3.038	0.003	2.235
IP4 < - IP	0.309	0.090	3.439	0.001	2.248
IS1 < - IS	0.169	0.027	6.280	0.000	2.027
IS2 < - IS	0.134	0.031	4.280	0.000	2.135
IS3 < - IS	0.189	0.030	6.301	0.000	2.175
IS4 < - IS	0.138	0.031	4.492	0.000	2.328
IS5 < - IS	0.162	0.026	6.314	0.000	2.489
IS6 < - IS	0.165	0.025	6.617	0.000	2.211
IS7 < - IS	0.154	0.027	5.811	0.000	2.748
IS8 < - IS	0.167	0.027	6.309	0.000	4.047
IT1 < - IT	0.127	0.043	2.945	0.003	1.809
IT2 < - IT	0.170	0.032	5.253	0.000	2.186
IT3 < - IT	0.150	0.030	5.071	0.000	2.523
IT4 < - IT	0.143	0.043	3.334	0.001	3.205
IT5 < - IT	0.148	0.027	5.458	0.000	2.637
IT6 < - IT	0.163	0.030	5.416	0.000	3.700
IT7 < - IT	0.160	0.030	5.331	0.000	3.913
IT8 < - IT	0.199	0.033	5.957	0.000	3.156
O1 < - O	0.125	0.021	6.052	0.000	2.730
O2 < - O	0.170	0.031	5.497	0.000	3.810
O3 < - O	0.148	0.026	5.622	0.000	3.362
O4 < - O	0.124	0.028	4.448	0.000	2.266
O5 < - O	0.146	0.026	5.568	0.000	2.712
O6 < - O	0.115	0.024	4.731	0.000	2.616
O7 < - O	0.140	0.028	4.924	0.000	4.081
O8 < - O	0.140	0.023	5.971	0.000	3.102
O9 < - O	0.125	0.022	5.748	0.000	3.621

are crucial for the prosperity of the construction industry. Examining human errors and their potential causes is essential, particularly in developing nations. By considering environmental variables, IT/technological elements, fixed individual factors, transitory individual factors, and organisational factors, human error and its consequences in the construction sector can be reduced.

This study's findings indicate that the primary external factors were hazardous working conditions and absence of a safety-oriented culture. The key problems in information systems and technology were inadequate maintenance management systems, outdated network systems, insufficient tools and equipment, and a lack of knowledge about required resources. Among individual factors, violating safety protocols, such as drug use, was deemed the most significant. The urgency to complete tasks, possibly caused by time constraints or irregular work schedules, was the primary individual component within the group. An essential organisational issue was the lack of a robust education structure within the company. In developing nations like Iran, managers and workers in the building industry should employ systemic thinking and cohesive management to address factors contributing to human errors.

6. Conclusions and practical implications

This study aimed to identify and examine the key factors contributing to human errors in the Iranian UPC. Key factors contributing to errors in the UCP were identified in scholarly literature and assessed through the Delphi approach over three iterations. The researcher created a questionnaire consisting of 5 categories and a 5-point Likert scale. The categories include environmental, information systems/technological, individual (permanent), individual (temporary), and organisational factors. Subsequently, the questionnaire was distributed to 37 construction experts in Iran. Confirmatory factor analysis was used to evaluate the construct validity of the test. The criterion and subcriteria were prioritised using the SWARA method. The study's results showed that the category "technological factors/information systems" was considered as the most important, followed by the group "individual factors (permanently related)" in second place, and the group "environmental factors" in third place. "Weak maintenance management systems" is the top factor in the ranking, followed by old network systems, absence of necessary tools and equipment, and lack of awareness of required resources. The factor "Defects in details and information and lack of design dynamism" is ranked second, followed by the factor "Violation of safety regulations (use of drugs, etc.)" in third place. Organisations are advised to identify key factors and establish standards and practices to minimise human errors in the construction business based on the research findings. Providing a well-defined safety management system greatly enhances the likelihood of minimising and managing human errors in the construction sector.

This study contributes to the improved management of safety in construction by identifying the factors that influence human error in the UCP. This topic has not been investigated in any quantitative study before. Regulating the actions of individuals and machinery, together with efficiently organising procedures, aids construction companies in improving their safety management efficiency and production. Construction businesses must prioritise effective organization, individual activity control, environmental conditions improvement, technological organization updates, and enhancing rescue facilities and equipment to excel in safety management. Therefore, the next study guidelines to further explore the identified findings are as follows: What are the key managerial and environmental factors that enhance construction businesses' safety performance? How might technological advancements enhance safety and contribute to the profitability of construction companies? What human error reduction measures may construction companies implement?

Beyond safety management, this research has broad real-world implications and applications for various research areas by addressing difficulties related to human error. For instance, understanding the reasons behind human errors in psychology and human resource management can help enhance cognitive functions and decision-making.

Table 10
R2 and Q2 indices for the endogenous variables in the model, as well as the effect size index and significance test for the path coefficients.

Factors	SSO	SSE	Q^2 (=1-SSE/SSO)	R square	R square adjusted	Path coefficients	SE	T statistics	P values	GOF	Effect size
E	222.000	179.296	0.192	0.306	0.286	0.553	0.158	3.494	0.001	0.440	0.505
IP	148.000	124.713	0.157	0.267	0.246	0.517	0.177	2.920	0.004	0.364	
IS	296.000	220.652	0.255	0.455	0.440	0.675	0.152	4.441	0.000	0.835	
IT	296.000	233.697	0.210	0.379	0.361	0.615	0.147	4.176	0.000	0.610	
O	333.000	256.296	0.230	0.393	0.376	0.627	0.122	5.153	0.000	0.647	

Table 11
Ranking of the identified human factors using the SWARA technique.

Groups	Weight (group)	Rank (group)	Factors	Weight (factor)	Rank (within the group)	Overall weight	Overall rank
IS	0.433	1	IT8	0.3444	1	0.1493	1
			IT2	0.2271	2	0.0985	2
			IT3	0.1648	3	0.0714	4
			IT6	0.1004	4	0.0435	8
			IT5	0.0716	5	0.0310	12
			IT4	0.0436	6	0.0189	16
			IT1	0.0295	7	0.0128	20
			IT7	0.0185	8	0.0080	24
IP	0.244	2	IP2	0.3916	1	0.0957	3
			IP3	0.2830	2	0.0692	5
			IP1	0.1928	3	0.0471	7
			IP4	0.1326	4	0.0324	11
E	0.157	3	E5	0.3867	1	0.0607	6
			E2	0.2446	2	0.0384	9
			E1	0.1563	3	0.0245	13
			E6	0.1011	4	0.0159	18
			E4	0.0685	5	0.0108	21
			E3	0.0427	6	0.0067	25
O	0.101	4	O4	0.3479	1	0.0351	10
			O8	0.2357	2	0.0238	14
			O5	0.1612	3	0.0163	17
			O9	0.0950	4	0.0096	23
			O1	0.0652	5	0.0066	26
			O2	0.0414	6	0.0042	29
			O7	0.0269	7	0.0027	31
			O6	0.0160	8	0.0016	33
			O3	0.0106	9	0.0011	35
IT	0.064	5	IS7	0.3465	1	0.0222	15
			IS2	0.2285	2	0.0147	19
			IS6	0.1513	3	0.0097	22
			IS1	0.1023	4	0.0066	27
			IS5	0.0702	5	0.0045	28
			IS3	0.0489	6	0.0031	30
			IS8	0.0314	7	0.0020	32
			IS4	0.0208	8	0.0013	34

Consequently, this enhances human performance in all areas of the project. This knowledge can be applied in areas such as education and organisational behaviour to enhance learning outcomes, promote safety, and increase workplace efficiency. In terms of construction engineering and technology, insights into the factors that lead to human errors can be utilised to create user-friendly systems and solutions that minimise the chances of mistakes. When error is considered a top concern in developing new products and systems, knowledge about human behaviour and functionality should be integrated into the design process. When viewed in this way, engineers can create tools and technologies that are more intuitive, efficient, and error-resistant. Enhancing safety measures, training procedures, and risk management in the transport sector could be considerably improved by gaining fresh insights into the role of humans in this line of work and the origins of errors. Utilising current study on human factors contributing to incidents can serve as a foundational framework for enhancing safety and error prevention, thereby decreasing transportation costs across many sectors.

This study relies significantly on the practical experiences and personal opinions of participants who completed the Delphi and questionnaire surveys to analyse the identified human error elements in the UCP in Iran. In light of this principal limitation, Future research can enhance the generalizability of the analytical survey results from a similar study by examining the quality of UCP accident reports and including a broader range of construction experts. Moreover, future research can improve the applicability of the suggested findings in a comparable study by expanding the pool of construction professionals for evaluation. As Chan et al. (2022) proposed analysing the factors influencing human errors based on the development level of the countries (developed or developing) to find parallels and differences. The study results can assist stakeholders in making more informed decisions to manage or decrease human errors.

Declaration competing of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Hadi Sarvari: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Alireza Babaie Baghbaderani:** Formal analysis, Investigation, Writing – original draft. **Daniel W.M. Chan:** Validation, Visualization, Writing – original draft, Writing – review & editing. **Michael Beer:** Conceptualization, Writing – original draft, Writing – review & editing.

Data availability

Data will be made available on request.

References

Adamson, G., Wang, L., Holm, M., Moore, P., 2017. Cloud manufacturing–a critical review of recent development and future trends. Int. J. Comput. Integr. Manuf. 30 (4–5), 347–380.

Adhiatma, A., Fachrunnisa, O., 2021. The relationship among zakat maal, altruism and work life quality. Int. J. Zakat 6 (1), 71–94.

Akyuz, E., Celik, M., Cebi, S., 2016. A phase of comprehensive research to determine marine-specific EPC values in human error assessment and reduction technique. Saf. Sci. 87, 63–75.

Amerian, M., 2024. Identifying the Impact of Social Capital on Quality of Urban Life (Evidence from Iran). Soc. Indic. Res. 1–16.

Arcuri, A., Briand, L., 2014. A hitchhiker's guide to statistical tests for assessing randomized algorithms in software engineering. Software Testing, Verification and Reliability 24 (3), 219–250.

Atkinson, A., 1998. Human error in the management of building projects. Constr. Manag. Econ. 16 (3), 339–349.

Aydin, M., Camliyurt, G., Akyuz, E., Arslan, O., 2021. Analyzing human error contributions to maritime environmental risk in oil/chemical tanker ship. Hum. Ecol. Risk Assess. Int. J. 27 (7), 1838–1859.

Barati, M., Jormand, H., Khazaei, S., Bashirian, S., Sadri, M., Afshari, M., 2024. Factors affecting subsequent dose of COVID-19 vaccine uptake based on BASNEF model among older adults. BMC Infect. Dis. 24 (1), 18.

Barbaranelli, C., Petitta, L., Probst, T.M., 2015. Does safety climate predict safety performance in Italy and the USA? Cross-cultural validation of a theoretical model of safety climate. Accid. Anal. Prev. 77, 35–44.

Bentley, M.J.C., 1981. Quality Control on Building Sites, Building Research Station Current Paper 7/81. Build. Res. Establishment.

Bentley, T., Tappin, D., Moore, D., Legg, S., Ashby, L., Parker, R., 2005. Investigating slips, trips and falls in the New Zealand dairy farming sector. Ergonomics 48 (8), 1008–1019.

Boal, K., Meckler, M., 2010. Decision errors of the 4th, 5th, and 6th kind. In: Handbook of Decision Making. John Wiley & Sons, Ltd., pp. 327–348

Boussabaine, A., Kirkham, R., 2008. Whole Life-Cycle Costing: Risk and Risk Responses. John Wiley & Sons.

Cáceres-Matos, R., Gil-García, E., Vázquez-Santiago, S., Cabrera-León, A., 2023. Factors that influence the impact of chronic non-cancer pain on daily life: a partial least squares modelling approach. Int. J. Nurs. Stud. 138, 104383.

Chan, D.W., Cristofaro, M., Nassereddine, H., Yiu, N.S., Sarvari, H., 2021. Perceptions of safety climate in construction projects between workers and managers/supervisors in the developing country of Iran. Sustainability 13 (18), 10398.

Chan, D.W.M., Baghbaderani, A.B., Sarvari, H., 2022. An empirical study of the human error-related factors leading to site accidents in the Iranian urban construction industry. Buildings 12 (11), 1858.

Chen, G.X., Shan, M., Chan, A.P.C., Liu, X., Zhao, Y.Q., 2019. Investigating the causes of delay in grain bin construction projects: the case of China. Int. J. Constr. Manag. 19 (1), 1–14.

Chin, W.W., 1998. The partial least squares approach to structural equation modeling. Mod. Methods Bus. Res. 295 (2), 295–336.

Crowl, D.A. (Ed.), 2007. Human Factors Methods for Improving Performance in the Process Industries. John Wiley & Sons.

Deacon, T.W., 2008. Shannon-Boltzmann—Darwin: redefining information (part II). Cognit. Semiotics 2 (Supplement), 169–196.

Dong, Y., Xia, T., Fang, X., Zhang, Z., Xi, L., 2019. Prognostic and health management for adaptive manufacturing systems with online sensors and flexible structures. Comput. Ind. Eng. 133, 57–68.

Falck, A.C., Rosenqvist, M., 2012. What are the obstacles and needs of proactive ergonomics measures at early product development stages?–an interview study in five Swedish companies. Int. J. Ind. Ergon. 42 (5), 406–415.

Fink, A., Kosecoff, J., Chassin, M., Brook, R.H., 1984. Consensus methods: characteristics and guidelines for use. Am. J. Public Health 74 (9), 979–983.

Gilchrist, A., Allouche, E.N., 2005. Quantification of social costs associated with construction projects: state-of-the-art review. Tunn. Undergr. Space Technol. 20 (1), 89–104.

Griffin, M.A., Neal, A., 2000. Perceptions of safety at work: a framework for linking safety climate to safety performance, knowledge, and motivation. J. Occup. Health Psychol. 5 (3), 347.

Gupta, J.P., 2002. The Bhopal gas tragedy: could it have happened in a developed country? J. Loss Prev. Process Ind. 15 (1), 1–4.

Gürcanlı, G.E., Baradan, S.E.L.İ.M., Uzun, M., 2015. Risk perception of construction equipment operators on construction sites of Turkey. Int. J. Ind. Ergon. 46, 59–68.

Hakawati, B., Mousa, A., Draidi, F., 2024. Smart energy management in residential buildings: the impact of knowledge and behavior. Sci. Rep. 14 (1), 1702.

Hameed, A., Khan, F., Ahmed, S., 2016. A risk-based shutdown inspection and maintenance interval estimation considering human error. Process. Saf. Environ. Prot. 100, 9–21.

He, Y., Zhao, Y., Han, X., Zhou, D., Wang, W., 2020. Functional risk-oriented health prognosis approach for intelligent manufacturing systems. Reliab. Eng. Syst. Saf. 203, 107090.

Holen, S.M., Yang, X., Utne, I.B., Haugen, S., 2019. Major accidents in Norwegian fish farming. Saf. Sci. 120, 32–43.

Kebede, A., Ermolo, T., Demie, T., Huluka, T., Tsega, W., 2017. Household solid waste generation rate and onsite handling practices in Debre Berhan town. Ethiopia. Sci. J. Public Health 5 (1), 31–34.

Khaleghi, P., Akbari, H., Alavi, N.M., Kashani, M.M., Batooli, Z., 2022. Identification and analysis of human errors in emergency department nurses using SHERPA method. Int. Emerg. Nurs. 62, 101159.

Khosravi, M., Sarvari, H., Chan, D.W., Cristofaro, M., Chen, Z., 2020. Determining and assessing the risks of commercial and recreational complex building projects in developing countries: a survey of experts in Iran. J. Facil. Manag. 18 (3), 259–282.

Klein, S.B., 2018. Learning: Principles and Applications. Sage Publications.

Kletz, T., 2018. An Engineer's View of Human Error. Routledge.

Knight, M., Oswal, S.K., 2018. Disability and accessibility in the workplace: some exemplars and a research agenda for business and professional communication. Bus. Prof. Commun. Q. 81 (4), 395–398.

Kohn, L.T., Corrigan, J.M., Donaldson, M.S., McKay, T., Pike, K.C., 2000. To err is human. In: Building a Safer Health System, 600, p. 2000.

Kumar, P., Gupta, S., Agarwal, M., Singh, U., 2016. Categorization and standardization of accidental risk-criticality levels of human error to develop risk and safety management policy. Saf. Sci. 85, 88–98.

Kyriakidis, M., Simanjuntak, S., Singh, S., Majumdar, A., 2019. The indirect costs assessment of railway incidents and their relationship to human error-the case of signals passed at danger. J. Rail Transp. Plann. Manage. 9, 34–45.

Labib, A., Champaneri, R., 2012. The Bhopal disaster-learning from failures and evaluating risk. Maintenance Eng. 27 (3), 41–47.

Lee, C.H., Wu, K.J., Tseng, M.L., 2018. Resource management practice through eco-innovation toward sustainable development using qualitative information and quantitative data. J. Clean. Prod. 202, 120–129.

Liu, H., Hwang, S.L., Liu, T.H., Chen, G.H., 2004. Implementation of human error diagnosis (HED) system. J. Chin. Inst. Ind. Eng. 21 (1), 82–91.

Love, P.E., Sohal, A.S., 2003. Capturing rework costs in projects. Manag. Audit. J. 18 (4), 329–339.

Lowe, C., 2008. A human factors perspective on safety management systems. In: Improvements in System Safety. Springer, London, pp. 139–153.

Majeed, R.A., Breesam, H.K., 2021, March. Application of SWARA technique to find criteria weights for selecting landfill site in Baghdad governorate. IOP Conference Series: Materials Science and Engineering 1090 (1), 012045. IOP Publishing.

Martin, L.S., Lipscomb, H., Cifuentes, M., Punnett, L., 2019. Perceptions of safety climate across construction personnel: associations with injury rates. Saf. Sci. 118, 487–496.

Meshkati, N., 1991. Human factors in large-scale technological systems' accidents: Three Mile Island, Bhopal, Chernobyl. Industrial Crisis Quarterly 5 (2), 133–154.

Mohd Khalil, A., Lee, K.L., Kamaruzzaman, Z.A., Ong, C.A., 2024. Effectiveness of simulation-based learning in Malaysian higher education: a case study of MonsoonSIM. Asian Educ. Dev. Stud. 13 (1), 64–77.

Morais, C., Estrada-Lugo, H.D., Tolo, S., Jacques, T., Moura, R., Beer, M., Patelli, E., 2022. Robust data-driven human reliability analysis using credal networks. Reliab. Eng. Syst. Saf. 218, 107990.

Mou, Z., Scheutz, C., Kjeldsen, P., 2015. Evaluation and application of site-specific data to revise the first-order decay model for estimating landfill gas generation and emissions at Danish landfills. J. Air Waste Manage. Assoc. 65 (6), 686–698.

Needham, D.L., Slaughter, D.C., Giles, D.K., Downey, D., 2006. Roadside Spray Control: On-board Monitoring and Recording of Environmental Conditions for the Prevention of Application in Adverse Conditions.

Nie, L., Oldenburg, B., Cao, Y., Ren, W., 2023. Continuous usage intention of mobile health services: model construction and validation. BMC Health Serv. Res. 23 (1), 442.

Onwuegbuzie, A.J., Combs, J.P., 2010. Emergent data analysis techniques in mixed methods research: A synthesis. Handbook of Mixed Methods in Social and Behavioral Research 2, 398.

Porathe, T., Hoem, Å.S., Rødseth, Ø.J., Fjørtoft, K.E., Johnsen, S.O., 2018. At least as safe as manned shipping? Autonomous shipping, safety and "human error". In: Safety and Reliability–Safe Societies in a Changing World. Proceedings of ESREL 2018, June 17–21, 2018, Trondheim, Norway.

Rafieyan, A., Sarvari, H., Chan, D.W.M., 2022. Identifying and evaluating the essential factors affecting the incidence of site accidents caused by human errors in industrial parks construction projects. Int. J. Environ. Res. Public Health 19 (16), 10209.

Rafieyan, A., Sarvari, H., Beer, M., Chan, D.W.M., 2024. Determining the effective factors leading to incidence of human error accidents in industrial parks construction projects: results of a fuzzy Delphi survey. Int. J. Constr. Manag. 24 (7), 748–760. https://doi.org/10.1080/15623599.2022.2159630 (in press), 1-13.

Ramiro, J.S., Aisa, P.B., 2012. Risk Analysis and Reduction in the Chemical Process Industry. Springer Science & Business Media.

Rolison, J.J., Regev, S., Moutari, S., Feeney, A., 2018. What are the factors that contribute to road accidents? An assessment of law enforcement views, ordinary drivers' opinions, and road accident records. Accid. Anal. Prev. 115, 11–24.

Saputra, M.C., Andajani, E., 2024. Analysis of factors influencing intention to adopt battery electric vehicle in Indonesia. ADI J. Recent Innov. 5 (2), 100–109.

Sarvari, H., Cristofaro, M., Chan, D.W.M., Noor, N.M., Amini, M., 2020. Completing abandoned public facility projects by the private sector: results of a Delphi survey in the Iranian water and wastewater company. J. Facil. Manag. 18 (5), 547–566.

Sarvari, H., Mehrabi, A., Chan, D.W.M., Cristofaro, M., 2021a. Evaluating urban housing development patterns in developing countries: case study of worn-out urban fabrics in Iran. Sustain. Cities Soc. 70, Article Number 102941.

Sarvari, H., Chan, D.W.M., Alaeos, A.K.F., Olawumi, T.O., Aldaud, A.A.A., 2021b. Critical success factors for managing construction small and medium-sized enterprises in developing countries of Middle East: evidence from Iranian construction enterprises. J. Build. Eng. 43, 103152.

Schefzik, R., Hahn, B., Schneider-Lindner, V., 2023. Dissecting contributions of individual systemic inflammatory response syndrome criteria from a prospective algorithm to the prediction and diagnosis of sepsis in a polytrauma cohort. Front. Med. 10, 1227031.

Schmidt, R.C., 1997. Managing Delphi surveys using nonparametric statistical techniques. Decis. Sci. 28 (3), 763–774.

Shanmugam, A., Robert, T.P., 2015. Ranking of aircraft maintenance organization based on human factor performance. Comput. Ind. Eng. 88, 410–416.

Soualhi, M., Nguyen, K.T., Medjaher, K., 2020. Pattern recognition method of fault diagnostics based on a new health indicator for smart manufacturing. Mech. Syst. Signal Process. 142, 106680.

Storey, H., 1994. Human factors in the development of automotive safety critical software. Contemp. Ergon. 205.

Tian, C., Zhu, H., Shi, L., Chen, X., Xie, T., Rui, Y., 2023. Is There a "Black Friday" for Geriatric Hip Fracture Surgery? Orthop. Surg. 15 (5), 1304–1311.

Tripathi, K.K., Jha, K.N., 2018. Determining success factors for a construction organization: a structural equation modeling approach. J. Manag. Eng. 34 (1), 04017050.

Volk, R., Stengel, J., Schultmann, F., 2014. Building information modeling (BIM) for existing buildings—literature review and future needs. Autom. Constr. 38, 109–127.

Whittingham, R., 2004. The Blame Machine: Why Human Error Causes Accidents. Routledge.

Yang, Z., Wang, S., Yoon, T.H., 2024. The effect of short-form video on travel decision-making process: an integration of AIDA and MGB models. Int. J. Tour. Res. 26 (1), e2632.

Zhang, J., Xu, K., You, G., Wang, B., Zhao, L., 2019. Causation analysis of risk coupling of gas explosion accident in Chinese underground coal mines. Risk Anal. 39 (7), 1634–1646.

Zhu, Y., Wang, Y., Song, B., Feng, Q., Lin, H., Tang, J., 2023. The interactive effects of extrinsic and intrinsic motivations on service recovery performance: the mediating role of self-efficacy. Tour. Manage. Stud. 19 (3), 7–22.

Zou, P.X., Sunindijo, R.Y., 2013. Skills for managing safety risk, implementing safety task, and developing positive safety climate in construction project. Autom. Constr. 34, 92–100.

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