Heliyon 10 (2024) e34599

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

A qualitative exploration and a Fuzzy Delphi validation of high-risk scaffolding tasks and fatigue-related safety behavioural deviation among scaffolders

Hanizah Mohd Yusoff [a], Pei Pei Heng [a,*], Mohamad Ridza Hj Illias [b], Saravanan Karrupayah [b], Mohd Anis Fadhli [b], Rozita Hod [a]

[a] *Department of Public Health Medicine, Faculty of Medicine, Universiti Kebangsaan Malaysia, Bandar Tun Razak, 56000, Wilayah Persekutuan Kuala Lumpur, Malaysia*

[b] *MKRS Training Institute, Malaysian Scaffold Academy, Bangi Hub Suntrack Industrial Park, 43650, Bandar Baru Bangi, Selangor, Malaysia*

ARTICLE INFO

Keywords:
High-risk scaffolding tasks
Unsafe behaviour
Scaffolders
Fuzzy delphi validation

ABSTRACT

Background: Most construction mishaps were caused by scaffolding incidents despite implementing various safety measures, and the association with human factors like fatigue has been widely reported. This study aims to identify all high-risk task sequences involved during the erection of the most commonly used scaffold; the deviation from the standard protocol led to a substandard fatigue state, followed by content validation using the Fuzzy Delphi Method.
Methods: Qualitative exploration was conducted via focal group discussions (FGDs) involving 30 certified experts. The findings generated from FGDs were further validated by utilising the Fuzzy Delphi Method (FDM) by consulting 19 experts with extensive practical experience and leadership roles in scaffolding safety.
Results: The FGDs identified a total of 7 constructs and 50 items for task sequences involved in the tubular scaffold erection, namely construct Instruction (3 items), Preparation (3 items), Foundation (10 items), First Lift (8 items), Working Platform (7 items), Guardrails (5 items) and Second Lift (14 items). In the FDM validation process, the experts' consensus for each construct was fulfilled with a threshold value (d) $\leq$ 0.2; thus, all constructs were accepted. Experts' consensus for all items achieved an expert agreement of 75 % and above. Items ranking was conducted using average fuzzy numbers. The highest average fuzzy number documented was 0.8, while the lowest was 0.588. None of the items with the lowest ranking was discarded as all items perfectly fulfilled the second prerequisite and obtained excellent experts' agreement.
Conclusions: The tool generated will help guide the development of a protocol for scaffolding safety management.

1. Introduction

The construction industry is perceived as a hazardous industry [1], due to its labour-intensive characteristics [2] and the requirement to work at heights where the workforce is prone to fatigue [3]. Global statistics have documented that most construction site accidents were reported related to scaffolding during scaffolding erection or dismantling, caused by malfunctioning and collapsing

* Corresponding author.
E-mail address: hengpeipei850717@gmail.com (P.P. Heng).

https://doi.org/10.1016/j.heliyon.2024.e34599
Received 12 May 2024; Received in revised form 2 July 2024; Accepted 12 July 2024
Available online 23 July 2024
2405-8440/

[4,5]. The scaffold accidents in Malaysia have also been widely reported [6–8]. The Department of Occupational Safety and Health in Malaysia recorded 20 fatal accidents involving scaffolding in the past decade. The rates of local scaffolding accidents are increasing [4]. A total of 30 accidents were reported by the Social Security Organisation in 2012, but this number increased to 227 cases in 2016. A recent local study even found that scaffolding-related incidents accounted for most (70 %) of all fatalities and injuries on construction sites. This is primarily because unsafe behaviours like lax inspections, shoddy assembly, a lack of a safety culture, unsafe behaviour, poor scaffold footing, and exposed planking were the root causes of these incidents [4]. The Occupational Safety and Health Administration of the United States reported that two-thirds of the construction workforce operates various scaffolds worldwide. Scaffolding safety protocol violations are reported to be fairly widespread. One reason is that construction managers pay minimal attention to temporary infrastructures [25].

A scaffold is a temporary building structure that enables work to be carried out at a height ranging from two to several dozen meters above the ground. It is used to construct new buildings, repair, and modernise existing buildings. The basic features that characterise scaffolding include dimensions (size), height, span width and length, the maximum load on a working platform, the maximum height of the last working platform, foundations, load-bearing capacity of the ground, a support's load-bearing capacity, and also the method and location of anchoring [9]. The primary function of scaffolding is to support building works at heights and places with poor access. Due to the various tasks of scaffolding, there are possibilities of hazardous occurrences related to the unforeseeable activity that endangers the worker in the area of scaffolding, such as injuries or falling of scaffolds outside the building sites [6,10]On the other hand, the unsafe scaffold installed will not only significantly increase the risk of falling from height among the scaffolders at work but also cause other scaffold users on the construction site to be at risk of falling accidents.

Although the construction industry has implemented various safety and health efforts and regulations, fall accidents remain a persistent and significant issue [11]. Most of the accidents reported are associated with human error secondary to fatigue. Given the increasing burden of fall-related scaffolding accidents, the body of knowledge on high-risk scaffolding tasks and the safety-related behavioural factors that contribute to fall accidents among scaffolders should be ascertained. The causes of scaffolding accidents were generally categorised into technical, environmental, human, and organisational factors by Ref. [6]. On the other hand, Olanranwaju et al. (2021) proposed by factor analysis that these causes can be categorised into unsafe behaviour and violation of the safety rules, experience, structural and capacity of the scaffold, general management and inappropriate PPE use. There is a lack of in-depth exploration of the precursors of scaffolding accidents [12]. Understanding this issue will aid in formulating adequate safety and preventive strategies for fall prevention management in the scaffolding industry. Given the scarcity of research on the experiences of industry experts and workers on the risk of fall accidents due to scaffolding work, a qualitative study using grounded theory was deemed necessary for this study. This study aims to identify all high-risk task sequences of tubular scaffold erection; the deviation from the standard protocol led to a substandard fatigue state, followed by content validation using the Fuzzy Delphi Method.

2. Materials and methods

2.1. Study design

This cross-sectional study was conducted from July 2023 until December 2023. A constructive grounded theory design was appropriate in exploring new perspectives on experts' insight and workers' experience on the precursors of scaffold accidents related to unsafe behaviours, as little is known about this phenomenon. This approach uncovered in-depth findings that are useful for future research in scaffolding safety management. The qualitative data collection was conducted via Focal Group Discussions (FGDs) that allowed respondents to exchange viewpoints, discuss disagreements and generate new insights into the group dynamics [13].

2.2. Sampling for item generation in FGD

A total of 30 experts were invited to participate through purposive sampling. The FGDs were conducted in four separate moderately homogeneous groups, considering the discrepancy in the literacy level and occupational background to avoid heterogenicity, which might limit the output exchange. Participants included 12 experienced scaffolders, 6 experienced scaffolding operators (supervisor), and another 12 experts experienced in the field investigation of scaffolding accidents (6 officers from the Building Construction Safety Division, Department of Occupational Safety and Health; 6 safety experts from the Malaysian Occupational Scaffolding Association, MOSA). The inclusion criteria for scaffolders include a minimum of 3 years of experience in scaffolding work and certification at the advanced scaffolding level. The inclusion criteria for scaffolding operators were at least 3 years of experience and competency at an advanced level.

2.3. Data collection protocol

Written consent for participation was obtained, and a 90-min session of face-to-face FGD was conducted for all four groups. The content of FGDs adhered to the Compensatory Controlled Model (CCM), which pinpointed the alternative control of performance regulation following the effects of work stressors, as in our context, the work fatigue [14]. The model provides a framework for individual adjustment to the work demand, such as fatigue or strain coping. In the FGDs, we extracted information based on three main concepts as guided by the CCM, namely.

i. What are the task sequences for erecting a primary tubular static tower with a double lift?

ii. What standard needs to be followed for each task sequence?
iii. What are the common errors or violations lead to the substandard state of fatigue? The substandard focused on task alterations and behavioural deviation.

Table 1 describes the structure of the semi-structured protocol and guide. Initially, each member of the group was asked to individually explain the high-risk scaffold erection task and unsafe behaviour in terms of error and violation. Upon completing the individual assessment, the group discussion was undertaken to reach a collective agreement on the factors. The FGDs were conducted until saturation was achieved, and no additional data was revealed. All four sessions were audio-recorded and transcribed verbatim.

2.4. Data trustworthiness and reliability

The study adhered to the grounded theory principles to ensure its credibility and data quality. Data triangulation with multiple data sources was performed to optimise the validity and reliability [15]. Existing pertinent documentation from government agencies (*Panduan Pemeriksaan Bahaya Perancah Pasang Siap*, DOSH) and the Job Safety Analysis (JSA) from the scaffolding sector were also studied. A purposeful sampling technique was utilised to select cases with the most information possible while making the best use of the limited resources available. Recruiting groups of participants who are particularly educated about or experienced in the scaffolding industry were employed [16]. Additionally, every transcript was examined to guarantee the data accuracy. The participants were called to clarify any imprecise answers. Expert knowledge and experience have been shared by the multi-source population, which consists of laypeople and field experts [17].

Table 1
The FGD protocol and guide.

Phase	Description	Possible Probing Questions
Introductory	• Welcome and thank everyone for the participation • Introduce the facilitator to the note-taker	–
Consent	• Distribute the consent form • Participants to ask questions • Verbal consent on note-taking and audio-recording with no individual identifying information will be attached to comments.	–
Overview of FGD	• Brief overview of the study objective • Provide information about the process, time and breaks • Distribute name tags	"We are talking to you to learn about the unsafe behaviours among scaffolders during the scaffolding erection task.
Basic guidelines	• Keep personal stories "in the room" • One person talks at a time. • Everyone has the right to talk. • Everybody has the right to pass on a question.	–
Opening questions	• Ice breaking to put the group at ease.	–
Focused topics	• Key questions for the focus group • Alert and cue participants to share relevant experiences and information that may not have been included in the answers to the key questions.	• Document review on the existing work process of the scaffold erection task had been conducted. • Researchers presented the findings from document review 1. "We have identified the task sequence involved in erecting a tubular basic static tower with a double lift, according to the document review of the existing work process. Do you agree with these task sequences? Is there any task that we missed out on? Is there any additional information you want to add or suggest?" 2. For each task, what is the standard that needs to be adhered to? 3. "Which of these tasks are related to fall accidents or near misses based on your work experience or accident investigation?" 3. "Why can the tasks stated lead to fall accidents or near misses?" 4. "How these tasks can lead to fall?" "What is the underlying mechanism/ sequential processes?" "Can you explain that?" "Can you give examples by sharing your experience?" 5. What common errors or violations lead to the substandard state of fatigue? The substandard focused on task alterations and behavioural deviation. 6. "What safety actions can be taken to prevent the substandard?" 7. "Is there anything else you want to share that we haven't discussed yet?"
Ending	• Request participants to recommend peers to participate in the subsequent FGD sessions • Thank all for participating.	–

2.5. Content validation with fuzzy delphi method (FDM)

The items generated from FGDs were validated by consulting a group of experts of our intended research scope via the Fuzzy Delphi Method (FDM). The application of the Fuzzy Delphi technique is justified as it overcomes several limitations encountered in the former Delphi technique, such as misinterpreting experts' judgements, time-consuming and necessitates repeat surveys [18].

The FDM applied the fuzzy set theory, which states that each set consisted of fuzzy numbers ranging from 0 to 1. Consequently, the approach minimises the time and cost needed to assess each item in the questionnaire, decreasing the number of surveys and raising the rate at which items are recovered. It also enables experts to express their opinions without bias or ambiguity, improving opinions' consistency and completeness. Finally, the approach obtains consensus from the experts without compromising their initial views [19].

2.6. Panel of experts' selection for FDM

A panel of experts is a collection of individuals with expertise within the study scope. Literature has documented the minimum sample of 10 experts in the Fuzzy Delphi studies to obtain optimal uniformity [20]. In our study, 19 experts in the scaffolding industry were selected via a non-probable, purposive sampling technique, excluding those who had participated in the FDGs earlier. They comprised 6 accident investigation officers from the Department of Occupational Safety and Health Malaysia, 9 trainers from three private scaffolding training centres, and 4 members of the Malaysian Occupational Scaffolding Association (MOSA). The specialists were chosen based on their extensive practical experience and leadership roles in scaffolding safety, as well as the representative of their professional occupational safety and health group [21]Therefore, each chosen expert in the present study fulfilled one of the following criteria: the scaffolder, scaffolding operator (supervisor), industry representative, training provider, or qualified assessor from the registered scaffolding company or the accident investigation officers from DOSH at the state/national level. The selected experts must have at least 5 years of experience in the scaffolding industry.

All experts were approached via phone call to explain the FDM process. Next, their verbal consent was obtained, and the tool was distributed face-to-face individually. All experts were instructed to rate each task sequence (items): "Below are the task sequences and the related standard for erecting a *tubular basic static tower. Please use the Likert scale of 1-5 (1-strongly disagree, 2-disagree, 3-not sure, 4-agree, 5-strongly agree), to rate your agreement level on the suitability of all items included in the following task sequences and also the suitability of all standards that need to be adhered for each task by the scaffolders. Comments and recommendations for improvements are welcomed.*"

2.7. FDM analysis

The FDM analysis was conducted using Microsoft Excel 2019. The study involved two steps: (1) Triangular Fuzzy Numbers (TFN) and (2) Defuzzification. In the first step of TFN, the Likert scores were converted into fuzzy numbers set (n1, n2, n3) ranging from 0 to 1 (Table 2). The linguistic definition in the Likert scale, for example, agree or highly agree, only allowed subjective expert interpretation. As a result, the rating given by the Likert scale alone consisted of uncertainty, subjectivity and ambiguity during the decision-making process [21]. One linguistic scale, hence, needs to be converted into three different fuzzy values, namely the minimum value (n1), the most reasonable value (n2) and the maximum value (n3). These fuzzy values provide an inclusive representative and a more precise expression of the experts' opinions. For example, when a rating of 4 from a Likert scale turned into TFN, it corresponded to the Fuzzy values of 0.4, 0.6, and 0.8, which indicates that the minimum value (n1) of expert agreement on an item is 0.4 or 40 %, the most reason value of expert consensus is 0.6 (60 %), while the maximum value (n3) is 0.8 (80 %) [22].

In the second step of defuzzification, the fuzzy numbers of n1, n2, n3 from each expert for every item were averaged into m1, m2, m3, followed by the defuzzification process (A max) with formula A max = 1/3 * (m1+m2+m3) for each item. The A-max values then guided the item ranking within each construct. The ranking determined the item's acceptability and whether to retain or discard it based on its importance level. After that, the Threshold value (d) for each item was generated with the formula $(d) = \sqrt{1/3\,[(m1-n1)^2 + (m2-n2)^2 + (m3-n3)^2]}$, followed by an average (d) from each expert for every item. The sum of this average (d) was produced for every construct, finally resulting in the d-construct via the formula of:

$$\text{d} - \text{construct} = \frac{\textit{sum of average } (d)}{\textit{total experts} * \textit{total items in the construct}}$$

The threshold value of d-construct indicates the selection of a particular construct based on the level of agreement among the experts. When the threshold value is more significant than 0.2, the second round of data collection must be conducted to fulfil the

Table 2
Fuzzy numbers for the 5-point Likert Scale.

Likert Scale Scoring	Linguistic definition	Fuzzy numbers (n1, n2, n3)
5	Highly agree	0.6, 0.8, 1.0
4	Agree	0.4, 0.6, 0.8
3	Moderately/Not sure	0.2, 0.4, 0.6
2	Disagree	0.0, 0.2, 0.4
1	Highly disagree	0.0, 0.0, 0.2

requirement for Fuzzy Delphi. The d-construct must not exceed 0.2 to obtain expert agreement and acceptability for the construct [23]. Nevertheless, the mathematical concept in FDM is considered a three-decimal-point number for item acceptance because of the minute value of fuzzy numbers evaluation, which ranges from 0 to 0.99999. As a result, in precision, the d value of $\leq$0.299 symbolises the expert agreement achieved for a particular item. Otherwise, the second round of the survey and FDM will be necessary [24].

A tool is considered valid and acceptable when FDM analysis adheres to three main prerequisites; firstly, the experts' consensus for each construct is fulfilled by a threshold value (d) $\leq$ 0.2. Secondly, the experts' consensus for each item is fulfilled at 75 %, while the third prerequisite aims to rank the items using average fuzzy numbers [21]. Items with lower ranks need to be discarded. In addition to retaining the items based on these three prerequisites, little modification was made to them based on the experts' recommendations without changing their nature and objective.

3. Results

In the FGD, we identified qualitatively from four distinctive groups of scaffolding experts that following work fatigue, scaffolders are more likely to deviate their behaviours towards work activities that require lower work effort. However, they entailed a high risk of errors. Table 3 represents the sample characteristics of all participants recruited in the FGDs. Most participants were aged 30–40 (53.3 %) and were male (86.7 %). Malay ethnic (80 %), with the job position of certified scaffolder (40 %) and with field experience of at least 5 years (56.7 %).

Fig. 1 elaborates on all input generated from the FGDs regarding the erection of a tubular basic static scaffold tower with two lifts, including the phase, task sequence, standards for each task, and common errors and violations in terms of behavioural-related task alteration that lead to substandard while fatigue.

Following the generation of output from the FGDs, the content was rated by the panel of experts for validation purposes. The expert demographic characteristics are described in Table 4. They are all from the Klang Valley area; the majority of them were male and consisted of 10 training providers, 6 investigation officers, and 3 administrative representatives of the scaffolding company. Almost two-thirds of the experts have more than 10 years of experience in this expert field of study.

In the FDM analysis, there was a total of 7 constructs and 50 items being generated from the focal group discussion (Table 4), namely construct Instruction (I) 3 items, Preparation (P) 3 items, Foundation (F) 10 items, First Lift (FL) 8 items, Working Platform (WP) 7 items, Guardrails (G) 5 items and Second Lift (SL) 14 items. All the 50 items within the 7 constructs had average Likert scoring ranging from 3.8 to 5 on the scale of agree to agree highly.

All constructs and items adhered to the three main prerequisites in the analysis. The experts' consensus for each construct was fulfilled whereby all the 7 constructs (100 %) had threshold value (d) $\leq$ 0.2; thus, all constructs were accepted. Furthermore, the experts' consensus for each of the 50 items (100 %) achieved an expert agreement of 75 % and above. None of the items were discarded. Three items (6 %) documented the lowest expert agreement, 79 %; seven items (14 %) documented expert agreement of 95 %; while the rest of the items (80 %) achieved maximum expert agreement of 100 %. As a result, all items in all constructs were accepted and retained. Average fuzzy numbers ranked all items in each construct. The highest average fuzzy number documented was 0.8, while the lowest was 0.588. Nevertheless, none of the items with the lowest ranking were discarded as all items perfectly fulfilled the second prerequisite and obtained excellent experts' agreement. The whole findings are summarised in Table 5. Figs. 2–4 demonstrate the graphical illustration of the FDM findings.

Table 3
Demographic characteristics of the FGD participants (n = 30).

Characteristics	n (%)
Age (years)	
20–30	6 (20.0)
30–40	16 (53.3)
40–50	6 (20.0)
>50	2(6.7)
Gender	
Male	26 (86.7)
Female	4 (13.3)
Ethnic	
Malay	24 (80.0)
Non-Malay	6 (20.0)
Roles	
Certified scaffolders	12(40.0)
Competent scaffolding operator	6 (20.0)
DOSH investigation officers	6 (20.0)
Member of MOSA	6 (20.0)
Field experience (years)	
<5	13(43.3)
At least 5	17 (56.7)

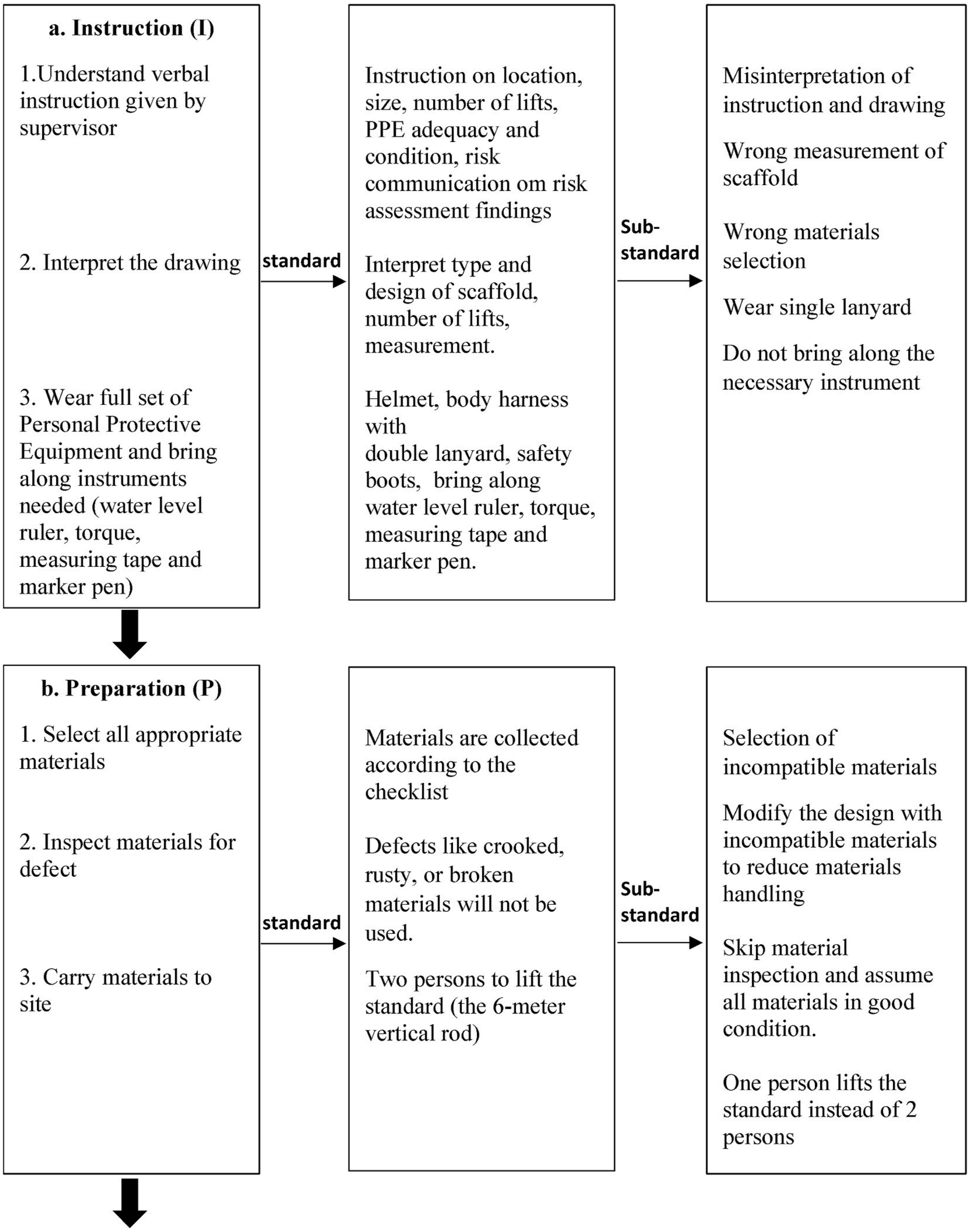

Fig. 1. The erection of a tubular basic static tower with 2 lifts: the task sequences, standard and safety behavioural deviation leading to substandard.

4. Discussion

Safety concerns in the construction sector persist and evolve over time. This study introduced a qualitative method to collect insightful and information-rich data from the ground expert, which was reliable for developing a task sequence protocol in scaffolding safety practice. The use of the FDM technique has affirmed that the experts accepted the findings generated from all FDGs without prejudice.

Globally, approximately 65 % of the construction sector's workforce operates various scaffolds. Meanwhile, scaffolding errors or violations continue to be the second most common violations cited by the Occupational Safety and Health Administration (OSHA).

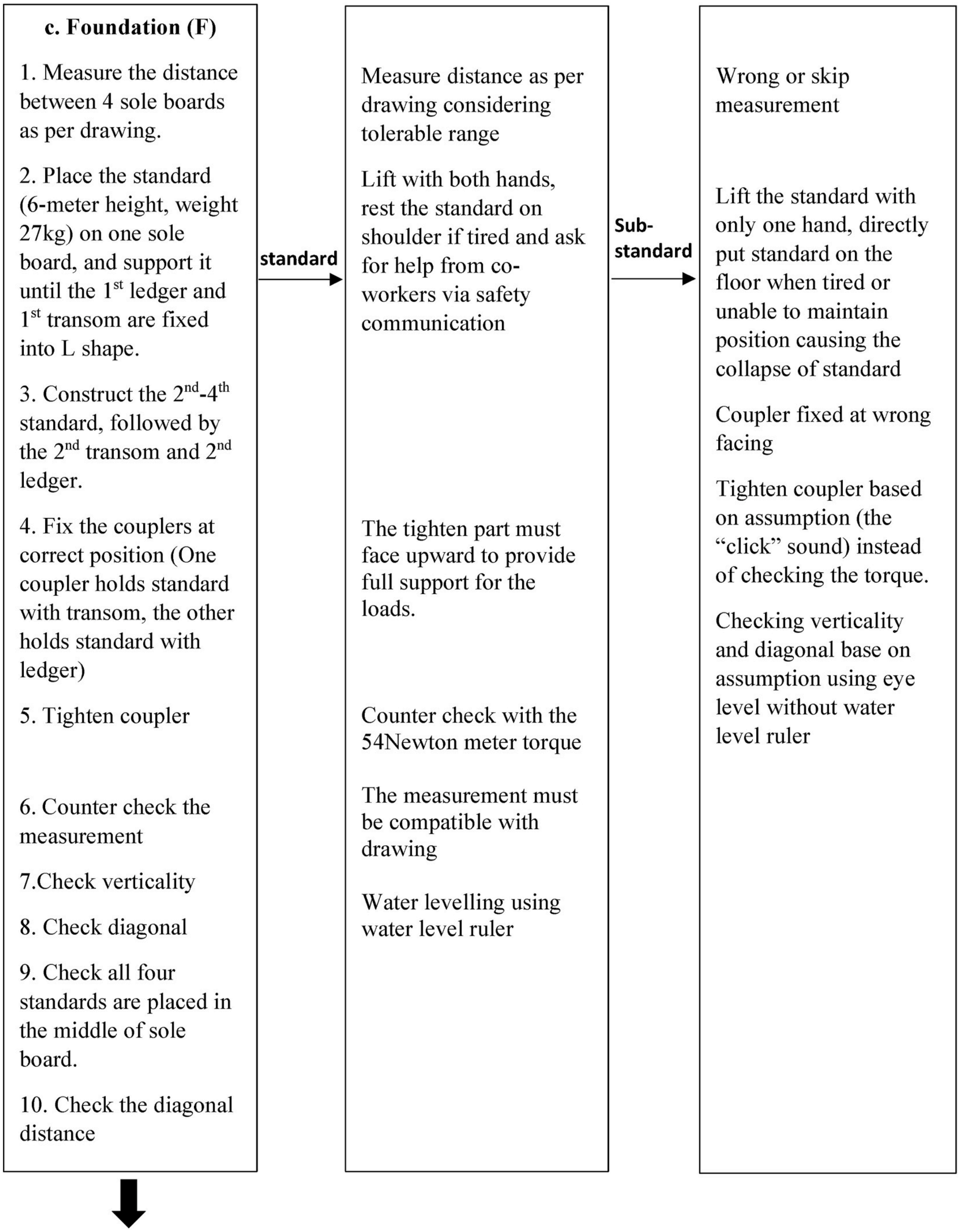

Fig. 1. (*continued*).

Construction managers frequently need to pay more attention to temporary infrastructure, and scaffolds are the most often utilised temporary structure [25]. In addition to providing a working platform and structural support, scaffolding can collapse or fall and cause serious injuries or even fatalities involving workers, contractors and public [26]. Therefore, this study demonstrated the objective of identifying and validating the high-risk task sequences during a scaffold erection, and the possible deviation from the standard protocol led to substandard by obtaining experts' consensus.

Human factors and mishandling are often cited as the aggravating factors of scaffolding accidents caused by safety violations [6]. Therefore, our study has qualitatively probed the issue of work fatigue, which can be the precursor of substandard practice via safety behaviour deviation at any level of scaffolding tasks. The comprehensive focal group discussions have adequately recruited both the scaffolding management experts and the layperson experts, who are the leading players in the industry. As a result, this study provided

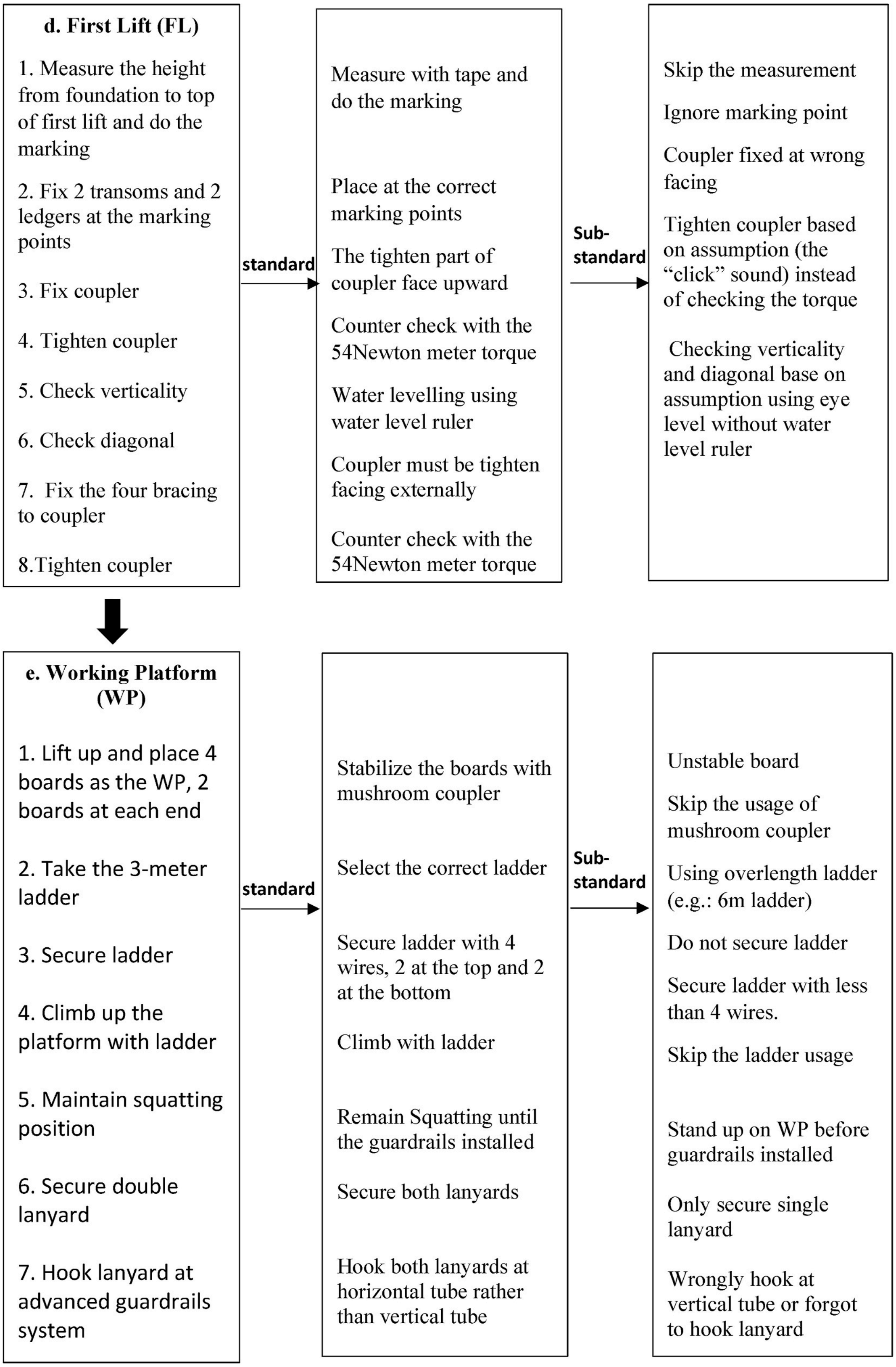

Fig. 1. (*continued*).

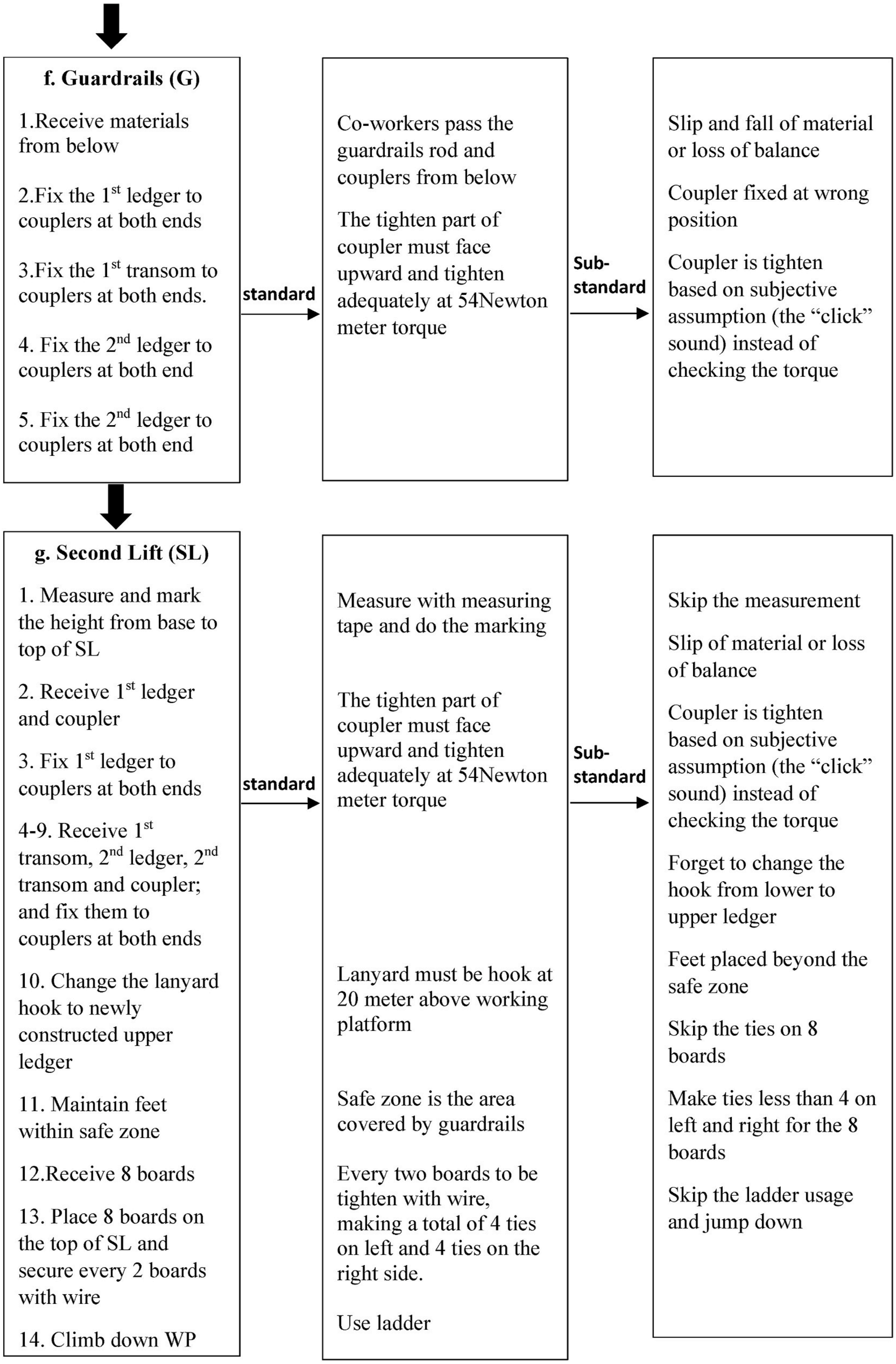

Fig. 1. (*continued*).

Table 4
The demographic characteristics of experts (n = 19).

Demographic variables	n (%)
Gender	
Male	17 (89.5)
Female	2 (10.5)
Age group (years)	
20–30	2 (10.5)
30–40	9 (47.4)
40–50	6 (31.6)
50–60	2 (10.5)
Educational level	
Diploma and degree	11 (57.9)
Master degree	6 (31.6)
PhD	2 (10.5)
Field of expert	
Administrative representative of scaffolding company	3 (15.8)
Qualified training providers	10 (52.6)
Investigation officers, DOSH	6 (31.6)
Experience in the scaffolding industry (year)	
5–10	7 (36.8)
More than 10	12 (63.2)

a thorough understanding of all 50 relevant task sequences involved in erecting the metal tubular basic static scaffold. The most popular and conventional type of scaffold utilised in the building sector is the metal scaffold, which consists of several components, including couplers, tubes, and metal braces fastened together [27]. Furthermore, metal scaffold erection is a known labour-intensive task and thus prone to work fatigue [28].

From each task sequence, we pinpointed standards and the substandards that resulted from task alteration and safe behavioural deviation due to work fatigue. This qualitative exploration is relevant because comprehending the incident causation is crucial as safety measures implemented at the regulatory, industry, organisational, or individual worker levels are influenced by comprehensive understandings or presumptions on the basic mechanisms behind safety occurrences [29]. It was observed that incident causation models have evolved from the simplistic characterisation of a sequence of steps which represented all operating factors in the entire work system [30]. The proper scaffolding erection and disassembly procedures are among the elements that have a significant correlation to an overall good safety rating [31]. Literature documented scaffold workers typically neglected these task sequences to expedite their work [25]. In addition, the safety of scaffolders can only be ensured by erecting and disassembling scaffolds adhering to the proper and standardised order [32]. In our study, almost all task sequences were assigned equally essential rankings. None of the items was discarded. Therefore, this preliminary input on the systematic task sequences during tubular scaffold erection will significantly enhance the safety-related theoretical framework for the incident investigation and risk assessment of human factors in the scaffolding industry in the future. As an impact, these inputs allow safety communication and understanding to be more efficient in the scaffolding industry.

Workers' unsafe behaviour was identified as one of the most prominent and direct causes of construction site accidents [33,34]. Thus, understanding its associated mechanisms is essential for developing targeted interventions. The respondents of FGDs have collectively realised that the unsafe behaviour and substandard practices for each task sequence in the tubular essential static tower scaffold erection could be attributed to physical or cognitive mechanisms. For example, slips and falls of material or loss of balance reflect physical mechanisms, while skipping tasks or modifying specific tasks, skipping the measurement or wearing a single lanyard rather than a double lanyard reflects the cognitive mechanism. The phenomenon of cognitive mechanism corresponded to the conceptualisation that human behaviour is the product of cognition. In contrast, abnormal behaviours, including unsafe behaviour, are the consequence of cognitive failure, as proposed by Hollnagel in 1998 [35]. Cognitive failure is "cognitive-based errors on simple tasks that a person should normally be able to complete without fault" [36]. Literature has documented malfunction in the underlying cognitive processes when dangerous behaviour occurs [37]. On the other hand, many research articles have also been published on the association between diminished cognitive functions and fatigue [38].

To the best of our knowledge, when most of the previous studies have primarily focused on the causes of scaffolding-related accidents, this study is among the first qualitative studies investigating unsafe behaviour as the human factor in the process of scaffold erection tasks. Additionally, employing the Fuzzy Delphi method to validate the findings generated from the FGDs has addressed all uncertainty in decision-making, judgment and consensus about hierarchical task analysis of the tubular metal scaffold erection. The FDM technique successfully and quantitatively merged all experts' opinions, which might vary due to different levels of knowledge, skill and experience among all experts. The study was also conducted at minimal cost. Nevertheless, this study was subjected to several limitations. The expert's selection was based on purposive sampling, depending on volunteers and availability. The study involves tedious processes, especially the planning and arrangement of multiple face-to-face sessions, which are time-consuming and may vary depending on the type and size of scaffolds. Our study only explored tasks involved in erecting the tubular basic static towers. Therefore, investigation of other types of scaffolds, such as modular and suspended types, should be considered in further research.

Table 5
Fuzzy Delphi Analysis: summary of all three prerequisite.

Construct/items	Average Likert Score	Threshold value, (d) construct ≤0.2	Percentage of Expert Consensus (%)	Average of Fuzzy Number	Rank-ing	Verdict
I (Instruction)		0.1228				Acceptable
I 1	4.7		100	0.747	1	Retained
I 2	4.7		100	0.747	1	Retained
I 3	4.7		100	0.747	1	Retained
P (Preparation)		0.1228				Acceptable
P 1	4.7		100	0.747	1	Retained
P 2	4.7		100	0.747	1	Retained
P 3	4.7		100	0.747	1	Retained
F (Foundation)		0.0004				Acceptable
F 1	4.7		100	0.747	3	Retained
F 2	4.7		100	0.747	3	Retained
F 3	4.7		100	0.747	3	Retained
F 4	4.7		100	0.747	3	Retained
F 5	4.7		100	0.768	2	Retained
F 6	4.7		100	0.768	2	Retained
F 7	4.7		95	0.747	3	Retained
F 8	4.7		95	0.747	3	Retained
F 9	5.0		100	0.800	1	Retained
F 10	4.7		100	0.768	2	Retained
FL (First Lift)		0.0004				Acceptable
FL 1	4.7		95	0.768	2	Retained
FL 2	4.0		100	0.600	4	Retained
FL 3	3.8		79	0.695	3	Retained
FL 4	4.7		100	0.768	2	Retained
FL 5	4.7		95	0.768	2	Retained
FL 6	5.0		100	0.768	2	Retained
FL 7	5.0		100	0.800	1	Retained
FL 8	5.0		100	0.800	1	Retained
Working Platform (WP)		0.0003				Acceptable
WP 1	4.7		100	0.747	2	Retained
WP 2	5.0		95	0.800	1	Retained
WP 3	5.0		100	0.800	1	Retained
WP 4	5.0		100	0.800	1	Retained
WP 5	5.0		100	0.800	1	Retained
WP 6	5.0		100	0.800	1	Retained
WP 7	5.0		100	0.800	1	Retained
Guardrails (G)		0.0005				Acceptable
G 1	5.0		100	0.800	1	Retained
G 2	5.0		100	0.800	1	Retained
G 3	5.0		100	0.800	1	Retained
G 4	4.7		100	0.747	2	Retained
G 5	4.7		100	0.747	2	Retained
Second Lift (SL)		0.0002				Acceptable
SL 1	4.7		100	0.747	2	Retained
SL 2	4.7		95	0.747	2	Retained
SL 3	4.0		100	0.600	3	Retained
SL 4	3.8		79	0.558	4	Retained
SL 5	4.7		100	0.747	2	Retained
SL 6	4.7		100	0.747	2	Retained
SL 7	4.7		100	0.747	2	Retained
SL 8	5.0		100	0.800	1	Retained
SL 9	5.0		100	0.800	1	Retained
SL 10	5.0		100	0.800	1	Retained
SL 11	4.7		95	0.747	2	Retained
SL 12	4.0		100	0.600	3	Retained
SL 13	3.8		79	0.558	4	Retained
SL 14	4.7		100	0.747	2	Retained

5. Conclusion

This study qualitatively identified the complete task sequences involved in erecting the most commonly used tubular primary static scaffold tower. We have also highlighted the standards required for each task and the unsafe behavioural risks causing deviation towards substandard. The output generated had undergone the Fuzzy Delphi validation method and confirmed the 7 constructs and 50 items involved in this scaffolding task. Since unsafe behaviour was responsible for over 80 % of the construction mishaps, the sub-standard might lead to hazardous impacts, significant fall accidents and collapsed scaffolds; our tool will help guide the protocol

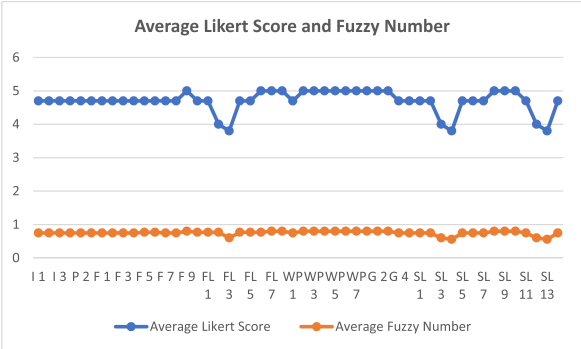

Fig. 2. The average Likert score and average Fuzzy number for all items.

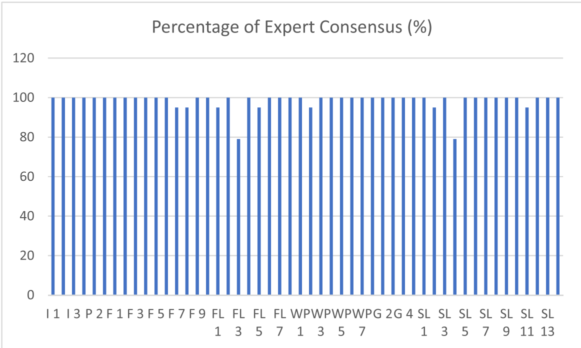

Fig. 3. The expert consensus for all items.

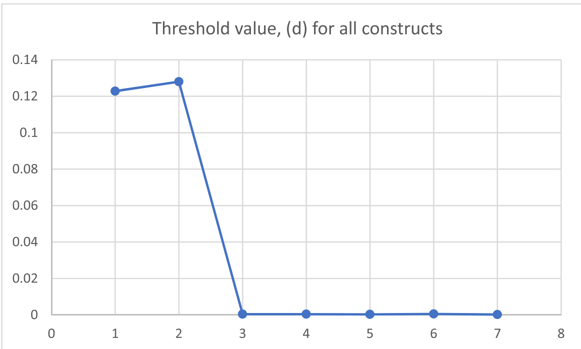

Fig. 4. The d-construct for all 7 constructs, all below 0.2.

development related to scaffolding safety management practice.

- In terms of the theoretical implication, this study affirmed empirical evidence on the high-risk scaffold erection duties associated with fall accidents. This enrichment in the body of knowledge will aid in the behavioural risk assessment and on-site evaluation of safety performance.
- Practically, due to the lack of previous studies, this preliminary data is valuable for identifying obstacles and opportunities for future large-scale implementation of national safety performance evaluation by our regulatory body, the Department of Safety and Health, Ministry of Human Resources Malaysia.
- Findings disseminated from this study can be utilised to yield tremendous interventions to safeguard scaffolders against unsafe behaviour and harm and strengthen the occupational safety and health system in Malaysia.
- With an enhanced understanding of the mechanism behind the substandard, targeted measures and appropriate managerial techniques can be proposed to cope with scaffolders' unsafe behaviours.

Funding

This study receives funding support from the University Kebangsaan Malaysia.

Declaration of generative AI in scientific writing

None.

Ethical statement

The ethical clearance and approval have been obtained from the Research Ethics Committee, Secretariat of Research and Innovation from the Faculty of Medicine, University Kebangsaan Malaysia (JEP 2022–604). All participants were provided with written informed consent before the study was conducted. No personal information was disclosed in all published materials.

Data availability statement

Data used in this manuscript will be made available upon reasonable request.

CRediT authorship contribution statement

Hanizah Mohd Yusoff: Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Pei Pei Heng:** Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Mohamad Ridza Hj Illias:** Validation, Project administration, Investigation. **Saravanan Karrupayah:** Project administration. **Mohd Anis Fadhli:** Project administration, Investigation. **Rozita Hod:** Supervision.

Declaration of competing interest

The authors declared that they have no conflicts of competing interest to this work. We also declared that we do not have any commercial or associative interest that represents a conflict of interest in connection with the work submitted.

All authors declare none of the generative AI was used in scientific writing.

Acknowledgement

We would like to thank the Dean of the Faculty of Medicine, Universiti Kebangsaan Malaysia and the Department of Public Health Medicine, Faculty of Medicine, Universiti Kebangsaan.

Malaysia for permission to conduct this study. We also thank MKRS (Bumi) Sdn. Bhd. for all technical support.

References

[1] S. Ahmed, Causes of accident at construction sites in Bangladesh, Organ. Technol. Manag. Construct. Int. J. 11 (1) (2019) 1933–1951.
[2] N. Zainon, L.S. Chuing, F. Mohd-Rahim, N.M. Aziz, C.W.N.S.C. Wan, A. Pauzi, A preliminary study of health problems among construction workers in Malaysia, J. Survey Construct. Property 9 (1) (2018) 1–8.
[3] N.S. Azmi, E.H. Sukadarin, H.A. Aziz, The performance of safety implementation towards accident occurrence in Malaysia construction industry, Malays. J. Publ. Health Med. 20 (Special1) (2020) 14–22.
[4] A. Olanrewaju, J.S. Khor, C.N. Preece, An investigation into occupational health and safety of scaffolding practices on construction sites in Malaysia, Front. Eng. Built Environ. 2 (1) (2021) 1–21.
[5] S. Winge, E. Albrechtsen, Accident types and barrier failures in the construction industry, Saf. Sci. 105 (2018) 158–166.
[6] N.H. Abas, M.R. Noridan, M.H. Rahmat, N.A. Abas, N.Q. Ibrahim, Causes of accidents involving scaffolding at construction sites, J. Tech. Manag. Bus 7 (1) (2020) 75–86.
[7] T.C. Keng, N.A. Razak, Case Studies on the Safety Management at Construction Site, 2014.
[8] B.H.C. Lee, J.C. Chen, K.W. Fo, Accidents in construction sites: a study on the causes and preventive approaches to mitigate accident rate, INTI journal 1 (3) (2018).
[9] B. Guo, Y. Goh, E. Scheepbouwer, Y. Zou, An ontology of control measures for fall from height in the construction industry, in: Proceedings of the 35th International Symposium on Automation and Robotics in Construction vol. 2018, ISARC 2018, Berlin, Germany, 2018, pp. 20–25.
[10] S.M. Salim, F. I Romli, J. Besar, O.A. Negin, A study on potential physical hazards at construction sites, J. Mech. Eng. (1) (2017) 207–222.
[11] F. Zhang, H. Fleyeh, X. Wang, M. Lu, Construction site accident analysis using text mining and natural language processing techniques, Autom. ConStruct. 99 (2019) 238–248.
[12] Z. Li, R. Mao, Q.F. Meng, X. Hu, H.X. Li, Exploring precursors of construction accidents in China: a grounded theory approach, Int. J. Environ. Res. Publ. Health 18 (2) (2021) 410.
[13] D.W. Stewart, P.N. Shamdasani, Focus Groups: Theory and Practice, vol. 20, Sage publications, 2014.
[14] G.R.J. Hockey, Compensatory control in the regulation of human performance under stress and high workload: a cognitive-energetical framework, Biol. Psychol. 45 (1–3) (1997) 73–93.
[15] J.W. Creswell, C.N. Poth, Qualitative Inquiry and Research Design: Choosing Among Five Approaches, Sage publications, 2016.
[16] L.A. Palinkas, S.M. Horwitz, C.A. Green, J.P. Wisdom, N. Duan, K. Hoagwood, Purposeful sampling for qualitative data collection and analysis in mixed method implementation research, Adm. Pol. Ment. Health 42 (2015) 533–544.

[17] G.O. Boateng, T.B. Neilands, E.A. Frongillo, S.L. Young, Best practices for developing and validating scales for health, social, and behavioral research: a primer, Front. Public Health 6 (2018) 366616.
[18] A.P. Sánchez-Lezama, J. Cavazos-Arroyo, C. Albavera-Hernández, Applying the Fuzzy Delphi Method for determining socio-ecological factors that influence adherence to mammography screening in rural areas of Mexico, Cad. Saúde Pública 30 (2014) 245–258.
[19] N.M. Noh, S.H. Abd Razak, N. Alias, S. Siraj, M.R.M. Jamil, Z. Hussin, Usage of Facebook: the future impact of curriculum implementation on students in Malaysia, Procedia. Soc. Behav. Sci. 103 (2013) 1261–1270.
[20] M. Adler, E. Ziglio, Gazing into the Oracle: the Delphi Method and its Application to Social Policy and Public Health, Jessica Kingsley Publishers, 1996.
[21] S.K. Manakandan, I. Rosnah, R. Mohd, R. Priya, Pesticide applicators questionnaire content validation: a fuzzy delphi method, Med. J. Malaysia 72 (4) (2017) 228–235.
[22] K. Ismail, R. Ishak, S.H. Kamaruddin, Development of professional learning communities model using fuzzy delphi approach, TEM J. 10 (2) (2021) 872.
[23] S.S. McMillan, M. King, M.P. Tully, How to use the nominal group and Delphi techniques, Int. J. Clin. Pharm. 38 (2016) 655–662.
[24] C.-T. Chen, Extensions of the TOPSIS for group decision-making under fuzzy environment, Fuzzy Set Syst. 114 (1) (2000) 1–9.
[25] S. Abbaszadeh, M. Jahangiri, M. Abbasi, S. Banaee, P. Farhadi, Risk assessment of probable human errors in the scaffold erection and dismantling procedure: a fuzzy approach, Int. J. Occup. Saf. Ergon. 28 (3) (2022) 1773–1778.
[26] M.I.P. Harahap, I. Othman, N.A.M. Dinata, Investigation on the nature of safety rule violations in high-rise construction projects, J. Adv. Res. Appl. Sci. Eng. Technol. 42 (2) (2024) 164–179.
[27] V. Viunov, Comparison of Scaffolding Systems in Finland and in Russia, 2011.
[28] B. Shao, Z. Hu, Q. Liu, S. Chen, W. He, Fatal accident patterns of building construction activities in China, Saf. Sci. 111 (2019) 253–263.
[29] H. Lingard, T. Cooke, G. Zelic, J. Harley, A qualitative analysis of crane safety incident causation in the Australian construction industry, Saf. Sci. 133 (2021) 105028.
[30] P. Katsakiori, G. Sakellaropoulos, E. Manatakis, Towards an evaluation of accident investigation methods in terms of their alignment with accident causation models, Saf. Sci. 47 (7) (2009) 1007–1015.
[31] K.M. Halperin, M. McCann, An evaluation of scaffold safety at construction sites, J. Saf. Res. 35 (2) (2004) 141–150.
[32] E. Błazik-Borowa, J. Szer, The analysis of the stages of scaffolding "life" with regard to the decrease in the hazard at building works, Arch. Civ. Mech. Eng. 15 (2) (2015) 516–524.
[33] C. He, B. McCabe, G. Jia, J. Sun, Effects of safety climate and safety behavior on safety outcomes between supervisors and construction workers, J. Construct. Eng. Manag. 146 (1) (2020) 04019092.
[34] J. Choi, B. Gu, S. Chin, J.-S. Lee, Machine learning predictive model based on national data for fatal accidents of construction workers, Autom. ConStruct. 110 (2020) 102974.
[35] E. Hollnagel, Cognitive Reliability and Error Analysis Method (CREAM), Elsevier, 1998.
[36] S.A. Simpson, E.J. Wadsworth, S.C. Moss, A.P. Smith, Minor injuries, cognitive failures and accidents at work: incidence and associated features, Occup. Med. 55 (2) (2005) 99–108.
[37] D. Fang, C. Zhao, M. Zhang, A cognitive model of construction workers' unsafe behaviors, J. Construct. Eng. Manag. 142 (9) (2016) 04016039.
[38] H.M. Abd-Elfattah, F.H. Abdelazeim, S. Elshennawy, Physical and cognitive consequences of fatigue: a review, J. Adv. Res. 6 (3) (2015) 351–358.