Examining the OHS of Green Building Construction Projects: A Hybrid Fuzzy-based Approach

Abstract

Green buildings (GBs) have been adopted mainly to minimize the negative effects of the design, construction, and building operations on the environment. However, the GB-related activities have been found to be jeopardizing the occupational health and safety (OHS) of related projects, thereby debilitating the safety and health of respective crew members. Despite such vital issues, no study has been conducted yet to investigate the safety issues associated with GB construction projects in developing countries, where the inclination towards the adoption of GB is on the rise. Using this as a point of departure, the present study assesses the safety risks caused by GB projects with the use of a fuzzy-based RAM, through the lenses of the experts in Kazakhstan. The proposed RAM integrates Fuzzy Delphi Method (FDM) and Fuzzy Best Worst Method (FBWM). The FDM results clearly indicated that sustainable buildings continue to endanger the safety and health of respective workers, while fall from height and overexertion are found to be the leading causes of GB-associated risks using the FBWM. Despite the research limitations, this study prudently assessed the OHS-related risks to the LEED-based (the most widely used certification in the country) projects, and offered a fertile ground for future research to be conducted in developing economy settings. The findings indicated that the construction key players need to pay more attention to the riskiest GB-related hazards by investing their efforts in making the built environment truly sustainable in a not-too-distant future, which can improve the well-being of workers involved.

Keywords: Sustainable construction; Occupational health and safety; Construction safety; Fuzzy modeling; Multi-criteria decision-making methods.

1. INTRODUCTION

Shifting towards sustainably performing (greener) construction industry, which aims to combat any environmental, economic, and social harms caused by the built environment (Kibert, 2016), has been a priority issue for most countries (Durdyev, Ismail, Ihtiyar, Abu Bakar, & Darko, 2018; Rock et al., 2019; Tokbolat, Karaca, Durdyev, & Calay, 2019). This is evidenced by a significant growth in green construction projects across the globe (Petrullo, Jones, Morton, & Lorenz, 2018), which is anticipated to continue as the majority of the industry practitioners have expressed their willingness to do their projects green (Petrullo et al., 2018).

Kazakhstan is no exception, as the number of green-certified projects – which are mainly in Astana and Almaty – have almost doubled during the last two-year period (they increased from 39 in 2018 (Tokbolat et al., 2019) to 73 in July 2020 (The Green Building Information Gateway, n.d.)). This is a clear evidence of the country's shift towards GBs after the Soviet Union period, as it is worth mentioning that the buildings of that period do not meet the GB imperatives from all environmental, economic, and social perspectives (Tokbolat, Karaca, Durdyev, Nazipov, & Aidyngaliyev, 2018).

The benefits of GBs have been a key subject of various reported studies (Kibert, 2016). Some of those benefits are significant improvement in productivity due to the improvement of indoor environment quality (Durdyev, Ismail, Ihtiyar, et al., 2018; Ries, Bilec, Gokhan, & Needy, 2006), environmental protection (Tokbolat et al., 2018), and increased property values (Tabatabaee, Mahdiyar, Durdyev, Mohandes, & Ismail, 2019). From a business perspective, a report recently published by (Petrullo et al., 2018) shows that GBs offer a considerable amount of savings in operational cost (8%) and increase the value of the asset (7%), while improved dweller's well-being has also been reported as the most significant social impact of GBs. To enable greening of the construction industry or, in other words, to realize all the above-mentioned benefits, there is a need for experts (e.g., architects, contractors, and suppliers) with new skills and up-to-date knowledge (Green, 2011). Thus, this has been reported to be another economic contribution as a driver for new job opportunities (Karakhan & Gambatese, 2017b; World Green Building Council, 2017).

The construction industry, unfortunately, has gained a negative reputation due to its poor safety records, hence being reported as one of the hazardous industries (Durdyev, Mohamed, Lay, & Ismail, 2017). Thus, Occupational Health and Safety (OHS) has attracted increasing attention from the academic community working on construction-related issues (Karakhan & Gambatese, 2017b; Mohandes et al., 2020). Despite the advancements in construction technology and automation, the industry continues to intensely rely on its workforce, which makes the industry to be known as a labor-intensive one (Durdyev, Ismail, & Kandymov, 2018). Thus, construction workforce plays a significant role in greening the built environment. Intensive reliance on the construction workforce, on the other hand, brings another challenge for the decision makers, particularly in the design and construction phases of GBs. Familiarity with green technology, material, and processes of the construction workforce needs to be assessed to ensure that the construction operations are executed under the OHS standards.

Review of the GB context reveals that there is an inconsistency between what GB imperatives encourage and what is happening on real-life construction sites. While one of the GB benefits is to enhance health and safety of both dwellers (Durdyev, Zavadskas, Thurnell, Banaitis, & Ihtiyar, 2018) and construction stakeholders (Hinze, Godfrey, & Sullivan, 2013), it has been widely reported that the OHS of those who are involved in the delivery of GB dwellings is overlooked (Dewlaney, Hallowell, & Fortunato III, 2012; Karakhan & Gambatese, 2017a). However, a building can only be considered as truly sustainable if the OHS of the workforce is addressed at the highest level (Rajendran, Gambatese, & Behm, 2009). (Rajendran et al., 2009) concluded that workforce safety is not considered by the major sustainable rating tools. This is a clear indication of industry's primary focus, which is the creation of resource-efficient dwelling and productivity of its dwellers. For example, Leadership in Energy and Environmental Design (LEED) identified and introduced the projects with more injuries recorded, after the investigation of 74 projects by (Rajendran et al., 2009). Fortunato III, Hallowell, Behm, and Dewlaney (2012) provided another supportive evidence that the design and delivery of sustainable projects create more safety risks. They reported that the most significant problem (in addition to the traditional construction OHS risks) is the unfamiliarity of the "traditional" workforce with the environment they are required to work in. Similarly, Mulhern (2008) reported safety issues associated with green roof installation. Fall hazards (due to the unfamiliarity with working at height) is the major issue for landscaping contractors. In addition, handling the required materials and equipment is another safety issue they have come across. A study conducted by (Karakhan & Gambatese, 2017a) reported that 12 out of 54 credits (Construction Waste Management and Heat Island Effect) – to achieve the LEED certification – generate unacceptable risks to worker's safety. Thus, the review of the literature suggests that – in addition to conventional projects – there are significant safety issues related to the design and construction of GBs (Fortunato III et al., 2012). This implies that to make GB projects truly sustainable, special attention is required in terms of improving their OHS performance. In another study undertaken by Hwang, Shan, and Phuah (2018) in Singapore, a comparative study between the safety issues associated the sustainable-oriented construction project and the traditional-built project was undertaken; it was witnessed that the sustainable-based project led to the emergence of more severe risks. Zhang and Mohandes (2020) also delved into the safety issues associated with green-based projects in Hong Kong using Z-numbers-based theories; it was also seen that many of the risks arising from the related projects were of significant magnitude. The findings from all the studies mentioned above stress the fact that the adoption of sustainable construction project leads to overshadowing the safety and health of involved crew members; thus, there is enough rooms for conducting more research on this fertile ground.

With bearing the above-mentioned issues in mind, there has been no research delving into the safety assessment of the risks that pose dangers to respective workers in developing countries. In fact, to the best of the authors' knowledge, this study is the first attempt to investigate the OHS issues related to the sustainable construction projects in the context of a developing county. The lack of such investigations not only overshadows the adoption of further sustainability within the buildings, but also debilitates the OHS of the respective working environment for the involved crew members. Thus, using Kazakhstan (due to its country- and industry-specific environment) as a case study, the present study aims at answering the following research questions:

- How can all the critical safety risks posing danger to the respective workers be determined?
- What are the magnitudes of the identified critical safety risks, for which the observed (or statistical) data have not been reported yet?
- What would be the suitable strategies for evaluating the analyzed critical safety risks?

To tackle the shortcomings mentioned above, this study aims at meticulously investigating the OHS of GB projects by undertaking the following objectives, through the proposed fuzzy-based RAM:

- To thoroughly review the context on the subject and identify potential safety risks threatening the well-being of the relative workers, and accordingly retain the critical ones using the Fuzzy Delphi Method (FDM).
- To analyze the identified safety risks using a fuzzy-reference-based optimization algorithm (i.e., FBWM).
- To propose the suitable evaluation strategies for the analyzed safety risks through the utilization of risk matrix.

The rest of the papers is structured as follows. Section 2 elucidates the steps involved in the adopted methodology to achieve the mentioned objectives. Sections 3 and 4 elaborate the results obtained and the validation, respectively. The discussions of the attained results are provided in Section 5, while Section 6 elaborates the conclusion as well as the future work to be done.

2. RESEARCH METHODOLOGY

The present section proposes a framework applicable to realizing the objectives of a holistic RAM related to the GB construction workers. The framework involves three main stages (see Fig. 1): 1) Identification of the relevant risk factors including the sub-factors under each factor, 2) Analyzing both factors and sub-factors, and 3) Evaluating the sub-factors on the basis of their magnitudes. In the following, each stage mentioned above is elaborated; however, prior to that, a brief explanations of the procedures involved in the related data collection is provided.

2.1 Data Collection Procedures

In order to fully and prudently achieve the objectives specified for the research, the involvement of experienced and knowledgeable experts in this study was a must from the very beginning. In doing so, three criteria were taken into account during the selection of qualified experts concerning the scope of this study as follows:

- They had to have at least 10 years of working experience by being involved in any related activities on construction sites.
- They had to have at least five years of relative experience to the sustainable construction projects. In other words, they had to be involved in either the design stage, construction stage, or post-construction stage (i.e., operation and maintenance) of the green-based building projects.
- They had to obtain at least undergraduate degree in civil engineering, architecture, and construction engineering and management.

Considering the criteria specified above, fifteen experts were deemed to be qualified for the involvement in this study. Table 1 illustrates the profile of the qualified experts selected for this research. As can be seen, they were involved throughout the different steps of the methodology adopted in this research (either interview or filling out the designed surveys).

Having that said, in order to further validate the results obtain, a focus-group-discussion approach was undertaken. To this purpose, the focus-group-discussion approach with the qualified experts were taken into account. To this end, five qualified experts from two construction firms, who met the criteria specified for the selection of experts, were interviewed using the mentioned approach (they were different from those 15 selected for the main round of research). It should be noted that owing to the outbreak of COVID-19, FGD was held online using ZOOM. The session was started with a brief introduction to the objectives specified for the research, followed by discussing the results obtained from the research in the second section. Then, in the second session, the invited experts were asked to provide their views regarding the precariousness of the identified risks based on their experiences. Table 2 shows the profile of the respective experts involved in the held discussion.

Table 1. Profiles of the experts who participated throughout the study

Code	**Position**	**Years of relative experience**	**Years of overall experience**	**Degree**	**Involvement in the study**		
					FDM (interview)	**FDM (survey)**	**FBWM**
EXP1	Safety inspector	5 - 10	10 -15	B.Eng. in Civil	■	■	■
EXP2	Academician	5 - 10	10 -15	Master’s in const. manag.	■	■	■
EXP3	Site supervisor	5 -10	10 -15	B.Eng. in Civil	—	■	■
EXP4	Safety inspector	5 - 10	10 -15	Bachelor	—	■	■
EXP5	Site supervisor	5 - 10	10 -15	B.Eng. in Civil	—	■	■
EXP6	Academician	5 - 10	10 -15	Master’s in const. manag.	■	■	■
EXP7	Academician	5 - 10	10 -15	Master’s in const. manag.	■	■	■
EXP8	Site supervisor	5 - 10	10 -15	B.Eng. in Civil	■	■	■
EXP9	Site supervisor	10 - 15	>15	B.Eng. in Civil	■	■	■
EXP10	Site supervisor	5 - 10	10 - 15	B.Eng. in Civil	—	■	■
EXP11	Safety inspector	5 - 10	10 - 15	Master’s in const. manag.	■	■	■
EXP12	Site supervisor	5 - 10	10 - 15	B.Eng. in Civil	■	■	■
EXP13	Civil Engineer	5 - 10	10 - 15	B.Eng. in Civil	■	■	■
EXP14	Project manager	5 - 10	> 15	B.Eng. in Civil	—	■	■

EXP15	Academician	5 - 10	10 - 15	Master's in Civil	—	■	■

Note: ■ shows that the relative expert was involved in the corresponding stage of the study, while — shows that the relative expert did not participate in the corresponding stage

Table 2. Profile of experts involved in the held focus-group-discussion-based session

Code	Position	Years of relative experience	Years of overall experience	Degree
EXP1	OHS officer	5 – 10	15 – 20	B.Eng. in Civil
EXP2	Contractor	5 – 10	25 – 30	B.Eng. in Civil
EXP3	Sub-contractor	5 – 10	15 – 20	B.Eng. in Civil
EXP4	OHS officer	5 – 10	15 – 20	B.Eng. in Civil
EXP5	Project manager	5 – 10	15 – 20	B. Mg. in Project Management

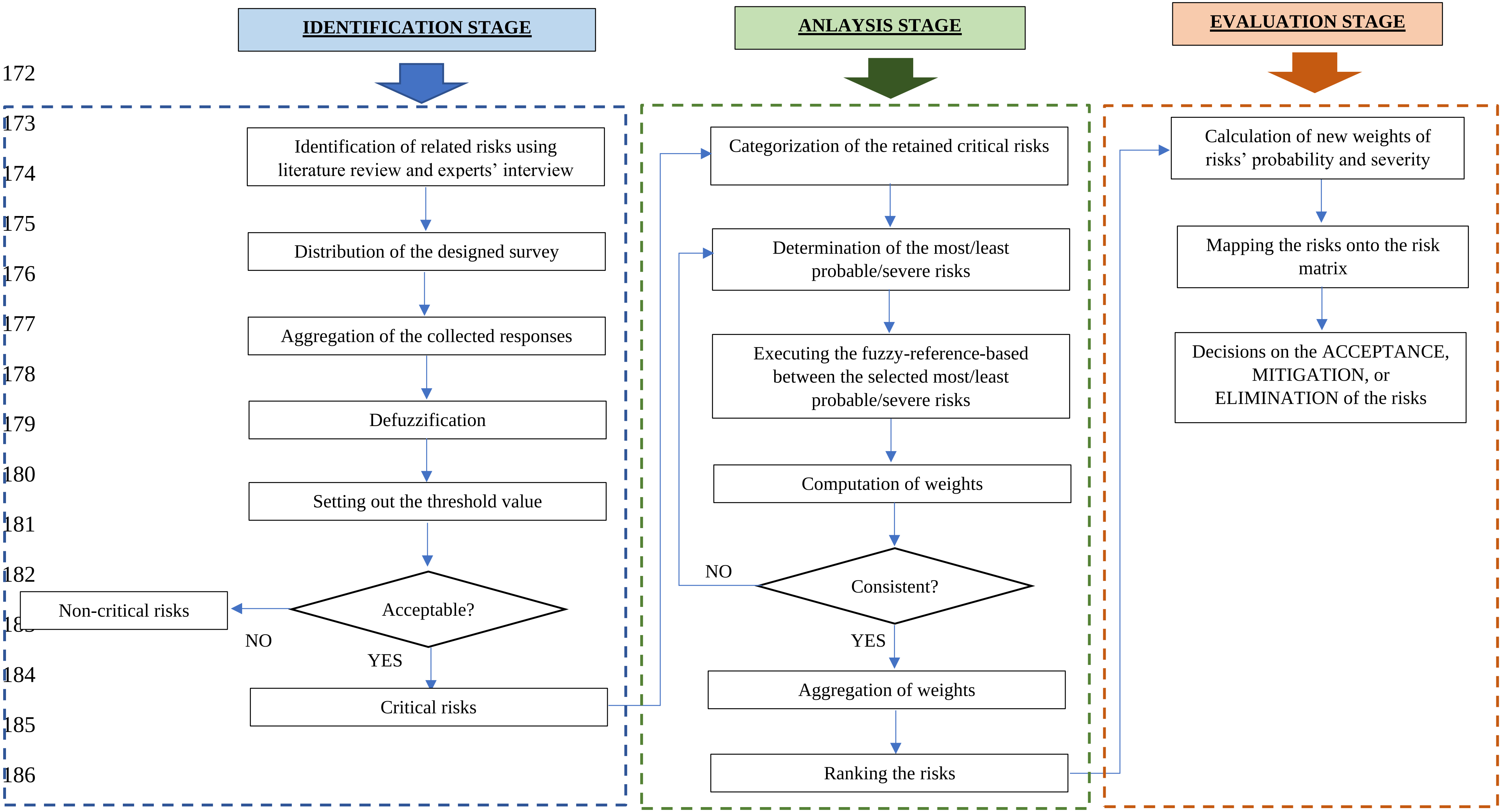


Fig. 1. The developed RAM

2.2 The Risk Identification Stage

Dalkey and Helmer (1963) adopted an opinion survey-based method for the aim of achieving a consensus amongst participating experts whether to select or reject the identified factors related to the research scope. This technique is called ‘Delphi’ that is essentially on the basis of three key features, i.e., responses anonymity, statistical group response as well as iteration and controlled feedback (Hsu & Sandford, 2007). The challenge is that, in real conditions, judgments made by experts cannot be always interpreted precisely into some quantitative values. In other words, human thinking normally suffers from some weaknesses such as vagueness, subjectivity, and inaccuracy. As a result, data extracted from such sources cannot be relied on when modelling real-world systems (Kannan, de Sousa Jabbour, & Jabbour, 2014). To cope with such problems, Zadeh (1965) proposed the Fuzzy set theory in order to make more reliable decisions in indefinite situations (Shen, Olfat, Govindan, Khodaverdi, & Diabat, 2013). Some years later, Ishikawa et al. (1993) made an integration of the Fuzzy inference system and Delphi technique, which made the FDM method. FDM was mainly used for the purpose of overcoming the vagueness that exists in Delphi. The superiority of FDM over Delphi has also been confirmed by Kuo and Chen (2008). In addition, the literature consists of several studies (e.g., (Lin & Yang, 2016; Qiu, Shi, Teng, & Zhou, 2017)) implementing FDM in risk management research.

The present study uses FDM through integrating FST and Delphi in order to make use of the advantages of both techniques. FDM was used for the identification of the significant risks related to the research scope, which was performed mainly by reviewing the current literature as well as asking the experts’ opinions (which is the essential part of Delphi). With the help of FST, the sub-factors that were found less critical were ignored and left without any further analysis. The current study takes into account the FDM method introduced by Bouzon, Govindan, Rodriguez, and Campos (2016) and Pham, Ma, and Yeo (2017). The integrated FDM was applied to identifying the critical risks and also selecting the most influential ones. This process was done in the following steps.

Step 1. The existing literature was reviewed comprehensively and some respondents with relevant experiences were interviewed to identify the risks associated with those workers who work in GB construction projects. In other words, the relative risks were extracted from the current body of relevant literature, then they were presented to the selected experts to add new risks that were missing. In this way, a comprehensive list of risks endangering workers’ safety that are working in sustainable construction projects in Kazakhstan was obtained.

Step 2. The provided questionnaires were distributed to a number of experts with relevant experiences. After the identification of the critical risks, 'n' number of experts (i.e., decision makers) from the industry and the academia were asked to measure the criticality of the defined risks through a questionnaire containing linguistic variables that ranged between 'very low' and 'very high' (see Table 3).

Step 3. The invited experts' opinions were collected with the use of decision group. This step involved the calculation of the values of the triangular fuzzy numbers related to each risk, which were indicated by the experts. The arithmetic mean (Ma, Shao, Ma, & Ye, 2011) was applied to exploring a common understanding of group decision. In the following, the computing formulas are expressed clearly:

Let us assume that the evaluation value of the criticality level of No. j sub-factor given by No. ith expert of n experts is $\widetilde{w}_{ij} = \left(a_{ij}, b_{ij}, c_{ij}\right) for$ for $i = 1, 2, 3, \ldots, n,$ and $j = 1, 2, 3, \ldots, m$. Then, the following equations could be obtained:

$$\widetilde{w}_j = \left(a_j, b_j, c_j\right) \tag{1}$$

$$a_j = min\left\{a_{ij}\right\} \tag{2}$$

$$b_j = \frac{1}{n}\sum_{i=1}^{n} b_{ij} \tag{3}$$

$$c_j = Max\left\{c_{ij}\right\} \tag{4}$$

where $\widetilde{w}_j$ stands for the fuzzy weighting of No. j sub-factor, a_j, b_j, and c_j denote the bottom threshold of all the experts' appraisal, the arithmetic mean of all the experts' appraisal, and the ceiling of all the experts' appraisal value, respectively. Notably, in order to check the consensus among the responses provided by the respective experts, two indicators were considered, namely Cronbach alpha (for checking the internal validity of the responses collected from all the experts), as well as Standard Deviation to Mean Ratio (for checking the consensus of the responses provided by all the experts for each sub-factor), as noted by Gunduz and Elsherbeny (2020) and Fang, Li, Fong, and Shen (2004). To do so, the following equations were taken into account:

$$\beta = \frac{SD}{M} \tag{5}$$

$$\varphi = \frac{N \times \beta/\omega}{1 + (N-1) \times \beta/\omega} \tag{6}$$

where φ, β, N, ω, SD, and M are respectively Cronbach alpha reliability test, standard deviation to mean ratio, number of items used for the scale, mean variance of the items, standard deviation, and mean of the items. In this regard, if β and φ together are more than 0.7 and lower than 30% respectively, then the responses provided are considered acceptable, and accordingly the desired consensus has been reached (there is no need for the second round of survey). Nevertheless, if any of these criteria is not met, the designed survey needs to be redistributed to the same experts by providing them with feedbacks collected from the first round of survey. In this way, they can adjust their responses, and this process continues to the point that both of the aforesaid criteria are met.

Step 4. At this step, defuzzification was done. For the defuzzification of the $\widetilde{w}_j$ of each risk to a definite value (S_j), the simple center of gravity method was employed as indicated below:

$$S_j = \frac{a_j+b_j+c_j}{3} \text{ for } j = 1,2,\dots,m \tag{7}$$

Step 5. The threshold value was set up. After the defuzzification process, the major risks could be singled out by setting the threshold (α) value as follows:

If $S_j \geq \alpha$, then No. j risk could be considered as having enough criticality for further analysis.

If $S_j < \alpha$, then reject No. j risk.

Remember that, in the current study, the fuzzy weights related to the threshold value (α) was computed on the basis of the average of all the sub-factors' weight. Subsequently, the simple center of the gravity method (see Eq. (5)) was applied to the defuzzification of the weighted threshold fuzzy weights.

Table 3. Linguistic scales related to the criticality level of the risks

Linguistic variables	Fuzzy number
The respective risk is of very low importance	(0, 0, 0.3)
The respective risk is of low importance	(0,0.3,0.5)
The respective risk is of moderate importance	(0.3,0.5,0.7)
The respective risk is of high importance	(0.5,0.7,1)
The respective risk is of very high importance	(0.7,1,1)

2.3 Risk Analysis Stage

When the critical risks threatening the workers' lives are identified, then it is time to perform the analysis stage that essentially calculates the magnitude of the risks (Gunduz & Laitinen, 2018). An effective method applicable to this stage is MCDM. In conditions of high complexity, this method is capable of providing optimum decisions for decision makers (Karasan, Ilbahar, Cebi, & Kahraman, 2018). The literature indicates that the construction sector has frequently implemented MCDM for the evaluation purposes. For instance, Zayed, Amer, and Pan (2008) made use of AHP in order to assess the risks associated with highway construction projects, Lu, Lin, and Ko (2007) employed ANP to assess the risks of the bridge construction projects in urban areas, and Wang, Liu, and Elhag (2008) applied TOPSIS to assessing the risks that may be associated with bridge construction projects. The comparison-based methods (in which pair-wise comparisons are made amongst some items in the same categories like ANP, AHP, etc.) have offered numerous benefits to users and decision makers; although, they suffer from a significant drawback: excessive number of comparisons to be made. Accordingly, an innovative MCDM method was introduced by Guo and Zhao (2017), which integrated FST and BWM, called FBWM. In this method, there is a need only for taking into account the reference-based comparisons. As a result, the number of pair-wise comparisons reduces significantly, which leads to the achievement of more accurate and consistent results. Consequently, in the present study, FBWM developed by Guo and Zhao (2017) is applied to the assessment of the risks that may occur to the people working in the GB construction projects. In the following, the steps that need to be taken into action when executing FBWM to obtain the weights of the retained risks are presented in detail.

Step 1. The categorization of the retained sub-factors considering the relevant factors.

Step 2. The specification of the most and the least probable factors and sub-factors under each category and naming them F_{MP} and F_{LP}, respectively.

Step 3. The identification of the most and the least severe factors and sub-factors under each category and naming them F_{MS} and F_{LS}, respectively.

Step 4. Making the fuzzy-reference-based comparisons amongst F_{MP}, F_{LP}, F_{MS}, and F_{LS} with the use of the linguistic variables presented in Table 4. After allocating proper variables to each risk factor and sub-factor, the following vectors can be obtained:

$$A_{MPO} = (a_{MPO1}, a_{MPO2}, \dots, a_{MPOn}) \tag{8}$$

$$A_{OLP} = (a_{OLP1}, a_{OLP2}, \dots, a_{OLPn}) \tag{9}$$

$$A_{MSO} = (a_{MSO1}, a_{MSO1}, \dots, a_{MSOn}) \tag{10}$$

$$A_{OLS} = (a_{OLS1}, a_{OLS2}, \dots, a_{OLSn}) \tag{11}$$

where A_{MPo} and A_{OLP} stand for the vectors that consist of respectively the fuzzy pair-wise comparisons between the most probable factor/sub-factor in each category as opposed to the others, and the fuzzy pair-wise comparisons between the other factors/sub-factors as opposed to the least probable one. Likewise, A_{MSO} and A_{OLS} respectively signify the vectors that consist of the fuzzy pair-wise comparisons between the most severe factor/sub-factor in each category as opposed to the others, and the fuzzy pair-wise comparisons between the other factors/sub-factors as opposed to the least severe one.

Table 4. Linguistic variables for comparing the probability and severity of factors/sub-factors

Linguistic variables	**TFNs**
The respective factors/sub-factors have the same probability/severity against one another (E)	(1,1,1)
A factor/sub-factor has slightly higher probability/severity compared to the other one (WM)	(2/3,1,3/2)
A factor/sub-factor has moderately higher probability/severity compared to the other one (MM)	(3/2,2,5/2)
A factor/sub-factor has significantly higher probability/severity compared to the other one (MM)	(5/2,3,7/2)
A factor/sub-factor has extremely higher probability/severity compared to the other one (EXM)	(7/2,4,9/2)

Step 5. Exploring the optimal weights related to ($w*_1$, $w*_2$, ..., $w*_n$) and $\tilde{\xi}^*$ with the use of the following equations (Mohandes & Zhang, 2019):

$$\min \ \tilde{\xi}$$

$$s.t.\begin{cases} \left|\frac{\tilde{w}_{MP}}{\tilde{w}_O} - \tilde{a}_{MPO}\right| \leq \tilde{\xi} \ for\ probability, and\ \left|\frac{\tilde{w}_{MS}}{\tilde{w}_O} - \tilde{a}_{MSO}\right| \leq \tilde{\xi} \ \ for\ severity \\ \left|\frac{\tilde{w}_O}{\tilde{w}_{LP}} - \tilde{a}_{OLP}\right| \leq \tilde{\xi} \ for\ probability, and\ \left|\frac{\tilde{w}_O}{\tilde{w}_{LS}} - \tilde{a}_{OLS}\right| \leq \tilde{\xi} \ for\ severity \\ \sum_{j=1}^{n} R\ (\tilde{w}_O) = 1 \\ l_j^w \leq m_j^w \leq u_j^w \\ l_j^w \geq 0 \\ j = 1,2,3,..,n \end{cases} \tag{12}$$

where $\tilde{w}_{MP} = (l_{MP}^w, m_{MP}^w, u_{MP}^w)$, $\tilde{w}_O = (l_O^w, m_O^w, u_O^w)$, $\tilde{w}_{LP} = (l_{LP}^w, m_{LP}^w, u_{LO}^w)$, $\tilde{a}_{MPO} = (l_{MPO}, m_{MPO}, u_{MPO})$, and $\tilde{a}_{OLP} = (l_{OLP}, m_{OLP}, u_{OLP})$. On the other hand, $\tilde{w}_{MS} = (l_{MS}^w, m_{MS}^w, u_{MS}^w)$, $\tilde{w}_O = (l_O^w, m_O^w, u_O^w)$, $\tilde{w}_{LS} = (l_{LS}^w, m_{LS}^w, u_{LS}^w)$, $\tilde{a}_{MSO} = (l_{MSO}, m_{MSO}, u_{MSO})$, and $\tilde{a}_{OLS} = (l_{OLS}, m_{OLS}, u_{OLS})$.

Note that Eq. (10) expresses the fuzzy-reference-based comparisons that can be used to measure the factors and sub-factors' probability weights, as well as severity weights. With finding a solution to model presented above, the relative optimal weights to ($w*_1$, $w*_2$, …, $w*_n$) and ξ^* can be achieved.

Step 6. Checking whether the obtained results are consistent, by means of Eq. (14) as follows.

$$CR = \frac{\xi^*}{CI} \tag{13}$$

where CR and CI stand for the consistency ratio and the consistency index, respectively. Remember that a_{MPLP} presented in Table 5 denotes the degree to which F_{MP} will more probably take place in comparison with F_{LP}, while a_{MSLS} denotes the degree to which F_{MS} is more severe than F_{LS}.

Table 5. *CI* related to each variable

Linguistic terms	**(E)**	**(WM)**	**(MM)**	**(SM)**	**(EM)**
a_{MPLP} or a_{MSLS}	(1,1,1)	(2/3,1,3/2)	(3/2,2,5/2)	(5/2,3,7/2)	(7/2,4,9/2)
CI	3.00	3.80	5.29	6.69	8.04

Step 7. After the CR corresponding to each expert is checked, it is time to take into consideration the following rules:

Rule A: If $CR \geq 0.10$, then the questionnaire must be redistributed to the corresponding expert.

Rule B: If $CR < 0.10$, then the corresponding responses can be relied on.

Step 8. The defuzzification of the accepted weights by means of the Graded Mean Integration Representation (GMIR).

Step 9. The aggregation of all responses received from the participating experts with the help of the arithmetic mean (i.e., related to local weights of factors and sub-factors).

Step 10. The computation of the sub-factors' global weights through multiplying the local weights of factors and local weights of sub-factors.

2.4 Risk Evaluation Stage

A common statement is that when the relative magnitude to the risks is computed, it is imperative to provide a picture that can illustrate their criticalities (Rausand, 2013). At the risk evaluation step, two facts must be provided for safety analysts: 1) the criticality levels of the risks analyzed in the former stage, and 2) appropriate strategies to handle the risks in the following step of risk management (i.e., Risk Mitigation Stage (RMS)). Accordingly, the present paper makes use of the rules suggested by Mohandes and Zhang (2019) with the use of the linear interpolation technique so that the risks analyzed in the former step could be assessed as follows:

Rule A: If x is mapped onto the green section of the common risk matrix, then the relative risk can be accepted, provided that it will be tracked periodically;

Rule B: If x is mapped onto the yellow section, then the relative risk is moderately critical; thus, its impact needs to be alleviated; and

Rule C: If x is mapped onto the red section, then the relative risk is highly critical; thus, all the activities related to its operation need to be stopped until its impact be alleviated to a defined threshold.

Notably, in each category, the highest value (i.e., the sub-factors' global weights, first, for the probability and then for the severity) should be set to 5 by means of FBWM, whereas, in the mentioned categories, the minimum value must be set to 1. Likewise, the other factors and sub-factors' weights in the same category must be set to 1-5. These numbers are selected depending on the range of ratings applied to the common risk matrix approach. The range of the numbers applied to the common risk matrix was adopted from the study conducted by Li, Bao, and Wu (2018).

3. RESULTS

As the initial step of the methodology, the past studies conducted in the area of OHS of GB projects were reviewed. First, the related risks were extracted from the relevant literature (Dewlaney et al., 2012; Fortunato III et al., 2012; Gambatese, Rajendran, & Behm, 2007; Hwang et al., 2018; Karakhan & Gambatese, 2017a, 2017b; Rajendran & Gambatese, 2009; Rajendran et al., 2009; Zhang & Mohandes, 2020); then, the finalized list was presented to the experts to add any missing ones. Table 6 summarizes all the relative safety risk factors along with their sub-factors retrieved from the literature and experts' interviews. The identified safety risk items were then circulated among the qualified experts to reject those that were not critical enough to menace the workers of the GB projects of Kazakhstan. Table 7 illustrates the results obtained regarding the criticality levels of the listed risks. Afterwards, the designed FBWM-based questionnaire was sent to them, based on which the magnitude pertaining to each safety risk was obtained along with their evaluation strategies to be taken. Eight experts from the selected panel members, who were contacted for filling out the FDM-based questionnaire, completed the analysis-related part. Figure 2 shows the aggregated weights (AP and AS stand for aggregated probability and aggregated severity, respectively) related to the main factors, whereas Figure 3 shows the aggregate weights of sub-factors, including local and global weights as well as final magnitude. Additionally, Figure 4 furnishes the evaluation stage results, which is based on the exploitation of the interpolation technique for calculating new weights for sub-factors as well as their locations on the common risk matrix approach.

Table 6. List of safety risk factors together with their related sub-factors extracted from the literature

RFs (code)	**RSFs (code)**	**Definition**
Safety (RF1)	Fall from height (RSF1)	Fall that results from working at height for achieving the required level of daylight luminance (i.e., the installation of skylights and atriums)
	Fall on same level due to slipping, tripping, or stumbling (RSF2)	Fall on the same level due to the installation of thermoplastic polyolefin (TPO) materials on roof
	Struck by or against objects (RSF3)	struck against heavy machinery (e.g., trucks), which results from diversion of waste into different dumpsters struck-by materials being lifted onto roof for the installation of photovoltaic panels on facility roof
	Electrocution (RSF4)	Electrocuted stemming from the increase in the volume of electrical works required for optimizing energy and atmosphere performance of green construction projects
	Fire (RSF5)	When welding/flame cutting in the presence of flammable materials, there is a risk of explosion/conflagration
	Cave-in (RSF6)	Being trapped caused by the sudden displacement of soil inside the excavation
	Trapped in/between objects (RSF7)	Being trapped between two objects such as a piece of metal and a building or two heavy machineries
	Scald (RSF8)	Contacting heated objects
	Puncturing (RSF9)	Contacting moving objects/nip points
	Arc-eye (RSF10)	Eye damage as a result of improper welding
	Eye strain (RSF11)	Results from the installation of thermoplastic polyolefin (TPO) materials on roof
	Abrasions (RSF12)	Being scraped that results from entering the dumpsters to sort the materials (i.e., dumpster diving)
	Sprains (RSF13)	Twisted ligaments of an ankle, wrist, or other joints, which results from entering the dumpsters to sort the materials (i.e., dumpster diving)
	Lacerations (RSF14)	A deep cut or tear in skin or flesh resulting from entering the dumpsters to sort the materials (i.e., dumpster diving)
Environmental (RF2)	Hypertension (RSF15)	Blood pressure increases as a result of extreme hot weather exposure
	Heat stroke (RSF16)	Extended physical exertion in or exposure to extreme hot weather
	Frostbite (RSF17)	Extreme cold weather exposure causes frozen skin and underlying tissue
	Hypothermia (RSF18)	Unexpected body temperature reduction as a result of extreme cold weather exposure

Ergonomic (RF3)	Carpal tunnel syndrome (RSF19)	Median nerve pressure as a result of heavy continuous installation of building shell and photovoltaic panels on roof
	Wrist tendonitis (RSF20)	Irritation and inflammation of the tendons around the wrist joint, which results from heavy continuous installation of building shell and photovoltaic panels on roof
	Ulnar nerve entrapment (RSF21)	The ulnar nerve in the arm becomes compressed or irritated, which results from heavy continuous installation of building shell and photovoltaic panels on roof
	Epicondylitis (RSF22)	Pressure on the extensor tendons of the elbow, which results from heavy continuous installation of building shell and photovoltaic panels on roof
	Shoulder tendonitis (RSF23)	Damage to tendons and muscles moving shoulders joint, which results from heavy continuous installation of building shell and photovoltaic panels on roof
	Hand-arm vibration syndrome (RSF24)	Damages to the fingers, hands, and arms as a result of working with vibrating tools or machinery caused by heavy continuous installation of building shell and photovoltaic panels on roof
	Back injury (RSF25)	Disc (on the spinal cord) damages as a result of frequent bending of back
	Tension neck syndrome (RSF26)	Neck pain and stiffness, and muscle spasms as a result of long periods of looking up
	Fatigue (strain) (RSF27)	Constant tiredness or weakness, which results from entering the dumpsters to sort the materials (i.e., dumpster diving)
Chemical (RF4)	Phlegm or asthma (RSF28)	Caused by exposure to airborne gypsum
	Silicosis (RSF29)	Caused by exposure to silica
	Dermatitis (RSF30)	Skin rashes that stem from the exposure to chemicals used in the on-site filtration processes
	Chemical burns (RSF31)	Burnt skin that stems from the exposure to chemicals used in the on-site filtration processes
	Internal organs disorders (RSF32)	Damages to the lung, kidney, or liver, which stem from the exposure to chemicals used in the on-site filtration processes
	Nervous system disorders (RSF33)	Damages to the mental nerve system, which stem from the exposure to chemicals used in the on-site filtration processes
	Hypertension (RSF34)	Increase in blood pressure as a result of a direct contact with some chemicals
	Eye injury (RSF35)	Eye injuries due to the contact of chemical liquid or powder with eye
	Suffocation (RSF36)	Suffocated owing to the exposure to the poisonous gas
	Heart diseases (RSF37)	Irregular heartbeats and/or heart strokes as a result of a contact with chemical substances

Table 7. Results obtained from the FDM application

RSFs	a_j	b_j	c_j	s_j	β	**Rejection/Selection**
RSF1	0	0.56	1	0.5200	13	S
RSF2	0	0.43	1	0.4778	15	S
RSF3	0	0.26	0.7	0.3200	21	R
RSF4	0	0.40	1	0.4667	16	S
RSF5	0	0.41	1	0.4711	23	S
RSF6	0	0.37	1	0.4556	14	S
RSF7	0	0.27	1	0.4222	17	R
RSF8	0	0.25	0.7	0.3178	15	R
RSF9	0	0.31	1	0.4378	29	S
RSF10	0	0.21	1	0.4044	17	R
RSF11	0	0.42	1	0.4733	14	S
RSF12	0	0.44	1	0.4800	18	S
RSF13	0	0.32	1	0.4400	15	S
RSF14	0	0.29	1	0.4311	09	R
RSF15	0	0.42	1	0.4733	13	S
RSF16	0	0.48	1	0.4929	17	S
RSF17	0	0.43	1	0.4778	16	S
RSF18	0	0.41	1	0.4689	13	S
RSF19	0	0.28	1	0.4267	18	R
RSF20	0	0.24	1	0.4133	15	R
RSF21	0	0.27	1	0.4222	21	R
RSF22	0	0.31	1	0.4356	16	S
RSF23	0	0.34	1	0.4467	16	S
RSF24	0	0.29	1	0.4289	13	R
RSF25	0	0.53	1	0.5089	09	S
RSF26	0	0.47	1	0.4889	15	S
RSF27	0	0.47	1	0.4889	13	S
RSF28	0	0.43	1	0.4778	17	S
RSF29	0	0.25	0.7	0.3156	18	R
RSF30	0	0.35	1	0.4511	18	S
RSF31	0	0.26	0.7	0.3200	16	R
RSF32	0	0.24	0.7	0.3133	16	R
RSF33	0	0.26	1	0.4200	15	R
RSF34	0	0.27	1	0.4244	21	R
RSF35	0	0.28	1	0.4267	16	R
RSF36	0	0.20	1	0.4000	18	R
RSF37	0	0.27	1	0.4244	21	R
α						0.4342
φ						0.8381

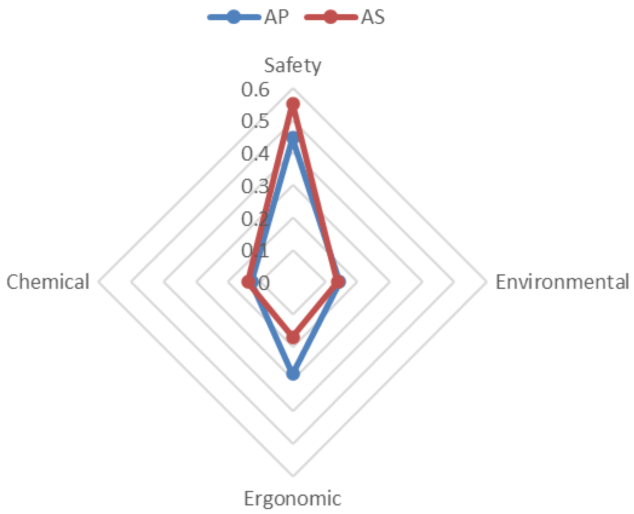
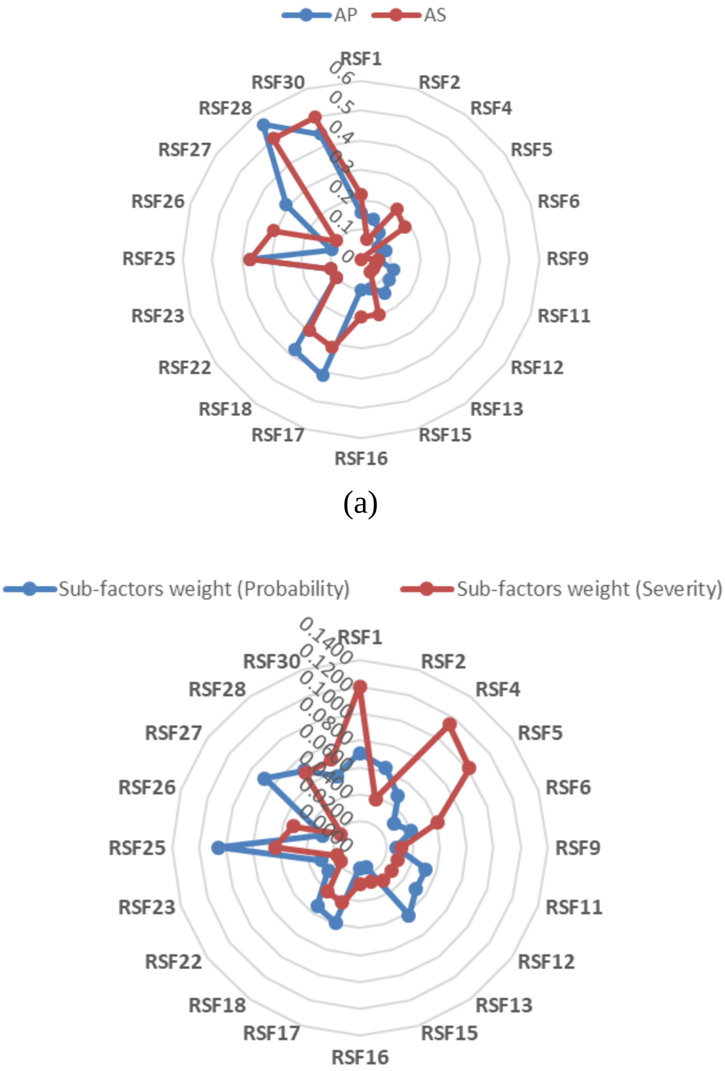
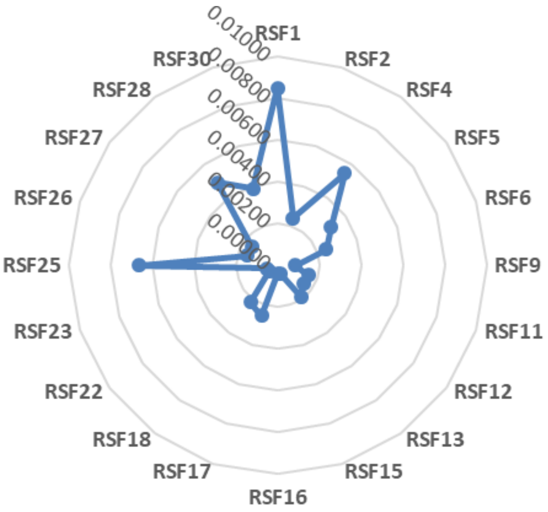


Fig. 2. The aggregated probability and severity weights of the main factors



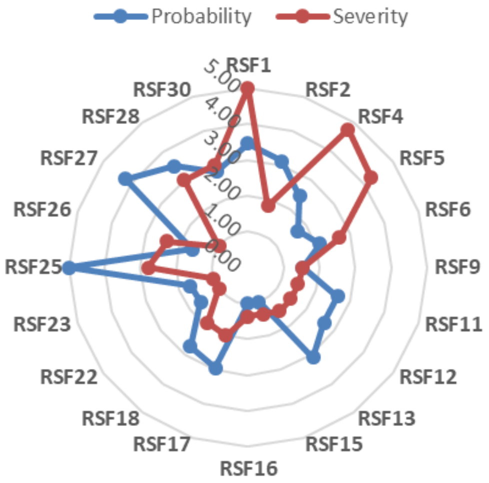
(a)

(b)

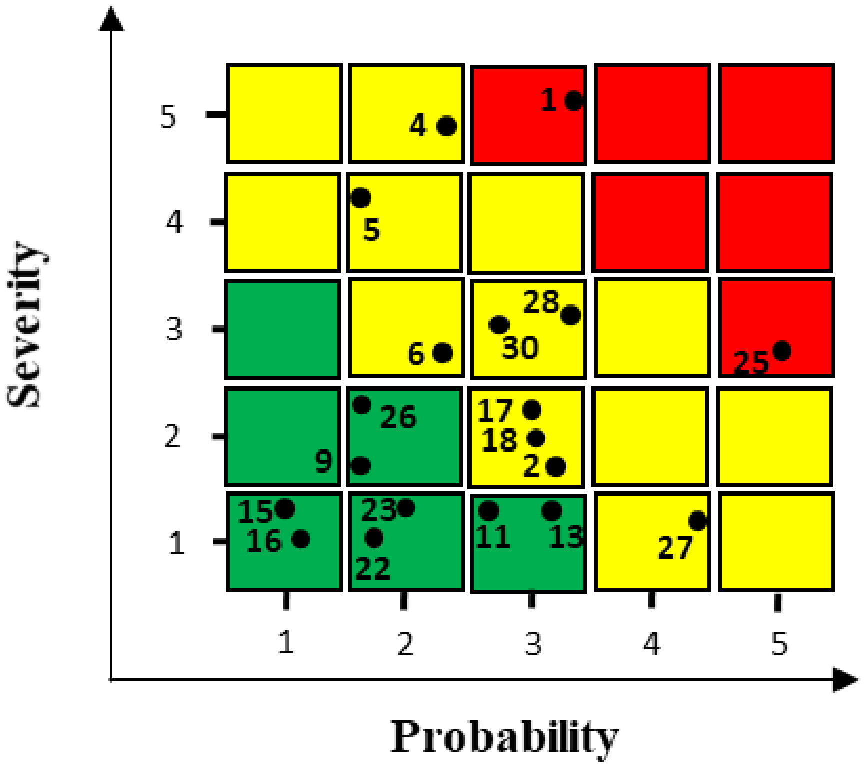


(c)

Fig. 3. The aggregated probability and severity weights of sub-factors: (a) local weights, (b) global weights, and (c) final magnitude



(a)



(b)

Fig. 4. Evaluations for the critical sub-factors: (a) newly-calculated weights of the sub-factors using LIT, (b) locations of the sub-factors on the risk matrix

4. RELIABILITY and VALIDATION

To check the reliability of the results obtained from the study, the consistency of the experts' responses at two stages were calculated. To do this, Cronbach alpha and CR were used to check the reliability of answers for FDM and FBWM, respectively, as suggested by Mohandes et al. (2020) and Wang et al. (2012). Based on the calculated value of 0.8381 for φ, as well as the fact that β for all the sub-factors were lower than 30 percentage, it could be asserted that the results collected from the experts involved in the FDM were of good consistency, and accordingly they reached consensus in the first round of survey. Additionally, as per the values calculated for CR (i.e., 0.0341), it was observed that the pair-wise comparisons made by the respective experts were of good consistency (for the application of FBWM); thus, the results obtained from the application of the RAM to the case of green building construction projects are of potent reliability.

Having said that, in order to demonstrate the generalizability of the findings of the study, as mentioned in the methodology section, the focus-group-discussion approach was undertaken. Table 8 summarizes their points of views on the criticality levels of the risks discussed in the second part of the session. As can be seen, the majority of the experts stressed the criticality levels of the risks that had been located on the red and yellow section of the used risk matrix. This indicates that the results obtained from the study could be largely generalized to the bigger picture of the projects equipped with sustainable construction settings.

Table 8. Results of validation

Risks	**Involvement of experts in the controlled discussion**					**Aggregation of responses**
	EXP1	**EXP2**	**EXP3**	**EXP4**	**EXP5**	
RSF1	5	5	5	5	5	5
RSF2	5	5	2	2	2	3.8
RSF4	2	5	5	5	5	4.6
RSF5	5	2	5	5	2	4.2
RSF6	5	2	2	5	1	3.6
RSF9	2	5	2	1	1	3
RSF11	2	2	1	5	1	3
RSF12	2	2	5	1	2	3.2
RSF13	1	2	5	2	1	3
RSF15	1	1	2	1	1	2.2
RSF16	2	2	2	1	2	2.8
RSF17	1	5	5	5	2	4
RSF18	1	5	5	2	1	3.4
RSF22	2	2	2	2	1	2.8
RSF23	2	2	2	1	1	2.4
RSF25	5	5	5	1	5	4.4
RSF26	1	2	2	5	1	3

Note: 1 and 5 denote that the respective risk was very low and very high critical, respectively.

5. DISCUSSION

As mentioned in the literature, the primary focus of the GB projects is on the environmental issues (Fortunato III et al., 2012). This has led to the necessity of investigating the safety performance of green projects, although it contrasts with the findings of Rajendran et al. (2009) who reported that the safety performances of green and its counterparts are same. Then, it is important to inspect why GB projects have been remaining risky in terms of their workers' health and safety performance? Several studies have claimed that these risks are due to additional requirements (green rating tools' requirements (e.g., LEED)) of GB design and construction. Bearing this in mind, this study assessed the risks that were identified though the GB literature, and this section discusses the outcomes of the proposed hybrid framework (based on the integration of FDM and FBWM) by comparing/contrasting them against the literature and the LEED credits. It is worth mentioning that the rationale behind the selection of LEED is due to its extensity in the Kazakhstan built environment.

The FDM results revealed that sustainable buildings continue to jeopardize workers' health and safety in Kazakhstan. For instance, the majority of the safety- (9 out of 14) and ergonomic-related (5 out of 9) risks are retained, while 8 of chemical-related risks out of 10 are rejected. The existence of the safety- and ergonomic-related safety risks has been clearly proved in the literature and can be attributed to the LEED credits (e.g., health island reduction and optimize energy performance), which require, for example, the installation of solar panels. Therefore, exposure to risks (e.g., fall injuries and lifting heavy materials) is increased while working at height. Note that all risks under the environmental category are retained, which would be because of extreme cold winters almost everywhere in, and hot summers in the south of, Kazakhstan. Finally, the retained chemical-related risks show the exposure of the GB project workers to airborne gypsum and various chemicals used for on-site filtration, which cause asthma and dermatitis, respectively.

While the aim of the green rating systems is to create resilient, resource-friendly, and more efficient built environment, meeting their requirements has increased the hazards faced by workforce. For example, many LEED credits (e.g., SS credit 6.2, WE credit 2, EA credit 2, and IEQ credit 1) require workers to execute the project task within a hazardous environment (e.g., fall and silica exposure). The risk matrix (as a result of FBWM) shows that there are two risk factors (RSF1 and RSF25) in the red zone, which can be considered as severe green job hazards and requires immediate attention. For example, the first option to meet heat island reduction credit ("LEED v.4.1 under Sustainable sites") is the installation of green roofs "to minimize effects on microclimates and human and wildlife habitats by reducing heat islands" (U.S. Green Building Council, 2021). However, these "vegetated roofs" require wide range of tasks (e.g., maintenance and irrigation), which increases the frequency of risk exposure to workers responsible for maintenance and operation (Omar, Quinn, Buchholz, & Geiser, 2013). As a result of a robust investigation, Behm (2012) reported various hazards that the workers are exposed to on vegetated roofs, namely unprotected roof-edges, lack of measures for fall protection, and unsafe access are some of the site-specific hazards. As an alternative to vegetated roofs, "high-albedo roofs" can also be installed to earn this credit (U.S. Green Building Council, 2016) despite the fact that it has not been mentioned by the LEED v4.1 (U.S. Green Building Council, 2021). This could be due to the fact that roofs with thermoplastic polyolefin (TPO) are heavy (Dewlaney et al., 2012) and have slippery surface (Omar et al., 2013). Perhaps, this could be a reason behind the RSF2 factor to lie in the yellow zone of the risk matrix. Instead, the LEED v4.1 recommends covering, for example, parking with “energy generating systems” (e.g., photovoltaics), which may still cause hazards such as RSF1 and RSF3 (Fortunato III et al., 2012).

Similarly, RSF25 lies in the red zone of the risk matrix, which concerns back injuries resulting from frequent bending of back. Review of the LEED v4.1 shows that there are several credits that require construction tasks because of which a worker can be exposed to long-lasting back injuries. For example, EA credit 6 (“optimize energy performance”), EQ credit (“daylight”), SS credit (“heat island reduction”), and MR credit (“construction and demolition waste management”) are associated with works that require lifting of heavy materials or equipment, which can increase back injuries (U.S. Green Building Council, 2021).

Remember that only two of the environmental related risk factors (i.e., RSF17 and RSF18) are located in the yellow zone of the risk matrix, which concern the extreme cold weather in Kazakhstan. This is justified as much of the construction works happen in outdoor environments, which makes workers more vulnerable to cold weather. And LEED-certified buildings are no excuse as there are construction tasks that require to work in outdoor environments such as window and GR installation (Feng & Hewage, 2014; U.S. Green Building Council, 2021), which results in the exposure to extreme cold weather. Another reason of having these risk factors in the yellow zone is that the majority of the LEED-certified buildings in the country are in Nur-Sultan (former Astana), which experiences cold weather almost seven months of a year.

6. CONCLUSION

This study has touched the safety and health issues associated with the GB construction projects, which is the first in its kind within the current body of literature within the scope of developing countries. To do this, a fuzzy-based RAM was utilized to identify, analyze, and evaluate the risks attributed to the GB construction projects. The RAM used in this study is based on the integration of FDM and FBWM. Following the attainment of main results of the study, a focus group discussion approach was employed in order to further validate the results obtained. With this in mind, the following concluding remarks were drawn after a careful investigation into the case of sustainable construction projects using the RAM exploited in this study.

The findings showed that the construction practices or design elements required to achieve truly-sustainable project objectives negatively impact the workers' OHS. In this regard, the majority of the identified risk factors were retained, while most of the chemical related risks were rejected. The FBWM results also showed consistency with these concluding remarks, where the top-ranking risks (e.g., RSF1, RSF4, and RSF25) are a clear indication of increase of fall and overexertion hazards in GBs. This clearly indicates that the GB workers are exposed to hazards as a result of activities such as working with electrical current, lifting heavy materials or equipment, and awkward positions and installation of components at height. Though, this should not mean that LEED credits and OHS risks have a cause-and-effect relationship. However, the presence of the OHS risks could be due to some other underlying reasons, for example, lack of resources (e.g., skilled labor force) and required training, the workers' unfamiliarity with the LEED requirements/methods, and hazardous environment the workers are exposed to. Although the integration of human health as an essential criterion of LEED looks to be promising, the Prevention through Design (known also as safety by design) concept could be properly implemented. This way, potential risks associated with the GB project risks could be evaluated and then communicated to workers to increase their familiarity with the GB processes, materials, and equipment.

6. 1 Research Implications

The results obtained from this study offer both academic and managerial implications. Regarding the academic implications, it puts forward a bunch of safety risks posing threats to the construction workers involved in GB construction projects. More specifically, it paves the way for further studies by not only identifying the potential safety risks associated with LEED-based construction projects in a developing country, but also systematically analyzing and evaluating the identified risks in terms of their criticality. All these results can be considered as a stepping-stone for conducting future studies on this stream in other developing countries.

Concerning the managerial implications, it is observed that the concerned safety officers and decision makers who are involved in the safety assessment of related projects are provided with unique insight in three ways as follow. First of all, they are provided with 37 safety risks that have potential to threaten the lives of workers involved in GB construction projects. Then, they are given insight about those risks that are of higher criticality, considering the environment of developing countries and the LEED-based construction type. Next, the rankings and proposed evaluations for dealing with the analyzed safety risks illuminate the path for the concerned parties towards improving the environment of such projects by reconsidering the related construction activities to be undertaken by the relative workers. On top of that, the concerned policy makers and regulators come to know regarding the hazardous codes and requirements to be followed for certifying LEED-based construction projects in developing countries.

6.2 Limitations and Future Directions

Although this study provides a novel insight into the safety and health of workers involved in GB construction projects for the first time in a developing country, it is bound with some limitations. The followings are the limitations encountered during the course of the present research and the relevant future research:

- Due to the outbreak of the COVID-19 pandemic, the size of experts' involvement in this study was not large, and the non-probability sampling technique was considered in this study. Even though the sampling size is quite prudent considering the types of techniques used throughout this research, future researchers can also benefit from the portability-sampling technique, in which more numbers of experts are involved (such as the utilization of structural equation modelling).
- Owing to the fact that the data required was mainly collected from Nur-Sultan (former Astana) and Almaty, the results obtained cannot be fully generalized to the whole Kazakhstan. Therefore, there is a need to consider other regions of Kazakhstan and, accordingly, make a comparison between the results obtained from this study and those of others.
- This study is only concerned with the safety risks posing threats to the respective workers; thus, future studies can be tilted towards investigating the causes leading to the occurrence of related risks by exploiting probabilistic-based techniques (e.g., Bayesian networks, bow-tie analysis, etc.).
- The magnitude of risks calculated in this study is based on the consideration of two parameters, namely probability and severity. However, there would be more parameters that can be considered during the assessment stage. Thus, future research can take into account more essential parameters to assess the identified risks.

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