

# A comprehensive risk assessment model based on a fuzzy synthetic evaluation approach for green building projects: the case of Vietnam

A  
comprehensive  
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model

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## Abstract

**Purpose** – Risks in implementing green building (GB) projects have emerged as a significant obstacle for GB development, especially in developing countries. In recent years, both academics and construction practitioners have paid considerable attention to the risks associated with GB. In this study, the authors aimed to create a comprehensive risk assessment model that considers three crucial risk features: impact level, probability of occurrence and risk manageability.

**Design/methodology/approach** – In the research, authors adopted the mean scoring and fuzzy synthetic evaluation method to assess GB risks. Based on expert assessments, this model can determine the significance of risk factors, risk groups and overall risk. Notably, this research applied the proposed model to assess GB risks in Vietnam by surveying 58 GB experienced professionals.

**Findings** – The findings revealed that GB risks are relatively high in Vietnam, implying that risk management is essential for GB projects to succeed. The results also showed that “lack of experience of GB designers” is the most critical factor, and “human resources risk in the design phase” is the top crucial risk group.

**Originality/value** – This study contributes a novel and practical model to help practitioners assess risks in GB projects. In addition, this research offers detailed GB risk evaluations in Vietnam and thus could be a valuable reference for construction practitioners and future studies.

**Keywords** Risk assessment, Fuzzy synthetic evaluation method, Green building, Sustainable construction, Developing countries, Vietnam

**Paper type** Research paper

## 1. Introduction

The construction industry has a crucial role in developing a country. Nevertheless, construction activities also affect the environment seriously, resulting in pollution and global climate change (Kientzel and Kok, 2011). According to previous studies, the construction industry utilizes 40% of raw stone and sand and 25% of natural wood globally (Robichaud and Anantatmula, 2011). In addition, construction activities account for 30–40% of energy and 16% of water use worldwide. Also, environmental pollution is becoming more and more critical due to the large amount of waste generated during traditional buildings' life cycles (Li *et al.*, 2016).

Green buildings (GBs) have emerged as a solution to reduce the negative influence on the environment of the construction industry (Retzlaff, 2010). Unlike traditional buildings, GBs



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emphasize environmental and social aspects (Ahmad *et al.*, 2019). Previous research revealed that GBs emit just 1/3 of the greenhouse gases, consume 1/3 of the electricity and water and recycle 96% of the demolition waste compared with traditional buildings (BIC Economics, 2014). Also, some empirical studies have indicated that GBs can help mitigate the threats posed by increasing urbanization, energy consumption and emissions (Dean *et al.*, 2016).

GB has several definitions. Notably, the term “green building” is frequently utilized interchangeably with “sustainable construction” (Woolley and Kimmins, 2003). GB refers to the quality and features of buildings constructed utilizing sustainable construction practices and principles (Kibert, 2016). Likewise, some authors considered that GB is a high-performance building that has a low impact on the environment and effectively improves human health and resource consumption (e.g. raw materials, water and energy) (Darko and Chan, 2016). From these definitions, GBs can be understood as “healthy facilities designed and built in a resource-efficient manner, using ecologically-based principles” (Kibert, 2016). Ahmad *et al.* (2016) also suggested that energy efficiency, reduced maintenance and operation cost and prolonged life are critical factors that motivate the adoption of GB. Many countries have developed GB standards, such as LEED in the US, BREAM in the UK and Green Star in Australia.

In recent years, GBs have become more popular worldwide (Ahmad *et al.*, 2019). To date, many governments have attempted to improve sustainable development in the construction industry (Hassan *et al.*, 2016). Notably, the development of GBs in several developing countries has experienced impressive growth, and the number of GBs in these countries is anticipated to increase significantly in the following years (Dodge Data and Analytics, 2018). Along with that, construction communities in developing countries have recognized the benefits of GBs (Chua and Oh, 2011). This phenomenon revealed that GBs had received attention not only in developed countries but also in developing countries.

However, GB development faces many hindrances. In which, risks in implementing GB projects have emerged as a substantial problem (Ahmad *et al.*, 2019). Indeed, “No construction project is risk-free” (Latham, 1994). Construction projects confront numerous challenges, such as cost, technical, human resources and quality issues (Taroun, 2014). Moreover, risks in different life cycle stages usually vary due to the complexity and uncertainty of construction projects (Zhao *et al.*, 2010). Notably, risks in GB projects are even higher than those in regular projects (Hwang *et al.*, 2017b). Compared with conventional projects, GB projects are riskier because of the application of novel technology and green materials to achieve green objectives in addition to common objectives (Guan *et al.*, 2020). Thus, GB projects will be more likely to fail if practitioners cannot appropriately identify, assess and respond to risks. This revealed that studying the risks in GB projects is necessary for the development of GBs.

The topic of risks in GB projects has recently received growing interest from academics (Nguyen and Macchion, 2022). However, current solutions still have limitations, such as the identification and classification of GB risks being less consistent. In addition, most previous studies only used traditional methods to evaluate risks (i.e. multiple impact levels with probability) (Nguyen and Macchion, 2022). Moreover, these studies were mainly limited to developed economies such as Singapore, Australia, US and China (Nguyen *et al.*, 2021). There has been a dearth of studies on GB risk in developing economies (Ahmad *et al.*, 2019; Nguyen and Macchion, 2022). This highlights the necessity to investigate risks in GB projects in developing countries.

To contribute to the literature, this research developed a comprehensive risk assessment (RA) model for GB projects. This model was then applied to thoroughly assess the GB risks in Vietnam. Vietnam was selected as a case study because it is a paradigmatic example of a developing country in Southeast Asia. In addition, the development of GBs has recently improved significantly in Vietnam, with an increasing number being built (Dodge Data and Analytics, 2018). Furthermore, according to previous research, risk in the implementation of

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GB projects is a noteworthy hindrance to developing GBs in Vietnam (Nguyen *et al.*, 2017). Therefore, this research fills the gap by contributing a practical RA model, thereby supporting the development of GBs in Vietnam as well as developing countries in general.

## 2. Theoretical background

### 2.1 Risks in GB projects

This section provides an overview of GB risk studies to position this research within the existing literature. The results of the literature review indicated that a growing number of studies had investigated risk in GBs in recent years (Nguyen and Macchion, 2022).

For example, Hwang *et al.* (2017a) endeavored to identify risks in residential GB projects in Singapore. The study revealed the 5 most essential risk factors and suggested 14 risk mitigation measures to handle these in residential GB projects in Singapore. Similarly, another study examined the risks related to commercial GB projects in Singapore (Hwang *et al.*, 2017b). The results revealed the top-five risk factors and proposed seven widely used risk mitigation measures in commercial GB projects. Notably, compared with conventional projects, these two studies concluded that risks in GB projects are more critical than in traditional projects. This finding is not surprising as adopting green solutions (e.g. green materials and technologies) introduces further risk factors into GB projects.

In the same vein, El-Sayegh *et al.* (2021) investigated risks in GB projects in the United Arab Emirates (UAE). A survey was conducted to assess 30 risk factors which were grouped into 5 categories. The results revealed the top-five critical risk factors that may help practitioners respond appropriately. Similarly, Ismael and Shealy (2018) explored the risks associated with sustainable buildings in Kuwait. A survey was conducted with 131 practitioners to assess 52 risk elements. According to the results, the lack of experience of designers and contractors with GBs is the most severe risk. In addition, a high initial cost for materials and overall project costs are also worth considering.

Tao and Xiang-Yuan (2018) investigated risk factors in GB projects based on the sustainability perspective in China. The results showed that the two most significant risks were “Lack of experienced management in the operational phase” and “The satisfaction of the public is meager”. Likewise, Qin *et al.* (2016) assessed risk factors in the life cycle of GB projects by multiplying the probability of occurrence and impact level. In addition, the outcomes revealed that project stakeholders have different risk preferences. This finding could help practitioners develop risk management (RM) strategies according to the stakeholders’ perceptions. Especially, Rafindadi *et al.* (2014) attempted to explore GB risks based on stakeholder opinions in 56 countries. The results showed no significant discrepancy among stakeholders’ attitudes toward sustainable project risks. The contradiction between these findings may suggest that GB risk assessments in various countries could also be different.

In another point of view, Guan *et al.* (2020) examined the interdependencies of GB risks factor by using interpretive structural modeling. This research identified 22 risks, 16 constraints and 11 objectives through a literature review. Also, this study created a hierarchical network structure to depict the cause-effect relationships between constraints, risk factors and objectives. Furthermore, the dependence/drive powers of risk interdependency were analyzed. The findings indicated the significance level of constraints/risk factors with the objectives and revealed critical risk factors/constraints in implementing GB projects.

In summary, a number of studies have attempted to investigate the risk factors in implementing GB projects in recent years (Nguyen and Macchion, 2022). However, the identification and classification of GB risks remain inconsistent in previous studies (Nguyen *et al.*, 2021). Several studies have attempted to create models for assessing risk levels in GB projects. Nevertheless, most of the previously proposed risk assessment (RA) models for GB

projects only considered the two traditional risk features, including the impact level and probability of occurrence. Notably, very few studies have examined the GB risks in developing countries. The findings reveal gaps that this research can exploit.

### *2.2 Fuzzy synthesis evaluation in RA*

RA is widely recognized as complicated and vague; thus, qualitative linguistic terms are inevitable when evaluating risk factors (Wang *et al.*, 2004). Fortunately, fuzzy set theory can solve ambiguous and subjective problems (Pedrycz *et al.*, 2011). Furthermore, mathematical operators can be used in the fuzzy domain using the fuzzy set theory (Ma and Kremer, 2015). The fuzzy set theory can also quantify linguistic aspects and the decision-making of individuals or groups (Zhao *et al.*, 2014). Therefore, it is suitable to adopt the fuzzy set theory in the RA process.

Fuzzy synthetic evaluation (FSE) applies fuzzy set theory and is a suitable method for evaluating decision-making with regard to various criteria. According to previous research, FSE can provide a synthetic assessment of an object associated with many factors/criteria in a fuzzy decision environment (Hsu and Yang, 1997). Notably, FSE is adopted in many fields, such as environmental analysis, human resource management and RA. For example, one study in China used FSE to evaluate contractors' RM competency in subway projects (Mu *et al.*, 2014). FSE has also been applied to analyze risks in sustainable projects in Singapore (Zhao *et al.*, 2016). According to previous studies, FSE has advantages in handling complicated evaluations with numerous characteristics and levels (Mu *et al.*, 2014; Xu *et al.*, 2010). Therefore, the authors selected FSE to develop the RA model in this study.

### *2.3 Identify the most significant risk factors in GB projects*

In the first step, GB risk factors were identified through a comprehensive literature review. The outcome of this step was a list of 90 risk factors. This list was then reviewed and refined through interviews and brainstorming with ten professionals. The final list consisted of 53 risk factors. In the second step, the authors conducted a questionnaire survey to assess the importance of the 53 risk factors. Based on the collected data from 207 GB practitioners, exploratory factor analysis was adopted to reveal the 30 most crucial risk factors loaded under the six risk components/groups: (1) human resources and technical risks in the construction phase; (2) performance risk in the operation phase; (3) human resource risk in the design phase; (4) financial risk; (5) regulation risk and (6) green material risk (Table 1). The authors used the 30 identified factors to create the RA model in this research.

## **3. Research methodology**

Figure 1 illustrates the overall research framework. The first block illustrates the steps to identify GB risks, which are presented in Section 2.3, whereas the second block shows the approaches to developing the RA model. The research methodology in the second block comprised the following steps: (1) developing an RA model; (2) collecting input from knowledgeable professionals; (3) calculating risk parameters and (4) discussing the findings.

### *3.1 Measures of the questionnaires*

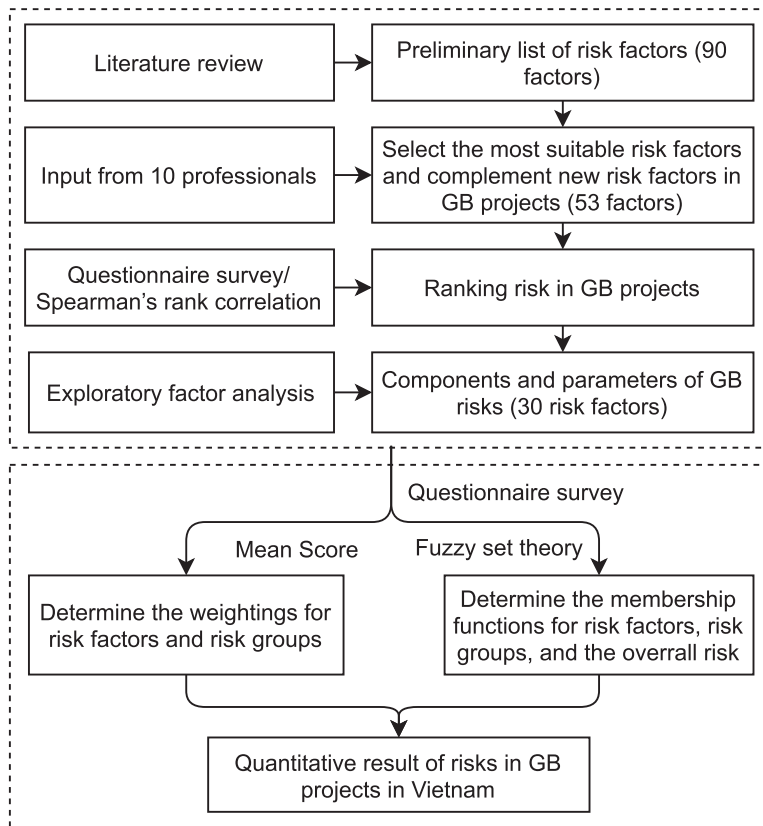
The questionnaire, consisting of three parts, was developed to collect ideas from GB professionals. Part 1 identifies participants' experiences with GBs, such as the frequency of participation in GB projects and GB knowledge. Part 2 involves assessing risk factors based on three criteria: impact level, probability of occurrence and manageability. The scales are presented in Table 2. Finally, Part 3 investigates the participants' backgrounds, such as project roles, experience, GB knowledge and position.

The impact level (I) of risk factors was assessed using an ordinal scale: 1 denotes “very low impact” and 5 means “very high impact”. Similarly, this study evaluated the occurrence probability (P) from 1 (likelihood of occurrence is very high) to 5 (likelihood of occurrence is very high). On the same scale, risk manageability (M) was assessed as follow: 1 = extremely easy to control (the probability of occurrence and the impact can be decreased/eliminated); 2 = easy to control; 3 = medium to control (the probability of occurrence or impact can be reduced at some level); 4 = difficult to control; 5 = considerably difficult to control (neither probability of occurrence nor impact can be decreased).

N	Code	Risk factors	
	<i>HC</i>	<i>Component 1: Human resource and technical risk in the construction phase</i>	
1	HC1	Lack of experience of contractors/subcontractors in GB construction	[1], [2], [4–7], [9]
2	HC2	Lack of professionals who are experienced and qualified about GB	[1–3], [5], [6], [9]
3	HC3	Project management consultant and/or project team lacks experience in construction management of GB projects	[6], [7], [9]
4	HC4	Unfamiliarity with green materials and construction process	[2]
5	HC5	Difficulty in the selection of contractors providing GB construction services	[4], [5], [9]
6	HC6	Improper quality control process for GB projects	[3], [5], [8], [9]
7	HC7	Detail design/green specifications are unclear or possible errors	[1–3], [9]
	<i>PO</i>	<i>Component 2: Performance risk in the operation phase</i>	
8	PO1	The performance of green solutions is not achieved as the original goal	[2], [4–6]
9	PO2	Lack of adequate GB maintenance	[5], [6]
10	PO3	Lack of experienced management agency in the operation phase	[5–7]
11	PO4	Project evaluation results did not reach the expected GB standard	[4–6], [9]
12	PO5	The lack of cooperation among the parties involved in the GB trial operation stage	[6]
13	PO6	Difficulties in operating green solutions	[10]
	<i>HD</i>	<i>Component 3: Human resource risk in the design phase</i>	
14	HD1	Late involvement of GB consultants in the design phase	[10]
15	HD2	Inefficient communication and coordination between parties	[1], [2], [5]
16	HD3	Project teams lack design management experience in GB projects	[1], [4], [9]
17	HD4	Lack of experience of designers about GB	[4–7], [9]
18	HD5	Owners lack determination as implementing GB projects	[10]
	<i>FR</i>	<i>Component 4: Financial risk</i>	
19	FR1	The payback period of GB projects may be longer than conventional projects	[5]
20	FR2	High costs of sustainable materials and equipment	[3], [6], [9]
21	FR3	Lack of accurate estimation of investment and long-term return	[5], [6], [8], [10]
22	FR4	Underestimation of initial investment cost	[2], [5]
23	FR5	Price inflation of construction materials and labor	[1–3], [5–9]
	<i>RR</i>	<i>Component 5: Regulations risk</i>	
24	RR1	Complex planning approval and permit procedures	[1], [5]
25	RR2	Change in local regulations/governmental policies that affect the implementation of GB projects	[3], [4], [5], [7], [9]
26	RR3	The regulations on duties, powers, and dispute resolution in the GB design contract are unclear	[1], [2], [7], [8]
27	RR4	Delay in decision-making	[1]
	<i>MR</i>	<i>Component 6: Green material risk</i>	
28	MR1	Green material quality problems	[1], [7]
29	MR2	Limited availability and reliability of green materials and products suppliers	[1–3], [5–9]
30	MR3	No general standards for testing the quality and origin of green materials	[10]

**Note(s):** [1] Zhao *et al.* (2016); [2] Hwang *et al.* (2017a); [3] Hwang *et al.* (2017b); [4] Yang *et al.* (2016); [5] Ahmad *et al.* (2019); [6] Qin *et al.* (2016); [7] Rafindadi *et al.* (2014); [8] Guan *et al.* (2020); [9] El-Sayegh *et al.* (2021); [10] Nguyen *et al.* (2021)

**Table 1.**  
Risk factors in GB projects



**Figure 1.**  
The overall research framework

**Table 2.**  
Likert scales for risk assessment

Scales	Impact level	Occurrence probability	Risk manageability
1	Very low	Rarely (<20%)	Extremely easy to control
2	Low	Somewhat likely (20–40%)	Easy to control
3	Moderate	Likely (40–60%)	Medium to control
4	High	Very likely (60–80%)	Difficult to control
5	Very high	Almost definite (>80%)	Considerably difficult to control

Risk manageability indicates the feasibility of mitigating the risk magnitude by reducing the risk impact and probability of occurrence. This feature is determined not only based on risk factors but also on practitioners' capacity. In other words, risk manageability is related to the attributes of both risk factors and practitioners. Thus, when assessing risk manageability, participants should consider two aspects: the first aspect is the capacity to control specific risks based on experience in dealing with them (Dikmen *et al.*, 2018); the second aspect is risk attributes (i.e. the natural controllability of risk factors). This implies that some risk factors are more controllable than others by their nature (Aven *et al.*, 2007).

### 3.2 Questionnaire survey

First, seven professionals were invited to participate in the pilot survey to validate the questionnaire. Professionals were required to (1) answer all questions and (2) write feedback to clarify the survey questions. The pilot test was completed once the professionals had reached a general consensus regarding the questionnaire content. As a result, the questionnaire had minor adjustments. The final questionnaire was distributed to the potential respondents.

A total of 250 survey questionnaires were sent to professionals. Potential respondents with rich GB risk experience were identified from the Vietnam Green Building Council, GB consultants and GB contractors. Finally, 195 respondents received questionnaires via email and 55 respondents took hard copies.

After three months, 69 complete questionnaires were obtained. The response rate was 27.6%, which is consistent with the average rate (20–30%) in most surveys in the construction industry (Akintoye, 2000). Among these responses, 11 incomplete responses were eliminated. Finally, 58 valid responses were used as the inputs for the RA model. The reliability test revealed a Cronbach's alpha coefficient of internal consistency value of 0.90 (>0.80), indicating that the data are reliable (Nunnally, 1994).

Table 3 summarizes the profiles of respondents. The majority of participants (93.10%) worked nationally or internationally (mainly in Southeast Asia). Thus, they should have a good understanding of the construction industry in Vietnam and developing countries. Furthermore, this survey covered numerous construction companies and stakeholders, such as owners, consultants and contractors. Regarding their positions, 24.14% were senior managers, 31.03% were managers and 41.38% were engineers. In addition, 28 (48.28%) respondents had worked for more than 10 years in the construction industry. Regarding GB knowledge, 39.66% of the participants were GB experts and 60.34% were familiar with GBs. In summary, the results indicate the trustworthiness of the collected data.

Demographic characteristics		Frequency	Percent (%)
Company scales	International	34	58.62
	National	20	34.48
	Multi-cities/provinces	3	5.17
	Within a city/province	1	1.72
Project roles	Owners	12	20.69
	Architects	7	12.07
	Engineering designers	2	3.45
	GB consultant	19	32.76
	PM consultant	8	13.79
	Contractors	5	8.62
Position in organization	Other	5	8.62
	Directorial level	14	24.14
	Managerial level	18	31.03
	Expert level	24	41.38
	Other	2	3.45
Year of experience	3–5 years	22	37.93
	6–10 years	8	13.79
	11–15 years	11	18.97
	More than 15 years	17	29.31
GB knowledge	Expert	23	39.66
	Familiar	35	60.34
		(n = 58)	

**Table 3.**  
The demographic  
background of  
respondents

### 3.3 Calculate risk parameters

The most common way to evaluate the significance of risk factors is to multiply the impact level and probability of occurrence. This is also the most popular method for evaluating risk factors in the construction literature (Taroun, 2014). The formula is as follows:

$$RA = P \times I \quad (1)$$

where  $RA$  = risk assessment,  $P$  = probability of occurrence, and  $I$  = impact level.

In this research, the authors complemented the traditional formula above by adding risk manageability ( $M$ ), which was recommended by previous research (Dikmen *et al.*, 2018; Taroun, 2014). According to previous studies, risk manageability reflects risk attributes and is related to practitioners' abilities and specific situations (Dikmen *et al.*, 2018; Xia *et al.*, 2017). Indeed, the higher the probability of occurrence and impact, the greater the risk significance. In contrast, risk significance decreases if the ability to manage risk increases.

To facilitate respondents' assessment, the scale of risk manageability was set similar to the scales of risk impact and probability: the higher the  $M$  value, the more difficult it is to manage risk. In addition, this helps the value of risk significance ( $RS$ ) be presented on the same scale as other criteria (from 1 to 5), thereby facilitating the interpretation of results. This is also suitable for the fuzzy technique because we can switch between linguistics and number values and vice versa. The formula for risk significance is

$$RS = \sqrt[3]{P \times I \times M} \quad (2)$$

### 3.4 Mean scoring ranking technique

The mean scoring (MS) method is a popular technique that can be applied to many fields. For example, the MS method has been applied to calculate the relative importance of various indices/criteria (Mu *et al.*, 2014; Xu *et al.*, 2010). In this study, MS was used as a statistical technique to determine the relative importance of GB risk factors (Mu *et al.*, 2014; Zhao *et al.*, 2016). The collected data were used to compute the MS according to each risk factor attribute, which determines the relative ranking of each feature of the risk factors. The formula of MS to calculate for each attribute of risk factors is illustrated by

$$MS = \frac{\sum_{i=1}^5 s_i f_i}{\sum_{i=1}^5 f_i} \quad (3)$$

where:

- (1)  $i$  denotes the response category index, from 1 = very low/rarely/extremely easy to control to 5 = very high/almost definite/greatly difficult to control;
- (2)  $s_i$  denotes the weight assigned to the  $i$ th response;  $s_i = 1, 2, 3, 4$  and  $5$  for  $i = 1, 2, 3, 4$  and  $5$ , respectively;
- (3)  $f_i$  denotes the frequency of the  $i$ th response.

### 3.5 Fuzzy synthetic evaluation

The purpose of FSE is to assess an object associated with various criteria in a fuzzy decision environment (Mu *et al.*, 2014). According to previous studies, FSE has advantages in handling complicated assessments with multiple criteria and multiple levels (Akter *et al.*, 2019; Xu *et al.*, 2010). Therefore, utilizing FSE to assess GB risks in this study is appropriate because risks also comprise multiple criteria and levels.



As is well known, risks in construction projects frequently comprise numerous risk factors and risk groups. Thus, risk factors and risk groups must be scrutinized during an RA process to ensure accuracy. This research applied FSE to create an RA model to evaluate risk factors in GB projects via three attributes: risk impact, probability of occurrence and risk manageability.

There are three essential components in the RA model as a multi-criteria assessment model (Mu *et al.*, 2014; Xu *et al.*, 2010):

- (1) A family of criteria/risk factors  $f = \{f_1, f_2, \dots, f_m\}$ . In this study,  $m$  was the number of risk factors.
- (2) A set of alternatives  $E = \{e_1, e_2, \dots, e_n\}$ , where  $n$  is the number of alternatives.
- (3) For every object, there is an evaluation matrix  $R = (r_{ij})_{m \times n}$ , where  $r_{ij}$  denotes the degree to which alternative  $e_j$  satisfies the criterion/risk factor  $f_i$ .

The evaluation results of the objects can be calculated based on these three elements. In addition, three hierarchical GB risks were investigated in this model: risk factors, risk groups and overall risk. The process of assessing risks includes three steps: first, the model calculates parameters to assess risk factors; the evaluation of risk groups is then determined based on risk factors; and, finally, the overall risk is determined.

**3.5.1 Evaluate GB risk factors.** First, the features ( $P$ ,  $I$  and  $M$ ) of all risk factors were identified based on the inputs from the questionnaire survey. According to Table 2, all of the features have the same value (from 1 to 5) in the set of alternatives  $E$ . Hence, set of  $E$  for probability is  $e_1 =$  rarely,  $e_2 =$  somewhat likely,  $e_3 =$  likely,  $e_4 =$  very likely and  $e_5 =$  almost definite; the set of  $E$  for impact contains  $e_1 =$  very low,  $e_2 =$  low,  $e_3 =$  moderate,  $e_4 =$  high and  $e_5 =$  very high; and the set of  $E$  for manageability is  $e_1 =$  extremely easy to control,  $e_2 =$  easy to control,  $e_3 =$  medium to control,  $e_4 =$  difficult to control and  $e_5 =$  considerably difficult to control.

Regarding the evaluation matrix,  $r_{ij}$  represents the degree to which alternative  $e_j$  satisfies the  $i$ th risk factor. For each GB risk factor, the membership function of each feature can be identified based on the collected data. For example, the  $P$  of factor HC2 (lack of experienced and qualified professionals about GB) shows that 3% of the responses evaluated the probability as very low, 19% as low, 31% as medium, 36% as high and 10% as very high. Thus, the membership function of  $P$  was calculated using

$$\frac{0.03}{\text{verylow}} + \frac{0.19}{\text{low}} + \frac{0.31}{\text{medium}} + \frac{0.36}{\text{high}} + \frac{0.10}{\text{veryhigh}} = \frac{0.03}{1} + \frac{0.19}{2} + \frac{0.31}{3} + \frac{0.36}{4} + \frac{0.10}{5} \quad (4)$$

The result could also be denoted in matrix form as

$$(R_i^P)_{1 \times 5} = (R_2^P)_{1 \times 5} = (r_{21}^P, r_{22}^P, r_{23}^P, r_{24}^P, r_{25}^P) = (0.03, 0.19, 0.31, 0.36, 0.10) \quad (5)$$

Similarly, the membership functions of all GB risk factors were identified using the same procedure. Subsequently, the parameter values of the  $i$ th risk factor were calculated using

$$P_i = (R_i^P)_{1 \times 5} \times E_{5 \times 1} = \sum_{j=1}^5 (r_{ij}^P \times e_j) \quad (6)$$

$$I_i = (R_i^I)_{1 \times 5} \times E_{5 \times 1} = \sum_{j=1}^5 (r_{ij}^I \times e_j) \quad (7)$$

$$M_i = (R_i^M)_{1 \times 5} \times E_{5 \times 1} = \sum_{j=1}^5 (r_{ij}^M \times e_j) \tag{8}$$

where  $e_j$  is the rating given to the  $i$ th risk factor, and represents the linguistic variable. In this research,  $e_1$  = rarely/very low/extremely easy to control;  $e_2$  = somewhat likely/low/easy to control;  $e_3$  = likely/moderate/medium to control;  $e_4$  = very likely/high/difficult to control and  $e_5$  = almost definite/very high/considerably difficult to control.

Risk significance ( $RS$ ) was used to measure the significant levels of risk factors. The risk significance of the  $i$ th risk factor was calculated using

$$RS_i = \sqrt[3]{P_i \times I_i \times M_i} \tag{9}$$

In addition, the authors calculated RA based on the traditional approach (Taroun, 2014). It might be interesting to compare the conventional approach with the proposed formula in this study. Also, this comparison provides a comprehensive view of the current GB risks in Vietnam. The RA of the  $i$ th risk factor was calculated using

$$RA_i = \sqrt{P_i \times I_i} \tag{10}$$

**3.5.2 Evaluate GB risk groups.** First, the weight of risk factors in each risk group must be identified using the MS ranking technique (Equation (3)). The weight vector of the  $t$ th risk group has the following form:  $W_t = \{w_1, w_2, \dots, w_k\}$ , where  $k$  is the number of risk factors in the risk group. In addition, this model identified three weight vectors separately for  $P, I$  and  $M$  in the risk groups. The weight of risk factors within a risk group can be computed using

$$w_i^P = \frac{P_i}{\sum_{i=1}^k P_i} \tag{11}$$

$$w_i^I = \frac{I_i}{\sum_{i=1}^k I_i} \tag{12}$$

$$w_i^M = \frac{M_i}{\sum_{i=1}^k M_i} \tag{13}$$

In the next step, the parameters of risk groups were calculated using the FSE model based on their membership functions, which were determined by their weight vector and the membership function of risk factors. The FSE commonly uses four methods to integrate the results. This model applies the fuzzy composition of the weight vector  $W$  and evaluation matrix  $R$  ( $D = W \times R$ ) to determine the membership function of the risk groups. As recommended by previous studies (Mu et al., 2014; Xu et al., 2010), this method is appropriate when considering numerous factors, and the variation in the weights is not significant. Therefore, this approach is suitable for this RA model because (1) the number of risk factors in risk groups is different and (2) the difference in the weight of risk factors is not significant. The membership functions of the  $t$ th risk group were computed using

$$(D_t^P)_{1 \times 5} = (W_t^P)_{1 \times k} \times (R_t^P)_{k \times 5} = (d_{t1}^P, d_{t2}^P, d_{t3}^P, d_{t4}^P, d_{t5}^P) \tag{14}$$

$$d_{ij}^P = \sum_{j=1}^5 \sum_{i=1}^k (w_i^P \times r_{ij}^P) \tag{15}$$

$$(D_t^I)_{1 \times 5} = (W_t^I)_{1 \times k} \times (R_t^I)_{k \times 5} = (d_{t1}^I, d_{t2}^I, d_{t3}^I, d_{t4}^I, d_{t5}^I) \quad (16)$$

$$d_{ij}^I = \sum_{j=1}^5 \sum_{i=1}^k (w_i^I \times r_{ij}^I) \quad (17)$$

$$(D_t^M)_{1 \times 5} = (W_t^M)_{1 \times k} \times (R_t^M)_{k \times 5} = (d_{t1}^M, d_{t2}^M, d_{t3}^M, d_{t4}^M, d_{t5}^M) \quad (18)$$

$$d_{ij}^M = \sum_{j=1}^5 \sum_{i=1}^k (w_i^M \times r_{ij}^M) \quad (19)$$

After identifying the membership functions of the  $t$ th risk group, we then calculated the values of the corresponding parameters using

$$P_{Gt} = (D_t^P)_{1 \times 5} \times E_{5 \times 1} = \sum_{j=1}^5 (d_{ij}^P \times e_j) \quad (20)$$

$$I_{Gt} = (D_t^I)_{1 \times 5} \times E_{5 \times 1} = \sum_{j=1}^5 (d_{ij}^I \times e_j) \quad (21)$$

$$M_{Gt} = (D_t^M)_{1 \times 5} \times E_{5 \times 1} = \sum_{j=1}^5 (d_{ij}^M \times e_j) \quad (22)$$

$$RA_{Gt} = \sqrt{P_{Gt} \times I_{Gt}} \quad (23)$$

$$RS_{Gt} = \sqrt[3]{P_{Gt} \times I_{Gt} \times M_{Gt}} \quad (24)$$

where  $e_j = 1, 2, 3, 4, 5$ .

**3.5.3 Evaluate the overall risk.** Similarly, we needed to calculate the weights of risk groups using the MS ranking technique to determine the overall risk parameters. The weight vector has the form  $W_G = \{w_{G1}, w_{G2}, \dots, w_{Gq}\}$ . In this formula,  $q$  denotes the number of risk groups; thus, in this study,  $q = 6$ . The weight of the  $t$ th risk group was determined by

$$w_{Gt}^P = \frac{(\sum_{i=1}^k P_i)_t}{\sum_{t=1}^q (\sum_{i=1}^k P_i)_t} \quad (25)$$

$$w_{Gt}^I = \frac{(\sum_{i=1}^k I_i)_t}{\sum_{t=1}^q (\sum_{i=1}^k I_i)_t} \quad (26)$$

$$w_{Gt}^M = \frac{(\sum_{i=1}^k M_i)_t}{\sum_{t=1}^q (\sum_{i=1}^k M_i)_t} \quad (27)$$

where  $(\sum_{i=1}^k P_i)_t$  indicates the total of  $P$  of  $k$  risk factors in group  $t$ ; similarly,  $(\sum_{i=1}^k I_i)_t$  denotes the sum of  $I$  of  $k$  risk factors in group  $t$ ; and  $(\sum_{i=1}^k M_i)_t$  indicates the total of  $M$  of  $k$  risk factors in group  $t$ .

Subsequently, the membership functions of the overall risk were identified using

$$(D_{All}^P)_{1 \times 5} = (W_G^P)_{1 \times q} \times (D_G^P)_{q \times 5} = (d_{All1}^P, d_{All2}^P, d_{All3}^P, d_{All4}^P, d_{All5}^P) \quad (28)$$

$$d_{Allj}^P = \sum_{j=1}^5 \sum_{t=1}^q (w_{Gt}^P \times d_{tj}^P) \quad (29)$$

$$(D_{All}^I)_{1 \times 5} = (W_G^I)_{1 \times q} \times (D_G^I)_{q \times 5} = (d_{All1}^I, d_{All2}^I, d_{All3}^I, d_{All4}^I, d_{All5}^I) \quad (30)$$

$$d_{Allj}^I = \sum_{j=1}^5 \sum_{t=1}^q (w_{Gt}^I \times d_{tj}^I) \quad (31)$$

$$(D_{All}^M)_{1 \times 5} = (W_G^M)_{1 \times q} \times (D_G^M)_{q \times 5} = (d_{All1}^M, d_{All2}^M, d_{All3}^M, d_{All4}^M, d_{All5}^M) \quad (32)$$

$$d_{Allj}^M = \sum_{j=1}^5 \sum_{t=1}^q (w_{Gt}^M \times d_{tj}^M) \quad (33)$$

where  $(D_G^P)_{q \times 5}$ ,  $(D_G^I)_{q \times 5}$ , and  $(D_G^M)_{q \times 5}$  are matrices that comprise  $q$  membership functions of risk groups (i.e.  $(D_t^P)_{1 \times 5}$ ,  $(D_t^I)_{1 \times 5}$ , and  $(D_t^M)_{1 \times 5}$ ) which are calculated in [Section 3.5.2](#).

Finally, the parameters of the overall risk were determined:

$$P_{All} = (D_{All}^P)_{1 \times 5} \times E_{5 \times 1} = \sum_{j=1}^5 (d_{Allj}^P \times e_j) \quad (34)$$

$$I_{All} = (D_{All}^I)_{1 \times 5} \times E_{5 \times 1} = \sum_{j=1}^5 (d_{Allj}^I \times e_j) \quad (35)$$

$$M_{All} = (D_{All}^M)_{1 \times 5} \times E_{5 \times 1} = \sum_{j=1}^5 (d_{Allj}^M \times e_j) \quad (36)$$

$$RA_{All} = \sqrt{P_{All} \times I_{All}} \quad (37)$$

$$RS_{All} = \sqrt[3]{P_{All} \times I_{All} \times M_{All}} \quad (38)$$

where  $s_j = 1, 2, 3, 4, 5$ .

## 4. Results and findings

### 4.1 The assessment of each risk factor

First, the membership functions of the risk factors were determined ([Table 4](#)). For instance, the  $P$  of risk factor RR1 (“Complex planning approval and permit procedures”) shows that 5% of the responses evaluated the probability very low, 19% low, 29% medium, 31% high and 16% very high. Thus, the  $P$  membership function of RR1 was identified by [Equations \(4–5\)](#):

$$\frac{0.05}{verylow} + \frac{0.19}{low} + \frac{0.29}{medium} + \frac{0.31}{high} + \frac{0.16}{veryhigh} = \frac{0.05}{1} + \frac{0.19}{2} + \frac{0.29}{3} + \frac{0.31}{4} + \frac{0.16}{5}$$

<i>N</i>	Code	Membership function of <i>P</i>	Membership function of <i>I</i>	Membership function of <i>M</i>
<i>Group 1: Human resource and technical risk in the construction phase</i>				
1	HC1	(0.03, 0.19, 0.31, 0.36, 0.10)	(0.03, 0.10, 0.33, 0.40, 0.14)	(0.02, 0.17, 0.53, 0.17, 0.10)
2	HC2	(0.03, 0.19, 0.36, 0.31, 0.10)	(0.00, 0.05, 0.24, 0.47, 0.24)	(0.00, 0.17, 0.47, 0.26, 0.10)
3	HC3	(0.00, 0.09, 0.43, 0.36, 0.12)	(0.00, 0.07, 0.28, 0.45, 0.21)	(0.00, 0.12, 0.55, 0.22, 0.10)
4	HC4	(0.00, 0.10, 0.43, 0.36, 0.10)	(0.00, 0.09, 0.45, 0.40, 0.07)	(0.00, 0.21, 0.53, 0.22, 0.00)
5	HC5	(0.02, 0.26, 0.45, 0.24, 0.03)	(0.02, 0.17, 0.50, 0.24, 0.07)	(0.02, 0.26, 0.43, 0.28, 0.02)
6	HC6	(0.03, 0.24, 0.38, 0.26, 0.09)	(0.02, 0.21, 0.29, 0.38, 0.10)	(0.00, 0.24, 0.50, 0.21, 0.05)
7	HC7	(0.03, 0.19, 0.38, 0.33, 0.07)	(0.02, 0.02, 0.34, 0.43, 0.19)	(0.00, 0.17, 0.50, 0.26, 0.07)
<i>Group 2: Performance risk in the operation phase</i>				
8	PO1	(0.00, 0.22, 0.38, 0.36, 0.03)	(0.00, 0.16, 0.26, 0.52, 0.07)	(0.00, 0.17, 0.47, 0.31, 0.05)
9	PO2	(0.00, 0.17, 0.34, 0.38, 0.10)	(0.00, 0.02, 0.40, 0.43, 0.16)	(0.02, 0.24, 0.43, 0.22, 0.09)
10	PO3	(0.02, 0.14, 0.40, 0.33, 0.12)	(0.00, 0.05, 0.43, 0.36, 0.16)	(0.00, 0.19, 0.50, 0.21, 0.10)
11	PO4	(0.07, 0.24, 0.43, 0.19, 0.07)	(0.02, 0.09, 0.36, 0.36, 0.17)	(0.00, 0.21, 0.59, 0.16, 0.05)
12	PO5	(0.03, 0.19, 0.52, 0.16, 0.10)	(0.02, 0.02, 0.40, 0.43, 0.14)	(0.02, 0.21, 0.52, 0.17, 0.09)
13	PO6	(0.09, 0.24, 0.36, 0.24, 0.07)	(0.03, 0.12, 0.36, 0.40, 0.09)	(0.07, 0.28, 0.34, 0.22, 0.09)
<i>Group 3: Human resource risk in the design phase</i>				
14	HD1	(0.00, 0.09, 0.60, 0.24, 0.07)	(0.00, 0.09, 0.29, 0.52, 0.10)	(0.02, 0.14, 0.36, 0.38, 0.10)
15	HD2	(0.00, 0.14, 0.45, 0.34, 0.07)	(0.00, 0.07, 0.24, 0.48, 0.21)	(0.02, 0.09, 0.50, 0.34, 0.05)
16	HD3	(0.00, 0.07, 0.34, 0.45, 0.14)	(0.05, 0.07, 0.24, 0.47, 0.17)	(0.02, 0.07, 0.48, 0.34, 0.09)
17	HD4	(0.02, 0.09, 0.31, 0.41, 0.17)	(0.00, 0.07, 0.26, 0.40, 0.28)	(0.00, 0.16, 0.45, 0.28, 0.12)
18	HD5	(0.02, 0.26, 0.24, 0.36, 0.12)	(0.05, 0.10, 0.16, 0.36, 0.33)	(0.00, 0.16, 0.21, 0.43, 0.21)
<i>Group 4: Financial risk</i>				
19	FR1	(0.02, 0.07, 0.36, 0.40, 0.16)	(0.02, 0.05, 0.33, 0.47, 0.14)	(0.02, 0.21, 0.52, 0.19, 0.07)
20	FR2	(0.00, 0.14, 0.36, 0.38, 0.12)	(0.00, 0.09, 0.36, 0.41, 0.14)	(0.02, 0.22, 0.45, 0.21, 0.10)
21	FR3	(0.02, 0.19, 0.45, 0.24, 0.10)	(0.02, 0.09, 0.28, 0.40, 0.22)	(0.03, 0.17, 0.48, 0.22, 0.09)
22	FR4	(0.02, 0.14, 0.34, 0.38, 0.12)	(0.02, 0.03, 0.28, 0.41, 0.26)	(0.00, 0.12, 0.48, 0.29, 0.10)
23	FR5	(0.02, 0.14, 0.43, 0.28, 0.14)	(0.02, 0.07, 0.33, 0.38, 0.21)	(0.03, 0.07, 0.34, 0.36, 0.19)
<i>Group 5: Regulations risk</i>				
24	RR1	(0.05, 0.19, 0.29, 0.31, 0.16)	(0.03, 0.12, 0.21, 0.40, 0.24)	(0.03, 0.14, 0.22, 0.31, 0.29)
25	RR2	(0.07, 0.38, 0.26, 0.19, 0.10)	(0.00, 0.22, 0.14, 0.40, 0.24)	(0.00, 0.17, 0.24, 0.26, 0.33)
26	RR3	(0.16, 0.21, 0.40, 0.19, 0.05)	(0.05, 0.10, 0.43, 0.33, 0.09)	(0.03, 0.26, 0.47, 0.14, 0.10)
27	RR4	(0.03, 0.14, 0.40, 0.31, 0.12)	(0.00, 0.05, 0.31, 0.45, 0.19)	(0.00, 0.09, 0.52, 0.31, 0.09)
<i>Group 6: Green material risk</i>				
28	MR1	(0.07, 0.17, 0.50, 0.24, 0.02)	(0.00, 0.09, 0.45, 0.43, 0.03)	(0.02, 0.21, 0.50, 0.26, 0.02)
29	MR2	(0.02, 0.12, 0.38, 0.31, 0.17)	(0.02, 0.07, 0.33, 0.36, 0.22)	(0.00, 0.16, 0.40, 0.34, 0.10)
30	MR3	(0.03, 0.22, 0.38, 0.22, 0.14)	(0.03, 0.10, 0.38, 0.41, 0.07)	(0.02, 0.19, 0.40, 0.33, 0.07)

**Table 4.**  
The membership  
functions of risk  
factors

$$(R_{24}^P)_{1 \times 5} = (r_{24-1}^P, r_{24-2}^P, r_{24-3}^P, r_{24-4}^P, r_{24-5}^P) = (0.05, 0.19, 0.29, 0.31, 0.16)$$

Subsequently, the values of all parameters were calculated using Equations (6–10) (Table 5). Table 5 also presents the rank of the risk factors according to each parameter value. The following example illustrates the calculation of the parameters of factor RR1:

$$P_{RR1} = \sum_{j=1}^5 (s_j \times r_{24-j}^P) = 1 \times 0.05 + 2 \times 0.19 + 3 \times 0.29 + 4 \times 0.31 + 5 \times 0.16 = 3.34$$

$$I_{RR1} = \sum_{j=1}^5 (s_j \times r_{24-j}^I) = 1 \times 0.03 + 2 \times 0.12 + 3 \times 0.21 + 4 \times 0.40 + 5 \times 0.24 = 3.70$$

$$M_{RR1} = \sum_{j=1}^5 (s_j \times r_{24-j}^M) = 1 \times 0.03 + 2 \times 0.14 + 3 \times 0.22 + 4 \times 0.31 + 5 \times 0.29 = 3.66$$

N	Code	Possibility (P)		Impact (I)		Manageability (M)		Risk assessment (RA)		Risk significant (RS)	
		Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank
	<i>HC</i>	<i>Group 1: Human resource and technical risk in the construction phase</i>									
1	HC1	3.28	17	3.52	23	3.13	20	3.4	20	3.31	21
2	HC2	3.23	18	3.90	2	3.29	12	3.55	11	3.46	12
3	HC3	3.51	4	3.83	4	3.27	13	3.67	2	3.53	7
4	HC4	3.43	8	3.48	24	3.04	28	3.45	19	3.31	21
5	HC5	3.00	25	3.17	30	3.05	27	3.08	29	3.07	29
6	HC6	3.14	23	3.33	28	3.07	26	3.23	26	3.18	26
7	HC7	3.22	19	3.75	9	3.23	16	3.47	16	3.39	18
	<i>PO</i>	<i>Group 2: Performance risk in the operation phase</i>									
8	PO1	3.17	22	3.53	22	3.24	15	3.35	22	3.31	21
9	PO2	3.38	11	3.76	8	3.12	22	3.56	9	3.41	15
10	PO3	3.42	9	3.63	18	3.22	17	3.52	14	3.42	14
11	PO4	2.95	28	3.57	21	3.08	24	3.25	24	3.19	25
12	PO5	3.11	24	3.68	15	3.13	21	3.38	21	3.3	23
13	PO6	2.96	27	3.4	25	2.98	30	3.17	28	3.11	28
	<i>HD</i>	<i>Group 3: Human resource risk in the design phase</i>									
14	HD1	3.29	16	3.63	19	3.40	7	3.46	17	3.44	13
15	HD2	3.34	13	3.83	5	3.31	11	3.58	7	3.49	10
16	HD3	3.66	1	3.64	17	3.41	6	3.65	4	3.57	3
17	HD4	3.62	3	3.92	1	3.39	8	3.77	1	3.64	1
18	HD5	3.3	15	3.82	6	3.72	2	3.55	12	3.61	2
	<i>FR</i>	<i>Group 4: Financial risk</i>									
19	FR1	3.64	2	3.69	13	3.11	23	3.66	3	3.47	11
20	FR2	3.48	6	3.6	20	3.15	18	3.54	13	3.4	16
21	FR3	3.21	20	3.74	10	3.14	19	3.46	18	3.35	19
22	FR4	3.44	7	3.86	3	3.34	10	3.64	5	3.54	6
23	FR5	3.41	10	3.72	11	3.58	4	3.56	9	3.57	4
	<i>RR</i>	<i>Group 5: Regulations risk</i>									
24	RR1	3.34	14	3.7	12	3.66	3	3.52	15	3.56	5
25	RR2	2.87	29	3.66	16	3.75	1	3.24	25	3.40	17
26	RR3	2.79	30	3.31	29	3.02	29	3.04	30	3.03	30
27	RR4	3.35	12	3.78	7	3.43	5	3.56	9	3.52	8
	<i>MR</i>	<i>Group 6: Green material risk</i>									
28	MR1	2.97	26	3.4	26	3.08	25	3.18	27	3.14	27
29	MR2	3.49	5	3.69	14	3.38	9	3.59	6	3.52	9
30	MR3	3.19	21	3.36	27	3.27	14	3.27	23	3.27	24

**Table 5.**  
The parameters of risk factors

$$RA_{RR1} = \sqrt{P_{RR1} \times I_{RR1}} = 3.52$$

$$RS_{RR1} = \sqrt[3]{P_{RR1} \times I_{RR1} \times M_{RR1}} = 3.56$$

#### 4.2 The assessment of risk groups

The first step identified the weight of the risk factors within each risk group (Table 6). For example, the weight of *P* for risk factor RR1 was calculated using Equation (11). Assuming that group RR (“Regulations risk”) has four risk factors, the denominator is the sum of the four elements:

$$W_{RR1}^P = P_{RR1} / \sum_{i=1}^4 P_{RRi} = \frac{3.34}{(3.34 + 2.87 + 2.79 + 3.35)} = 0.270$$

Subsequently, the membership functions of the risk groups were determined using formulas (14–19). Table 7 presents the membership functions for all risk groups and the overall risk. For example, the membership function of  $P$  for the risk group MR (“Green material risk”) was calculated as follows:

$$\begin{aligned} (D_{MR}^P)_{1 \times 5} &= (W_{MR}^P)_{1 \times 3} \times (R_{MR}^P)_{3 \times 5} = [0.308 \quad 0.362 \quad 0.331] \\ &= \begin{bmatrix} 0.07 & 0.17 & 0.50 & 0.24 & 0.02 \\ 0.02 & 0.12 & 0.38 & 0.31 & 0.17 \\ 0.03 & 0.22 & 0.38 & 0.22 & 0.14 \end{bmatrix} \\ &= (0.039 \quad 0.169 \quad 0.417 \quad 0.259 \quad 0.114) \end{aligned}$$

where  $(W_{MR}^P)_{1 \times 3}$  is a weight matrix of  $P$  for the group MR that contained the  $P$  weights of the 3 factors, and matrix  $(R_{MR}^P)_{3 \times 5}$  is a membership function matrix composed of the  $P$  membership functions of the 3 factors in the MR.

The probability of risk group MR was calculated according to Equation (20):

$$\begin{aligned} P_{G-MR} &= \sum_{j=1}^5 (e_j \times d_{MR-j}^P) = 1 \times 0.039 + 2 \times 0.169 + 3 \times 0.417 + 4 \times 0.259 + 5 \times 0.114 \\ &= 3.23 \end{aligned}$$

Similarly, the  $I$  and  $M$  membership functions of group MR were identified by applying Equations (16–19). Subsequently, Equations (21) and (22) were used to calculate  $I$  and  $M$  of this group:

$N$	Code	$P$	Weights		$N$	Code	$P$	Weights	
			$I$	$M$				$I$	$M$
	<i>HC</i>	<i>0.232</i>	<i>0.229</i>	<i>0.225</i>		<i>FR</i>	<i>0.175</i>	<i>0.171</i>	<i>0.167</i>
1	HC1	0.144	0.141	0.142	19	FR1	0.212	0.198	0.191
2	HC2	0.142	0.156	0.149	20	FR2	0.203	0.193	0.193
3	HC3	0.154	0.153	0.148	21	FR3	0.187	0.201	0.192
4	HC4	0.150	0.139	0.138	22	FR4	0.200	0.207	0.205
5	HC5	0.132	0.127	0.138	23	FR5	0.198	0.200	0.219
6	HC6	0.138	0.133	0.139					
7	HC7	0.141	0.150	0.146					
	<i>PO</i>	<i>0.193</i>	<i>0.198</i>	<i>0.192</i>		<i>PR</i>	<i>0.126</i>	<i>0.133</i>	<i>0.141</i>
8	PO1	0.167	0.164	0.173	24	PR1	0.270	0.256	0.264
9	PO2	0.178	0.174	0.166	25	PR2	0.232	0.253	0.271
10	PO3	0.180	0.168	0.172	26	PR3	0.226	0.229	0.218
11	PO4	0.155	0.166	0.164	27	PR4	0.271	0.262	0.247
12	PO5	0.164	0.171	0.167					
13	PO6	0.156	0.158	0.159					
	<i>HD</i>	<i>0.175</i>	<i>0.173</i>	<i>0.176</i>		<i>MR</i>	<i>0.098</i>	<i>0.096</i>	<i>0.099</i>
14	HD1	0.191	0.193	0.197	28	MR1	0.308	0.325	0.317
15	HD2	0.194	0.203	0.192	29	MR2	0.362	0.353	0.347
16	HD3	0.213	0.193	0.198	30	MR3	0.331	0.322	0.336
17	HD4	0.210	0.208	0.197					
18	HD5	0.192	0.203	0.216					

**Table 6.**  
Weights of risk factors  
and risk groups

$$I_{G-MR} = \sum_{j=1}^5 (e_j \times d_{MR-j}^I) = 1 \times 0.017 + 2 \times 0.086 + 3 \times 0.385 + 4 \times 0.399 + 5 \times 0.110$$

$$= 3.49$$

$$M_{G-MR} = \sum_{j=1}^5 (e_j \times d_{MR-j}^M) = 1 \times 0.013 + 2 \times 0.186 + 3 \times 0.432 + 4 \times 0.311 + 5 \times 0.065$$

$$= 3.25$$

Finally, the *RA* and *RS* values of the risk group MR were determined:

$$RA_{G-MR} = \sqrt{P_{G-MR} \times I_{G-MR}} = 3.36$$

$$RS_{G-MR} = \sqrt[3]{P_{G-MR} \times I_{G-MR} \times M_{G-MR}} = 3.32$$

Table 8 lists parameter values of risk groups. To facilitate the comparison among risk groups, Table 8 also shows the rank of risk groups according to each parameter.

#### 4.3 The assessment of the overall risk

To identify the overall risk, we first needed to calculate the weights for the risk groups. In this model, the number of risk groups was six. The results are listed in Table 6. For example, the weights of the group FR (“Financial risk”) were determined using Equations (25–27):

**Table 7.**  
The membership functions of risk groups and the overall risk

Code	Membership function of <i>P</i>	Membership function of <i>I</i>	Membership function of <i>M</i>
HC	(0.020, 0.177, 0.392, 0.319, 0.088)	(0.012, 0.098, 0.342, 0.400, 0.150)	(0.006, 0.190, 0.502, 0.232, 0.068)
PO	(0.033, 0.198, 0.404, 0.280, 0.083)	(0.011, 0.075, 0.370, 0.417, 0.133)	(0.018, 0.216, 0.476, 0.216, 0.078)
HD	(0.008, 0.128, 0.386, 0.363, 0.116)	(0.020, 0.080, 0.238, 0.445, 0.22)	(0.012, 0.125, 0.396, 0.356, 0.116)
FR	(0.016, 0.135, 0.387, 0.338, 0.129)	(0.016, 0.066, 0.315, 0.413, 0.195)	(0.020, 0.155, 0.451, 0.257, 0.112)
RR	(0.074, 0.225, 0.337, 0.255, 0.110)	(0.019, 0.122, 0.269, 0.397, 0.193)	(0.014, 0.162, 0.354, 0.259, 0.21)
MR	(0.039, 0.169, 0.417, 0.259, 0.114)	(0.017, 0.086, 0.385, 0.399, 0.110)	(0.013, 0.186, 0.432, 0.311, 0.065)
All	(0.028, 0.17, 0.388, 0.308, 0.104)	(0.015, 0.087, 0.319, 0.413, 0.168)	(0.014, 0.173, 0.442, 0.267, 0.105)

**Table 8.**  
The parameters of risk groups and the overall risk

Code	<i>P</i>		<i>I</i>		<i>M</i>		RA		RS	
	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank
HC	3.27	3	3.58	5	3.16	5	3.42	3	3.33	4
PO	3.18	5	3.6	4	3.13	6	3.38	4	3.3	6
HD	3.45	1	3.77	1	3.45	2	3.61	1	3.55	1
FR	3.44	2	3.72	2	3.27	3	3.58	2	3.47	2
RR	3.11	6	3.62	3	3.49	1	3.36	5	3.4	3
MR	3.23	4	3.49	6	3.25	4	3.36	6	3.32	5
All	3.28		3.64		3.28		3.46		3.40	



$$w_{G-FR}^P = \frac{\left(\sum_{i=1}^5 P_i\right)_4}{\sum_{t=1}^6 \left(\sum_{i=1}^k P_i\right)_t} = \frac{17.18}{98.19} = 0.175$$

$$w_{G-FR}^I = \frac{\left(\sum_{i=1}^5 I_i\right)_4}{\sum_{t=1}^6 \left(\sum_{i=1}^k I_i\right)_t} = \frac{18.61}{108.9} = 0.171$$

$$w_{G-FR}^M = \frac{\left(\sum_{i=1}^5 M_i\right)_4}{\sum_{t=1}^6 \left(\sum_{i=1}^k M_i\right)_t} = \frac{16.32}{97.99} = 0.167$$

These weights were then utilized to determine the membership functions of the overall risk. For instance, to determine the membership function of  $P$  for the overall risk, we calculated the fuzzy composition by multiplying the weight vector and evaluation matrix (Equation (28)):

$$\begin{aligned} (D_{All}^P)_{1 \times 5} &= (W_G^P)_{1 \times 6} \times (D_G^P)_{6 \times 5} = [0.232 \quad 0.193 \quad 0.175 \quad 0.175 \quad 0.126 \quad 0.098] \\ &\quad \times \begin{bmatrix} 0.020 & 0.177 & 0.392 & 0.319 & 0.088 \\ 0.033 & 0.198 & 0.404 & 0.280 & 0.083 \\ 0.008 & 0.128 & 0.386 & 0.363 & 0.116 \\ 0.016 & 0.135 & 0.387 & 0.338 & 0.129 \\ 0.074 & 0.225 & 0.337 & 0.255 & 0.110 \\ 0.039 & 0.169 & 0.417 & 0.259 & 0.114 \end{bmatrix} \\ &= (0.028 \quad 0.170 \quad 0.388 \quad 0.308 \quad 0.104) \end{aligned}$$

Subsequently, the  $P$  of the overall risk can be calculated using Equation (34):

$$\begin{aligned} P_{All} &= \sum_{j=1}^5 (s_j \times d_{All-j}^P) = 1 \times 0.028 + 2 \times 0.170 + 3 \times 0.388 + 4 \times 0.308 + 5 \times 0.104 \\ &= 3.28 \end{aligned}$$

Similarly, the overall  $I$  value was identified using Equations (30), (31) and (35):

$$\begin{aligned} (D_{All}^I)_{1 \times 5} &= (W_G^I)_{1 \times 6} \times (D_G^I)_{6 \times 5} = (0.015 \quad 0.087 \quad 0.319 \quad 0.413 \quad 0.168) \\ I_{All} &= \sum_{j=1}^5 (e_j \times d_{All-j}^I) = 1 \times 0.015 + 2 \times 0.087 + 3 \times 0.319 + 4 \times 0.413 + 5 \times 0.168 \\ &= 3.64 \end{aligned}$$

Using the same process, the value of  $M$  of the overall risk was determined by using Equations (32), (33) and (36):

$$(D_{All}^M)_{1 \times 5} = (W_G^M)_{1 \times 6} \times (D_G^M)_{6 \times 5} = (0.014 \quad 0.173 \quad 0.442 \quad 0.267 \quad 0.105)$$

$$M_{All} = \sum_{j=1}^5 (e_j \times d_{All-j}^M) = 1 \times 0.014 + 2 \times 0.173 + 3 \times 0.442 + 4 \times 0.267 + 5 \times 0.105$$

$$= 3.28$$

Finally, *RA* and *RS* of the overall risk were obtained using [Equations \(37\) and \(38\)](#):

$$RA_{All} = \sqrt{P_{All} \times I_{All}} = \sqrt{3.38 \times 4.21} = 3.46$$

$$RS_{All} = \sqrt[3]{P_{All} \times I_{All} \times M_{All}} = 3.40$$

This result indicated that risks in GB projects in Vietnam are relatively high.

## 5. Discussion

This study proposed a practical *RA* model for GB projects and then adopted it to assess the current GB risks in Vietnam. The result implied that risk in GB projects is relatively high, with the significance of the overall risk being 3.40. This result is generally lower than expected because previous studies have claimed that GB risks are very high ([Hwang et al., 2017b](#); [Zhao et al., 2016](#)). However, this does not mean that GB risks in Vietnam are less critical because respondents' evaluations are somewhat relative and depend on subjective factors. Therefore, this section concentrates on analyzing risk groups and top risk factors based on their *RS* rankings.

### 5.1 Risk group assessment

This section discusses the assessment results of risk groups. This provides an overview of the current GB risks in Vietnam.

- (1) Human resource risk in the design phase (HD): *RS* = 3.55

Human resource risk during the design phase was the most critical risk group. This is also the risk group with the highest possibility and the most significant impact ([Table 8](#)). This result indicates that qualified professionals play a crucial role in GB projects, especially during the design phase ([Hwang et al., 2017a](#)). This is understandable because GBs are complex buildings and require various techniques and innovations in design. This finding reflects a common problem in Vietnam: the lack of GB professionals. This result is also aligned with the literature because the shortage of GB professionals has been recognized as a significant barrier for GB development in previous studies ([Hwang et al., 2017a](#); [Qin et al., 2016](#)). In the current situation in Vietnam, providing training courses on GBs for construction practitioners is considered a suitable solution for the construction industry.

- (2) Financial risk (FR): *RS* = 3.47

Financial risk is also a critical risk group in GB projects and is ranked second. Finance is a fundamental problem and plays an essential role in construction projects, particularly in large and complex construction projects. Thus, for GB projects, which are considered complicated, the finance problem is even more crucial compared with traditional projects. This is understandable because GBs adopt novel materials and the latest construction technologies; therefore, cost estimation is challenging and regularly faces uncertainty

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(Hwang *et al.*, 2017b). Moreover, the values of GBs include various intangible benefits (e.g. improving the indoor environment and business advantages) that are not straightforward to evaluate monetarily (Guan *et al.*, 2020).

(3) Regulation risk (RR):  $RS = 3.40$

In the third position, the regulation risk is a significant problem in the implementation process of GB projects. Indeed, implementing GB projects is much more complicated and involves more procedures than traditional projects. For example, GB projects usually apply green solutions (e.g. solar photovoltaic and rain harvesting systems), resulting in lengthy and complicated approval-permit procedures (Qin *et al.*, 2016; Zhao *et al.*, 2016). Furthermore, approval frequently requires the participation of various stakeholders. Thus, this problem can cause significant delays in the implementation process, leading to the failure of GB projects.

(4) Human resources and technical risks in the construction phase (HC):  $RS = 3.33$

The risk group ranked fourth is human resources and technical risks in the construction phase. Similar to the design phase, the construction phase of GB projects also requires experienced professionals to handle problems at construction sites (Hwang *et al.*, 2017a). Therefore, the lack of qualified managers, engineers and workers can significantly affect the costs, schedules and quality of GB projects, even in developed countries such as Singapore (Hwang *et al.*, 2017b; Zhao *et al.*, 2016). In the current situation of Vietnam, the most reasonable solution to develop the GB workforce is to provide training courses for construction practitioners.

(5) Green material risk (MR):  $RS = 3.32$

The fifth position was a common problem that recently received much attention from construction practitioners in GB projects: green material risks. GB frequently uses novel and innovative materials that aim to be more environmentally friendly (Nguyen *et al.*, 2017). In general, green materials (e.g. unburnt bricks or organic paints) are produced using different methods compared with traditional materials. Nevertheless, this is also why many construction practitioners doubt the quality of green materials. There are still many issues related to the quality, certification and supply of green materials in practice. Indeed, such problems can significantly affect GB projects and investors' trust, thereby somewhat restraining GB development. Similarly, several previous studies also claimed that green material risk is a substantial hindrance to GB development (Nguyen *et al.*, 2017; Shi *et al.*, 2013).

(6) Performance risk in the operation phase (PO):  $RS = 3.30$

Finally, the risk in the operation phase is also worth considering. Indeed, by investing in GB projects, owners hope there could be benefits for their business (e.g. saving energy and water and improving the indoor environment). However, many practitioners claim that the performance of GBs frequently does not meet initial expectations (Hwang *et al.*, 2017a; Qin *et al.*, 2016). Simulation tools are usually used to quantify GB performance at the beginning of projects. Based on the analysis results, investors decide whether to invest in GBs. Thus, performance problems in the operation phase could temper investors' beliefs and consequently restrict the development of GBs. This is also a common problem in GB projects, as mentioned in previous studies (Ismael and Shealy, 2018; El-Sayegh *et al.*, 2021).

### 5.2 The most critical risk factors

This section discusses the top-10 risk factors based on  $RS$  values. This finding may provide insight into the risks in GB projects and benefit construction practitioners in the RM process.

(1) HD4 ("Lack experience of GB designers"):  $RS = 3.64$

The most critical risk factor is HD4, which relates to GB designers' lack of experience. This indicates that the incapacity of GB designers is a major problem in the design phase of GB projects in Vietnam (Nguyen *et al.*, 2021). This research also revealed that this risk factor has the greatest impact (impact level ranked first) and is a common problem in Vietnam (probability of occurrence ranked third). This result is understandable because GB projects frequently require qualified designers to handle sustainable designs. This outcome is in line with the GB literature because this risk factor has also been evaluated in previous studies (Ismael and Shealy, 2018). Notably, Qin *et al.* (2016) rated this factor as the third critical risk in China. Fortunately, the risk manageability of this factor was ranked 8th, indicating that we can still mitigate this risk (e.g. by training GB designers).

(2) HD5 (“Owners lack determination when implementing GB projects”):  $RS = 3.61$

The second position belonged to HD5, which reflected an issue in GB projects in Vietnam: if owners face considerable obstacles in implementing GB projects, they may give up. Interestingly, this factor does not have a high probability of occurrence (probability of occurrence rated 15th), but its impact is relatively substantial (impact level ranked sixth). Notably, managing this factor is very difficult (risk manageability ranked second), which makes this risk factor critical. If we used the traditional approach to assess (only considering  $I$  and  $p$ ) this factor would be ranked 12th. However, this factor became more severe as we examined risk manageability. This finding provides insight and could help practitioners develop a suitable strategy to deal with this factor in implementing GB projects. This result aligns with the research of Nguyen *et al.* (2021), who rated this risk factor as the most critical risk factor. Indeed, this problem could restrain the development of GBs; thus, enhancing owners' awareness and knowledge could mitigate this risk (Nguyen *et al.*, 2021).

(3) HD3 (“Project teams lack design management experience”):  $RS = 3.57$

The third position is the factor HD3, which refers to the crucial coordinating role of the project team in the design phase of GB projects. This finding is aligned with results in the literature, as this factor was also significant in previous studies (El-Sayegh *et al.*, 2021; Yang *et al.*, 2016). Notably, this risk factor was the most common risk in Vietnam (probability of occurrence ranked first), whereas its impact was ranked 17th. In addition, mitigating this risk factor is somewhat challenging in developing countries such as Vietnam, as demonstrated by its sixth rated RM. The most feasible solution is to train construction practitioners about GB projects, especially project manager positions.

(4) FR5 (“Price inflation of construction materials and labor”):  $RS = 3.57$

In the fourth position, the risk factor FR5 refers to the uncertainty of green materials and labor price in implementing GB projects, which has received significant attention in previous studies (Hwang *et al.*, 2017b). Indeed, this problem could lead to cost overruns in practice and the consequent failure of GB projects. The results showed that the probability and impact of this factor were rated 10th and 11th, respectively. Notably, managing this risk factor is challenging (risk manageability is ranked fourth), making this risk highly critical. This revealed that GB projects still face inflation risks, even though Vietnam's inflation rate has been somewhat stable in the past few years. This is understandable because the proportion of the cost for green materials and skilled labor in GB projects is much higher than in traditional projects.

(5) RR1 (“Complex planning approval and permit procedures”):  $RS = 3.56$

Complex planning approval and permit procedures is also a critical risk factor that is difficult to control. This factor reflects the inherent issue that procedures in GB projects are more

complex than conventional projects. This is reasonable because GB applies green solutions; thus, approval permit procedures are frequently prolonged and complicated (Zhao *et al.*, 2016). Consequently, this issue could lead to delays in the implementation of GB projects. Moreover, project teams tend to handle this problem by speeding up the schedule, which could lead to failure or low-quality projects (Zou and Couani, 2012). Notably, although this risk factor is neither highly common nor significantly influential for GB projects ( $p$  and  $I$  were ranked 14th and 12th, respectively), the difficulty in controlling this factor makes it more severe (RM rated third). This is the most critical risk factor in China (Qin *et al.*, 2016). This revealed that the severity of this risk might depend on the current laws in each country's construction industry.

(6) FR4 ("Underestimation of initial investment cost"):  $RS = 3.54$

One of the most impactful factors in GB projects is the "Underestimation of the initial investment cost" (impact level ranked third). Moreover, this risk is still a common problem in Vietnam, as shown by its probability of occurrence rated seventh. This revealed that project teams frequently underrated the initial cost of GB projects, such as green materials, technology and GB consultant costs (Hwang *et al.*, 2017a). This result is in line with the literature, as this risk factor had a high evaluation in developed countries such as Singapore (Hwang *et al.*, 2017a). Notably, the initial investment cost is considered a significant obstacle for the development of GBs in Vietnam (Nguyen *et al.*, 2017). Fortunately, we could still mitigate this risk by increasing the practitioners' awareness. This may be why the RM of this factor was rated 10th.

(7) HC3 ("Project management consultant and/or project team lacks experience in construction management of GB projects"):  $RS = 3.53$

Another common risk in Vietnam is HC3, with the probability of occurrence and impact level ranked fourth. Therefore, considering only the probability of occurrence and impact level, this risk factor would be ranked second. This result is aligned with previous studies that evaluated this risk factor as high (El-Sayegh *et al.*, 2021; Yang *et al.*, 2016). This reflects a critical problem in Vietnam: a lack of qualified project managers who have experience in GB projects. Fortunately, the RM of this risk factor was ranked 13th; consequently, this factor became less severe. Indeed, this risk can be mitigated by training practitioners and by choosing capable project managers for GB projects.

(8) RR4 ("Delay in decision-making"):  $RS = 3.52$

In the eighth position is the risk factor RR4, which signifies the issues in decision-making in GB projects. This problem is related to the complexity of GB projects and the complicated procedures involved in the approval process. The results also showed that this risk factor is relatively common (probability of occurrence rated 12th) and has a significant impact (impact level ranked seventh) in GB projects. Moreover, managing this risk factor is also a challenge reflected by its RM, which is ranked fifth. This finding is aligned with results in the literature, as this factor was evaluated as the second most critical factor in Singapore (Zhao *et al.*, 2016).

(9) MR2 ("Limited availability and reliability of green materials and suppliers"):  $RS = 3.52$

Another critical risk factor is MR2, which is related to the limited availability and reliability of green materials and suppliers. Although the impact level of this factor is ranked 14th, this is a prevalent problem (probability of occurrence rated fifth). This is unsurprising as conventional materials still dominate and outnumber green materials in the construction industry, especially in developing countries such as Vietnam. Moreover, there are still some

problems and uncertainty about the quality and certification of green materials that can reduce user confidence. In addition, this problem is not easy to mitigate (RM ranked ninth) because it depends on the development of technologies and objective factors. According to previous studies, the shortage of green material supplies is a critical barrier to the development of GBs (Nguyen *et al.*, 2017).

(10) HD2 (“Inefficient communication and coordination between parties”):  $RS = 3.49$

Finally, in 10th position is the risk factor HD2, with a relatively high impact (impact level ranked fifth). This risk reflects a significant problem: communication and coordination among stakeholders are still ineffective, particularly between GB consultants and other consultants. According to previous studies, collaboration among parties could improve the quality of work and speed up the progress; thereby, stakeholder collaborations are vital in GB projects (Hwang *et al.*, 2017a; Zhao *et al.*, 2016). Indeed, collaboration is essential for any construction project, specifically in complex construction projects. Thus, for distinctive projects such as GB projects, the coordinator role of GB consultants is even more crucial (Zhao *et al.*, 2016). Fortunately, this factor’s probability of occurrence and RM were ranked 13th and 11th, respectively. This implies that practitioners can still mitigate this risk using a suitable RM strategy. Project management consultants play an essential role in addressing this risk. Thus, investors should choose capable project management consultants experienced in GB projects.

## 6. Conclusion

GB is an inevitable trend in sustainable construction to mitigate adverse impacts on the environment. However, GB projects frequently face many risks during implementation. In this study, we developed an RA model for GB projects based on mean scores and the FSE method to ease this problem. Notably, this model evaluates risk factors based on three features: impact level, probability of occurrence and RM. Furthermore, this research applied the proposed model to evaluate the risks in GB projects in Vietnam by surveying practitioners.

First, this study has provided a novel and reliable model to evaluate GB risks in the GB literature. Thus, this research could be a useful reference for future research to examine GB risks in more depth. In addition, the model could be a helpful tool for construction professionals in the RM process of GB projects. As a second contribution, this research applied the proposed model to thoroughly assess GB risks in Vietnam. The results revealed that risks in implementing GB projects in Vietnam could be regarded as “relatively high”, which implied RM is necessary. Also, this study indicated the top-five critical risk factors are “lack experience of GB designers”, “owners lack determination as implementing GB projects”, “project teams lack design management experience”, “price inflation of green materials and labor” and “complex planning approval and permit procedures”. Regarding risk groups, the most critical risk group is “Human resource risk in the design phase”. Furthermore, we have discussed the assessment results of risk groups and the top risk factors to provide insight into the current risks in GB projects in Vietnam. This could facilitate practitioners in the RM process, thereby, helping to enhance the development of GBs in Vietnam.

Despite the authors’ efforts, this study has some limitations. First, the data used in this research were collected from a developing country, Vietnam. Therefore, caution should be exercised when generalizing the results to other developing countries and should not be generalized to developed countries. Nevertheless, the proposed model can be replicated to assess risk in conventional construction projects, other countries and other sectors. Second, the respondents evaluated risk factors based on their knowledge and individual judgment; thus, the subjectivity of the collected data is inevitable. However, this problem is common in research involving questionnaire surveys or participants’ subjective assessments. Moreover,

the RA process regularly depends on specific project teams and GB projects, especially as this model considers the RM aspect. Thus, practitioners should apply the proposed model to assess risks in specific GB projects based on their team and use this research result as a reference.

Future studies should compare risks in GB projects in different countries, especially between developing and developed countries. In addition, exploring the relationship between RM and project performance (e.g. cost, schedule and customer satisfaction) is a promising research direction. Also, it may be helpful for practitioners to investigate how to reduce GB risks through practical measures.

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