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A fuzzy synthetic evaluation approach for risk assessment: a case of Singapore's green projects

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ABSTRACT

In recent years, green building has attracted wide attention from both academia and industry. As green building projects are inevitably plagued with risks, this study attempted to assess the risks in green building projects in Singapore. Categorizing a list of 28 risk factors into 11 groups, the study performed a questionnaire survey and received 31 responses from project managers in Singapore. A risk assessment model was developed using the fuzzy synthetic evaluation approach. Using the proposed model, the likelihood of occurrence, magnitude of impact and risk criticality of each risk factor, group and the overall risk were calculated. "Inaccurate cost estimation" was the top risk factor, and "cost overrun risk" was the most critical risk group. The overall risk criticality was high, implying risk management was still necessary for green construction in Singapore. The proposed risk assessment model is reliable and practical for professionals in the green building industry, and can be applied in risk assessment in other countries. As few studies focused on risks in green projects, this study expands the knowledge and literature.

1. Introduction

Recently, there has been a growing concern on global climate change, as a result of increasing greenhouse gas (GHG) emissions (Huang et al., 2015; Wu et al., 2014a; Yuan et al., 2015). If no measures were taken to reduce GHG emissions, at least 5% of the global GDP would be expended because of the adverse influence of climate change (Stern, 2007; Wu et al., 2015). As one of the largest sources of GHG emissions, the building and construction industry is facing increasing pressure to reduce GHG emissions (Wu et al., 2014b; Zuo et al., 2015). Thus, green construction has attracted more attention in recent years and there have been an apparent shift towards green construction (Hwang et al., 2015b; Zuo et al., 2012). Green construction has evolved to become a necessity for the environmentally conscious industry professionals, owners, developers, government officials and the rest of the stakeholders (Durmus-Pedini and Ashuri, 2010; Shi et al., 2012; Wu and Low, 2014). In addition, higher energy prices, increased building material costs, legislations and regulatory incentives are also pushing the green construction market to grow and expand. Thus, environmentally sustainable building construction has experienced significant growth in the past 10 years (Lim et al., 2015; Zuo et al., 2013).

This trend of going green has also been seen in Singapore. The construction industry has played a key role in the economy of Singapore. According to the Building and Construction Authority (BCA, 2015a), Singapore's construction output was about S$37.7 billion in 2014 and will remain strong in 2015. The level of environmental awareness in Singapore's construction industry has been rising (Ofori et al., 2000; Singhaputtangkul et al., 2013). Singapore has been viewed as a leader in advocating sustainability in the building and construction industry with its efficient green strategies and initiatives (WorldGBC, 2013). The Green Mark, a certification scheme for green buildings in Singapore, was launched in January 2005 as an initiative to drive Singapore's construction industry towards more environment-friendly buildings. In the recent years, construction of green projects has been gaining great foothold in Singapore.

Construction projects are inevitably plagued with complex and diverse risks (Deng et al., 2014; Hlaing et al., 2008; Zhao et al., 2014b). Similar to traditional building projects, there are risks

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associated with going green (Durmus-Pedini and Ashuri, 2010) but this may be a different set of risks due to usage of new materials, technologies and design approaches (Odom et al., 2008), sustainable construction practices and achievement of third party green certification (Greenwald, 2012). If the risks associated with green projects are not appropriately managed, they will continue to become barriers to the green construction movement (Durmus-Pedini and Ashuri, 2010). Thus, risk management is necessary to assure the success of green construction.

The objectives of this study are to (1) identify the risk factors and groups associated with green building projects in Singapore; (2) develop a risk assessment model using the fuzzy synthetic evaluation (FSE) approach; and (3) assess the risk factors and groups using this model. To achieve the objectives, a questionnaire survey was conducted to collect data from project managers experienced in green construction, and then the data were input into the FSE model for risk assessment. Although there have been studies focused on cost, performance aspects and the benefits of green projects, few have attempted to investigate risk management in green projects. Thus, this study can contribute to the literature. Additionally, this study provides practitioners with a clear understanding of the critical risks in green building construction and allows them to allocate the limited resources to the risks that are worth more attention.

2. Background

The green building concept has been widely accepted by both academics and industry practitioners around the world. This trend of going green has also been seen in Singapore, and supported by the government. Green building projects are also plagued with various risks and thus risk management is necessary for these projects. FSE can be seen as an appropriate approach to risk assessment.

2.1. Green building in the world

The researches have been performed and proved that sustainable building practices can substantially diminish consumption of resources and produce benefits. Wedding and Crawford-Brown (2008) found that non-green buildings experienced energy use that was 50% greater than green buildings, outdoor water use at 100% greater and indoor water use at 30% greater. In addition to the significant environmental benefits, social, commercial and intangible benefits can be reaped (Yuan and Zuo, 2013; Zuo and Zhao, 2014). The US Green Building Council (USGBC, 2007) revealed that green construction projects had social impacts on health and well-being of building occupants, which was further substantiated by Tollin (2011) that certified green buildings would provide healthier environments for work and play. This could potentially result in lower absenteeism and higher productivity rates among employees. Other intangible benefits include improved occupant comfort and health, reduced water and material use, reduced climate change impact, and enhanced ecology (Lucuik et al., 2005). Moreover, there are also tangible benefits from green buildings. In the US, compared with traditional buildings, green buildings can reduce operating cost by 8–9%, increase building value by 7.5%, increase occupancy ratio by 3.5%, and improve return on investment by 6.6% (Durmus-Pedini and Ashuri, 2010).

2.2. Green building in Singapore

In order to reduce the GHG emissions, and contribute to the global climate change mitigation efforts, the Building and Construction Authority (BCA) of Singapore launched the Green Mark for Building Scheme in 2005. The voluntary scheme involved a green building rating system that evaluated a building for its environmental impact and performance. In December 2006, the BCA formulated the 1st Green Building Masterplan to encourage, enable and engage industry stakeholders to increase their efforts in environmental sustainability. To push for better environmental performance, the Building Control (Environmental Sustainability) Regulations were enacted in 2008 to make the Green Mark mandatory in the construction industry. With that, industry stakeholders began to recognize that going green had shifted from being a choice to being an obligation. The thrust towards more buildings being certified with Green Mark has grown beyond Singapore to overseas such as Thailand, Vietnam, Indonesia, and China (Hwang and Tan, 2012).

As sustainable development remains a key national priority going forward, the 2nd Green Building Masterplan and the Sustainable Development Blueprint were unveiled in 2009 and one of the key targets is to have at least 80% of all the buildings being green by 2030 (BCA, 2009). For continuous improvement in the building industry, all new buildings should comply with a higher BCA Green Mark standard after December 2010. This essentially translates into an additional 10% in energy savings from buildings compared to current standards. The minimum energy efficiency standard is also 28% higher than that released in 2005 when the Green Mark was launched. To accelerate the process of going green, the BCA has launched on the 3rd Green Building Masterplan, which highlights building capability in the industry, engaging the tenants and occupants for closer partnership between the people, private and public sectors, driving consumption behavioral adjustments, as well as developing an environment that addresses the well-being of the people (BCA, 2014).

2.3. Risks in green building projects

Green building projects are inevitably plagued with risks, which include the risks common to all kinds of construction projects and those closely associated with green construction. Thus, risk management is necessary to assure successful delivery of green projects as well as the achievement of the key targets set by the government. A large number of studies have attempted to identify many risk factors in various construction projects. These risk factors, all of which will be handled in this study by categorizing them into 11 groups, are indicated in Table 1.

2.4. Fuzzy synthetic evaluation

As risk assessment is complex and ambiguous, qualitative linguistic terms are unavoidable (Wang et al., 2004). In addition, the perceptions on likelihood and impact of risk factors by respondents are typically subjective and uncertain (Shan et al., 2015). The fuzzy set theory can deal with the problems relating to ambiguous, subjective and imprecise judgments (Pedrycz et al., 2011; Zhao et al., 2013). The fuzzy set theory also allows mathematical operators to be applied to the fuzzy domain (Ma and Kremer, 2015; Xia et al., 2011), and can quantify the linguistic facet of available data and preferences for individual or group decision-making (Zhao et al., 2014a; Zimmermann, 2001). Thus, the fuzzy set theory is considered as appropriate for risk assessment. As an application of the fuzzy set theory, fuzzy synthetic evaluation (FSE) aims to provide a synthetic evaluation of an object relative to an objective in a fuzzy decision environment with multiple criteria (Mu et al., 2014). FSE has been adopted in several risk management studies. For instance, Mu et al. (2014) applied this method to assess risk management capability of contractors in subway projects in Mainland China; Xu et al. (2010a) developed a fuzzy synthetic risk allocation

Table 1
Risk factors in green building projects identified from previous studies.

Group	Code	Risk factor	References									
			1	2	3	4	5	6	7	8	9	10
Macro-economic risk	R01	Increasing inflation rate	√	√			√	√	√	√	√	√
	R02	Currency exchange rate fluctuation	√	√	√	√	√		√	√		
	R03	Increasing tax rate		√		√			√			
Contract problems	R04	Unclear contract conditions for dispute resolution					√		√			√
	R05	Unclear contract conditions for claims and litigations	√									
Client-related risk	R06	Unclear requirements of clients	√			√						
	R07	Intervention of clients	√		√		√				√	
	R08	Delayed payments from clients			√		√			√		
Design problems	R09	Unclear detailed design or specifications	√	√		√	√					
	R10	Poor design	√			√	√		√		√	√
	R11	Variations in design	√	√		√	√	√		√	√	
Safety risk	R12	Strict safety and health regulations	√	√	√	√						
	R13	Construction accidents	√		√			√	√		√	√
Procedure complexity	R14	Complex planning approval and permit procedures	√	√	√	√				√	√	
	R15	Delay in issuance of documents	√				√		√			
Technical problems	R16	Technical complexity	√			√	√		√	√		
	R17	Use of new construction method and technology		√	√		√	√	√			
Human resource risk	R18	Constraints on laborer employment	√	√	√	√						
	R19	Lack of management staff	√			√	√	√			√	
	R20	Poorly trained laborers	√		√			√			√	
Material and equipment problems	R21	Material quality problems	√				√					
	R22	Availability of equipment and materials	√				√					
	R23	Default supply of materials, equipment and plants	√	√	√	√	√		√			√
Project team risk	R24	Project teams without relevant knowledge	√								√	
	R25	Inefficient communication and coordination	√					√			√	
	R26	Unfavorable sub-contractors	√		√		√				√	√
Cost overrun risk	R27	Inaccurate cost estimation	√					√				
	R28	Labor and materials price fluctuations	√		√							

References: 1 = Zhi (1995); 2 = Baker et al. (1999); 3 = Hlaing et al. (2008); 4 = Eybpoosh et al. (2011); 5 = El-Sayegh (2008); 6 = Lu and Yan (2013); 7 = Panthi et al. (2009); 8 = Al-Bahar and Crandall (1990); 9 = Zou et al. (2007); 10 = Kartam and Kartam (2001).

model for public-private partnership (PPP) projects in China; and Liu et al. (2013) used this method to analyze risks in ultra-deep scientific drilling projects. The advantage of FSE lies in dealing with complicated evaluation with multiple attributes and levels (Mu et al., 2014; Xu et al., 2010a).

3. Method and data presentation

A questionnaire survey was performed to achieve the objectives of this study. Preliminary interviews were conducted with three experienced project managers from different companies who have managed green construction projects previously. All three project managers interviewed have more than 10 years of experience in the construction industry and at least two years of experience in green projects. Their opinions provided an insight to risks in green projects. Thus, the interviewees helped identify the more relevant risks and modified those gathered from the literature review.

The finalized questionnaire included the questions meant to profile the firms and respondents. Additionally, the 28 risk factors were presented in the questionnaire. The respondents were requested to assess the likelihood of occurrence (LO) and the magnitude of impact (MI) of each risk in green projects. A five-point scale was used to rate the LO and MI of each risk factor (1 = very low; 2 = low; 3 = medium; 4 = high; and 5 = very high).

According to the BCA (2015b), the registry grade represents different tendering limits for different contractors. Contractors with the registry grade of A1 have unlimited tendering limits while A2 indicates its limit at S$90 million. Grades B1 and B2 have tender limits of S$42 million and S$14 million, respectively. The target audience comprised the project managers experienced in green building from the companies with BCA financial grades A1 to B2. The BCA contractor registry directory served as the sampling frame. A total of 277 questionnaires were sent out to all the general building contractors registered with financial grades A1 to B2. The selection was restricted to financial grades A1 to B2 because their higher financial capabilities and resources allow them to undertake green projects. Moreover, a cross check on the green buildings constructed in Singapore revealed that most of these green projects were undertaken by larger companies classified under these categories.

A total of 31 completed responses were received, yielding a response rate of 11.2%, which was low compared with the norm of 20–30% of most questionnaire surveys in the construction industry (Akintoye, 2000). The low response rate could result from the busy schedules of project managers that prevented them from completing the surveys on time, and the confidentiality and sensitivity of information that companies were reluctant to divulge. Despite the small sample size, statistical analysis can still be applied because the central limit theorem holds true with a sample size greater than 30 (Hwang et al., 2015a; Ott and Longnecker, 2001). Indeed, there has been no criterion on the sample size of FSE. For example, in the previous studies using FSE, the sample sizes were eight in Liu et al. (2013), six in Onkal-Engin et al. (2004), and 58 in Mu et al. (2014), respectively.

The profile of the companies and respondents is shown in Table 2. A total of 74.2% of the respondents were from A1 contractors and 77.4% had over 10 years of experience in the construction industry and more than three years of experience in green projects. Among the 114 green projects managed by the respondents, 69.3% were either commercial or residential projects, and 83.3% were new construction.

In this study, there are three levels of risks: risk factors (level 1), risk groups (level 2), and the overall risk (level 3). Therefore, it is appropriate to adopt FSE to develop a risk assessment model in this study.

Table 2
Profile of companies, respondents and projects.

Characteristics			N	%
Company (N = 31)	Registry grades[a]	A1	23	74.2%
		A2	5	16.1%
		B1	2	6.5%
		B2	1	3.2%
Respondent (N = 31)	Experience in construction industry	<5 years	2	6.5%
		5-10 years	5	16.1%
		>10 years	24	77.4%
		Mean	*15.0*	–
	Experience in green building	<3 years	7	22.6%
		3-4 years	11	35.5%
		5-10 years	13	41.9%
		Mean	*6.7*	–
Project (N = 114)	Type	Commercial	45	39.5%
		Residential	34	29.8%
		Education	23	20.2%
		Industry	8	7.0%
		Other	4	3.5%
	Nature	New construction	95	83.3%
		Addition and alteration	19	16.7%

[a] BCA grading system: A1-unlimited tendering limit; A2-up to S$90 million; B1-up to S$42 million; B2-up to S$14 million.

As a multi-criteria evaluation model, the proposed risk assessment model requires three basic elements (Mu et al., 2014; Xu et al., 2010b):

(1) A set of basic criteria/factors $C = \{c_1, c_2, \ldots c_m\}$, where m is the number of criteria/factors;
(2) A set of alternatives $E = \{e1, e2, \ldots en\}$, where n is the number of alternatives; and
(3) An evaluation matrix $R = (r_{ij})_{m\times n}$, where r_{ij} denotes the degree to which the alternative e_j satisfies the criterion c_i.

The proposed risk assessment model involves three steps:

Step 1: Calculating LO, MI, RC of risk factors
Step 2: Calculating LO, MI, RC of risk groups
Step 3: Calculating LO, MI, RC of overall risks

3.1. Step 1: calculate LO, MI and RC of risk factors (level 1)

In this study, the LO and MI of each risk factor was collected in the questionnaire survey with a five-point scale. Thus, in the set of alternatives E, for both LO and MI, e_1 = very low; e_2 = low; e_3 = medium; e_4 = high; and e_5 = very high.

In the evaluation matrix, r_{ij} denotes the degree to which the alternative e_j satisfies the risk factor i. For example, the results on the LO of risk factor "Increasing inflation rate" (R01) indicate that 23% of the respondents opined the LO as very low, 26% as low, 35% as medium, 16% as high and 0% as very high, the membership function of the LO is given by equation (1):

$$\frac{0.23}{\text{very low}}+\frac{0.26}{\text{low}}+\frac{0.35}{\text{medium}}+\frac{0.16}{\text{high}}+\frac{0.00}{\text{very high}} = \frac{0.23}{1}+\frac{0.26}{2}+\frac{0.35}{3}+\frac{0.16}{4}+\frac{0.00}{5} \quad (1)$$

It can also be written as a matrix in equation (2):

$$\left(R_i^{LO}\right)_{1\times 5} = \left(r_{i1}^{LO}, r_{i2}^{LO}, r_{i3}^{LO}, r_{i4}^{LO}, r_{i5}^{LO}\right) \quad (2)$$

The LO and MI of risk factor i can be calculated using equations (3) and (4), respectively:

$$LO_i = \sum_{j=1}^{5}\left(s_j \times r_{ij}^{LO}\right) \quad (3)$$

$$MI_i = \sum_{j=1}^{5}\left(s_j \times r_{ij}^{MI}\right) \quad (4)$$

where s_j is the rating given to factor i, namely $s_j = 1, 2, 3, 4, 5$. In risk management studies, risk criticalities (RC) is usually adopted to measure how critical a risk factor is, and considered as the product of LO and MI. In this study, to keep the scale of RC consistent with LO and MI, RC of risk factor i is calculated using equation (5):

$$RC_i = \sqrt{LO_i \times MI_i} \quad (5)$$

3.2. Step 2: calculate LO, MI and RC of risk groups (level 2)

To calculate the LO and MI of each risk group (level 2), the weight of each risk factor (level 1) within each risk group, $W = \{w_1, w_2, \ldots w_k\}$, should be determined. Here, k is the number of the risk factors within a risk group. The weights assigned to the LO and MI of risk factor i can be calculated by equations (6) and (7), respectively:

$$w_i^{LO} = LO_i \Big/ \sum_{i=1}^{k} LO_i \quad (6)$$

$$w_i^{MI} = MI_i \Big/ \sum_{i=1}^{k} MI_i \quad (7)$$

In FSE, the results of the evaluation are obtained by calculating the fuzzy composition of the weight vector W and the evaluation matrix R, namely $D = W \times R$. Thus, the LO and MI membership functions of risk group t can be calculated using equation (9)–(11), respectively:

$$d_{tj}^{LO} = \sum_{i=1}^{k} w_i^{LO} \times r_{ij}^{LO} \quad (8)$$

$$\left(D_t^{LO}\right)_{1\times5} = \left(W_i^{LO}\right)_{1\times k} \times \left(R_i^{LO}\right)_{k\times5} = \left(d_{t1}^{LO},\ d_{t2}^{LO},\ d_{t3}^{LO},\ d_{t4}^{LO},\ d_{t5}^{LO}\right) \tag{9}$$

$$d_{tj}^{MI} = \sum_{i=1}^{k} w_i^{MI} \times r_{ij}^{MI} \tag{10}$$

$$\left(D_t^{MI}\right)_{1\times5} = \left(W_i^{MI}\right)_{1\times k} \times \left(R_i^{MI}\right)_{k\times5} = \left(d_{t1}^{MI},\ d_{t2}^{MI},\ d_{t3}^{MI},\ d_{t4}^{MI},\ d_{t5}^{MI}\right) \tag{11}$$

Such a model is suitable when a number of factors are considered and the difference in the weights of factors is not great (Liu et al., 2013; Mu et al., 2014; Xu et al., 2010b).

With the LO and MI membership functions of risk group t, the LO, MI and RC of risk group t can be calculated using equation (12)–(14), respectively:

$$LO_{Gt} = \sum_{j=1}^{5}\left(s_j \times d_{tj}^{LO}\right) \tag{12}$$

$$MI_{Gt} = \sum_{j=1}^{5}\left(s_j \times r_{tj}^{MI}\right) \tag{13}$$

$$RC_{Gt} = \sqrt{LO_{Gt} \times MI_{Gt}} \tag{14}$$

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

3.3. Step 3: calculate overall LO, MI and RC (level 3)

To calculate the LO and MI of the overall risk (level 3), the weight of each risk group (level 2), $W_G = \{w_{G1}, w_{G2}, \ldots w_{Gq}\}$, should be determined. Here, q is the number of risk groups. The weights assigned to the LO and MI of risk group t can be calculated by equations (15) and (16), respectively:

$$w_{Gt}^{LO} = \left(\sum_{i=1}^{k} LO_i\right)_t \Bigg/ \sum_{t=1}^{q}\left(\sum_{i=1}^{k} LO_i\right)_t \tag{15}$$

$$w_{Gt}^{MI} = \left(\sum_{i=1}^{k} MI_i\right)_t \Bigg/ \sum_{t=1}^{q}\left(\sum_{i=1}^{k} MI_i\right)_t \tag{16}$$

where $(\sum_{i=1}^{k} LO_i)_t$ denotes the sum of LO of k risk factors under group t; and $(\sum_{i=1}^{k} MI_i)_t$ denotes the sum of MI of k risk factors under group t.

The LO and MI membership functions of the overall risk can be calculated using the equation (17)–(20), respectively:

$$d_{Allj}^{LO} = \sum_{t=1}^{q} w_{Gt}^{LO} \times d_{tj}^{LO} \tag{17}$$

$$\left(D_{All}^{LO}\right)_{1\times5} = \left(W_G^{LO}\right)_{1\times q} \times \left(D_G^{LO}\right)_{q\times5} = \left(d_{All1}^{LO},\ d_{All2}^{LO},\ d_{All3}^{LO},\ d_{All4}^{LO},\ d_{All5}^{LO}\right) \tag{18}$$

$$d_{Allj}^{MI} = \sum_{t=1}^{q} w_{Gt}^{MI} \times d_{tj}^{MI} \tag{19}$$

$$\left(D_{All}^{MI}\right)_{1\times5} = \left(W_G^{MI}\right)_{1\times q} \times \left(D_G^{MI}\right)_{q\times5} = \left(d_{All1}^{MI},\ d_{All2}^{MI},\ d_{All3}^{MI},\ d_{All4}^{MI},\ d_{All5}^{MI}\right) \tag{20}$$

where $(D_G^{LO})_{q\times5}$ and $(D_G^{MI})_{q\times5}$ are $q \times 5$ matrices that contain q matrices of $(D_t^{LO})_{1\times5}$ and $(D_t^{MI})_{1\times5}$, respectively.

With the overall LO and MI membership functions, the overall LO, MI and RC can be calculated using equation (19)–(21), respectively:

$$LO_{All} = \sum_{j=1}^{5}\left(s_j \times d_{Allj}^{LO}\right) \tag{21}$$

$$MI_{All} = \sum_{j=1}^{5}\left(s_j \times d_{Allj}^{MI}\right) \tag{22}$$

$$RC_{All} = \sqrt{LO_{All} \times MI_{All}} \tag{23}$$

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

4. Risk assessment results

Using the FSE approach, the LO and MI membership functions of each risk factor were obtained, as indicated in Table 3. For example, the LO membership function of "increasing inflation rate" (R01) is calculated using equation (2):

$$\left(R_1^{LO}\right)_{1\times5} = \left(r_{11}^{LO},\ r_{12}^{LO},\ r_{13}^{LO},\ r_{14}^{LO},\ r_{15}^{LO}\right) = (0.23,\ 0.26,\ 0.35,\ 0.16,\ 0.00)$$

Then, the LO, MI and RC can be calculated using equation (3)–(5), respectively:

$$LO_1 = \sum_{j=1}^{5}\left(s_j \times r_{1j}^{LO}\right) = 1 \times 0.23 + 2 \times 0.26 + 3 \times 0.35 + 4 \times 0.16 + 5 \times 0.00 = 2.45$$

$$MI_1 = \sum_{j=1}^{5}\left(s_j \times r_{1j}^{MI}\right) = 1 \times 0.00 + 2 \times 0.00 + 3 \times 0.35 + 4 \times 0.39 + 5 \times 0.26 = 3.90$$

$$RC_1 = \sqrt{LO_1 \times MI_1} = 3.09$$

To assess each risk group (level 2), the LO and MI weights of each risk factor within each risk group were calculated using equations (6) and (7), as shown in Table 4. For example, the weight assigned to the LO of "increasing inflation rate", which was one of the three risk factors ($k = 3$) within risk group "macro-economic risk", was obtained using equation (6):

$$w_1^{LO} = LO_1 \Bigg/ \sum_{i=1}^{3} LO_i = 2.45/(2.45 + 1.97 + 1.87) = 2.45/6.29 = 0.39$$

The LO and MI membership functions of risk groups were also calculated for assessing these risk groups, as shown in Table 5.

Table 3
LO, MI and RC of risk factors calculated using the FSE risk assessment model.

Group	Risk code	Risk factor	LO		MI		RC	Rank
			Value	Membership function	Value	Membership function		
Macro-economic risk	R01	Increasing inflation rate	2.45	(0.23, 0.26, 0.35, 0.16, 0.00)	3.90	(0.00, 0.00, 0.35, 0.39, 0.26)	3.09	26
	R02	Currency exchange rate fluctuation	1.97	(0.39, 0.29, 0.29, 0.03, 0.00)	3.74	(0.00, 0.06, 0.35, 0.35, 0.23)	2.71	28
	R03	Increasing tax rate	1.87	(0.48, 0.26, 0.16, 0.10, 0.00)	4.39	(0.00, 0.00, 0.13, 0.35, 0.52)	2.86	27
Contract problems	R04	Unclear contract conditions for dispute resolution	4.00	(0.00, 0.06, 0.06, 0.68, 0.19)	4.03	(0.00, 0.03, 0.13, 0.61, 0.23)	4.02	17
	R05	Unclear contract conditions for claims and litigations	3.61	(0.00, 0.06, 0.35, 0.48, 0.10)	4.61	(0.00, 0.00, 0.10, 0.19, 0.71)	4.08	15
Client-related risk	R06	Unclear requirements of clients	4.32	(0.00, 0.03, 0.10, 0.39, 0.48)	4.55	(0.00, 0.00, 0.03, 0.39, 0.58)	4.43	4
	R07	Intervention of clients	4.19	(0.00, 0.00, 0.23, 0.35, 0.42)	4.45	(0.00, 0.00, 0.13, 0.29, 0.58)	4.32	7
	R08	Delayed payments from clients	4.23	(0.00, 0.00, 0.16, 0.45, 0.39)	4.26	(0.00, 0.00, 0.16, 0.42, 0.42)	4.24	10
Design problems	R09	Unclear detailed design or specifications	4.29	(0.00, 0.10, 0.03, 0.35, 0.52)	4.74	(0.00, 0.03, 0.00, 0.16, 0.81)	4.51	3
	R10	Poor design	3.23	(0.00, 0.00, 0.77, 0.23, 0.00)	3.65	(0.00, 0.00, 0.39, 0.58, 0.03)	3.43	25
	R11	Variations in design	4.29	(0.00, 0.06, 0.16, 0.19, 0.58)	4.29	(0.00, 0.00, 0.06, 0.58, 0.35)	4.29	9
Safety risk	R12	Strict safety and health regulations	4.35	(0.00, 0.00, 0.06, 0.52, 0.42)	4.42	(0.00, 0.00, 0.13, 0.32, 0.55)	4.39	6
	R13	Construction accidents	3.71	(0.00, 0.00, 0.39, 0.52, 0.10)	4.65	(0.00, 0.00, 0.00, 0.35, 0.65)	4.15	12
Procedure complexity	R14	Complex planning approval and permit procedures	3.71	(0.00, 0.03, 0.35, 0.48, 0.13)	4.35	(0.00, 0.00, 0.16, 0.32, 0.52)	4.02	16
	R15	Delay in issuance of documents	4.39	(0.00, 0.06, 0.06, 0.29, 0.58)	4.74	(0.00, 0.03, 0.00, 0.16, 0.81)	4.56	2
Technical problems	R16	Technical complexity	3.58	(0.00, 0.00, 0.45, 0.52, 0.03)	4.06	(0.00, 0.03, 0.06, 0.71, 0.19)	3.81	20
	R17	Use of new construction method and technology	3.16	(0.00, 0.13, 0.58, 0.29, 0.00)	4.13	(0.00, 0.00, 0.26, 0.35, 0.39)	3.61	24
Human resource risk	R18	Constraints on laborer employment	3.94	(0.00, 0.00, 0.23, 0.61, 0.16)	4.48	(0.00, 0.00, 0.03, 0.45, 0.52)	4.20	11
	R19	Lack of management staff	3.97	(0.00, 0.06, 0.16, 0.52, 0.26)	3.97	(0.00, 0.10, 0.13, 0.48, 0.29)	3.97	18
	R20	Poorly trained laborers	3.48	(0.00, 0.10, 0.35, 0.52, 0.03)	4.06	(0.00, 0.00, 0.16, 0.61, 0.23)	3.76	21
Material and equipment problems	R21	Material quality problems	3.48	(0.00, 0.03, 0.58, 0.26, 0.13)	3.94	(0.00, 0.00, 0.32, 0.42, 0.26)	3.70	23
	R22	Availability of equipment and materials	3.48	(0.00, 0.00, 0.52, 0.48, 0.00)	3.94	(0.00, 0.00, 0.19, 0.68, 0.13)	3.70	23
	R23	Default supply of materials, equipment and plants	4.10	(0.00, 0.06, 0.13, 0.45, 0.35)	4.74	(0.00, 0.03, 0.03, 0.10, 0.84)	4.41	5
Project team risk	R24	Project teams without relevant knowledge	3.74	(0.00, 0.03, 0.29, 0.58, 0.10)	4.19	(0.00, 0.00, 0.13, 0.55, 0.32)	3.96	19
	R25	Inefficient communication and coordination	3.90	(0.00, 0.06, 0.19, 0.52, 0.23)	4.35	(0.00, 0.03, 0.13, 0.29, 0.55)	4.12	14
	R26	Unfavorable sub-contractors	3.94	(0.00, 0.03, 0.26, 0.45, 0.26)	4.35	(0.00, 0.00, 0.13, 0.39, 0.48)	4.14	13
Cost overrun risk	R27	Inaccurate cost estimation	4.65	(0.00, 0.06, 0.06, 0.03, 0.84)	4.81	(0.00, 0.00, 0.06, 0.06, 0.87)	4.73	1
	R28	Labor and materials price fluctuations	3.97	(0.00, 0.06, 0.26, 0.32, 0.35)	4.65	(0.00, 0.03, 0.03, 0.19, 0.74)	4.29	8

Take "macro-economic risk" for example, its LO membership function was obtained using equations (8) and (9):

$$\left(D_1^{LO}\right)_{1\times5} = \left(W_1^{LO}\right)_{1\times3} \times \left(R_1^{LO}\right)_{3\times5} = [0.39 \quad 0.31 \quad 0.30] \times \begin{bmatrix} 0.23 & 0.26 & 0.35 & 0.16 & 0.00 \\ 0.39 & 0.29 & 0.29 & 0.03 & 0.00 \\ 0.48 & 0.26 & 0.16 & 0.10 & 0.00 \end{bmatrix}$$
$$= (0.35,\ 0.27,\ 0.28,\ 0.10,\ 0.00)$$

where $(W_1^{LO})_{1\times3}$ is the LO weight matrix of this risk group, comprised of the LO weights of the three risk factors within this group; and $(R_1^{LO})_{3\times5}$ is the LO membership function matrix, comprised of the LO membership functions of the three risk factors within this group.

Then, the LO of "macro-economic risk" can be calculated using equation (12):

$$LO_{G1} = \sum_{j=1}^{5}\left(s_j \times d_{tj}^{LO}\right) = 1 \times 0.35 + 2 \times 0.27 + 3 \times 0.28 + 4 \times 0.10 + 5 \times 0 = 2.13$$

Similarly, the MI membership function of this risk group was calculated using equations (10) and (11), and the MI was obtained using equation (13). Thus, the RC of risk group "macro-economic risk" was obtained using equation (14):

$$RC_{G1} = \sqrt{LO_{G1} \times MI_{G1}} = \sqrt{2.13 \times 4.03} = 2.93$$

The LO and MI weights of risk groups are shown in Table 4. The number of risk groups (k) is 11. For example, the weights assigned to the LO and MI of "macro-economic risk" were obtained using equations (15) and (16):

$$w_{G1}^{LO} = \left(\sum_{i=1}^{3} LO_i\right)_1 \Bigg/ \sum_{t=1}^{11}\left(\sum_{i=1}^{k} LO_i\right)_t = 6.29/104 = 0.06$$

$$w_{Gt}^{MI} = \left(\sum_{i=1}^{k} MI_i\right)_t \Bigg/ \sum_{t=1}^{q}\left(\sum_{i=1}^{k} MI_i\right)_t = 12.03/120.45 = 0.10$$

The LO and MI weights of risk groups were used to assess the overall risk level (level 3). The overall LO membership function was

Table 4
Weights of risk factors and groups calculated using the FSE risk assessment model.

Group	Code	LO				MI			
		Value	Group sum	Factor weight	Group weight	Value	Group sum	Factor weight	Group weight
Macro-economic risk	R01	2.45	6.29	0.39	0.06	3.90	12.03	0.32	0.10
	R02	1.97		0.31		3.74		0.31	
	R03	1.87		0.30		4.39		0.36	
Contract problems	R04	4.00	7.61	0.53	0.07	4.03	8.65	0.47	0.07
	R05	3.61		0.47		4.61		0.53	
Client-related risk	R06	4.32	12.74	0.34	0.12	4.55	13.26	0.34	0.11
	R07	4.19		0.33		4.45		0.34	
	R08	4.23		0.33		4.26		0.32	
Design problems	R09	4.29	11.81	0.36	0.11	4.74	12.68	0.37	0.11
	R10	3.23		0.27		3.65		0.29	
	R11	4.29		0.36		4.29		0.34	
Safety risk	R12	4.35	8.06	0.54	0.08	4.42	9.06	0.49	0.08
	R13	3.71		0.46		4.65		0.51	
Procedure complexity	R14	3.71	8.10	0.46	0.08	4.35	9.10	0.48	0.08
	R15	4.39		0.54		4.74		0.52	
Technical problems	R16	3.58	6.74	0.53	0.06	4.06	8.19	0.50	0.07
	R17	3.16		0.47		4.13		0.50	
Human resource risk	R18	3.94	11.39	0.35	0.11	4.48	12.52	0.36	0.10
	R19	3.97		0.35		3.97		0.32	
	R20	3.48		0.31		4.06		0.32	
Material and equipment problems	R21	3.48	11.06	0.31	0.11	3.94	12.61	0.31	0.10
	R22	3.48		0.31		3.94		0.31	
	R23	4.10		0.37		4.74		0.38	
Project team risk	R24	3.74	11.58	0.32	0.11	4.19	12.90	0.33	0.11
	R25	3.90		0.34		4.35		0.34	
	R26	3.94		0.34		4.35		0.34	
Cost overrun risk	R27	4.65	8.61	0.54	0.08	4.81	9.45	0.51	0.08
	R28	3.97		0.46		4.65		0.49	

obtained by calculating the fuzzy composition of the risk group weight vector and the evaluation matrix using equations (17) and (18):

$$\left(D_{All}^{LO}\right)_{1\times5} = \left(W_G^{LO}\right)_{1\times11} \times \left(D_G^{LO}\right)_{11\times5}$$

$$= [\,0.06 \quad 0.07 \quad 0.12 \quad 0.11 \quad 0.08 \quad 0.08 \quad 0.06 \quad 0.11 \quad 0.11 \quad 0.11 \quad 0.08\,] \times \begin{bmatrix} 0.35 & 0.27 & 0.28 & 0.10 & 0.00 \\ 0.00 & 0.06 & 0.22 & 0.58 & 0.14 \\ 0.00 & 0.01 & 0.16 & 0.40 & 0.43 \\ 0.00 & 0.06 & 0.27 & 0.26 & 0.40 \\ 0.00 & 0.00 & 0.21 & 0.52 & 0.27 \\ 0.00 & 0.05 & 0.20 & 0.38 & 0.37 \\ 0.00 & 0.06 & 0.51 & 0.42 & 0.02 \\ 0.00 & 0.05 & 0.24 & 0.55 & 0.16 \\ 0.00 & 0.03 & 0.39 & 0.40 & 0.17 \\ 0.00 & 0.04 & 0.25 & 0.52 & 0.19 \\ 0.00 & 0.06 & 0.15 & 0.17 & 0.61 \end{bmatrix}$$

$$= (\,0.02 \quad 0.06 \quad 0.26 \quad 0.40 \quad 0.27\,)$$

Table 5
LO, MI and RC of risk groups and the overall risks calculated using the FSE risk assessment model.

Group	LO_G			MI_G			RC_G	Rank
	Weight	Value	Membership function	Weight	Value	Membership function		
Macro-economic risk	0.06	2.13	(0.35, 0.27, 0.28, 0.10, 0.00)	0.10	4.03	(0.00, 0.02, 0.27, 0.37, 0.34)	2.93	11
Contract problems	0.07	3.82	(0.00, 0.06, 0.22, 0.58, 0.14)	0.07	4.34	(0.00, 0.02, 0.11, 0.39, 0.48)	4.07	7
Client-related risk	0.12	4.25	(0.00, 0.01, 0.16, 0.40, 0.43)	0.11	4.42	(0.00, 0.00, 0.11, 0.37, 0.53)	4.33	2
Design problems	0.11	4.00	(0.00, 0.06, 0.27, 0.26, 0.40)	0.10	4.27	(0.00, 0.01, 0.13, 0.42, 0.43)	4.13	5
Safety risk	0.08	4.06	(0.00, 0.00, 0.21, 0.52, 0.27)	0.08	4.54	(0.00, 0.00, 0.06, 0.34, 0.60)	4.29	4
Procedure complexity	0.08	4.08	(0.00, 0.05, 0.20, 0.38, 0.37)	0.08	4.56	(0.00, 0.02, 0.08, 0.24, 0.67)	4.31	3
Technical problems	0.06	3.38	(0.00, 0.06, 0.51, 0.42, 0.02)	0.07	4.10	(0.00, 0.02, 0.16, 0.53, 0.29)	3.73	10
Human resource risk	0.11	3.81	(0.00, 0.05, 0.24, 0.55, 0.16)	0.10	4.18	(0.00, 0.03, 0.10, 0.51, 0.35)	3.99	8
Material and equipment problems	0.11	3.71	(0.00, 0.03, 0.39, 0.40, 0.17)	0.10	4.24	(0.00, 0.01, 0.17, 0.38, 0.43)	3.97	9
Project team risk	0.11	3.86	(0.00, 0.04, 0.25, 0.52, 0.19)	0.11	4.30	(0.00, 0.01, 0.13, 0.41, 0.45)	4.08	6
Cost overrun risk	0.08	4.33	(0.00, 0.06, 0.15, 0.17, 0.61)	0.08	4.73	(0.00, 0.02, 0.05, 0.13, 0.81)	4.53	1
Overall		**3.83**	**(0.02, 0.06, 0.26, 0.40, 0.27)**		**4.33**	**(0.00, 0.01. 0.13, 0.38, 0.48)**	**4.07**	

Thus, the overall LO value was calculated using equation (21):

$$LO_{\mathrm{All}} = \sum_{j=1}^{5}\left(s_j \times r_j^{LO}\right) = 1 \times 0.02 + 2 \times 0.06 + 3 \times 0.26 + 4 \times 0.40 + 5 \times 0.27 = 3.83$$

Similarly, the overall MI can be calculated using equations (19), (20) and (22):

$$\left(D_{All}^{MI}\right)_{1\times 5} = \left(W_{G}^{MI}\right)_{1\times 11} \times \left(D_{G}^{MI}\right)_{11\times 5} = (0.00,\ 0.01.\ 0.13,\ 0.38,\ 0.48)$$

$$MI_{All} = \sum_{j=1}^{5}\left(s_j \times r_j^{MI}\right) = 1 \times 0.00 + 2 \times 0.01 + 3 \times 0.13 + 4 \times 0.38 + 5 \times 0.48 = 4.32$$

Finally, the overall RC was obtained using equation (23):

$$RC_{All} = \sqrt{LO_{All} \times MI_{All}} = \sqrt{3.83 \times 4.32} = 4.07$$

Because the linguistic term mapped to 4.00 is “high”, the overall RC of the green projects in Singapore was considered as high.

5. Discussion

The top 10 risk factors and top three risk groups are discussed in this section. The high overall RC confirmed that risk management was necessary for green construction.

5.1. Risk factors

(1) Inaccurate cost estimation: $RC_{27} = 4.73$

Among the 28 risk factors, “inaccurate cost estimation” was ranked top, mainly attributed to its high LO and MI values. Cost has been considered as one of the most important factors to contractors (Hlaing et al., 2008) and with the introduction of green features, there are more rooms for errors. This is supported by Robichaud and Anantatmula (2010) who argued that the sustainable building product was a relatively immature market given the youth of the green construction industry and that there had been no particular company standing out in the green building materials (McGraw-Hill Construction, 2006). Additionally, expensive technologies, products and materials as well as consultancy services with green buildings are likely to take a toll on the construction budget (Hwang and Tan, 2012). As a result, there is great difficulty in accurately estimating costs and any inaccurate estimation will pose a critical risk to green projects.

(2) Delay in issuance of documents: $RC_{15} = 4.56$

“Delay in issuance of documents” occupied the second position in green projects. Late issuance of relevant documents is likely to result in project delay (Hwang et al., 2013), especially when it occurs on the critical path. If the change order is not issued on time and the construction activities have been done, rework will occur and cost will increase. Thus, this risk factor was rated high.

(3) Unclear detailed design or specifications: $RC_9 = 4.51$

“Unclear detailed design or specifications” was ranked third, attributed to its high LO and MI scores. Green projects typically incorporate more advanced and intricate systems of interacting elements (Kubba, 2010). During design, the impact of the elements on each system should be considered as a whole. If the architect developed the design before the design engineers were selected, little attention would be given to the mechanical, electrical and hydraulic services of the building (Love et al., 1999). Thus, design engineers and contractor engineers would not be clear about the design, leading to construction errors and rework.

(4) Unclear requirements of clients: $RC_6 = 4.43$

“Unclear requirements of clients” received the fourth position and was considered to pose a high risk to contractors in green projects. In green construction, due to the complexity involved, clients may not be able to give clear requirements and instructions and requirements, which increased the difficulty of contractors in carrying out projects.

(5) Default supply of materials, equipment and plants: $RC_{23} = 4.41$

“Default supply of materials, equipment and plants” was ranked fifth in green projects. This risk factor tends to lead to the unavailability of materials, equipment and plants, and project delay. In green projects, some materials, equipment or plants specifically for green building are likely to be imported from overseas, requiring several weeks or months to be delivered on site. In addition, few alternative supply sources make replacement difficult should a delay in shipment occur. Thus, any technical hitch on the delivery of imported materials, especially those concerning the critical activities in a schedule, would adversely impact project schedule. This result was consistent with the finding of Hwang et al. (2015c) that late delivery of materials and equipment was one of the most critical causes of delay in green projects in Singapore.

(6) Strict safety and health regulations: $RC_{12} = 4.39$

“Strict safety and health regulations” received the sixth position. Workers in green projects face new, high-risk tasks. Specifically, Fortunato et al. (2012) found that workers in green projects suffered a 24% increase in falls to lower levels during roof work when installing solar panels, experienced a 19% increase in eyestrain when installing reflective roof membranes, and faced a 14% increase in exposure to harmful substances when installing innovative wastewater technologies. The Ministry of Manpower (MOM, 2006) of Singapore has issued the Workplace Safety and Health (Risk Management) Regulations. All the contractors should comply with these regulations and assess the safety and health risks.

(7) Intervention of clients: $RC_7 = 4.32$

Another risk factor from clients was “intervention of clients”, ranked seventh, implying that improper intervention of clients was not uncommon in green projects. This result was consistent with the argument of Durmus-Pedini and Ashuri (2010) that clients may not be willing to leave their comfort zone in dealing with new team members, new technologies and processes, and that this may increase the probability of occurrence of intervention.

(8) Labor and materials price fluctuations: $RC_{28} = 4.29$

“Labor and materials price fluctuations” occupied the eighth position. Price fluctuations have been active due to a sharp fluctuation in oil and steel prices worldwide (Skorupka, 2008). Green materials, which are inevitably used in green projects, are generally more expensive. Because the increased material price would result in lower profitability of contractors, this risk was rated high by project managers.

(9) Variations in design: $RC_{11} = 4.29$

"Variations in design" was another critical risk. Clients, especially private clients, tend to change designs according to the changing economic climate, to meet customer needs, or for marketing reasons. Variations in design impacts the plans of contractors and may even require extensive redesign (Ogunlana et al., 1996). In Singapore, variations in design have been found to significantly contribute to rework and delay in construction projects (Arain and Low, 2006), and client-initiated variations was one of the most critical causes of delay in green projects (Hwang et al., 2015c).

(10) Delayed payments from clients: $RC_8 = 4.24$

"Delayed payments from clients" received the tenth position. This risk factor was usually attributed to the financial difficulties of clients because financing by clients ensures the progress payment of completed work (Hwang et al., 2013). Delayed payments from clients would result in poor financial status of contractors, project delays or even shutdown (Long et al., 2008). In contrast, projects tend to achieve better performance than desired when payments to the contractor were released promptly (Iyer and Jha, 2006).

5.2. Risk groups

(1) Cost overrun risk: $RC_{G11} = 4.53$

Among the 11 risk groups, "cost overrun risk" was ranked top, suggesting that cost overrun was the most critical problem in green projects. In the context of green construction, cost overrun may make green construction unattractive because a client may consider that the green features of the building lead to the cost overrun. In addition, the cash flow is the lifeline for business continuity but the high upfront costs associated with green construction are likely to threaten the achievement of the cost objectives of green projects. Although Singapore's government provided various financial incentives schemes, such as the Green Mark Incentive Scheme for Existing Buildings (GMIS-EB) and the Building Retrofit Energy Efficiency Financing (BREEF) schemes, they would not significantly assist the building owners financially because of the uncertainty in receiving the cash incentives, which greatly increases the difficulty in accurately estimating the costs of green projects.

(2) Client-related risk: $RC_{G3} = 4.33$

"Client-related risk" received the second position, implying that green projects were plagued with the client-related problems. All the risk factors within this group were ranked within the top 10. The unclear requirement, intervention and late payment were the typical problems related to clients. This result echoed Hwang et al. (2014), who reported that the problems of clients were the most importance causes of rework and low productivity in Singapore. Additionally, unclear requirements of clients usually lead to designers' misinterpretation of the requirements, which was recognized as a critical factor influencing green project schedule performance in Singapore (Hwang et al., 2015c).

(3) Procedure complexity: $RC_{G6} = 4.31$

This risk group was ranked third. Green construction projects tend to involve higher-level complexity, which result in more complex planning approval and permit procedures (Greenwald, 2012). Also, the procedure complexity may result in delay in planning approval and permit, thus possibly leading to poor schedule performance of green projects.

It merits attention that "macro-economic risk" ($RC_{G1} = 2.93$) was the least critical group but it still had a high MI value, suggesting that once this risk occurred, its impact would be high. The low LO value resulted from the perception that Singapore had a relatively stable macro-economic environment. In addition, the low RC of this risk group was attributed to the low RC of its three risk factors, which were ranked the last three in the risk ranking, as shown in Table 3.

5.3. The overall risk

In terms of the overall risk, the high overall RC also confirmed that risk management was necessary for green construction. The overall high risk was attributed to the high MI_{All} ($MI_{All} = 4.32$), as well as the high RC values of "cost overrun risk", "client-related risk" and "project complexity". This result also echoed the argument of Durmus-Pedini and Ashuri (2010) that risks should be well managed to prevent them from hindering the green building movement. Additionally, risk management can ensure the achievement of the going green target set up by Singapore's government as well as the success and subsequent benefits of green projects.

6. Conclusion and recommendation

The Singapore construction industry has exhibited the trend of going green, and all the new buildings and major building renovation must obtain the Green Mark certification. As green projects are inevitably plagued with risks, this study attempts to assess the risks associated with green projects.

A risk assessment model was developed using the FSE approach. The fuzzy set theory can handle the problems relating to ambiguous, subjective and imprecise judgments, which are inevitably involved in risk assessment, and allows mathematical operators to be applied to the fuzzy domain. As an application of the fuzzy set theory, FSE can handle complicated evaluation with multiple attributes and levels. The proposed risk assessment approach allows professionals to make judgments on LO and MI of risk factors by means of linguistic terms, outputs RC of risk groups and the overall RC, and reduces ambiguity, subjectivity and imprecision in judgments. Thus, the proposed risk assessment model can be deemed as reliable and practical for professionals in the green building industry.

Categorizing 28 risk factors into 11 groups, the study performed a questionnaire survey and received 31 responses from project managers in Singapore. Using the proposed risk assessment model and the data from the survey, the LO, MI and RC of the risk factors, groups and the overall risk were obtained. The results indicated that "inaccurate cost estimation", "delay in issuance of documents" and "unclear detailed design or specifications" were the top three risk factors in terms of their RC values. At the risk group level, "cost overrun risk", "client-related risk" and "procedure complexity" were the top three. In addition, the overall RC was high, indicating that risk management is still necessary for green construction in Singapore.

Although the objectives were achieved, there were some limitations to the conclusions. First, the analyses were performed based on contractors' point of view, and did not include the perspectives of other players involved in a green project. Also, the sample size in this study was small, despite no criterion concerning the sample size of FSE. With a higher response rate, it would be able to project a more accurate industrial perspective on the risks in green projects. Lastly, the findings from this study were well interpreted in the context of Singapore, which may be different from the context of other countries.

Nonetheless, the implications of this study are not limited to Singapore because the proposed risk assessment model can also be applied in risk assessment in other countries. In addition, as few studies have attempted to assess risks in green construction, this study can expand the literature. Furthermore, the findings of risk assessment allow the practitioners to understand the priorities to handle risks, ultimately contributing to the effective risk assessment and management.

As for future studies, the opinions of clients and consultants would be collected to provide a more comprehensive picture of risks associated with green projects. Also, the interrelationships among risks would be investigated using structural equation modeling, thus contributing to a more in-depth understanding of the risks associated with green buildings. Finally, in-depth case studies would be performed to show how risks are managed in specific green projects.

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