ADDRESSING RISKS IN GREEN RESIDENTIAL BUILDING CONSTRUCTION PROJECTS: THE CASE OF SINGAPORE

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ABSTRACT

Over the past decade, an increasing number of green residential buildings have been developed worldwide owing to active promotion from the authorities and the increasing interest from customers. However, in the same way as traditional residential buildings, the construction of green residential buildings has been facing various risks. The aims of this study are to identify and assess the diverse risks in green residential building construction projects, compare their risk criticalities with those in traditional counterparts, and propose helpful risk mitigation measures. To achieve these goals, a comprehensive literature review was conducted first, and then a questionnaire was administered to 30 construction companies in Singapore. The analysis results showed that "complex procedures to obtain approvals", "overlooked high initial cost", "unclear requirements of owners", "employment constraint", and "lack of availability of green materials and equipment" were the top five critical risks in green residential building construction projects. It also reported that green residential building projects were facing risks at a more critical level than those traditional residential building projects. Furthermore, this study proposed fourteen risk mitigation measures that can effectively tackle the risks in green residential building construction projects. This study contributes to the body of knowledge by identifying and evaluating the critical risks and the responding mitigation measures in green residential building construction projects. The findings from this study can also provide practitioners with an in-depth understanding of risk management in green residential building construction projects, and thereby benefiting the industry.

Keywords: *Critical Risks; Green Residential Building Construction Projects; Mitigation Measures.*

1. INTRODUCTION

Today, it is widely recognized that human activities are accountable for various global crises such as climate change, resource depletion, and environmental degradation, and one representative of these activities is construction (Zhao et al., 2016). According to the United Nations Environment Program (UNEP, 2001), the construction industry has become a big energy consumer who uses 40–50 percent of global energy and 40 percent of global raw materials; and also a principal waste contributor who releases 40 percent of global greenhouse gas emissions and produces 40 percent of solid waste worldwide. These anxiety-provoking numbers exert considerable pressure on authorities worldwide who therefore decide to adopt and promote the concept of green building in the global construction industry (Qin et al., 2016).

In a typical densely populated city-state like Singapore, a large number of residential buildings must be built to satisfy people's need for housing (Agarwal et al., 2016). Based on the statistics released by Department of Statistics (2017), residential buildings occupy 37 percent of building work in Singapore and are the largest ingredient of the local construction market. Thus, naturally, the residential buildings came to be the primary target for the authorities of Singapore to promote green buildings. Over the recent years, considerable efforts have been made by the local authorities. For instance, in 2007, the Housing and Development Board (HDB) began developing environmentally-friendly public housing blocks (e.g. Punggol Eco-Town) in Singapore (HDB, 2016b). In 2012, HDB started retrofitting the existing, old and traditional residential buildings by installing green and sustainable features (HDB, 2016a). Furthermore, the Building and Construction Authority

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(BCA) of Singapore launched a series of green regulations like BCA Green Mark for New Residential Buildings and BCA Green Mark for Existing Residential Buildings since 2010, in order to regulate and foster the development of green building in the residential building sector of Singapore (BCA, 2010; BCA, 2011).

Inevitably, construction projects face diverse risks (Hwang et al., 2015a), and the green residential building construction projects are no exception. Particularly, due to extensive use of complicated construction technologies and innovative materials, the risks embedded in green residential building construction projects might be different from those involved with traditional residential building construction projects (Zhao et al., 2016). Thus, this paper proposed a research hypothesis that the risk criticalities between green and traditional residential building construction projects were different. To test this hypothesis, this study therefore identified risks in green residential building construction projects, assessed and compared their risk criticalities between the green and traditional contexts. Moreover, this paper also provided a set of useful risk mitigation measures to tackle the risks in green residential building construction projects.

Although there are already several studies addressing risks in green building construction projects (Dewlaney et al., 2011; Yang & Zou, 2014, Qin et al., 2016, Yang et al., 2016), very few investigated the risks in green residential building construction projects. Therefore, this study can contribute to the body of knowledge of green buildings. Additionally, findings from this study can also enhance practitioners' awareness of risk management in green residential building construction projects, and thus contribute to the industry.

2. BACKGROUND

2.1. GREEN BUILDINGS AND GREEN RESIDENTIAL BUILDINGS IN SINGAPORE

Singapore is a city-state with limited natural resources and land area (Hwang et al., 2015a; Zhao et al., 2016), making sustainability a necessity rather than an option to the country. Over the past three decades, Singapore has been struggling to integrate sustainability in its various industries, and the construction industry is one of its primary emphases. In 2005, Singapore government kick-started the green building campaign by introducing BCA Green Mark scheme. Since then, Singapore has advanced three rounds of Green Building Masterplans (i.e., Masterplans of 2006, 2009, and 2014) successively to promote the green building movement in the country (BCA, 2014). In the meantime, Singapore government also launched a series of incentive schemes (e.g., Green Mark Incentive Scheme for New Buildings in 2006 and Green Mark Incentive Scheme for Existing Buildings in 2009) to encourage building owners, developers, and contractors to develop and construct more green buildings (BCA, 2015c; BCA, 2015d). Stimulated by this comprehensive suite of policies and initiatives, the green built environment in Singapore achieved rapid development, and the numbers of green buildings increased greatly, from 17 in 2005 to over 2,100 in 2014 (BCA, 2014).

Singapore has devoted considerable efforts to greening residential buildings in the past few years. In 2010, BCA launched BCA Green Mark for New Residential Buildings to encourage developers, building owners, and architecture firms to develop green and sustainable buildings that can achieve more energy and resource savings (BCA, 2010). In 2011, BCA launched BCA Green Mark for Existing Residential Buildings further to help building owners and facility operators retrofit their existing buildings with green and sustainable features (BCA, 2011). Meanwhile, Singapore has also started to develop new sustainable residential blocks. In 2007, HDB, National Environment Agency, Public Utilities Board, and the Economic Development Board jointly developed the Treelodge@Punggol (Punggol, Singapore), the first eco-precinct in Singapore (HDB, 2016b). Additionally, in 2012, HDB launched HDB Green Print scheme retrofitting the existing, traditional, and old residential buildings (HDB, 2016a). This scheme has been piloted successfully in Yuhua Estate, Singapore between 2012 and 2015, which has benefited the 3,200 households living in that estate (Kelleher, 2015).

2.2. RISKS IN GREEN BUILDING CONSTRUCTION PROJECTS

Although research of the risks in green residential building construction projects is limited, research in generic green construction projects keeps increasing recently (Hwang *et al*., 2015a). Considering risks in generic green construction projects are also applicable to green residential building construction projects, a comprehensive review of risks in generic green construction projects was therefore conducted aiming to help create a comprehensive list of risks for green residential building construction projects.

Existing literature has addressed a wide range of risks in generic green construction projects. Ranaweera and Crawford (2010) emphasized that green building construction projects faced a higher financial risk compared to their traditional counterparts because the adoption of the environmental strategies typically required a higher investment which would cause cost overruns to projects. Dewlaney *et al.* (2011) and Fortunato Iii *et al*. (2011) found that workers on LEED certified projects were exposed to work at height, near unstable soils, with electrical current, and near heavy vehicles and equipment for a longer duration than those working on traditional projects. Tollin (2011) stated that green building construction projects confronted a significant risk of failure due to defects and omissions by design professionals, contractors, and subcontractors. Also, Tollin (2011) emphasized that owners of green building construction projects would face risks of being sued by occupants or tenants, losing tax credit, and losing beneficial financing or loan, if their projects fail to achieve the expected level of green certification. Zou and Couani (2012) summarized 40 risks associated with green building development in Australia and conducted a survey. Their survey results suggested that the top five important risks were a higher investment, lack of commitment in the supply chain, lack of shared information on green building, additional costs in skills development, and lack of expertise regarding green building. Using the approach of Social Network Analysis (SNA), Yang and Zou (2014) and Yang *et al.* (2016) developed stakeholder-associated risk models to examine the risks in green building construction projects. They found that diverse stakeholders recognized ethical/reputational risks more widely and that technological risks were not important as perceived. Hwang *et al.* (2015a) identified and evaluated 20 risk factors in green retrofit projects, and they discussed the top eight risk factors in details, which were risks associated with post-retrofit tenants' cooperation, regulations, market demand, project finance, pre-retrofit tenants' cooperation, concerns from stakeholders, material supply and availability, and construction quality. Through a questionnaire survey, Qin *et al.* (2016) assessed risks in Chinese green building construction projects and found the top five critical risks were complicated approval procedures due to government bureaucracy, poor maintenance in green buildings, lack of design experience on green buildings, lack of experienced property management for green buildings, and inaccurate green goal established by the owner/developer. The in-depth review above provided a solid basis for the identification of risks in green residential building construction projects.

2.3. Risk Mitigation Measures in Green Building Construction Projects

Accompanying the identification of risks are recommendations for risk mitigation measures. Ranaweera and Crawford (2010) proposed a decision-making tool to assess the potential of incorporating environmental strategies into to the development of building projects, which may alleviate financial risks caused by sustainable design. Tollin (2011) recommended that insurance products could be used to minimize financial risks in green building construction projects. To mitigate safety risks of LEED certified projects, Fortunato Iii *et al*. (2011) suggested encouraging the use of prefabrication, because prefabrication allowed workers to assemble green-tech equipment indoors, which could spare workers from ascending and descending ladders and lifting components overhead during installation on site and thus minimize the potential safety hazard. Zou and Couani (2012) stated that risks in green construction projects could be alleviated by strengthening research and development (R&D), providing professionals with proper training and education, and ensuring coordination and information sharing among various contracting parties. After using their SNA-based risk management model to analyse risks in one green education building construction project in Australia, Yang and Zou (2014) found that improving communications and interactions among various contracting parties could effectively mitigate risks in green construction projects. In addition, Hwang *et al.* (2015a) recommended a set of measures to tackle risks in green retrofitting projects, and they highly recommended the following measures, hiring consultants with sufficient experience in managing green building construction projects to mitigate regulatory risk, increasing public awareness of the benefits of green buildings to minimize market risk, using the delivery method of Design and Build to settle communication issues among various contracting parties, and using equipment and materials that have been sufficiently tested to ensure project quality.

3. Research Methods and Data Presentation

3.1. Data Collection and Presentation

This study administered a questionnaire to assess risks and the relevant mitigation measures in green residential building projects in Singapore. Based on the literature review, 42 risks and 14 risk mitigation measures were identified and then used to form a questionnaire. Two industry experts who had at least five years of experiences in both traditional and green building constructions in Singapore were involved reviewing the questionnaire to check statement comprehensiveness, readability, and accuracy. The finalized questionnaire consisted of three sections, which were to; (1) profile respondents and their affiliated companies, (2) assess the likelihood and impact of each risk in both green and traditional residential building construction projects, and (3) evaluate the effectiveness of the risk mitigation measures. Furthermore, open-ended questions were also positioned in the questionnaire, allowing for any supplement of new risks and mitigation measures.

The population of the questionnaire was the BCA registered construction companies that have experience in both green and traditional building constructions in Singapore. After a careful check of the work scope and experiences, a total of 100 qualified companies were randomly identified from the BCA directory for data collection. Questionnaires were sent to these companies via emails. Phone calls and email reminders were sent every week if the dispatched questionnaires were not returned. Finally, 30 valid responses were received, representing a response rate of 30 percent. This response rate was aligned with the norm of 20 to 30 percent in most questionnaire surveys in construction engineering and management research (Akintoye, 2000). Table 1 profiles the backgrounds of the companies and respondents. It could be noted that the respondent companies comprised various project stakeholders such as consultants, developers, contractors, and architecture firms. Moreover, 53 percent of respondents had at least five years' experience in traditional residential building construction projects, and 63 percent of respondents had at least three years' experience in green residential building construction projects, suggesting that the respondent panel had requisite experience to address the research questions of the questionnaire.

Table 1: Backgrounds of the Respondents and their Companies

Profile	Frequency	Percentage
Company (total = 30)		
Type		
Consultancy	12	40.00
Developer	1	3.33
Contractor	10	33.33
Architecture firm	7	23.33
Respondent (total = 30)		
Job title		
Project Manager	1	3.33
Architect	6	20.00
Engineer	3	10.00
Quantity Surveyor	15	50.00
Consultant	5	16.67
Years of experience in traditional residential building projects		
Less than one year	2	6.67
1 to 2 years	4	13.33
3 to 4 years	8	26.67
5 to 10 years	11	36.67
More than ten years	5	16.67
Years of experience in green residential building projects		
Less than one year	3	10.00
1 to 2 years	8	26.67
3 to 4 years	12	40.00
5 to 10 years	7	23.33
More than ten years	0	0.00

4. DATA ANALYSIS AND DISCUSSIONS

4.1. LIKELIHOOD, IMPACT AND CRITICALITY OF RISKS IN GREEN RESIDENTIAL BUILDING CONSTRUCTION PROJECTS

This paper calculated the mean values of the likelihood of occurrence (LO) and magnitude of impact (MI) of each risk in green residential building construction projects and presented them in Table 2. Regarding the LO values, 28 out of 42 risks were assessed above 3, suggesting 67 percent of risks were fairly likely to occur in green residential building construction projects. As for the MI values, 37 out of 42 risks received MI values above 3, suggesting 88 percent of risks had fairly significant impacts on green residential building construction projects. Furthermore, this paper calculated the risk criticality (RC) of each risk by multiplying its LO and MI value, following the recommendation of Deng et al. (2014). As the assessments of LO and MI were both carried out with a five-point rating system, the RC was thus on a full scale of 25. Accordingly, this paper established a benchmark of 9 to identify the critical risks, namely the product of the median values of LO and MI rating scales. According to the results in Table 2, 35 out of 42 risks scored above 9, suggesting 83 percent of risks were critical risks to green residential building construction projects. Particularly, the top five risks in RC, namely "R6 - Complex procedures to obtain approvals", "R26 - Overlooked high initial cost", "R15 - Unclear requirements of owners", "R8 - Employment constraint", and "R28 - Lack of availability of green materials and equipment," scored above 14, indicating they were extremely critical to green residential building construction projects. Due to the space limit, only these five risks were discussed in details in this paper. As the respondents of the questionnaire have different backgrounds, Kruskal-Wallis test was conducted to check if different backgrounds of the respondents could affect their assessments. The test results reported no significant differences among the respondents, indicating the respondents held unanimous views.

Table 2: Assessments of Risks in Green and Traditional Residential Building Construction Projects

Code	Description	Green						Traditional		Wilcoxon signed-rank test	
		RC	Rank	LO	Rank	MI	Rank	RC	Rank	Difference	p-value
R6	Complex procedures to obtain approvals	17.27	1	4.20	1	4.00	1	9.73	2	7.54	0.000*
R26	Overlooked high initial cost	16.67	2	4.13	2	3.97	2	8.60	9	8.07	0.000*
R15	Unclear requirements of owners	15.07	3	3.90	3	3.73	6	8.40	13	6.67	0.000*
R8	Employment constraint	14.47	4	3.83	4	3.73	6	10.00	1	4.47	0.000*
R28	Lack of availability of green materials and equipment	14.17	5	3.57	6	3.80	4	7.40	23	6.77	0.000*
R22	Lack of qualified professionals with proper design expertise	13.53	6	3.53	8	3.70	8	5.50	32	8.03	0.000*
R24	Unfamiliarity of job requirement	13.50	7	3.37	14	3.87	3	7.10	25	6.4	0.000*
R27	Technical Issues	13.00	8	3.70	5	3.40	14	7.53	22	5.47	0.000*
R19	Unclear design details and specifications	12.87	9	3.53	8	3.43	12	7.63	21	5.24	0.000*
R40	Unfamiliarity with new technology rates	12.77	10	3.57	6	3.40	14	8.00	16	4.77	0.000*
R41	Fluctuations in labor/material rates	12.63	11	3.40	12	3.50	11	9.57	3	3.06	0.000*
R33	Unskilled workers	12.23	12	3.47	11	3.30	22	9.27	5	2.96	0.004*
R42	High Target for Green Mark Rating	12.00	13	3.40	12	3.40	14	6.20	28	5.8	0.000*
R36	Inefficient Communication	11.83	14	3.20	20	3.53	10	9.30	4	2.53	0.021*
R29	Lack of technical expertise	11.67	15	3.33	16	3.37	20	6.43	27	5.24	0.000*
R39	Inaccurate estimation	11.57	16	3.37	14	3.30	22	9.13	6	2.44	0.001*

Code	Description	Green						Traditional		Wilcoxon signed-rank test	
		RC	Rank	LO	Rank	MI	Rank	RC	Rank	Difference	p-value
R20	Being fined for failing to achieve Green Mark standards	11.53	17	3.13	25	3.23	26	4.70	35	6.83	0.000*
R14	Shortage of funds	11.50	18	2.97	29	3.77	5	8.33	14	3.17	0.000*
R25	Exposed to lawsuit for failing to achieve GM standards	11.43	19	3.03	28	3.60	9	6.03	29	5.4	0.000*
R34	Poor Design	11.37	20	3.27	18	3.43	12	8.27	15	3.1	0.002*
R31	Lack of experience	11.33	21	3.23	19	3.20	30	6.03	29	5.3	0.000*
R7	Safety and health	11.30	22	3.20	20	3.40	14	9.27	5	2.03	0.030*
R30	Unfamiliarity with green materials and construction technologies	11.23	23	3.53	8	3.00	37	5.87	31	5.36	0.000*
R38	Unfamiliarity with construction process	11.17	24	3.30	17	3.23	26	8.40	13	2.77	0.013*
R32	Setting expectations too high	11.00	25	3.20	20	3.17	32	8.50	12	2.5	0.011*
R4	Fluctuation in exchange rates	10.97	26	3.10	27	3.23	26	7.70	19	3.27	0.034*
R9	Pollution restrictions	10.63	27	3.17	23	3.20	30	8.53	11	2.1	0.051
R12	Unclear contract conditions for dispute resolution	10.60	28	3.13	25	3.27	25	8.57	10	2.03	0.000*
R11	Unclear contract conditions for claims and litigations	10.27	29	2.93	30	3.40	14	7.93	17	2.34	0.003*
R35	Poor Workmanship	10.03	30	3.17	23	3.10	36	9.00	8	1.03	0.168
R21	Poor communication among projects stakeholders	9.87	31	2.90	32	3.33	21	9.10	7	0.77	0.325
R37	Lack of management staff	9.83	32	2.80	34	3.17	32	7.53	22	2.3	0.011*
R3	Inflation	9.80	33	2.93	30	3.13	35	7.87	18	1.93	0.003*
R23	Claims of overstated or unverifiable benefits	9.73	34	2.87	33	3.40	14	6.60	26	3.13	0.001*
R17	Loose control over subcontractors	9.13	35	2.77	35	2.97	38	7.67	20	1.46	0.002*
R18	Warranties to homeowners of green building	8.93	36	2.77	35	2.90	39	5.37	34	3.56	0.000*
R10	Import/ export restrictions	8.93	36	2.60	38	3.30	22	6.60	26	2.33	0.003*
R16	Inappropriate interventions of clients	8.63	38	2.77	35	2.87	40	6.20	28	2.43	0.015*
R13	Unclear allocation of roles and responsibilities	7.60	39	2.40	39	2.77	41	7.27	24	0.33	0.916
R2	Energy saving uncertainty	7.47	40	2.23	40	3.17	32	6.00	30	1.47	0.137
R1	Green building policies change	6.10	41	1.87	41	3.23	26	5.47	33	0.63	0.059
R5	High crime rate	3.37	42	1.50	42	1.90	42	3.03	36	0.34	0.776

Note: *The Wilcoxon signed-rank test is significant at the 0.05 significance level.

"R6-Complex procedures to obtain approvals" was the most critical risk due to receiving the highest RC value of 17.27. This was because green residential building projects always involve some particular green features (e.g., solar photovoltaic system, pneumatic waste conveyance system, and rain harvesting system), which would result in lengthier planning approval and permit procedures (Zhao *et al*., 2016). This risk has also been assessed as the most critical risk in Chinese green building projects by Qin et al. (2016). "R26-Overlooked high initial cost" was ranked second with a RC value of 16.67, attributed to its second highest LO and MI values. Compared to traditional residential building construction projects, green residential building construction projects involve higher initial costs owing to the enormous up-front costs caused by the use of green technologies and materials and additional consultancy services (Zou & Couani, 2012). This result echoed findings from Robichaud and Anantatmula (2010) who also stressed that high initial cost was a significant barrier to the promotion of green buildings. "R15-Unclear requirements of owners" received the third position with a RC value of 15.07. Owners who have insufficient knowledge and experiences of green residential buildings might not be able to give clear and specific requirements to designers and contractors. For instance, the unclear requirements from the clients might result in designers' misinterpretation or misunderstanding of the clients' real purposes, which would lead to numerous design changes and considerable reworks eventually. This result also echoed Hwang *et al*. (2015b) who recognized unclear requirements of owners as a critical issue affecting the performances of green building construction projects in Singapore.

"R8-Employment constraint" was ranked fourth with a RC value of 14.47. Being a country with limited human resources, Singapore is always leveraging on foreign workforces to ensure its economic growth (Robichaud & Anantatmula, 2010). Nonetheless, the Singapore government has established some control mechanisms to regulate the number of foreign workers to avoid the local Singaporeans being priced out of the job market. Unfortunately, foreign workforces with green residential building construction experiences are categorized by the Ministry of Manpower Singapore as the unskilled or semi-skilled workforce, which are under the strict control on issuing work permit (Low, 2002). Thus, the constructions of local green residential building projects might face a lack of sufficient workforce because of this employment constraint. "R28-Lack of availability of green materials and equipment" was assessed as the fifth most critical risk with a RC value of 14.17. In Singapore, the majority of construction equipment, materials and even plants designated for green residential building construction projects need to be imported from overseas, which normally requires a long period to be delivered on site (Hwang *et al.,* 2015a; Hwang *et al.*, 2015b; Zhao *et al.*, 2016). Therefore, any hang-up relating to the delivery of imported equipment and materials, especially for those referring to the critical activities in project scheduling, would significantly affect the successful delivery of the project. Such a result was in line with the findings from Zhao *et al*. (2016) who also emphasized that availability of materials and equipment was a significant risk requiring additional attention in green building construction projects.

4.2. RISK CRITICALITIES: GREEN VERSUS TRADITIONAL RESIDENTIAL BUILDING CONSTRUCTION PROJECTS

To explore the possible differences in RC values between green and traditional residential building construction projects, this paper conducted the Wilcoxon signed-rank test. This method is a non-parametric statistical test comparing two sets of scores that come from the same participants, without requiring the data must be normally distributed (Hwang & Leong, 2013). In this study, test results showed that the p-values of 35 risks were less than 0.05, suggesting there were significant differences in RC values of the most risks between green and traditional residential building construction projects. These results meant that the hypothesis of this study, namely, risk criticalities between green and traditional residential building projects were different, was supported. Furthermore, the RC values of these 35 risks in green residential building construction projects were statistically greater than those in traditional residential building construction projects, implying that green residential building construction projects are facing risks at a more critical level.

"R26-Overlooked high initial cost" received the greatest difference between the two types of projects. The RC value of this risk in green residential building construction projects (i.e. 16.67) is almost two times of that in traditional residential building construction projects (i.e. 8.60). This was probably because, compared to traditional residential building construction projects, green residential building construction projects requires considerable upfront expenditures on green technologies, materials, and equipment (Shiers *et al.,* 2006). This result was also supported by Zou and Couani (2012) who claimed that the perceived higher upfront costs were the largest obstacle to green building development. "R22-Lack of qualified professionals with proper design expertise" received the second greatest difference in RCs. This risk received a high rank in green residential building construction projects (i.e. 6), but a low rank in traditional residential building construction projects (i.e. 32), implying that it was more critical to green residential building construction projects. This might be because, compared to those traditional ones, green residential building construction projects require skilled design professionals to handle specialized green and sustainable designs; while the reality in Singapore is that competent and experienced local green design professionals are extremely deficient (Hwang *et al.,* 2015a).

"R6-Complex procedures to obtain approvals" obtained the third greatest difference in RCs. Although this risk received high ranks in both groups, its RC values were significantly different between two types of projects: 17.27 with green versus 9.73 with traditional. This result could be explained by the fact that green residential building construction projects involve more innovative technologies, materials, and equipment compared to traditional construction projects. Thus, it has to undergo a stricter approval process imposed by the construction authority (Zhao *et al.*, 2016), which inevitably makes the processing time longer than that for traditional residential building construction projects. "R20-Being fined for failing to achieve Green Mark standards" received the fourth greatest difference in the RC assessment, and in particular, its RC value in green residential building construction projects (i.e., 11.53) was much higher than that in traditional ones (i.e., 4.70). In fact, this is a unique risk of green residential building construction projects. In Singapore, the Building Act has required that any new buildings and existing ones that undergo major retrofitting must achieve the minimum Green Mark Certified Level; otherwise, a certain amount of fines will be imposed (Ismail, 2013). "R28-Lack of availability of green materials and equipment" was ranked fifth in RC difference. This risk received a low rank (i.e., 23rd) in traditional residential building construction projects, but a high rank (i.e., 5th) in green ones. This was probably because the green construction industry in Singapore was a young industry and thus the supply of green materials and equipment might be still limited; in contrast, the traditional construction industry had already been fully mature, and thus the common materials and equipment were more widely available comparatively (Hwang *et al.*, 2015a). This result was also in line with Hwang and Leong (2013) who argued that material supply and availability was more critical in green building construction projects compared to traditional building construction projects.

4.3. PROPOSED MITIGATION MEASURES

This study also asked respondents to evaluate the effectiveness of the 14 risk mitigation measures (RMMs) generated from literature. As Table 3 shows, all 14 risk mitigation measures received mean values higher than 3, indicating all of them were effective in tackling risks in green residential construction building projects in Singapore. Those mitigation measures that received evaluations above four are discussed as follows.

Table 3: Assessments of Risk Mitigation Measures for Green Residential Building Construction Projects in Singapore

Code	Risk mitigation measure	Mean	Rank
RMM10	Improving communication and coordination among contracting parties	4.57	1
RMM12	Understanding owner's goal of the Green Mark Standard	4.27	2
RMM13	Using past successful green residential projects as references	4.20	3
RMM5	Developing training programs to upgrade workers' skills and knowledge on new technologies and materials	4.20	3
RMM1	Allowing for contingency funds	4.13	5
RMM6	Devoting adequate resources to planning and research	3.90	6
RMM9	Front end planning	3.83	7
RMM2	Communicating about targeted green mark rating and ways to achieve that with a clear roles and responsibilities chart	3.77	8
RMM3	Contract language to be precise and give provision to limit each parties' liabilities	3.67	9
RMM4	Constant design evaluation and verifications	3.53	10
RMM11	Implementing passive design instead of complicated active building design	3.50	11
RMM7	Enhanced communication tool for better collaboration (e.g., BIM software)	3.4	12
RMM14	Working with experienced insurance agent to receive better coverage protection	3.30	13
RMM8	Effective change management	3.10	14

"RMM10-Improving communication and coordination among contracting parties" was assessed as the most effective measure with the highest evaluation of 4.57. To ensure the success of a green residential building construction project, a higher level of communication among the contracting parties is demanded. This is because green residential building construction projects normally require a multidisciplinary team with a more comprehensive professional composition to handle those complicated and innovative technologies, equipment, and materials adopted in such projects (Yang & Zou, 2014). Any information isolation among team members will probably raise various issues such as rework, delay, and cost overrun. This result was in line with Hwang and Tan (2012) who also stated that project team's communication was an effective solution to overcome obstacles in green building construction projects. "RMM12-Understanding owner's goal of the Green Mark Standard" received the second highest value (i.e., 4.27) in the effectiveness evaluation. In Singapore, each new residential building is mandatory to achieve some Green Mark Standard (BCA, 2015b). Thus, it is crucial for the designer, consultant, and contractor to understand owner's goal of Green Mark Standard for the building before they start working on the project. Zou and Couani (2012) obtained the similar conclusion that communicating green building objectives clearly to all the project team members is vital to secure the success of a green building construction project.

“RMM13-Using past successful green residential projects as references” was assessed as the third most effective measure with an evaluation of 4.20. Referring to successful experiences of past projects is an effective measure to mitigate risks in new construction projects. To date, Singapore has accumulated some valuable experiences in developing green residential buildings since it introduced the Green Mark for Residential Buildings in 2011. These experiences can render considerable help to new green residential building construction projects in mitigating risks and achieving a better project performance. This result was comparable to Zou and Couani (2012) who stated that experience accumulation was an important strategy to reduce risks in green building supply chain. “RMM5-Developing training programs to upgrade workers’ skill and knowledge of new technologies and materials” was also assessed as the third most effective measure with a value of 4.20. During constructions of green building projects, one major issue is that frontline workers might be unfamiliar with innovative technologies and materials adopted in such projects (Hwang & Tan, 2012). Thus, it is crucial to develop a series of training programs for those frontline workers and make sure that they are well trained and informed of the green technologies they are about to use. Currently, the BCA has rolled out some green courses (e.g., Green Mark Professional course and Green Mark Facilities Professional course) to help the local industry advance their knowledge and capability in undertaking green building construction projects, which are very popular with local construction community (BCA, 2015a). “RMM1-Allowing for contingency funds” received the fourth highest value (i.e. 4.13) in the effectiveness evaluation. This risk mitigation measure was highlighted as the complex nature of green residential building construction projects makes the exact budget of the project impossible to forecast accurately. Also, innovative and complicated green technologies adopted in green residential building construction projects might require additional tests and inspections (Häkkinen & Belloni, 2011), which would also lead to additional cost beyond the original project estimation. Therefore, it is extremely necessary to set aside some contingency funds to entail some unexpected but possible risks. In fact, contingency funds have also been used widely by traditional construction projects to manage their risks (Ford, 2002).

5. CONCLUSIONS AND RECOMMENDATIONS

Green residential buildings have achieved a rapid development over recent years due to its positive efficacy of saving energy and resources consumptions. However, risks embedded in the construction of green residential buildings are not adequately addressed. As a result, this paper conducted an exploratory research to investigate risks and the relevant mitigation measures in green residential building construction projects.

A total of 42 risks and 14 mitigation measures were identified from a comprehensive literature review first and then included in a questionnaire administered with 30 Singapore-based construction companies. The results of the questionnaire showed that the top five critical risks in green residential building projects were “complex procedures to obtain approvals”, “overlooked high initial cost”, “unclear requirements of owners”, “employment constraint”, and “lack of availability of green materials and equipment”. It also revealed that 35 out of 42 identified risks obtained significantly higher assessments in green residential building construction projects than in traditional residential building construction projects, suggesting that they are more critical in the former. Moreover, the results of the questionnaire presented the top five most effective risk mitigation measures in green residential building construction projects: “improving communication and coordination among contracting parties”, “understanding owner’s goal of the Green Mark Standard”, “using past successful green residential projects as references”, “developing training programs to upgrade workers’ skill and knowledge of new technologies and materials”, and “allowing for contingency funds”.

In spite of the detailed investigation of critical risks and the relevant risk mitigation measures in green residential building construction projects, some limitations are still present in this study. First, the sample size of the survey in this study is relatively small. Thus, cautions should be given when the analysis results are interpreted and generalized. Second, the risk criticality index calculated in this study is subjective to a certain extent and may be biased subject to individual experience and risk preference. Third, findings from this study apply to Singapore exclusively, which may vary in other different countries. Despite these limitations, this study is still valuable. This is the first systematic investigation of the various risks and the relevant mitigation measures in green residential building construction projects. Thus, this study contributes to the current body of knowledge. Furthermore, this study is also useful to the practice. As the findings from this study are derived from the first-hand experiences gathered from the industry practitioners of Singapore, which is a widely recognized pioneer and a global leader in the area of green building construction. This study is also useful to other countries that are about to promote green residential buildings. For instance, relying on the findings from this study, industry practitioners in other countries can gain a deeper understanding of risks in green residential building construction projects, develop a customized risk check list for their own green residential building construction projects, and also may come up with some more effective strategies to address those risks.

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