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Investigating Reworks in Green Building Construction Projects: Magnitude, Influential Factors, and Solutions

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ABSTRACT: Rework is a stubborn issue in the construction industry, and it has been drawing considerable attention from the industry and academia over the past decades. However, so far, little effort has been made to investigate reworks in green building construction projects. This study aims to assess the status quo of rework in green building construction projects in Singapore, identify and evaluate the rework factors in green building construction projects, compare their criticalities with those in the conventional counterparts, and propose a set of feasible solutions. To achieve these aims, a questionnaire survey was administered, and data collected from 30 different construction companies were analyzed. Results showed that, compared to conventional building construction projects, green building construction projects tended to have a lower incidence of rework, but suffered more from the rework's adverse impacts in terms of cost overrun and schedule delay. Results also showed that the top four most critical rework factors in green building construction projects were "owner change", "design change", "design error/omission" and "contractor's error/ omission". In addition, this study proposed five practical solutions that can help curb reworks in green building construction projects. This study contributes to the body of knowledge by examining the rework problem in green building construction projects. Meanwhile, this study contributes to the industry by providing the practitioners with an in-depth understanding of rework in green building construction projects. The specific solutions proposed by this study can also offer the industry practitioners direct help in reducing works in such projects.

Key words: Rework, Rework factors, Solutions, Green building construction projects

INTRODUCTION

Over the past two decades, there has been a growing concern for global climate change, resource depletion and environmental degradation because of the various human activities, and one of the most representative activities is the building and construction (Ranaweera ans Crawford, 2010; Zhao et al., 2016). Previous studies showed that the building and construction industry is a big energy consumer who has consumed 40-50 percent of global energy and 40 percent of global raw materials; and also a principal waste contributor that has released 40 percent of global greenhouse gas emissions and 40 percent of waste disposed of in the landfills (Yang and Zou, 2014; Yang et al., 2016). These anxiety provoking figures have put considerable pressure on policy makers who eventually decided to adopt and advocate green buildings. During the recent decade, there has been a significant growth in green building construction worldwide (Zuo and Zhao, 2014; Qin et al., 2016).

Singapore is a city-state with the limited land area and natural resources, both of which have made sustainability a necessity rather than an option to the country(Hwang et al., 2015). Over the past five decades, Singapore has been struggling to chase sustainability in its various industries (Ministry of the Environment and Water Resources and Ministry of National Development, 2014), and the building and construction industry is one of its primary emphases. In Singapore, green buildings refer to structures those are energy and water efficient, with a high quality and healthy indoor environment, integrated with green spaces and constructed from eco-friendly materials (BCA, 2016). In 2005, the Singapore Government embarked on the green building movement by launching the Building and Construction Authority (BCA) Green Mark scheme, and since then, it has

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successively advanced three rounds of Green Building Masterplans (i.e., Masterplans of 2006, 2009, and 2014) to promote the green building development throughout the country (BCA, 2014). In the meantime, the Singapore government has also launched a series of incentive plans (e.g., Green Mark Incentive Scheme for New Buildings in 2006 and Green Mark Incentive Scheme for Existing Buildings in 2009) to encourage developers, building owners and project consultants to adopt environmentally-friendly design, technologies and practices in their building projects (BCA, 2015b, 2015a). Stimulated by the comprehensive suite of policies and initiatives, the green building and construction industry in Singapore has achieved a rapid development, and the number of green buildings has grown exponentially, from 17 in 2005 to more than 2100 in 2014, equivalent to 25 percent of the total built-up areas in the country (BCA, 2014).

Defined as the unnecessary effort of re-doing a process or activity that was incorrectly implemented at the first time (Love and Edwards, 2004; Hwang et al., 2014), rework has been widely recognized as a significant concern to the construction industry. Rework may origin from construction changes, design errors and omissions, and coordination issues among contracting parties at site (Palaneeswaran et al., 2008; Hwang et al., 2014), and eventually leading projects to cost and schedule overruns (Hwang et al., 2009). According to the Construction Industry Institute (2005), costs caused by rework amounted to five percent of total construction expenditures in the U.S. construction industry. In the Australian construction industry, main direct and indirect rework costs were found to be 6.4 and 5.6 percent of the original contract value, respectively (Love, 2002). In Singapore, rework has been accused of contributing to an average of 25 percent of the construction schedule growth (Hwang and Yang, 2014). These findings reveal that rework is a significant issue affecting project performance in the construction industry.

Green building construction projects also suffer from rework (Chandramohan et al., 2012). This is because green building construction projects always tend to use innovative materials and complicated technologies to reinforce their green performances, whereas these green materials and technologies might be unstable and cause contingencies to the projects, which eventually leads to rework (Kang et al., 2013). However, until now, very few research efforts have been made to investigate the rework issues in green building construction projects. Therefore, using the green building construction projects in Singapore as backgrounds, this study aims to: (1) assess the status quo of rework in green building construction projects, (2) identify and evaluate the rework factors in green building construction projects, (3) compare their criticalities with those in conventional counterparts, and (4) propose feasible solutions to reduce rework in green building construction projects. This study contributes to the body of knowledge by exploring the rework problem in green building construction projects. Also, this study is beneficial to the industry as it can provide the practitioners with a comprehensive picture of reworks in green building construction projects as well as a set of feasible solutions.

MATERIALS & METHODS

To achieve its research aims, this study conducted a comprehensive literature review to identify the various rework factors and solutions in green building construction projects. As the research of rework related to green building construction projects is limited, this study expanded its literature search scope and incorporated the rework studies related to conventional building construction projects. Based on the literature review, eight rework factors and 11 solutions were identified, as shown in Tables 1 and 2. The identified rework factors and solutions formed a self-explanatory questionnaire which consisted of six sections. Sections A and B gathered respondents' and their companies' demographics, respectively. Section C solicited the status quo of rework within the green and conventional building construction projects undertaken by the respondents' companies. Sections D and E evaluated the likelihood and impact of rework factors within green and conventional building construction projects, using two five-point Likert rating scales (i.e. 1 = least likely/least significant, 2 = less likely/less significant, 3 = neutral/neutral, 4 = more likely/more significant, and 5 = most likely/most significant). Section F assessed the effectiveness of the identified solutions in the context of green building construction projects.

The population of this questionnaire targeted at industry experts with experience in both green and conventional building construction projects in Singapore. A total of 127 questionnaires were disseminated to BCA certified companies via electronic mail. The data collection effort produced 30 complete sets of the questionnaire from 30 different companies, yielding a response rate of 23.6 percent, which was consistent with the norm of 20-30 percent in most surveys in the construction industry (Akintoye, 2000). Tables 3 and 4 profile the respondents, companies and

Table 1. Rework factors identified from literature

Cause of rework	Source												
	A	B	C	D	E	F	G	H	I	J	K	L	M
Owner Change			√	√	√	√	√			√		√	
Design Error/Omission	√	√	√	√	√	√	√	√	√		√		√
Design Change	√		√	√	√	√	√	√			√	√	√
Contractor's Error/Omission			√	√			√		√		√		√
Constructor Change			√	√			√					√	√
Vendor Error/Omission				√	√		√		√		√		
Vendor Change				√	√		√					√	
Transportation Error					√		√		√		√		

Note: A = Love et al. (1999), B = Love et al. (2000), C = Love and Li (2000), D = Josephson et al. (2002), E = Love and Smith (2003), F = Love and Edwards (2004), G = Hwang et al. (2009), H = Love et al. (2011), I = Love et al. (2014), J = Hwang et al. (2014), K = Hwang and Yang (2014), L = Forcada et al. (2014), and M = Ekambaram et al. (2014)

Table 2. Solutions identified from literature review

Solution to reduce rework	Source						
	A	B	C	D	E	F	G
Use communication tools for design coordination	√	√			√		
Ensure the correctness of design	√	√					
Ensure the compatibility of design and specifications	√	√					
Establish an effective channel for communication	√	√			√	√	
Ensure a sound change management		√		√	√		
Design review and verification	√	√					
Inter-organizational collaboration and learning	√					√	√
Corrective action planning		√	√	√			
Front-end planning		√	√				
Enhanced access to information	√	√			√		
Rework-tracking system		√		√			

Note: A = Love and Li (2000), B = Josephson et al. (2002), C = Love and Smith (2003), D = Zhang et al. (2012), E = Hwang and Yang (2014), F = Love et al. (2014), and G = Love et al. (2015)

projects sampled in the survey, respectively. It is noted that 90 percent of companies and more than 50 percent of respondents have more than ten years of experience in conventional building construction projects, and that 70 percent of companies and 60 percent of respondents have three years of experience or above in green building construction projects, indicating the respondents surveyed were experienced enough to address the research questions of this study.

A series of statistical methods were used to analyze the data collected from the questionnaire. The Chi-squared test was conducted to check if the occurrence of rework was associated with the sustainable nature of the projects. This method was selected as it was a common approach to check the significant difference between the expected frequencies and the observed frequencies in one or more categories (Uher and Brand, 2008). The One Sample T-test was performed to verify whether each rework factor occurred significantly in or had a significant impact on green and conventional building construction projects. This method is usually used to examine the mean difference between the sample and the known value of the population mean (Lam et al., 2011). The Wilcoxon signed-rank test was adopted to check the difference among the evaluations of rework factors between green and conventional building construction projects. This method is widely used in comparing two matched or related samples and determining whether there is significant difference between these two samples (Ameyaw et al., 2016). The Spearman's rank correlation was performed to examine the ranking agreement of rework factors between green and conventional building construction projects. This is a widely used method to compute the correlation between the ranks of scores of two groups (Hwang et al., 2015).

Table 3. Demographics of respondents and companies

Profile	Number	Percentage (%)
Respondent (N = 30)		
Occupation		
Contractors	13	43.33
Architects	5	16.67
Quantity surveyors	3	10.00
Consultants	9	30.00
Years of experience in conventional building construction projects		
<10 years	13	43.33
10-20 years	14	46.67
20-30 years	2	6.67
>30 years	1	3.33
Years of experience in green building construction projects		
<3 years	12	40.00
3-5 years	12	40.00
5-10 years	6	20.00
>10 years	0	0.00
Number of conventional building construction projects involved in past 5 years		
<3	2	6.67
3-5	10	33.33
5-10	13	43.33
>10	5	16.67
Number of green building construction projects involved in past 5 years		
<3	16	53.33
3-5	8	26.67
5-10	6	20.00
>10	0	0.00
Company (N = 30)		
Type		
Architecture	6	20.00
Developer	7	23.33
Quantity surveyor	4	13.33
Contractor	13	43.33
Years of experience in conventional building construction projects		
<10 years	3	10.00
10-20 years	25	83.33
20-30 years	2	6.67
>30 years	0	0.00
Years of experience in green building construction projects		
<3 years	9	30.00
3-5 years	15	50.00
5-10 years	6	20.00
>10 years	0	0.00

Table 4. Demographics of building construction projects undertaken by respondents' companies

Project profile	Traditional building projects (total = 210)		Green building projects (total = 102)	
	Number	Percentage (%)	Number	Percentage (%)
Type				
Residential	50	23.81	15	14.71
Industrial	19	9.05	13	12.75
Office	128	60.95	64	62.75
Retail	13	6.19	10	9.80
Size (million)				
< SGD 15	99	47.14	37	36.27
SGD 15 - SGD 50	76	36.19	32	31.37
SGD 50 - SGD 100	16	7.62	19	18.63
SGD 100 <	19	9.05	14	13.73

RESULTS & DISCUSSION

Table 5 shows the status quo of rework in green and conventional building construction projects involved in the survey. To check if there is relationship between the projects' sustainable nature and its status of rework, Chi-squared test was conducted. Data collected from Section C of the questionnaire were input SPSS Statistics 17.0 software to perform the test, and the test result reported a p-value of 0.014, which was less than the significance level of 0.05. This result indicated a significant relationship between the projects' sustainable nature and its status of rework. Moreover, Table 5 shows that 29.41 percent of green building construction projects experienced rework, while the ratio under the context of conventional building construction projects was 43.81 percent. Such a significant discrepancy reveals that green building construction projects enjoyed a relatively lower incidence of rework, which would be beneficial for the further promotion of green building construction projects.

Cost overrun and schedule delay are two inevitable consequences of rework (Love, 2002; Love et al., 2010; Hwang and Leong, 2013), and they were also examined in frequency within the two types of projects by the questionnaire. Results in Table 5 show that, among the 92 conventional building construction projects where rework had occurred, 21 (23 percent) suffered cost overrun, 40 (43 percent) suffered schedule delay, and 31 (34 percent) suffered both. By contrast, among 30 green building construction projects where rework had occurred, two (7 percent) suffered cost overrun, seven (23 percent) suffered schedule delay, and 21 (70 percent) suffered both. Obviously, green building construction projects are more vulnerable to the adverse impacts of rework than conventional building construction projects. This may be attributed to the fact that green building projects are more complex within its designs, construction technologies and materials, and hence, more serious consequences would be incurred if rework occurs in such projects (Shi et al., 2016; Yang et al., 2016).

Table 6 presents the evaluation results of rework factors in green and conventional building construction projects. According to its evaluations in likelihood, the top four significant rework factors in green building construction projects were "owner change", "design change", "design error/omission", and "contractor's error/omission", and its active occurrence were further proved by the One Sample T-test (test value = 3) because their mean scores were statistically greater or equal to the test value at the 95 percent confidence interval. By contrast, the rest four rework factors occurred insignificantly in green building construction projects as their likelihood evaluations were less than the test value at the 95 percent confidence interval. In addition, the Spearman Rank Correlation Coefficient for the two types of projects was 0.976 (p-value = 0.000), which suggested that the rankings of rework factors in likelihood evaluation were highly associated at the 99 percent confidence interval.

"Owner change" received the highest value in the likelihood evaluation and thus was regarded as the rework factor that occurred most frequently in green building construction projects. This was probably because sustainability was an exclusive goal set up by the owner for green building construction projects (Li et al., 2011), and the owner might propose as many changes as they can to achieve the goal and maximize its environment friendly effect, which would inevitably lead to more reworks. In addition, the survey results revealed that "owner change" scored similarly between green and conventional building construction projects, suggesting that the rework factor was of similar likelihood of occurrence between the two types of projects.

"Design change" was ranked 2nd in the likelihood evaluation in green building construction projects. As

Table 5. Rework status of projects involved in the survey

Project rework status	Conventional building projects (total = 210)		Green building projects (total = 102)	
	Number	Percentage (%)	Number	Percentage (%)
With rework	92	43.81	30	29.41
Cost overrun	21	22.83	2	6.67
Schedule delay	40	43.48	7	23.33
Cost overrun and project delay	31	33.70	21	70.00
Without rework	118	56.19	72	70.59
P-value of Chi-squared test = 0.014*				

Note: *The Chi-squared test result is significant at the level of 0.05 (two-tailed)

Table 6. Evaluations of rework factors in green and conventional building construction projects

Rework Factor	Likelihood							Impact							Criticality						
	Green Projects			Conventional Projects			P-value	Green Projects			Conventional Projects			P-value	Green Projects			Conventional Projects			P-value
	Rank	Mean	P-value	Rank	Mean	P-value		Rank	Mean	P-value	Rank	Mean	P-value		Rank	Mean	P-value	Rank	Mean	P-value	
Owner Change	1	4.43	0.000[a]	1	4.47	0.000[a]	0.317	1	4.37	0.000[a]	1	4.37	0.000[a]	1.000	1	19.73	0.000[a]	1	19.93	0.000[a]	0.285
Design Error/Omission	3	3.17	0.305	3	3.07	0.625	0.366	3	3.10	0.522	3	2.97	0.823	0.046[b]	3	10.23	0.173	3	9.43	0.578	0.001[b]
Design Change	2	4.00	0.000[a]	2	3.57	0.000[a]	0.000[b]	2	3.73	0.000[a]	2	3.43	0.000[a]	0.003[b]	2	14.90	0.000[a]	2	12.30	0.000[a]	0.041[b]
Contractor's Error/Omission	4	2.80	0.110	4	2.63	0.009[a]	0.025[b]	4	3.00	1.000	4	2.87	0.403	0.046[b]	4	8.60	0.479	4	7.77	0.031[a]	0.010[b]
Constructor Change	5	2.07	0.000[a]	5	1.83	0.000[a]	0.059	5	1.90	0.000[a]	5	1.93	0.000[a]	0.317	5	4.23	0.000[a]	5	3.80	0.000[a]	0.074
Vendor Error/Omission	6	1.77	0.000[a]	6	1.70	0.001[a]	0.317	5	1.90	0.000[a]	6	1.87	0.000[a]	0.317	6	3.83	0.000[a]	6	3.50	0.000[a]	0.317
Vendor Change	8	1.53	0.000[a]	7	1.53	0.000[a]	1.000	7	1.73	0.000[a]	7	1.73	0.000[a]	1.000	7	3.40	0.000[a]	7	3.00	0.000[a]	0.655
Transportation Error	7	1.63	0.000[a]	8	1.47	0.000[a]	0.025[b]	8	1.57	0.000[a]	8	1.50	0.000[a]	0.157	8	3.00	0.000[a]	8	2.97	0.000[a]	0.024a
Spearman Rank Correlation Coefficient	0.976						0.000[c]	0.994						0.000[c]	1.00						0.000[c]

Note: [a] The One Sample T-test result is significant at the level of 0.05 (two-tailed).
[b] The Wilcoxon Signed-rank Test result is significant at the level of 0.01 (two-tailed).
[c] The Spearman rank correlation is significant at the level of 0.01 (two-tailed).

it known to all, a prominent characteristic of green building construction projects is its unique and innovative designs. However, a concomitant issue of these unique and innovative designs is that they might be less commonly used in practice and thus lacks sufficient application experience (Kang et al., 2013). Under such circumstances, "design change" occurs inevitably and finally results in rework. Moreover, based on the result of Wilcoxon Singed-rank Test, the mean score of "design change" in green building construction (i.e., 4.00) projects was statistically higher than that in conventional building construction projects (i.e., 3.57) at the 99 percent confidence level, suggesting the rework factor occurred more frequently in green building construction projects than in conventional building construction projects. This result also echoed the foregoing justification that uncertainties in the innovative designs in green building construction projects were apt to lead to design changes and resulted in reworks eventually.

"Design error/omission" was ranked 3rd in the likelihood evaluation in green building construction projects. In fact, numerous previous studies have marked that "design error/omission" was a significant issue that would lead to rework in conventional building construction projects (Love et al., 2000; Josephson et al., 2002; Love and Smith, 2003; Hwang et al., 2009), and this study has further demonstrated that this factor was also a significant contributor to the rework in green building construction projects. However, the mean score of "design error/omission" (i.e., 3.17) was considerably lower than that (i.e., 4.00) of "design change", the 2nd most frequent rework factor, which indicated that the former occurred less frequently than the latter significantly. Such discrepancy was also in line with the common sense that error/omission occurred sometimes rather than always.

"Contractor's error/omission" received the 4th ranking in the likelihood evaluation in green building construction projects, with a mean evaluation of 2.80. The occurrence of "contractor's error/omission" is mainly up to the familiarity of contractor with the construction technologies and methods applied during project implementation, and green building construction projects always tend to use some new and innovative technologies and methods that might be unfamiliar to contractors at times (Kang et al., 2013). Thus, errors and omissions of contractor workers might be raised by their improper activities and eventually result in rework. Meanwhile, this result implied indirectly that the experienced contractors with expertise of green building construction in the Singaporean construction industry were scarce currently.

According to Table 6, rework factors that have significant impacts on green building construction projects are "owner change", "design change", "design error/omission", and "contractor's error/omission", for their mean scores were statistically greater or equal to the test value of the One Sample T-test, namely, 3 at the 95 percent confidence interval. Meanwhile, the calculated Spearman Rank Coefficient for the rankings of impact evaluations of rework factors within green and conventional building construction projects is 0.994 (p-value = 0.000), suggesting the rankings within two types of projects are highly associated.

"Owner change" was ranked 1st with the highest value of 4.37 in the impact evaluation, suggesting it was the most impactful rework factor in green building construction projects. Such result was unsurprising because the owner occupied the predominant position in the current construction industry, and their change orders were always inarguable and impacted projects significantly. Similar conclusions were also achieved by previous studies that "owner change" was the most impactful factor on the project performances in conventional building construction projects (Josephson et al., 2002; Love and Smith, 2003; Hwang et al., 2009; Hwang et al., 2014).

"Design change" received the 2nd ranking and a high value of 3.73 in impact evaluation, indicating itself also an impactful rework factor in green building construction projects. This result echoed the Josephson et al. (2002) that any change related to design would definitely cause concatenate consequences and probably result in rework. In addition, the result of Wilcoxon Singed-rank Test revealed that the mean score of "design change" in green building construction projects (i.e., 3.73) was statistically higher than that in conventional building construction projects (i.e., 3.43) at the 99 confidence interval, which indicated that the rework factor was more impactful in green building construction projects. This could be attributed to the fact that design was more critical to green building construction projects than conventional building construction projects (Li et al., 2011), thus variations of design in green building construction projects would cause worse consequences.

"Design error/omission" and "Contractor's error/omission" were the 3rd and 4th most impactful rework factors in green building construction projects, respectively. The mean values of these two rework factors (i.e., 3.10 and 3.00) were considerably lower than those of the top two rework factors (i.e., 4.37 and 3.73), which indicated that the impacts of "design error/omission" and "contractor's error/omission" on green building construction projects were significantly less than the top two rework factors. Nonetheless, the results of mean evaluation and Wilcoxon Signed-rank Test showed that the impacts of "design error/omission" and "contractor's error/omission" on green building construction projects were greater than those on conventional building construction projects, which implied that special attention to these two rework factors in green building construction projects was required.

To reflect the rework factors more comprehensively, the concept of criticality was adopted, as inspired by Shen et al. (2001). The criticality of each rework factor was determined by calculating the product of its likelihood and impact evaluations, and the relevant calculation results as well as its statistical test results were presented in Table 6. Results showed that the most critical rework factors in green building construction projects were "owner change", "design change", "design error/omission", and "contractor's error/omission", because their mean scores were statistically greater or equal to the test value of the One Sample T-test, namely, 9, the product of the median values of likelihood and impact rating scales. In addition, the result of Wilcoxon Signed-rank Test revealed that the criticality evaluations of "design change", "design error/omission", and "contractor's error/omission" in green building construction projects were statistically higher than those in conventional building construction projects at the 99 confidence interval, indicating these three rework factors were more critical to green building construction projects than conventional building construction projects. Such results were generally in line with the likelihood and impact evaluation results of rework factors in green building construction projects, which further proved that the four rework factors were of particular importance to the rework problem in green building construction projects.

This study recommended 11 solutions to reduce reworks in green building construction projects, which were also assessed in the questionnaire survey. Two different assessing approaches were employed. First, a five-point Likert rating scale (1 = least effective and 5 = most effective) was utilized to measure the effectiveness of diverse solutions. Second, a ranking preference rating system was adopted to request respondents to rank the whole 11 solutions from 1 (the most effective) to 11 (the least effective). To highlight the most effective solutions, evaluation results generated from the preference rating approach were reported in the frequency of top five selected solutions.

Table 7. Solutions to reduce reworks in green building construction projects

Solutions	Likert rating scale			Top five selected	
	Rank	Mean	p-value	Rank	Frequency
Use communication tools for design coordination	1	3.60	0.000*	4	17
Ensure the correctness of design	2	3.53	0.003*	1	23
Ensure the compatibility of design and specifications	3	3.33	0.030*	1	23
Establish an effective channel for communication	4	3.30	0.037*	3	21
Ensure a sound change management	5	3.03	0.879	5	16
Design review and verification	6	2.70	0.095	8	9
Inter-organizational collaboration and learning	7	2.53	0.017*	9	8
Corrective action planning	7	2.53	0.100	6	13
Front-end planning	9	2.43	0.088	6	13
Enhanced access to information	10	2.33	0.000*	10	3
Rework-tracking system	11	1.60	0.000*	10	3
Spearman Rank Correlation Coefficient = 0.878 (p-value = 0.000**)					

Note:* The One Sample T-test result is significant at the level of 0.05 (two-tailed).
**The Spearman Rank Correlation Coefficient is significant at the level of 0.01 (two-tailed).

Table 7 illustrates the evaluation results. For the results generated from Likert rating, One Sample T-test was conducted with a hypothesized value of 3 to check the effectiveness of each recommended solution. The test results revealed that, "inter-organizational collaboration and learning", "enhanced access to information", and "rework-tracking system" were statistically ineffective because their mean values and relevant p-values were less than 3 at the 95 percent confidence interval; while the rest eight solutions were regarded statistically effective. In addition, the calculated Spearman Rank Correlation Coefficient value for the two rating systems was 0.878 with a p-value of 0.000, suggesting that the two rankings of solutions were highly associated. Meanwhile, it was noteworthy that the two rating approaches reached the same top five effective solutions, namely, "use communication tools for design coordination", "ensure the effectiveness of design", "ensure the compatibility of design and specifications", "establish an effective channel for communication", and "ensure a sound change management".

Results in Table 7 showed that the top three solutions generated from Likert rating were all design-related solutions, and in particular, two of them, namely, "ensure the correctness of design" and "ensure the compatibility of design and specifications", were tied for first in the top five selected rating. Such results reflected that design was crucial to the reduction of reworks in green building construction projects. "Ensure the correctness of design" was ranked first in the top five selected rating and second in Likert rating. This could be attributed to the fact that construction of a facility was highly dependent on design, and any error or omission in the design documents could affect the construction process and eventually result in rework (Hwang and Yang, 2014). To avoid design error or omission, the respondents further suggested that the drawings could undergo a cross-check before they were delivered to the further construction process. "Use communication tools for design coordination" and "Ensure the compatibility of design and specifications" received the first and third ranks in the Likert rating, respectively. Design work of a facility is comprised of several different branches, such as architectural, structural and mechatronic design. Normally each branch has its own design protocol and standard to follow during the design process (Cheng et al., 2013). However, conflicts and clashes might occur when designs from different branches are integrated, which would lead to rework eventually. To address this issue, the application of design coordination tools was suggested in this study. Design coordination tools refer to computer-aided design modeling instruments such as AutoCAD and REVIT, which can facilitate information transfer and coordination among stakeholders efficiently (Zaneldin et al., 2001). By utilizing these tools, project stakeholders can gain a better understanding of the works to be performed by other parties, and design issues such as conflicts and design errors might also be identified and rectified in the early stages of the project, which can minimize the reworks in projects. Meanwhile, the usage of design coordination tools can enhance the compatibility of design and specifications, which can also reduce the likelihood of occurrence of rework in green building construction projects.

"Establish an effective channel for communication" was ranked fourth in the Likert rating scale and third in the top five selected rating. Communications among different stakeholders was one of the significant challenges in undertaking green building construction projects (Hwang and Ng, 2013). Compared with traditional building construction projects, green building projects involve more complex technologies and designs that requires more communications among project stakeholders (Kang et al., 2013). Therefore, it is extremely important to establish an effective channel to improve the communications among the various project stakeholders. The respondents also mentioned that such channels could be periodical project meetings and integrated construction management systems.

"Ensure a sound change management" received the fifth ranking in both Likert and top five selected ratings. Change orders are one of the major sources of rework in construction projects (Love and Li, 2000; Hwang and Yang, 2014), and can be derived from various origins, such as owner-induced enhancements, design errors and omissions, and contract omissions. A sound change management is thus crucial to the reduction of rework in construction projects. To mitigate reworks caused by change orders, two specific measures were suggested by the respondents. First, a high quality design with least design errors and omissions should be generated and fully communicated with owner to make sure that the owner's intention and requirement for the project were already embodied thoroughly. Second, a detailed change order database was strongly recommended. The database would collect various types of change orders in terms of their sources, nature, and final treatments. It is believed that such a database could render valuable reference of change management for future projects.

CONCLUSIONS

This study performed a detailed investigation of rework issues in green building construction projects. Results showed that although the incidence of rework in green building construction projects was lower than that of conventional building construction projects, the adverse impacts of rework on green building construction projects were higher than that on conventional projects. This study also unveiled that the top four critical rework factors in green building construction projects were “owner change”, “design change”, “design error/omission”, and “contractor’s error/omission”, and that these four rework factors were generally more critical to green building construction projects than conventional projects.

Finally, this study recommended five practical solutions, namely “use communication tools for design coordination”, “ensure the correctness of design”, “ensure the compatibility of design and specifications”, “establish an effective channel for communication”, and “ensure a sound change management”, to reduce reworks in green building construction projects.

Although the objectives of the study were achieved, there were some limitations. First, as the sample size in this study was small, cautions should be warranted when the analysis results are interpreted and generalized. Second, nearly half of the respondents were from contractors, which might make the survey results more closely represent contractor’s perspectives while opinions of the other construction-related firms might be under-represented. Last, the findings from this study are well interpreted in the context of Singapore, which might vary in other countries. Nonetheless, the findings derived from this study are still valuable because they provide practitioners and researchers with an in-depth understanding of rework in green building construction projects. The practical solutions recommended in this study were also useful to mitigating reworks in such projects. Further research can be directed to developing a measuring model to assess the impact of rework on the cost and schedule performance of green building projects. It would also be interesting to examine the interrelationships among various rework factors in green building construction projects.

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