Factors Affecting Productivity in Green Building Construction Projects: The Case of Singapore

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Abstract: The construction of green buildings differs from that of traditional buildings in terms of the design, materials, and processes. The barriers to the development of green buildings, such as the high cost and project delay, further indicate that the productivity of green building construction needs to be tackled. This study aims to identify the critical factors affecting the productivity of green building construction projects by assessing the likelihood, impact, and criticality of the factors with comparisons against traditional projects. To achieve the objective, 26 factors were identified from a comprehensive literature review and interviews with industry experts. A questionnaire survey was then performed with 32 professionals experienced in green building projects, and three postsurvey interviews were also conducted. The results indicated that workers' experience, technology, design changes, workers' skill level, and planning and sequencing of work were the top five most critical factors affecting the productivity of green building construction projects. Furthermore, the differences in the criticality of the technical factors between green and traditional projects were remarkable, which should draw the practitioners' attention. The findings from this study not only fill a gap in the project management body of knowledge for green buildings but also help practitioners identify specific adjustments to traditional project management processes and practices achieving a more productive delivery of green buildings. **DOI: 10.1061/(ASCE)ME.1943-5479.0000499.**

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Introduction

Green buildings and green construction have the greatest opportunity to reduce the greenhouse gas (GHG) emissions. According to United Nations Environment Programme (UNEP 2011), global buildings are responsible for up to 40% of global energy consumption and 30% of GHG emissions. The building sector has the greatest potential for delivering significant cuts in GHG emissions at a low or no-cost or net savings to economies. In recent years, there has been an increasing focus on sustainability and an apparent shift toward green buildings and green construction all over the world (McGraw-Hill Construction 2013).

In Singapore, the construction industry is one key contributor to its economy growth. According to the report from Ministry of Trade and Industry Singapore (MTI 2015), the construction industry growth was approximate 3% in 2014, which was higher than the overall economic growth. The Building and Construction Authority (BCA) of Singapore reported that Singapore's construction output was approximately 37.7 billion Singapore dollars (SGD) in 2014 and would be 26–37 billion SGD from 2015 to 2018 (BCA 2015b). The adoption of green building and sustainability movement is an approach to gain a competitive edge in the environmental/ecological technology and to export services to developing countries (MTI 2016). Singapore has embarked on a mission to make construction more environmentally friendly and launched a series of green building masterplans and green mark scheme to improve the industry.

In 2005, BCA introduced the green mark scheme to aid in the greening of Singapore's current and future buildings. To intensify the green building movement, BCA introduced the 1st and 2nd green building masterplan in 2006 and 2009, respectively. The key target of the 2nd green building masterplan is to have at least 80% of the buildings in Singapore to be green by 2030 (BCA 2009). To achieve this target, a number of initiatives, such as the retrofitting scheme to encourage existing buildings to go green and be more energy efficient and require new buildings more than 2,000 m^2 to attend green mark certification, have been introduced. With these initiatives, the number of Singapore's green building stock increased from 17 in 2005 to 2300 in 2015, accounting for approximately 27% of Singapore's total gross floor area (BCA 2014, 2015c). In light of the long way to the vision of 2030, BCA introduced the 3rd green building masterplan to accelerate the green agenda (BCA 2014). Three strategic goals, namely, continued leadership, wider collaboration and engagement, and prove sustainability performance, were included in the agenda to guide the future initiatives towards its vision and goal productively (BCA 2014).

In addition to the aforementioned initiatives, green buildings must be constructed in a more productive manner. The term productivity describes the relationship between output and the associated inputs used to generate that output (CII 2010), revealing the efficiency and effectiveness of resource usage. However, the current development situation of green buildings poses a great challenge to the green target. First, the high initial cost was indicated as the greatest obstacle to the development of green buildings (McGraw-Hill Construction 2006). In addition, the cost overrun is another hindrance, which could be caused by many requirements to achieve a green certificate and shareholders' unfamiliarity of the green requirements and technologies (CII 2008; Nalewaik and Venters 2010). Furthermore, the schedule performance of green building construction projects was found worse than that of traditional projects (Hwang and Leong 2013). Apart from the aforementioned

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barriers, it was reported that the productivity of the overall construction industry was poor, lagging behind its manufacturing counterpart (Mojahed and Aghazadeh 2008; PwC 2013), and there was a slight improvement in the productivity for the majority of the construction industry (FMI 2012). Therefore, the productivity improvement of green buildings is urgent for the industry to achieve the green target.

To improve the construction productivity, a lot of research on factors affecting the construction productivity has been done. However, few have attempted to analyze factors affecting the productivity of green building construction projects. Such kind of research is important first because the construction of green buildings differs from that of traditional buildings in terms of the design, materials, and processes (Mokhlesian and Holmén 2012). Moreover, the existing project management techniques or business models struggle to handle the high levels of complexity of green building construction projects (Mokhlesian and Holmén 2012; Pulaski and Horman 2005). Specific adjustments to traditional project management practices and processes need to be identified.

In light of the previous, the objective of this study is to identify the critical factors affecting the productivity of green building construction projects by assessing the likelihood, impact, and criticality of the factors with comparisons against traditional projects. The findings from this study not only add significantly to the existing research on both green building and green construction but also help practitioners identify specific adjustments to traditional project management processes and practices. To construct green buildings in a more productive manner, practitioners can focus and act on the factors with a high criticality or a large difference in criticality between green and traditional projects. Furthermore, practitioners attempting to enter the green building industry also can possess a prior practical knowledge of such factors from this study, avoiding productivity losses in their future projects.

Background

Green Buildings Construction Projects

A green building is the creation of structures that are environmentally-responsible and resource-efficient throughout a building's lifecycle (Environmental Protection Agency 2016). It includes elements that are energy-efficient, water-efficient, and environmentally friendly, providing a good indoor environmental quality and having green features to better a building performance (BCA 2016a, b). Because of the special characteristics of green buildings, the means in which they are constructed would be different as compared with traditional building projects (Dwaikat and Ali 2016).

First, the design of a green building is different from that of a traditional building because designers need to adopt an integrated design approach. Designers should understand interactions between different building systems and interactions between building systems and the environment so as to allow each system to be optimized (BCA 2010). Special design factors, such as the building envelope, space orientation and building materials, need specific considerations. The building envelope limits the amount of external forces, such as the daylight and temperature, by shielding the interior of a building from the exterior environment (BCA 2010). Space orientation aims to reduce some external forces by considering the direction of sun travel (BCA 2010). Moreover, sustainable building construction materials are considered and crafted to precise specifications so as to ensure a building is environmentally friendly (BCA 2013). These design factors are thought of best practices in the context of a traditional building design, but not a necessity.

In addition, to successfully deliver green buildings, specific modifications to traditional project management processes and practices are needed (Robichaud and Anantatmula 2011). For example, as a design having a great impact on the cost, the aforementioned special design factors need to be considered early in the design stage, which affects a project delivery method. Different types of delivery methods, such as the most frequently used design-bid-build (DBB) and the increasingly popular design-build (DB) model, should be first considered (CMAA 2012). The finding of an empirical research showed that DB was used for 75% of the sample of green building construction projects (Molenaar et al. 2009). DB and construction management at risk (CMR) have better chances to provide high levels of integration by facilitating the early involvement of contractors (Mollaoglu-Korkmaz et al. 2013). In light of this, the selection of a DB contractor was also thought of critical importance (Xia et al. 2015).

Furthermore, a green building construction project values the efficient use of resources in its construction and in the usage of the building (Dwaikat and Ali 2016). In contrast to a traditional building construction, a green building construction usually needs to follow an additional set of requirements to help a building gain a green recognition. To protect the environment, the use of sustainable construction practices, such as the use of recycled concrete aggregates, can help a building to gain points for the consideration of green mark (BCA 2013). In leadership in energy and environmental design (LEED), considerations have also been made for the waste management in the storing and collection of recyclables and for workers' health in terms of having the reasonably good air quality during the construction phase (USGBC 2009).

Green Buildings Construction Productivity

Productivity is generally used to describe the relationship between output and the associated inputs used to generate that output, with it assessing the effectiveness and efficiency of resource usage in achieving the output (CII 2010; SPRING Singapore 2011). It is crucial for both countries and organizations to achieve and maintain a long-term competitiveness and profitability (SPRING Singapore 2011). For instance, before the 1997 Asian financial crisis, the increase in productivity contributed to 60% of Singapore's economic growth, because of which Singapore was once labeled as one of the Four Asian Tigers (Kiat 1991).

As discussed previously, Singapore aims to green at least 80% of buildings in Singapore by 2030. Construction productivity can be a basic and determining factor to secure the achievement of this target. However, the declining productivity of the construction industry of Singapore poses a great question mark to the achievement of this target. The labor productivity, which is a crucial productivity index, of the Singapore construction industry had been continuing declined from 4.0% in 2010 to −2.7% in 2013. The values of the first and second quarter in 2014 were −0.7 and −2.0%, respectively, which were still negative (Department of Statistics Singapore 2014). In light of this situation, BCA implemented the first and second construction productivity roadmap in 2011 and 2015, respectively, to improve the productivity in the long-term (BCA 2011, 2015a). With the endorsement of the National Productivity and Continuing Education Council, the goal of the first roadmap was to have a competent construction sector that is advanced and supported by a skilled workforce by 2020 (BCA 2011). The second roadmap aims to equip the construction with high technologies (BCA 2015a).

Furthermore, the low productivity of the development of green buildings also poses a great challenge to the green target because a low construction productivity generally leads to cost and schedule problems (Doloi et al. 2012; Gündüz et al. 2013). First, the capital costs of green building developments are perceived higher than that of traditional buildings, leading to the inactive development of the green building industry (Dwaikat and Ali 2016). As explained previously, the design and construction of green buildings are different from that of traditional buildings, leading to a high design and construction costs (Chan et al. 2009; Robichaud and Anantatmula 2011). To motivate the industry, firms are recommended to change their business models to maximize their profits from green constructions (Mokhlesian and Holmén 2012). In addition, the cost overrun is another hindrance which could be caused by many requirements to achieve a green certificate and the unfamiliarity with green technologies leading to technical difficulties during a construction process (CII 2008; Zhang et al. 2011). As for the schedule performance, the empirical study of Hwang and Leong (2013) found that 16% of the traditional projects were delayed, whereas 32% of the green building construction projects were completed behind schedule.

As can be inferred from the literature review, specific adjustments to traditional project management practices and processes need to be identified so as to overcome the barriers. Furthermore, the productivity improvement for green buildings is also imperative for the sustainable development of green buildings in a long run. The construction industry needs to not only quickly adopt eco-friendly practices and materials that reduce its impact but also take its own initiatives and find alternative ways to build green buildings in a more productive manner. To avoid aimless efforts, the foremost thing is to exam the causes affecting the project productivity of green buildings before making any improvement effort.

Factors Affecting Productivity

Many studies have been conducted to evaluate factors affecting the productivity in the the construction industry (Dulaimi and Dalziel 1994; Fox et al. 2002; Mojahed and Aghazadeh 2008). Some researchers focused on labor productivity by directly surveying the workforce instead of the management because of the easily obtained labor information (Chan 2002; Kaming et al. 1997). Considering the significant contributions of other factors, a growing number of researchers opted to measure total factor productivity instead (Crawford and Vogl 2006). Therefore, different factors affecting productivity need to be further examined.

Factors affecting the productivity in the construction industry and their classifications vary depending on the views taken by researchers (Jarkas and Bitar 2014; Yi and Chan 2014). After a comprehensive literature review on factors affecting construction productivity, this study identified 26 factors and grouped them into five major categories, namely, project factor (6), manpower factors (6), management factors (7), technical factors (5) and external factors (2), as summarized in Table 1.

Project Factors

Project factors are inherent in any project but would differ because of the different directions taken in planning and execution. The means of procurement is vital as it states how a project would continue in terms of delivery and financing. According to Dulaimi and Dalziel (1994), the use of a DB method not only improves the communication between parties, but also has a positive impact on the project performance being recorded. The research result from Thomas et al. (1999) showed that different construction methods for the same work led to different productivity results. Makulsawatudom et al. (2004) identified reworks and the inability to finance material payments as factors affecting productivity. Design changes were identified by Kaming et al. (1997) and Olomolaiye et al. (1987) as a cause for reworks and should be further investigated. Fox et al. (2002) also indicated that the design of a building affected productivity.

Manpower Factors

Manpower factors refer to factors affecting the labor involved in a construction project. Lim and Alum (1995) identified five main factors affecting construction productivity which were the difficulties in the recruitment of supervisors and workers, the high rate of labor turnover, absenteeism at the worksite and the communication problems with foreign workers. Olomolaiye and Ogunlana (1989) found that workers from different sites had different productivity outputs and perceptions on their supposed productivity. The results indicated that workers with the perception of a higher productivity would exhibit a better production output. Han et al. (2008) and El-Gohary and Aziz (2014) identified that workers' experience and skills greatly influenced the construction labor productivity and ultimately affected a project productivity. Through a survey of 243 craftsmen, Kaming et al. (1997) examined the relationship between the views of craftsmen and the productivity problems in Indonesia. The result showed that absenteeism was one of the top five productivity problems affecting the productivity of craftsmen. Lately, Jarkas and Bitar (2014) and El-Gohary and Aziz (2014) found that the lack of incentive scheme for workers was a critical factor affecting the labor productivity.

Management Factors

Management factors are important as they deal with the management operation and execution of a project. A high quality of management can ensure the smooth running of a project. According to Kaming et al. (1997), poor work planning, inadequate sequencing, the poor site layout, whereby materials were stored improperly, and poor communications were some reasons for material shortages and reworks. Therefore, looking into such factors to understand the root factors of productivity is imperative. From the aspect of a higher management, Chan (2002) identified that the key differences between productive and nonproductive projects were labor planning, the organization of all aspects of work, workers' feeling part of the team, having job security and site welfare. From the aspect of project management, incompetent supervisors, poor communication, instruction time, poor site layout and inspection delay were factors among the top ten most significant factors affecting the construction productivity identified by Makulsawatudom et al. (2004).

Technical Factors

Technical factors presented in this study refer to the design aspects, materials, and tools needed to efficiently finish a project. According to Olomolaiye and Ogunlana (1989), the availability of materials, equipment and tools coincided with a higher productivity as compared with those that did not. The findings of El-Gohary and Aziz (2014) also showed that the availability of the material and ease of handling was one of the most significant factors influencing construction labor productivity. Through a site survey of 243 craftsmen, Kaming et al. (1997) identified that the lack of material, rework, interference, and the lack of tools were four of the top five productivity problems affecting the productivity of craftsmen. According to Makulsawatudom et al. (2004), incomplete drawings were also one of the key factors affecting the construction productivity. Moreover, the inclusion of technology as one of the technical factors also needs to be considered. According to Goodrum and Haas (2002), the changes in technology contributed to the increase in productivity.

Table 1. Factors Affecting Construction Productivity

Factor category	Code	List of factors	References														
			Dulaimi and Dalziel (1994)	Olomolaiye and Ogunlana (1989)	Thomas et al. (1999)	Makulsawatudom et al. (2004)	Jarkas and Bitar (2014)	Olomolaiye et al. (1987)	Kaming et al. (1997)	Fox et al. (2002)	Chan (2002)	Mojahed and Aghazadeh (2008)	Lim and Alum (1995)	Goodrum and Haas (2002)	Chan et al. (2013)	Han et al. (2008)	El-Gohary and Aziz (2014)
Project factors	P1	Procurement method	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	P2	Construction method	—	X	X	—	—	—	—	—	—	—	—	—	—	—	—
	P3	Timely payments	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—
	P4	Proportion of outsourced work	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—
	P5	Reworks	—	—	—	—	—	X	X	—	—	—	—	—	—	—	—
	P6	Building design	—	—	—	—	X	—	—	X	—	—	—	—	—	—	—
Manpower factors	MP1	Motivation of workers	—	—	—	—	X	—	—	—	X	X	—	—	—	—	X
	MP2	Workers' skill level	—	—	—	—	—	—	—	—	—	X	—	—	—	X	X
	MP3	Absenteeism	—	—	—	—	—	X	X	—	—	—	X	—	—	—	—
	MP4	Labor turnover	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—
	MP5	Workers' experience	—	—	—	—	—	—	—	—	—	X	—	—	—	X	X
	MP6	Difficulty in recruitment of workers	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—
Management factors	MG1	Supervision of labor	—	—	—	X	X	—	—	—	—	—	—	—	—	—	—
	MG2	Planning and sequencing of work	—	—	—	—	—	—	—	—	X	X	—	—	—	—	—
	MG3	Competency of project manager	—	—	—	X	X	—	—	—	—	—	—	—	—	—	X
	MG4	Poor site layout	—	—	—	X	—	—	X	—	—	—	—	—	—	—	—
	MG5	Inspection delay	—	—	—	X	—	—		—	—	—	—	—	—	—	—
	MG6	Communication of information	—	—	—	X	X	—		—	—	—	X	—	—	—	—
	MG7	Poor instructions	—	—	—	X	—	—	X	—	—	—	—	—	—	—	—
Technical factors	T1	Materials availability	—	X	—	—	—	X	X	—	—	—	—	—	—	—	X
	T2	Tools and equipment	—	X	—	—	—	X	X	—	—	—	—	—	—	—	—
	T3	Design changes	—	—	—	—	—	X	X	—	—	—	—	—	—	—	—
	T4	Incomplete design	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—
	T5	Technology	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—
External factors	E1	Industry initiatives	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—
	E2	Weather	—	—	X	—	—	—	—	—	—	—	X	—	X	—	—

External Factors

External factors are those which are uncontrollable but would still affect a project. According to Thomas et al. (1999), the effects of weather on productivity were significant. The productivity losses due to snow and cold temperatures were 41 and 32%, respectively. As for Singapore, a heavy downpour during the monsoon season and an interference rainy weather can affect the construction productivity (Lim and Alum 1995). Meanwhile, hot weather also affects the labor productivity and thermal work limit was recommended as an environmental determinant of heat stress for construction workers (Chan et al. 2013). Industry level factors, such as the governmental interference and regulation, were factors affecting productivity identified by Mojahed and Aghazadeh (2008). Although it was not a top five factors, industry initiatives would affect productivity in Singapore significantly. With the feature of heavy government interference, BCA and the Singapore government have constantly introduced initiatives to improve productivity. For instance, the increase in labor levy or increased green initiatives would affect manpower factors and thus should be explored further.

Method and Data Presentation

Data Collection and Presentation

The questionnaire survey is a systematic method of collecting data based on sample (Tan 2011). It has been widely used to collect professional views in sustainable construction research (Hwang et al. 2015; Wu and Low 2012). For this study, a questionnaire survey was carried out to investigate the criticalities of the various factors affecting the green building construction projects with comparisons against traditional projects. Based on a comprehensive literature review, a questionnaire was developed. Afterward, a two-step process was adopted to test the validity and relevance of the questionnaire. The questionnaire was first reviewed by an expert on question construction, ensuring that the survey did not contain common errors such as leading, confusing, or double-barreled questions. Then, a presurvey was conducted with three construction industry professionals who had several years' experience in the local construction industry, especially in green building construction projects. After receiving the feedback from them, the relevant changes were made to form the final survey.

The finalized questionnaire first explained the definitions of three critical terms to the respondents, which is a crucial premise for the comparison between green and traditional building construction projects. Productivity refers to the effective and efficient use of its resources in achieving its desired output. Green buildings are buildings that have obtained the Singapore green mark certification, whereas traditional buildings are those that did not obtain the certification. The questionnaire then included the questions meant to profile the companies and respondents. Afterward, the 26 factors affecting the construction productivity were grouped and presented in separate tables according to their categories. During the survey, the respondents were asked to assess the likelihood and impact of the factors affecting the productivity in both traditional and green building construction projects concurrently. To rate the likelihood and impact, the five-point scale was used. To have a better understanding of the survey, the questionnaire is provided in Appendix S1.

In addition, postsurvey interviews were conducted with three industry experts who possess the relevant experience in both traditional and green construction. In postsurvey interviews, the experts were provided with the results obtained from the survey questionnaire. They all confirmed that the findings of this study were reasonable and consistent with their expectations, which helped validating the findings from the survey. To gain an in-depth understanding of the findings, they were also requested to provide some possible explanations for the results.

The population of this study consisted of all the professionals who were from companies under the BCA directory of registered contractors and licensed builders, professionals who were from firms under the Singapore Institute of Surveyors and Valuers (SISV) and project managers with the relevant green mark certification such as green mark managers (GMM) and green mark professionals (GMP). A total of 130 sets of survey questionnaires were randomly sent out to gather responses from developers, contractors, and consultants. Finally, 32 complete sets were received, representing a response rate of 24.6%. Although the sample size was not large, statistical analysis could still be performed because the central limit theorem holds true even when the sample size is no less than 30 according to the generally accepted rule (Hwang et al. 2015; Ott and Longnecker 2010; Xianbo et al. 2013).

The profiles of the respondents and companies are provided in Table 2. The respondents consisted of 16 project managers (PM), 13 quantity surveyors (QS), and 3 team members (TM) from 8 contractors, 12 consultants, and 12 developer firms.

Criticality Index

The respondents were asked to rate the likelihood (L) and impact (I) of the factors affecting the productivity in the traditional and green

Table 2. Profiles of Respondents and Companies

Characteristics	Frequency	Percentage	Years of experience					
			Construction industry			Green building projects		
			1–2	3–4	≥5	1–2	3–4	≥5
Respondent								
PM	16	50.0	2	1	13	6	2	8
QS	13	40.6	9	1	3	9	2	2
TM	3	9.4	0	0	3	2	0	1
Subtotal	32	100	11	2	19	17	4	11
% by year	—	—	34.4	6.3	59.3	53.1	12.5	34.4
Company								
Contractor	8	25.0	0	0	8	0	4	4
Consultant	12	37.5	0	0	12	0	0	12
Developer	12	37.5	0	1	11	0	1	11
Subtotal	32	100	0	1	31	0	5	27
% by year	—	—	0	3.1	96.9	0	15.6	84.4

Table 3. Five-Point Likert Scales for Likelihood and Impact

Likelihood			Impact	
L	Linguistic terms	Likelihood references (%)	I	Linguistic terms
1	Least likely	<20	1	Very low
2	Less likely	20–40	2	Low
3	Neutral	40–60	3	Medium
4	Likely	60–80	4	High
5	Most likely	>80	5	Very high

building construction projects, respectively. For the criticality evaluation of each factor which is complex and vague, qualitative linguistic terms can be used (Hwang et al. 2015). Thus, five-point Likert scales were adopted in this study, as shown in Table 3.

The L and I of each factor can be calculated using Eqs. (1) and (2), respectively:

$$L^i = \frac{\sum_{j=1}^{n} L_j^i}{n} \tag{1}$$

$$I^i = \frac{\sum_{j=1}^{n} I_j^i}{n} \tag{2}$$

where n = number of respondents; L^i = likelihood of factor i; L_j^i = likelihood of factor i rated by respondent j; I^i = impact of factor i; I_j^i = impact of factor i rated by respondent j. Thus, the L and I of each factor are actually the mean values rated by the respondents.

This study adopted the criticality index (CI) to evaluate the criticality of each factor. Criticality has been widely recognized as the function of the L and I (Hwang et al. 2015; Ke et al. 2011; Zou et al. 2007). Hence, the CI of a factor can be computed using Eq. (3):

$$\mathrm{CI}^i = \frac{\sum_{j=1}^{n} \mathrm{CI}_j^i}{n} = \frac{\sum_{j=1}^{n} L_j^i \times I_j^i}{n} \tag{3}$$

where CI_j^i = criticality index of the factor i by respondent j; and CI^i = criticality index of factor i. Thus, CI is on a full scale of 25.

Results and Discussions

The following sections provide the results of likelihood, impact, and criticality index, respectively. Although these three results are mutually connected, analyses of these factors from different dimensions can further explore the causes of the productivity problem of green building construction projects and help practitioners make different mitigation strategies. For example, for a factor with a high likelihood, a mitigation strategy should focus on reducing the likelihood that the factor will occur; whereas for a factor with a high impact, a mitigation strategy should focus on reducing the impact that the factor will have if it does occur and have contingency plans in place just in case it does.

Likelihood Ranking in Green and Traditional Building Projects

Using Eq. (1), this study calculated the average likelihoods of the various factors. This study also analyzed the likelihoods of the various factors by adopting methods including descriptive means, one sample t-test, paired t-test, and Spearman rank correlation for comparisons of means amongst the factors and between green and traditional projects. First, the one sample t-test was used to test the mean scores of the likelihood of the factors against the mean value of three which is the middle value of the scale. Furthermore, the paired t-test was used to test whether the means of the likelihood of the factors for the green building construction projects were statistically different from those for the traditional projects. The null hypothesis H_0 is that there is no statistically significant difference in the means of the likelihood of a factor for traditional and green building construction projects, whereas the alternative hypothesis H_1 is that there is a statistically significant difference in the means of the likelihood of a factor for traditional and green building construction projects. Finally, the Spearman rank correlation, which is a method of computing a correlation between the ranks of scores between two groups, was performed to test for any agreement on the ranking of factors between traditional and green building construction projects. Without the consideration of normality or equal variance of data, this method focuses on differences in rank orders of data rather than differences in means (Hwang et al. 2015). The coefficient value falls between the range $[-1, +1]$, with $+1$ being the strongest positive correlation and -1 being the strongest negative correlation. All the aforementioned tests were conducted at a confidence level of 95% with a p-value of 0.05. If a p-value is less than 0.05, the null hypothesis should be rejected. The test results of the likelihood of the factors are shown in Table 4.

From the results of one sample t-test, the mean scores of the likelihood of all factors except timely payments were statistically greater than the test value of three with respect to both traditional and green building construction projects. The result indicated that these factors were significantly likely to affect the project productivity. For the factor timely payments, the likelihood of affecting project productivity was not statistically significant. This could be contributed by the Singapore's Security of Payments Act (SOPA) introduced to ensure the timely payments to contractors and provide secured cash flow for projects. The objectives of this act on improving the cash flow to contractors and the effectiveness of adjudication introduced under this act were addressed in the study conducted by Teo (2008).

From the results of mean, the top three factors most likely to affect the productivity of green building construction projects were workers' experience, competency of project manager, and technology. Workers' experience was ranked first ($L = 4.44$). First, the works of the construction industry are heavily reliant on labor which is more casual in nature (Debrah and Ofori 1997; Jarkas and Bitar 2014). As such, the workers' experience is most likely to affect the productivity. Furthermore, because the green building construction projects have only been around for the last ten years, the workers' experience would be limited. Hence, the likelihood of the productivity of green building construction projects being affected by the workers' experience is high.

The factor competency of project manager was ranked second ($L = 4.28$). According to Frank (2001), a project manager has a direct influence over 34–47% of a project success. From procurement to construction, green building construction projects would need to have project managers being more competent as they are newer and more difficult to integrate. A project manager fulfills not only traditional roles of project management but also must manage a project in the most efficient and effective manner with respect to green building construction projects. A research study substantiated that the different knowledge areas of a green construction affected the competency of project manager in comparison to a traditional construction (Hwang and Ng 2013). Moreover, the need for competent specialists increases with the increase in the number of green building construction projects. In light of this, the BCA of Singapore introduced the certified green mark professional program to expand the industry's capability in the area of sustainable design and development (BCA 2016c).

Table 4. Test Results of the Likelihood of Factors

Factor category	Code	List of factors	Green (G) Mean	Green (G) Rank	Green (G) $P(o)$	Traditional (T) Mean	Traditional (T) Rank	Traditional (T) $P(o)$	Diff.	SD	$P(p)$
Project factors	P1	Procurement method	3.56	20	0.00	3.47	18	0.00	0.09	0.64	0.41
	P2	Construction method	4.22	5	0.00	4.19	2	0.00	0.03	0.54	0.75
	P3	Timely payments	2.97	26	0.44	2.91	26	0.29	0.06	0.56	0.54
	P4	Proportion of outsourced work	3.53	21	0.00	3.41	24	0.01	0.12	0.94	0.46
	P5	Reworks	3.72	17	0.00	3.81	9	0.00	−0.09	0.86	0.54
	P6	Building design	4.13	8	0.00	3.88	6	0.00	0.25	0.72	0.06
Manpower factors	MP1	Motivation of workers	3.41	24	0.01	3.44	22	0.00	−0.03	0.18	0.33
	MP2	Workers' skill level	4.22	5	0.00	4.03	3	0.00	0.19	0.59	0.08
	MP3	Absenteeism	3.41	25	0.02	3.31	25	0.04	0.10	0.30	0.08
	MP4	Labor turnover	3.50	23	0.00	3.44	22	0.00	0.06	0.35	0.33
	MP5	Workers' experience	4.44	1	0.00	4.19	1	0.00	0.25	0.67	0.04
	MP6	Difficulty in recruitment of workers	3.97	11	0.00	3.47	18	0.00	0.50	0.92	0.00
Management factors	MG1	Supervision of labor	3.91	13	0.00	3.59	16	0.00	0.32	0.64	0.01
	MG2	Planning and sequencing of work	4.19	7	0.00	3.91	5	0.00	0.28	0.58	0.01
	MG3	Competency of project manager	4.28	2	0.00	3.94	4	0.00	0.34	0.65	0.00
	MG4	Poor site layout	3.94	12	0.00	3.84	8	0.00	0.10	0.39	0.18
	MG5	Inspection delay	3.66	19	0.00	3.47	18	0.00	0.19	1.06	0.33
	MG6	Communication of information	3.88	14	0.00	3.63	13	0.00	0.25	0.67	0.04
	MG7	Poor instructions	3.72	18	0.00	3.66	12	0.00	0.06	0.44	0.42
Technical factors	T1	Materials availability	3.81	16	0.00	3.56	17	0.00	0.25	0.57	0.02
	T2	Tools and equipment	3.84	15	0.00	3.47	18	0.00	0.37	0.75	0.00
	T3	Design changes	4.25	4	0.00	3.78	10	0.00	0.47	0.67	0.00
	T4	Incomplete design	4.06	9	0.00	3.63	13	0.00	0.43	0.76	0.00
	T5	Technology	4.28	2	0.00	3.69	11	0.00	0.59	1.01	0.00
External factors	E1	Industry initiatives	4.03	10	0.00	3.88	6	0.00	0.15	0.51	0.10
	E2	Weather	3.53	22	0.00	3.63	13	0.00	−0.10	0.73	0.48

Note: Diff. = difference in mean; $P(o)$ = p-value in one sample t-test; $P(p)$ = p-value in paired t-test; SD = standard deviation. The sample size of t-test is 32. The rank correlation between green and traditional is 0.86 with p-value of 0.00.

The factor technology was received the third position ($L = 4.28$). Green construction specifications and methods differ from those for a traditional construction. Green technologies and techniques are critical for such specifications to be drafted and implemented effectively (Lam et al. 2010). Although green technologies can offer plenty of sustainable solutions to help buildings and the environment, practitioners still need time to learn them and get proficiency in these technologies. Furthermore, interviewees from postsurveys felt that green building construction projects were more unproductive than traditional construction projects. They thought a possible explanation would be attributable to the unfamiliarity with green technologies and technical difficulties during the construction process. These causes have been also indicated as two of the main challenges faced in green construction projects (Tagaza and Wilson 2004; Zhang et al. 2011).

From the result of the Spearman rank correlation, it can be inferred that the factors likely to affect the productivity in green building construction projects have a strong positive correlation with the factors in traditional projects because the correlation value was 0.86 and the p-value was less than 0.05. However, from the results of the paired t-test, 11 factors were considered to be significant as the p-values of these factors were below 0.05. As such, the null hypothesis for the 11 factors should be rejected, indicating that the differences in likelihood between traditional and green building construction projects for these factors were statistically significant. It is worth noting that five factors among the 11 factors were technical factors, representing that people think that green building construction projects are more difficult in technology than traditional ones. From the results of the mean difference, difficulty in recruitment of workers (Diff. = 0.50), supervision of labor (Diff. = 0.32), competency of project manager (Diff. = 0.34), tools and equipment (Diff. = 0.37), design changes (Diff. = 0.47), incomplete design (Diff. = 0.43), and technology (Diff. = 0.59) were factors having higher mean difference values (Diff. $\geq$ 0.30). In light of the aforementioned, factors with a high likelihood and factors with a high mean difference should draw practitioners' attention.

Impact Ranking in Green and Traditional Building Projects

This study further calculated the average impact of various factors using Eq. (2), and analyzed the impacts of the various factors by using the same methods discussed previously. The test results of the impact of the factors are shown in Table 5.

From the results of the one sample t-test, the mean scores of the impact of all factors except absenteeism were statistically greater than the test value of three with respect to both traditional and green building construction projects. The results indicated that these factors had a significant impact on the project productivity. For the factor absenteeism, although the means for green ($I = 3.3$) and traditional ($I = 3.09$) were both greater than three, the p-values were also greater than 0.05, indicating that the impact of this factor was not statistically significant. The negation of the impact of absenteeism on productivity could be attributable to the abundance of cheap foreign labor in Singapore which results in the easy recruitment when there is absenteeism.

From the results of the mean, the top three factors having a high impact on the productivity of green building construction projects were workers' experience, technology, and design changes. Workers' experience was ranked first ($I = 4.41$). Because of the use of

Table 5. Test Results of the Impact of Factors

Factor category	Code	List of factors	Green (G)			Traditional (T)					
			Mean	Rank	$P(o)$	Mean	Rank	$P(o)$	Diff.	SD	$P(p)$
Project factors	P1	Procurement method	3.81	15	0.00	3.66	15	0.00	0.15	0.45	0.06
	P2	Construction method	4.16	7	0.00	4.09	1	0.00	0.07	0.44	0.42
	P3	Timely payments	3.50	21	0.00	3.53	19	0.00	−0.03	0.18	0.33
	P4	Proportion of outsourced work	3.56	20	0.00	3.47	21	0.00	0.09	0.78	0.50
	P5	Reworks	4.03	12	0.00	4.00	6	0.00	0.03	0.40	0.66
	P6	Building design	4.25	5	0.00	4.06	2	0.00	0.19	0.64	0.11
Manpower factors	MP1	Motivation of workers	3.38	24	0.02	3.44	22	0.01	−0.06	0.35	0.33
	MP2	Workers' skill level	4.22	6	0.00	3.84	9	0.00	0.38	0.71	0.01
	MP3	Absenteeism	3.03	26	0.43	3.09	26	0.29	−0.06	0.56	0.54
	MP4	Labor turnover	3.38	24	0.01	3.25	25	0.04	0.13	0.61	0.26
	MP5	Workers' experience	4.41	1	0.00	4.06	2	0.00	0.35	0.65	0.01
	MP6	Difficulty in recruitment of workers	3.75	17	0.00	3.41	23	0.00	0.34	0.60	0.00
Management factors	MG1	Supervision of labor	3.72	19	0.00	3.59	17	0.00	0.13	0.61	0.26
	MG2	Planning and sequencing of work	4.28	4	0.00	4.03	4	0.00	0.25	0.76	0.07
	MG3	Competency of project manager	4.06	11	0.00	4.00	6	0.00	0.06	0.44	0.42
	MG4	Poor site layout	3.75	17	0.00	3.53	19	0.00	0.22	0.49	0.02
	MG5	Inspection delay	3.41	23	0.00	3.28	24	0.02	0.13	0.66	0.29
	MG6	Communication of information	3.81	15	0.00	3.75	14	0.00	0.06	0.62	0.57
	MG7	Poor instructions	3.84	14	0.00	3.66	15	0.00	0.18	0.54	0.06
Technical factors	T1	Materials availability	4.13	8	0.00	3.84	9	0.00	0.29	0.52	0.01
	T2	Tools and equipment	4.00	13	0.00	3.78	13	0.00	0.22	0.42	0.01
	T3	Design changes	4.31	3	0.00	4.03	4	0.00	0.28	0.52	0.01
	T4	Incomplete design	4.13	8	0.00	3.84	9	0.00	0.29	0.52	0.01
	T5	Technology	4.38	2	0.00	3.81	12	0.00	0.57	0.76	0.00
External factors	E1	Industry initiatives	4.09	10	0.00	3.91	8	0.00	0.18	0.69	0.14
	E2	Weather	3.50	21	0.00	3.56	18	0.00	−0.06	0.56	0.54

Note: The sample size of t-test is 32. The rank correlation between green and traditional is 0.90 with p-value of 0.00.

casual workers in green building construction projects, workers' inexperience can affect productivity through mistakes leading to reworks, changes and delays in projects. Reworks could greatly affect a project's productivity from the aspects of cost and schedule (Hwang et al. 2009). Furthermore, the postsurvey interviewees disclosed that the market was lack of workers with the experience of green building projects and with a green certificate. Although the BCA introduced the certified green mark professional program, some workers are still hesitating to join the program whereas some workers have not finished the program.

Technology received the second position ($I = 4.38$). Energy-efficient technologies could not only cut down waste on site but also decrease the effort put in by all parties in a construction process, which is an essentially productivity improvement. The impact of technology on productivity was also supported by Goodrum and Haas (2004), stating that improvements of technology in the United States' construction industry had increased the productivity over the course of 25 years.

Design changes, which are prevalent in the construction industry, was ranked third ($I = 4.31$). To quickly finish a project, the time spent on the planning stage is usually not enough. Taking Taiwan highway construction for an example, the insufficient time and resources spent during the planning stage led to the increased frequency of design changes (Wu et al. 2005). While design should be ironed more in green building projects earlier on, failure to do so can lead to designs with little integration or design changes during the construction. The high number and various types of design changes can invariably result in a drop off in the efficiency in construction (Thomas and Napolitan 1995).

From the result of the Spearman rank correlation, it can be inferred that the factors have an impact on the productivity in green building construction projects have a strong positive correlation with the factors in traditional projects because the correlation value was 0.90 and the p-value less than 0.05. However, from the results of the paired t-test, nine factors were considered to be significant as the p-value of these factors were below 0.05. As such, the null hypothesis for the nine factors should be rejected, indicating that the differences in impact on productivity between traditional and green building construction projects for these factors were statistically significant. It is worth noting that the majority of the nine factors were from manpower factors (three) and technical factors (five). From the results of the mean difference, workers' skill level (Diff. = 0.38), workers' experience (Diff. = 0.35), difficulty in recruitment of workers (Diff. = 0.34), and technology (Diff. = 0.57) were factors having higher mean difference values (Diff. ≥ 0.30). In light of the aforementioned, factors with a high impact and factors with a high mean difference should draw practitioners' attention.

Criticality Ranking in Green and Traditional Building Projects

Using Eq. (3), this study finally calculated the criticality index of each factor on the project productivity for traditional and green building construction projects. This study analyzed the criticalities of the various factors by using the same methods discussed previously. One difference is that the test value of the one-sample t-test was nine. The test results of the criticality are shown in Table 6.

From the results of the one sample t-test, all factors were significantly critical to affecting the productivity of both traditional and green building construction projects because all mean values were greater than nine and all p-values were less than 0.05. From the results of the mean, the top five factors (CI > 18) critical to

Table 6. Test Results of the Criticality of Factors

Factor category	Code	List of factors	Green (G)			Traditional (T)					
			Mean	Rank	$P(o)$	Mean	Rank	$P(o)$	Diff.	SD	$P(p)$
Project factors	P1	Procurement method	13.97	19	0.00	12.94	19	0.00	1.03	2.87	0.05
	P2	Construction method	17.91	6	0.00	17.53	1	0.00	0.38	2.92	0.47
	P3	Timely payments	11.00	25	0.03	10.78	26	0.00	0.22	1.95	0.53
	P4	Proportion of outsourced work	13.06	20	0.00	12.34	20	0.00	0.72	5.91	0.50
	P5	Reworks	15.44	13	0.00	15.63	7	0.00	−0.19	4.51	0.82
	P6	Building design	17.75	7	0.00	16.09	4	0.00	1.66	4.53	0.05
Manpower factors	MP1	Motivation of workers	11.94	24	0.00	12.28	21	0.00	−0.34	1.94	0.33
	MP2	Workers' skill level	18.31	4	0.00	16.03	5	0.00	2.28	4.17	0.00
	MP3	Absenteeism	10.91	26	0.04	10.81	25	0.00	0.10	1.96	0.79
	MP4	Labor turnover	12.22	23	0.00	11.56	24	0.00	0.66	3.02	0.23
	MP5	Workers' experience	19.78	1	0.00	17.34	2	0.00	2.44	4.46	0.00
	MP6	Difficulty in recruitment of workers	15.28	14	0.00	12.09	22	0.00	3.19	5.58	0.00
Management factors	MG1	Supervision of labor	15.00	16	0.00	13.22	18	0.00	1.78	4.14	0.02
	MG2	Planning and sequencing of work	18.19	5	0.00	16.19	3	0.00	2.00	4.13	0.01
	MG3	Competency of project manager	17.69	8	0.00	16.00	6	0.00	1.69	3.61	0.01
	MG4	Poor site layout	15.13	15	0.00	14.00	13	0.00	1.13	3.11	0.05
	MG5	Inspection delay	12.91	22	0.00	11.78	23	0.00	1.13	6.14	0.31
	MG6	Communication of information	15.00	16	0.00	13.84	15	0.00	1.16	3.92	0.11
	MG7	Poor instructions	14.94	18	0.00	14.00	13	0.00	0.94	3.69	0.16
Technical factors	T1	Materials availability	16.50	11	0.00	14.38	11	0.00	2.12	3.83	0.00
	T2	Tools and equipment	15.66	12	0.00	13.28	17	0.00	2.38	3.92	0.00
	T3	Design changes	18.72	3	0.00	15.59	8	0.00	3.13	4.56	0.00
	T4	Incomplete design	17.28	9	0.00	14.31	12	0.00	2.97	4.82	0.00
	T5	Technology	19.13	2	0.00	14.44	10	0.00	4.69	6.05	0.00
External factors	E1	Industry initiatives	16.94	10	0.00	15.53	9	0.00	1.41	4.46	0.08
	E2	Weather	13.00	21	0.00	13.47	16	0.00	−0.47	4.23	0.54

Note: The sample size of t-test is 32. The overall rank correlation between green and traditional is 0.89 with p-value of 0.00.

affecting the productivity of green building construction projects were workers' experience, technology, design changes, workers' skill level, and planning and sequencing of work. The five factors are discussed as follows.

The factor workers' experience was ranked first (CI = 19.78). The highest likelihood and impact of this factor contributed to the top ranking. The possible reasons for the high likelihood and impact were discussed previously. Moreover, the criticality of workers' experience was also demonstrated in Mojahed and Aghazadeh (2008) and El-Gohary and Aziz (2014) in which one of the top five factors critical to productivity was workers' experience. The view that workers' experience is critical to the productivity of green building projects could also because such projects are relatively new and experience is hard to come by.

Technology received the second position (IC = 19.13). The reasons for the high likelihood and impact of technology were discussed previously. Moreover, different forms of technology employed would differ depending on the type of work done and level of technology employed by contractors in completing a task. As the design and construction practices of green buildings being more complex due to high integrations and new green materials, new technologies have to be adopted and are critical for the productivity of green building projects.

Design changes was ranked third (CI = 18.72). The insufficient knowledge or technical expertise and unfamiliarity with the products, materials, system, or design actually cause certain obstacles for developers, clients, and contractors (Eisenberg et al. 2002), which would easily lead to design changes. Moreover, the high integration of green technologies and its impact on other building elements at the planning and design stage are very important. A failure to take into account the integration would result in construction conflicts and design changes. Design changes were identified as a cause for rework during the design or construction stages, both of which would cause the decrease of productivity (Kaming et al. 1997; Olomolaiye et al. 1987). In the light of this, building information modeling (BIM) was recommended to use in green building construction projects (Wu and Issa 2014). The criticality of design changes was also supported by Kaming et al. (1997) and Olomolaiye et al. (1987), with both indicating the importance of design changes.

Workers' skill level was ranked fourth (CI = 18.31). Burleson et al. (1998) indicated that the multiskilling of workers could improve an overall project productivity through the potential cost saving in labor, reduction in workforce and an average increase in employment duration. However, labor-related issues cannot be ignored currently. Lack of the technical skill regarding green technologies and techniques, workers' unaware of the correct methods and procedures, and the resistance to change from their traditional practices were indicated as three labor-related challenges in green building projects (Hwang and Ng 2013). Based on the acknowledgment of the criticality of workers' skill level, the productivity movements had been launched by the construction industry in Singapore, targeting the improvement in skills to improve productivity (BCA 2011). Under these movements, more training on green construction should be provided to the workers. The postsurvey interviewees also emphasized the incapability of the labor in Singapore. The cheap foreign labor just can handle small tasks and are always waiting for the instructions from supervisors, resulting in a low productivity.

Planning and sequencing of work was the fifth most critical factor (CI = 18.19). The lengthy planning and approval process for new green technologies and recycled material was pointed out as one of the main challenges faced in green building construction projects (Tagaza and Wilson 2004; Zhang et al. 2011). From this perspective, making a good planning and sequencing of work by a higher management can lead to improvements in productivity, which was also supported by Chan (2002) and Mojahed and Aghazadeh (2008). Moreover, Liu et al. (2011) also proved that productivity does improve when workflow is made more predictable. Furthermore, implementing green construction practices onsite needs more time because green technologies require complicated techniques and construction processes (Hwang and Tan 2012; Zhang et al. 2011). Therefore, more efforts are needed to integrate the green construction practices to the planning and sequencing of work for traditional projects. Otherwise, more resource would be allocated to keep a project on schedule, which would cause a low project productivity.

The overall rank correlation was 0.89 with the p-value less than 0.05. This result indicated that the factors affecting the productivity in green building construction projects have a strong positive correlation with the factors in traditional projects. However, from the results of the paired t-test, there were still 11 factors (almost half) that were considered to be significant as the p-values of these factors were below 0.05. As such, the null hypothesis for the 11 factors should be rejected, indicating that the differences in criticality between traditional and green building construction projects for these factors were statistically significant.

Overall, the mean values for green building construction projects generally tend to be higher than those for traditional projects in Tables 4–6. This can mean that most of the factors investigated in this study have higher likelihoods and impacts for green building projects than for traditional projects. It also possibly represents the respondents' perception about green building projects. Factors with a high difference in criticality, such as workers' skill level (Diff. = 2.28), workers' experience (Diff. = 2.44), difficulty in recruitment of workers (Diff. = 3.19), planning and sequencing of work (Diff. = 2.0), and all technical factors (Diff. ≥ 2.12), are actually what people think green building construction projects are more difficult than traditional ones.

Due to the quick rise of green building constructions, there is an increasing need for green skilled workers. The different perceptions of workers' skill level, workers' experience, and difficulty in recruitment of workers could be attributable to the shortage of skilled workers across the green building industry. Coupled with other factors and the increase in green construction projects, it has led to a shortage of green construction workers, with 86% of architectural and engineering firms and 90% of general construction firms facing difficulties in recruitment (McGraw Hill Construction 2012). The postsurvey interviewees also emphasized the similar situation and difficulties facing in Singapore.

As for technical factors, Lam et al. (2010) identified that green technologies, techniques, and materials were the most important and difficult factors for the implementation of green specifications in construction. Green materials usually require special orders and manufacturing, greatly affecting the construction productivity (Kibert 2008). However, the impact of technology on a traditional project productivity was not emphasized in previous studies. In light of the aforementioned, it can be inferred that technology has a great different impact on the productivity of traditional and green building construction projects. The designs for green buildings are more integrated, considering many aspects to ensure its environmental friendliness (BCA 2010). Interviewees from postsurvey agreed that a design had a greater emphasis on green construction than in traditional, resulting in the difference in criticality on productivity. In addition, green specifications and technologies have not been widely grasped by the majority of practitioners or contractors. Similarly, postsurvey interviewees stated that the difference between the tools used in green construction would result in the difference in productivity. In light of the aforementioned, factors with a high criticality and factors with a large mean difference should draw practitioners' attention. Meanwhile, these factors should be first considered when practitioners make specific adjustments to traditional project management practices and process in the construction of green buildings.

Conclusions and Recommendations

The construction of green buildings differs from that of traditional buildings in terms of the design, materials, and processes. To overcome the existing productivity related barriers, such as the high cost, cost overrun and project delayed, this study identified the critical factors affecting the productivity of green building construction projects by assessing the likelihood, impact, and criticality of the factors with comparisons against traditional projects. A total of 26 factors were identified from a comprehensive literature review and presented in a questionnaire. Afterward, a questionnaire survey was performed with 32 professionals in Singapore to assess the likelihood and impact of these factors. The results from this study first showed that workers' experience, technology, design changes, workers' skill level, and planning and sequencing of work were the top five factors greatly affecting the productivity of green building construction projects. In addition, the differences in criticality between traditional and green building construction projects of 11 factors were statistically significant. Furthermore, the differences in the criticality of the technical factors were remarkable.

As the first attempt to present critical factors affecting the productivity of green building construction projects, the empirical results of this study fill a gap in the project management body of knowledge for green buildings. Moreover, industry practitioners can improve the productivity of green building construction projects efficiently and effectively by focusing and acting on the factors with a high criticality and factors with a large mean difference. The results of this study can also help the practitioners make specific adjustments to traditional project management processes and practices achieving a more productive delivery of green buildings. For practitioners attempting to enter the green building industry, the findings of this study can also help them possess a prior practical knowledge of such factors and reduce productivity-related risks.

Although the objectives were achieved, some limitations still exist. First, the criticality index proposed in this study could be influenced by the experience and attitude of the respondents because it was subjective. Apart from this, cautions should be given when the analysis results are interpreted and generalized because the sample size was relatively small. Moreover, the findings from this study were well interpreted in the context of Singapore, which may be different from the contexts of other countries.

Nonetheless, this study still provides an in-depth understanding of factors greatly affecting the productivity of green building construction projects. Because Singapore has got a global reputation in promoting green construction, the implications of this study can also be helpful and useful to the practitioners in other countries. Future studies could consider and develop plausible solutions that can tackle the factors negatively affecting the productivity of green building construction projects. It is also recommended to establish productivity benchmarks and metrics for different types of green projects which will help practitioners to measure and improve their productivities and competitiveness in green construction.

Supplemental Data

Appendix S1 is available online in the ASCE Library (http://www.ascelibrary.org).

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