PAPERS

Green Building Construction Projects in Singapore: Cost Premiums and Cost Performance

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ABSTRACT

This study aims to investigate the cost premiums and cost performance of green building projects. After an extensive literature review, relevant data from 242 traditional and 121 green building projects performed by 30 different companies were collected through a survey in Singapore. The results indicate that the green cost premiums range from 5% to 10% and that project type and size are significant factors affecting the cost premiums. Furthermore, the cost performance is mostly over budget, ranging from 4.5% to 7%. Finally, this study proposes some feasible solutions for cost premiums reduction and cost performance improvement.

KEYWORDS: green building; cost premiums; cost performance; cost improvement

Project Management Journal, Vol. 48, No. 4, 67–79

Published online at www.pmi.org/PMJ

INTRODUCTION

Green buildings are becoming increasingly popular and more evident in countries, including the United States, Germany, the United Kingdom (Menassa, Mangasarian, El Asmar, & Kirar, 2012; Rosenow, Eyre, Bürger, & Rohde, 2013), and Singapore (Darko & Chan, 2016; Zhao, Hwang, & Gao, 2016). Moreover, Dodge Data and Analytics (2016) reported that the green expansion would continue in developed countries such as the United States, Germany, and the United Kingdom. Singapore is also in the midst of a robust increase in the level of green activities (Dodge Data & Analytics, 2016), driven by Green Building Masterplans and several green initiatives (Building and Construction Authority [BCA], 2014, 2016). The term '*green' building* refers to the use of environmentally friendly techniques and technologies in the design and construction of the built environment (Love, Niedzweicki, Bullen, & Edwards, 2012). According to the United Nations Environment Programme (UNEP, 2009), a 30% to 80% cut in energy consumption of buildings is attainable if the right green technologies are used. Additionally, the World Green Building Council (WorldGBC, 2014) reported that the design of an office building impacts the health, well-being, and productivity of its occupants. Therefore, green buildings also bring social and financial benefits to key stakeholders.

In spite of the benefits of green buildings and the various efforts being made to promote a sustainable built environment, key building stakeholders are still somewhat skeptical about the financial benefits that green buildings can deliver. Many industry professionals have the perception that the design and construction costs of green buildings are 10% to 20% higher than those of traditional buildings (WorldGBC, 2013). In light of this perception, the higher costs associated with "going green," which were termed *green cost premiums*, are the most common reason hindering the widespread development of green buildings (Dodge Data & Analytics, 2016; Robichaud & Anantatmula, 2011.

As a result, the objectives of this study are: (1) to investigate the cost premiums of green building projects and the significant reasons for them; (2) to compare the cost performance between green and traditional building projects; and (3) to examine plausible solutions that can improve the cost performance of green building projects, eventually cutting off their cost premiums. This study will contribute to the green building body of knowledge by adding to discussions of cost premiums and the cost performance of green building projects. Furthermore, the findings from this study can assist key building professionals in making better cost-related decisions right at the beginning of green building projects.

Background

Green Buildings and the Rationales

The green building revolution is sweeping across most of the world. The definition of *green building* varies from different construction perspectives. Generally, the goal of a green building is to take responsibility for achieving energy and resource efficiency, realizing long-term economic, environmental, and social health (Sahamir & Zakaria, 2013; Yoon & Lee, 2003; Zhao, Hwang, & Lee, 2016). The terms *green building* and *sustainable construction* are sometimes used interchangeably. However, the term *sustainable construction* is applied from the period of preconstruction to the disposal of the building and focuses on the ecological, social, and economic issues involved with a building (Kibert, 2008). From this perspective, green building is an integral part of the sustainable construction.

Green buildings have environmental, economic, and social benefits. Green buildings first benefit the environment. Globally, buildings are responsible for 40% of annual energy consumption, including 12% of all fresh-water use and produce up to 40% of our solid waste (UNEP, 2011). Moreover, buildings were responsible for about one-third of greenhouse gas (GHG) emissions in the world (WorldGBC, 2013). Therefore, the building sector could lead to a great and efficient reduction of GHG emission if appropriate green technologies, materials, and construction methods were used (Wu, Xia, Pienaar, & Zhao, 2014; Wu, Zia, & Zhao, 2014). Green buildings also bring economic benefits to the key stakeholders involved. Green buildings can bring about energy and water savings, which lower operating costs. Fowler and Rauch (2008) reported that some green buildings consumed 26% less energy and saved 13% of maintenance costs when compared to average commercial buildings. Carpenter (2009) showed that the average energy savings of six green building projects were up to 40%, and believed that the long-term energy savings could be higher if the first year operational issues were worked out.

Green buildings not only lead to energy savings but also provide the comfortable environment that can improve social benefits, including the increase in occupants' satisfaction, and positive impacts on occupants' health and productivity (Asdrubali et al., 2013). Singh, Syal, Grady, and Korkmaz (2010) and Thatcher and Milner (2014) investigated the effects of a green office building on the perceived health and productivity of occupants and identified that the green building significantly contributed to an increase in the self-reported productivity and physical well-being of employees. In addition, Barrett, Zhang, Moffat, and Kobbacy (2013) carried out a study on 751 students from 34 various classrooms in seven different schools in the United Kingdom. The results showed that the "best" and "worst" classrooms, defined by six significant built environment design parameters—color, choice, connection, complexity, flexibility, and light—were estimated to have a significantly different impact on a student's study progress. Because of these social benefits, green buildings have the additional potential to generate higher rent and sale prices. A study carried out in Hong Kong indicated that "green development" is one of the considerations when people purchase apartments. Additionally, end users are generally willing to pay more to purchase apartments with green features (Chan, Qian, & Lam, 2009).

Cost Premiums of Green Building Projects

The development of green buildings is often greatly discouraged by the perceived higher costs, commonly termed *green cost premiums*, compared with traditional non-green buildings, despite the fact that green buildings have economic, social, and environmental benefits (Dodge Data & Analytics, 2016). There is no standardized definition for green cost premiums and no clear methodology to describe the components and estimation methods of green cost premiums (Dwaikat & Ali, 2016; Houghton, Vittori, & Guenther, 2009). Kats (2010) defined green cost premiums as the differential cost between a green and traditional version of the same building. Houghton et al. (2009) defined green cost premiums as the additional design and construction costs associated with specific green components. In terms of the general costs of a typical building, which consist of capital costs, operation costs, as well as repair and maintenance costs (Hendrickson & Au, 1989), Furr and colleagues (2009) stated that the additional capital costs of green building features are commonly termed *green premium* by the industry. Moreover, Dodge Data and Analytics (2016) found that the higher costs, which were ranked as the top challenge to green building, were actually referred to additional capital costs because they were used to make comparisons with the decreased operating costs of green buildings. In light of the above review, this study defines green cost premiums as the additional capital costs of green building features.

Design and construction costs are perceived as contributing to the green cost premiums. Green building projects generally have more complex designs as compared with traditional building projects (Johnson, 2000). In order to achieve sustainability, green building projects generally require the use of special specifications, materials, construction methods, and building practices (Lam, Chan, Poon, Chau, & Chun, 2010; Robichaud & Anantatmula, 2011). Moreover, the productivity of the design and construction of green building projects is currently lower than that of traditional projects because practitioners still need time to learn and become proficient in these technologies. Furthermore, unfamiliarity with green technologies and technical difficulties during the construction process can not only affect the project schedule, but can also lead to cost increases through rework (Hwang, Thomas, Haas, & Caldas, 2009; Hwang, Zhao, & Tan, 2015; Tagaza & Wilson, 2004).

Properly facing this barrier, some countries, such as the United States, United Kingdom, and Australia, investigated high green cost premiums (Dwaikat & Ali, 2016). Kats (2010) conducted a large-scale study based on extensive financial and technical analyses of more than 150 green buildings in the United States and 10 other countries. The results of the study showed that green buildings cost roughly 2% more to build than traditional buildings. Moreover, Kim, Green, and Kim (2014) concluded that the green cost premiums for residential project development in Los Angeles were 10.77%. In addition, Houghton et al. (2009) found that the green cost premiums for healthcare buildings in the United States ranged from 0% to 5% without any financial incentives. In the United Kingdom, Building Research Establishment (BRE) and Cyril Sweett (2005) asserted that the green cost premium ranged from 0% to 7%. In Australia, Davis Langdon (2007) reported that the impact on the construction cost ranged from 3% to 5% for a five-star rating, and more than 5% for six-star, non-iconic design solutions. Dodge Data and Analytics (2016) also conducted a study on the challenges of green buildings and identified that higher perceived first costs were one of the top three challenges in nearly all of the 13 surveyed countries. This challenge was selected by over 50% of the respondents only in the United States (70%), Mexico (54%), Colombia (67%), Germany (52%), the United Kingdom (52%), and China (60%).

The building industry of Singapore recognizes the importance of sustainable construction to create a high-quality living environment for all. The Building and Construction Authority of Singapore (BCA) has launched three editions of its Green Building Masterplan from 2006 to aid in the greening of Singapore's current and future buildings (Building and Construction Authority [BCA], 2009, 2014). Singapore is now in the midst of a robust increase in the level of green activity (Dodge Data & Analytics, 2016) and plans to green at least 80% of buildings by 2030 (Building and Construction Authority [BCA], 2014). Particular attention should be paid to the fact that, given the influence of the mandate in the Singapore Green Plan 2012, environmental regulations are clearly the driving force for green adoption (Dodge Data & Analytics, 2016). On the other hand, the high premium cost associated with green building construction, the lack of expressed interest from clients or market demand, and the costly green building practices were identified as significant obstacles encountered in Singapore (Hwang & Tan, 2012). Furthermore, higher up-front costs were recognized as the top obstacle to green development in Singapore (Chan et al., 2009; Hwang & Tan, 2012).

However, compared with other leading countries, Singapore lacks knowledge and data on green cost premiums. Furthermore, there is limited research on green cost premiums and cost performance in Singapore. Wong, Tay, Wong, Ong, and Sia (2003) examined the initial cost implication of having a green roof in Singapore and identified that the initial costs were 82%, 36%, and 50% higher for an inaccessible extensive green roof, an accessible intensive roof with shrubs, and an accessible intensive green roof with trees, respectively, than those for counterpart conventional roofs. Deng and Wu (2014) investigated the economic returns of residential green building investment in Singapore from developers' perspectives to clear public doubt regarding the financial viability of investments in energy efficiency. An investment in energy-efficient real estate development can only be financially sustainable if the additional selling price of a green building, termed *green price premiums*, is large enough compared to the green cost premiums. The results of this study showed that the developers claimed 4% market premium of green mark-rated units at the presale stage to cover the additional costs of energy efficiency during construction. Goh (2016) investigated the whole-life costs of nonresidential green-rated building developments in Singapore to propose a whole-life building cost index. The limitation of the study was that the formulation of the proposed index lacked data support.

Cost Performance of Green Building Projects

Cost overrun is another hindrance in green building projects. Because green buildings use more technologies and material with less environmental impact, they are more complicated than traditional buildings. Moreover, many requirements to achieve a green certificate and shareholders' unfamiliarity with the requirements and technologies tend to lead to cost overruns, project delays, and productivity losses (CII, 2008; Nalewaik & Venters, 2010). Hwang and Leong's (2013) empirical study in the context of Singapore also found that about 32% of green building projects were completed behind schedule, while 16% of the traditional building projects were delayed.

Cost performance indicates how well costs are kept under control, in other words, over budget or under budget. Cost overrun is generally a symptom of poor management. Thus, many researchers start to pay great attention to the research on cost overrun assessment (Chandramohan, Narayanan, Gaurav, & Krishna, 2012), identification of important factors affecting cost performance (Son, Lee, & Kim, 2015), and comparison of the impact of pre-project planning between green and traditional building on cost performance (Kang, Kim, Son, Lee, & Limsawasd, 2013). In addition, considering the unique characteristics of green buildings and green construction, Robichaud and Anantatmula (2011) tried to improve the chances of delivering the project within acceptable costs by suggesting some construction management adjustments to traditional project management practices. However, there is generally still a lack of studies that investigate the actual cost performance of green building projects.

A few studies have been conducted on the cost performance of traditional building projects as compared with green building projects. Two indicators commonly used for measuring the general project cost performance by the construction industry institute (CII) (Thomas, Macken, Chung, & Kim, 2002) are project cost growth and project budget factor. The formulas for the two indicators are shown in Equation 1 and Equation 2.

$$\text{Project Cost Growth} = \frac{\text{Actual Total Project Cost} - \text{Initial Predicted Project Cost}}{\text{Initial Predicted Project Cost}} \quad \text{(Equation 1)}$$

$$\text{Project Budget Factor} = \frac{\text{Actual Total Project Cost}}{\text{Initial Predicted Project Cost} + \text{Approved Changes}} \quad \text{(Equation 2)}$$

Using these two indicators, Thomas et al. (2002) conducted a survey on 617 U.S. domestic and international traditional construction projects to investigate the impacts of two delivery systems—design-build (DB) and design-bid-build (DBB)—on project cost performance. The results showed that the project cost growths for DB and DBB projects were −0.041 and −0.030, respectively, from the owners' perspective; the project cost growths for DB and DBB projects were 0.038 and 0.056, respectively, from the contractors' perspective. The results indicated that the cost performance of the U.S. traditional construction projects was below or slightly above budget. The project budget factor for DB and DBB projects were 0.966 and 0.948, respectively, from the contractors' perspective, indicating that the changes generally contributed to a 3% to 5% cost increase. Shrestha, Burns, and Shields (2013) also conducted a survey to investigate the magnitude of construction cost and schedule overrun in public projects in the United States. The results showed that the mean construction cost and schedule overrun for the 363 sample projects were 2.95% and 1.54%, respectively.

In addition, Xiao and Proverbs (2002) compared the levels of contractor cost performance in three countries: Japan, the United Kingdom, and the United States. The survey results showed that the estimated percentage of total budget overrun against the original contract price was 5%. The percentages of budget overrun for Japan, the United Kingdom, and the United States were 3.63%, 5.89%, and 5.05%, respectively. The total number of design variations, which have been identified as one of the major contributing factors for budget overruns, was 54.55. Using project cost growth, Chen, Zhang, and Zhang (2014) investigated the impacts of different types of owner–contractor conflict on cost performance in Chinese construction projects. In light of the above, this study used the project cost growth to investigate the cost performance of green building projects in Singapore. This study did not use the project budget factor because valuing changes/variations is, practically speaking, very challenging for respondents.

Methodology and Data Presentation

The questionnaire survey technique was adopted in this study because it is a systematic method of collecting data and has been widely used to collect professional views in sustainable construction research (Hwang, Zhu, & Ming, 2017; Wu & Low, 2012). This study first carried out an extensive literature review from multiple sources, such as government websites, reports from private institutions, and journal papers, to provide a better understanding of the current market situation of green building and the issues relating to cost premiums and cost performance of green building construction projects. Then a survey questionnaire was subsequently developed (1) to capture the current perceptions of professionals on cost premiums and cost performance of green building projects, (2) to identify the significant reasons for cost premiums, and (3) to gauge the effectiveness of proposed solutions to reduce green cost premiums and improve cost performance. The collected data were analyzed by the Statistic Package for Social Science (SPSS) statistical software.

The questionnaire first provided a definition of green cost premiums, which was the premise of the survey. Subsequently, the questionnaire included questions meant to profile the companies and respondents. Furthermore, the respondents were asked to indicate the cost premiums of green building projects by different project types and sizes. They were also asked to rate the significance of the reasons for the difference in the cost premiums between green and traditional building projects by using a five-point scale (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly agree). Afterward, the number of traditional and green building projects with different cost performance values was indicated. Finally, the effectiveness of the solutions to reduce the cost premiums of green buildings and improve their cost performance was rated by using the five-point scale (1 = least efficient, 2 = somewhat efficient, 3 = neutral, 4 = efficient, and 5 = most efficient). In addition, post-survey interviews were carried out with two green building professionals who had more than three years of experience in the green building industry, especially in green building costs management, to validate the findings from the survey.

The population of this study consisted of all the professionals who were past award winners of the BCA Green Mark certificate, members of the Singapore Institute of Surveyors and Valuers (SISV), as well as the BCA directory of registered contractors and licensed builders with more than three years of experience in the green building industry and who specialized in green building cost performance. The survey questionnaires were randomly sent out to the professionals via email. Thirty responses were received. Although the sample size was relatively small, statistical analysis could still be performed because the central limit theorem holds true when the sample size is no less than 30, which is a generally accepted rule (Ott & Longnecker, 2010). The profiles of the respondents, companies, and projects are provided in Table 1.

The respondents consisted of project managers, quantity surveyors, and contractors. Most of the respondents (70%) had at least two years' experience in green building construction. Because the duration of a normal building project is around two years in Singapore, the years of working indicated that the respondents could have reliable cost assessments and objective judgment, implying that the collected cost-related information is reliable. The percentages of respondents from architecture, quantity surveying, and contractor firms are 7%, 17%, and 76%, respectively.

A total of 242 and 121 traditional and green building projects were recorded from the survey, respectively. The percentages of the three types of projects (office, commercial, and residential) in traditional and green building project are generally comparable. The number of office building projects recorded from the survey is notably smaller than the numbers of commercial and residential building projects.

Classification			Number	Percentage (%)
Respondents	Job title	Project manager	8	27
		Quantity surveyor	5	17
		Contractor	17	56
	Years of experience of respondents in green building construction	Less than 1	9	30
		1 to less than 2	0	0
		2 to less than 3	5	17
		3 to less than 4	6	20
		4 and above	10	33
Type of company	Architecture		2	7
	Quantity surveying		5	17
	Contractor		23	76
Projects	Traditional	Commercial	124	51
		Offices	20	8
		Residential	98	41
	Green	Commercial	57	47
		Offices	10	8
		Residential	54	45

Table 1: Profiles of respondents, companies, and projects.

Analysis Results and Discussions

Overall Perceptions on Green Cost Premiums

The overall perceptions of the survey respondents regarding cost premiums for green buildings are summarized in Figure 1.

A total of 43% of the respondents perceived green cost premiums to be 5% ~ 10%, followed by 34% and 23% of the respondents who perceived green

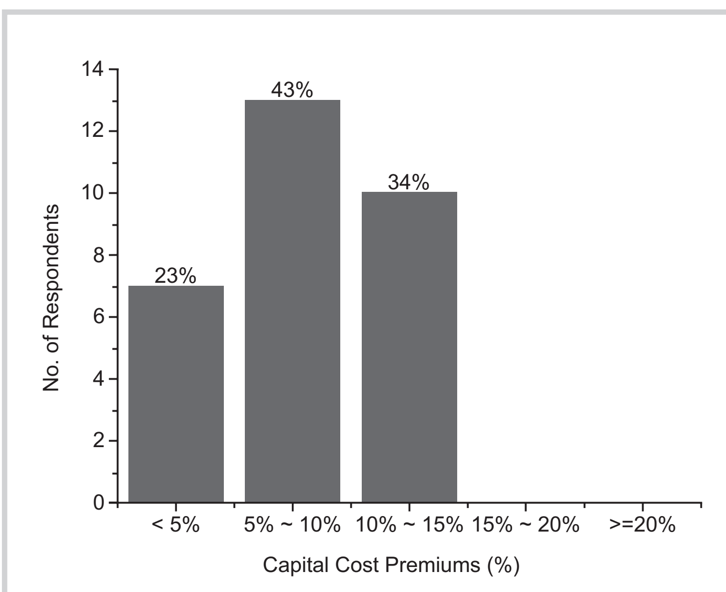

Figure 1: Overall perception on green cost premiums.

Project Size (S$ · million)	Capital Cost Premiums (CCP)	Number of Green Commercial	Number of Green Offices	Number of Green Residential
Less than 5 (small)	0% = < CCP < 5%	1	2	0
	5% = < CCP < 10%	9	1	1
	10% = < CCP < 15%	0	0	4
	15% = < CCP < 20%	0	0	0
	20% = < CCP	0	0	0
5 to 50 (medium)	0% = < CCP < 5%	12	0	0
	5% = < CCP < 10%	9	4	2
	10% = < CCP < 15%	9	0	3
	15% = < CCP < 20%	2	0	2
	20% = < CCP	0	0	0
50 and above (large)	0% = < CCP < 5%	11	3	32
	5% = < CCP < 10%	4	0	5
	10% = < CCP < 15%	0	0	5
	15% = < CCP < 20%	0	0	0
	20% = < CCP	0	0	0

Table 2: Cost premiums of green building projects by project type and size.

cost premiums to be 10% ~ 15% and 0% ~ 5%, respectively. None of the respondents perceived green cost premiums to be above 15%. This result was in line with the argument made by Houghton et al. (2009) that green cost premiums were getting lower as a result of decreasing capital cost over time. Furthermore, according to a report from WorldGBC (2013), building professionals—both with experience and without any experience in green projects—tended to perceive green cost premiums to be up to 13% and 18%, respectively, which was not significantly different from the analysis results of this study.

Actual Cost Premiums of Green Building Projects

The cost premiums for green projects by project size (i.e., less than S$5 million, S$5 million to less than S$50 million, S$50 million and above) and type (i.e., green commercial, office, and residential buildings) are summarized in Table 2.

This result was derived from the respondents' inputs, which were based on green building projects in which they had been involved. As shown in Table 2, there were indeed cost premiums for going green, generally ranging from 0% to less than 15%, regardless of the project type and size. This result was consistent with the overall perception on the green cost premiums presented in the previous section.

Actual Cost Premiums by Project Type

To obtain the mean cost premiums by project size and type, the mid-values of the four ranges of the premiums, in other words, 2.5%, 7.5%, 12.5%, and 17.5%, were used in this study. The mean cost premiums of green building projects by project size and type are shown in Table 3.

The overall mean of green cost premiums ranged from 2.5% to 12.5%. This result was comparable with the conclusion drawn by Kansal and Kadambari (2010) that the initial costs of a green building were 7.5% more than those of the ordinary building. Additionally, it is obvious that green residential has the highest cost premiums, followed by green commercial and green offices for three different size classifications. The mean for the residential green building was very close to the result found by Kim et al. (2014) that green residential building costs were 10.77% more than those of the traditional residential buildings. The relatively higher cost premiums for green residential projects could be a result of the respondents' lack of green expertise in green residential as compared with green commercial and office building

	Mean of Green Cost Premiums		
Project Size (S$ · million)	Commercial	Office	Residential
Less than 5 (small)	7.0%	4.2%	11.5%
5 to 50 (medium)	7.7%	7.5%	12.5%
50 and above (large)	3.8%	2.5%	4.3%

Table 3: Mean cost premiums of green building projects by project size and type.

projects. Respondents without sufficient green building expertise in residential projects would have difficulty in complying with the green specifications, leading to delays and increased costs (Architecture Week, 2001).

Although the BCA Green Mark for Office Interiors had been launched recently, in 2009, the learning curve for green offices were relatively steep, resulting in the lowest green cost premiums (Nalewaik & Venters, 2010). The opinion from post-survey interviews revealed that it may be much easier to comply with green specifications for green office projects. Another reason could be a result of the relatively small data set for green office building projects recorded from the survey responses.

A one-way analysis of the variation (ANOVA) test was performed to test whether the project type has a significant effect on green cost premiums. The null hypothesis H_0 is that there is no statistically significant difference in the cost premiums by project type; the alternative hypothesis H_1 is that there is a statistically significant difference in the cost premiums by project type. Because the one-way ANOVA test does not show which specific building types significantly differ, the Tukey post hoc (TPH) test was subsequently performed to further analyze the difference. Table 4 summarizes the results.

The p-values from the ANOVA test for projects under S$50 million were smaller than 0.05, indicating that the hypothesis H_0 should be rejected at a 95% confidence level. This result implied that the building type had a significant effect on the mean of green cost premiums when the project size was small or medium. When the project size was large, the building type did not have a statistically significant effect on the mean of green cost premiums.

According to the results from the TPH test, the means of the cost premiums were statistically different between commercial and residential building projects, and between office and residential building projects when the project size was small. As for medium-sized projects, only commercial and residential building projects had statistically different cost premiums.

Project Size (S$ · million)	p-value (ANOVA)	p-value (Tukey Post Hoc)	
Less than 5 (small)	0.000	C vs R	0.002
		R vs O	0.000
		C vs O	0.110
5 to 50 (medium)	0.045	C vs R	0.038
		R vs O	0.197
		C vs O	0.998
50 and above (large)	0.601	No difference	
Note: C, O, and R denote commercial, office, and residential building, respectively.			

Table 4: ANOVA and TPH results by project type.

Actual Cost Premiums by Project Size

From the perspective of project size, large-scale projects have the lowest means of green cost premiums for all three building types, followed by small- and medium-scale projects, as shown in Table 3. One possible explanation for this result is that respondents involved in large-scale projects were mainly professionals with a good deal of experience in green building projects. Professionals who have sufficient green building experience are able to efficiently utilize green products without increasing overall design and construction costs (Malin, 2000). Additionally, the cost of green buildings might not increase if the right strategies were used (Bordass, 2000). Respondents with sufficient experience in green building were more likely to adopt the right strategies, lowering green cost premiums accordingly. Another reason derived from the post-survey interviews was due to the economies of scale for green features, products, and materials.

A one-way ANOVA test was performed to test whether the project size has a significant effect on green cost premiums. The null hypothesis H_0 is that there is no statistically significant difference in the cost premiums by project size; the alternative hypothesis H_1 is that there is a statistically significant difference in the cost premiums by project size.

The results generated from the ANOVA and TPH tests are shown in Table 5. The p-values from the ANOVA test for three building types were all smaller than 0.05, indicating that the hypothesis H_0 should be rejected at a 95% confidence level. This result implied that the project size had a

Project Type	p-value (ANOVA)	p-value (Tukey Post Hoc)	
Commercial projects	0.010	Small vs. medium	0.888
		Medium vs. large	0.008
		Small vs. large	0.124
Office projects	0.010	Small vs. medium	0.059
		Medium vs. large	0.009
		Small vs. large	0.428
Residential projects	0.000	Small vs. medium	0.875
		Medium vs. large	0.000
		Small vs. large	0.000

Table 5: ANOVA and TPH results by project size.

significant effect on the mean of green cost premiums regardless of the building type.

Further analysis based on the p-value from the TPH test indicated that green cost premiums were statistically different for medium- and large-scale projects in all three building types, whereas cost premiums were statistically different for small- and large-scale projects only in residential projects.

Reasons for Different Cost Premiums Between Green and Traditional Building Projects

The one-sample t-test was performed to determine whether each of the reasons had a significant effect on the difference in cost premiums between green and traditional building projects. Because a five-point scale was used, the test value was 3, which is the middle value of the scale. Table 6 summarizes the test results as well as the ranking of the reasons.

With the analysis result, it can be concluded that R1, R5, and R6 had the statistically different means from the test value of three because the p-values of these reasons were all below 0.05. Because the mean of R5 (3.70) was much greater than 3, R5 had a statistically significant effect on the difference; however, because the means of R1 and R6 were much lower than 3, the effects of R1 and R6 could not be considered significant. Although the p-values of R2, R3, R4, and R7 were greater than 0.05, their mean values were all greater than the test value of 3, implying that these could be relevant reasons for explaining the difference as well.

The analysis results suggested that the "high cost of green technologies and materials" was the top reason for the difference in cost premiums between green and traditional building projects. As the design and construction practices of green buildings grow more complex, green technologies and materials not only greatly affect the capital cost, but also affect project productivity (Hwang et al., 2017; Lam et al., 2010). Moreover, green materials usually have higher production costs because these materials lack the economies of scale and also require special orders and manufacturing (Kibert, 2008; Malin, 2000). All the interviewees who participated in the post-survey interview also agreed with this result.

"High research and development costs for green building products and systems" was ranked second, further contributing to the difference in the cost premium. New green products and systems usually require more efforts in testing and code approvals, which leads to an increase in research and development costs (Malin, 2000). "Lack of required green expertise and information," which ranked third, could also lead to an unnecessary increase in cost premiums because the key building players are unable to utilize green products efficiently (Malin, 2000). Additionally, without sufficient green building expertise, key building players most probably encounter reworks and changes because they have difficulty in complying with the green standards, leading to an increase in the capital cost for green building projects (Architecture Week, 2001).

"Lack of government incentives/subsidies for green building projects" is not a significant reason. This finding coincides with the results from Hwang and Tan (2012) in which the lack of government support (e.g., incentives) is not an obstacle encountered in Singapore green building projects. This is most probably because of the extensive efforts made by the government to support the building industry in Singapore. "Higher consultant and designer fees" was not rated as a significant reason, perhaps because it is not the root cause or a direct reason. Another possible reason may be that getting specialized consultants and designers is not difficult and the cost is not very high (Architecture Week, 2001).

Comparison of Cost Performance Between Traditional and Green Building Projects

Table 7 summarizes the cost performances of traditional and green building projects by project type.

The negative and positive percentages indicate an "under budget" and "over budget" cost performance of projects, respectively. Using the mid-values of the four ranges of the performance, in other words, −7.5%, −2.5%, 2.5%, and 7.5%, the mean cost growth of the traditional and green building projects by project type were calculated and are depicted in Figure 2.

SN	Reasons	p-value	Mean	Rank
R1	Higher consultant and designer fees	0.022	2.60	6
R2	Lack of required green expertise and information	0.315	3.10	3
R3	Difficulty in getting green services from contractors and subcontractors	0.5000	3.00	5
R4	Difficulty in getting green resources, e.g., materials, technologies, etc.	0.444	3.03	4
R5	High cost of green technologies and materials	0.000	3.70	1
R6	Lack of government incentives/subsidies for green building projects	0.034	2.57	7
R7	Higher research and development costs for green building products, systems, technologies, etc.	0.221	3.13	2

Table 6: Ranking of the reasons for the difference in cost premiums.

Cost Growth (CG)	Numbers of Commercial Projects		Number of Office Projects		Number of Residential Projects	
	Traditional	Green	Traditional	Green	Traditional	Green
$-10\% <= CG < -5\%$	10	0	7	0	30	0
$-5\% <= CG < 0\%$	60	6	4	0	42	0
$0\% <= CG < 5\%$	54	22	7	1	21	32
$5\% <= CG < 10\%$	0	29	2	9	5	22
Total	124	57	20	10	98	54

Table 7: Cost performances of traditional and green building projects.

As can be seen in Figure 2, traditional projects had negative mean cost growth. In contrast, green projects had positive mean cost growth for all three types of projects. This result meant that green projects generally had a cost overrun, whereas traditional projects were generally under budget. The cost overrun of green building projects first could be a result of the key building players' unfamiliarity and insufficient expertise in green building projects compared with traditional projects. Another possible reason for the cost overrun of green building projects was that they were more likely to be delayed than traditional projects. Hwang and Leong (2013) found that 33.33% of green projects encountered a delay, as opposed to only 17.39% for traditional projects. Furthermore, green office projects had the highest mean cost overrun among the three types of projects. One possible reason was that the respondents were unfamiliar with green office projects, which could be inferred from the small data set for such projects.

In order to statistically identify the equality in cost growth between green and traditional projects, the independent sample t-test for mean and Levene's test for variance were carried out. The results are summarized in Table 8.

The means of cost growth between green and traditional projects in all three types of projects were statistically different because all p-values under t-test were lower than 0.05. Moreover, the variances of cost growth between green and traditional projects in office and residential types of projects were

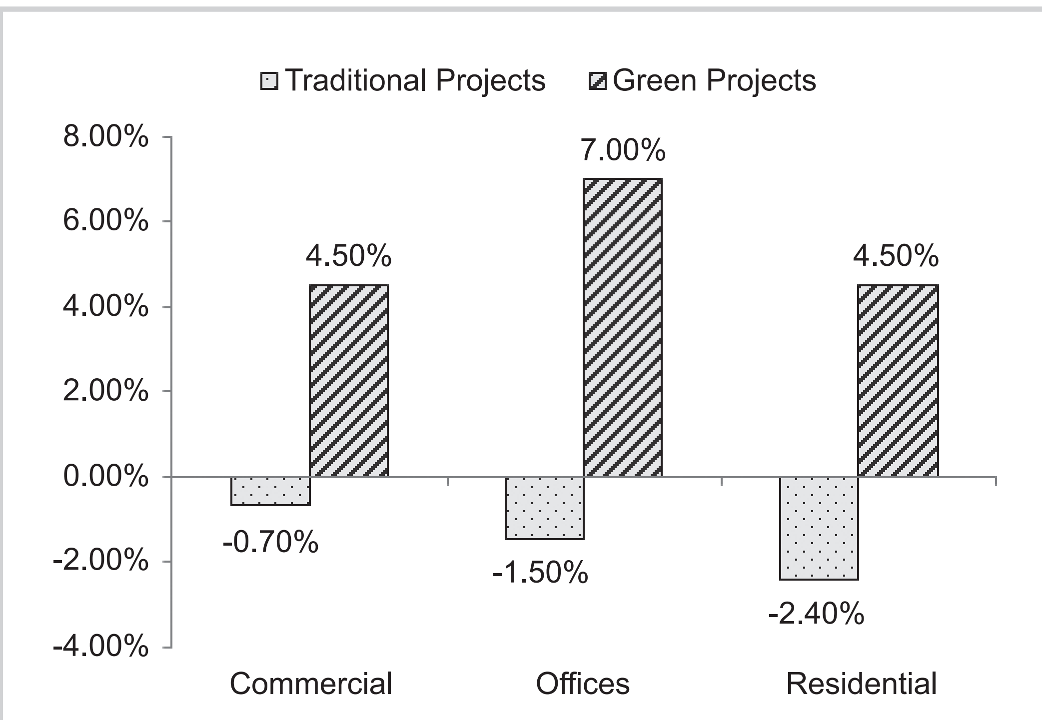

Figure 2: Comparison of the mean cost growth for traditional and green projects.

Project Types	p-value	
	Levene's test (Variance)	T-test (Mean)
Commercial	0.315	0.000
Office	0.000	0.000
Residential	0.071	0.000

Table 8: Test results for cost growth.

statistically different. Overall, it could be concluded that cost performance between green and traditional building projects was statistically different. One reason for the difference could be that the management of the green building construction was challenging as a result of the complexity of green technologies and requirements.

The findings of this study should alert the green construction industry to pay further attention to cost management. Green practitioners should adopt proper strategies, tools, or techniques to manage the cost performance of green building projects from the perspectives of time and cost.

Solutions for Cost Premiums Reduction and Cost Performance Improvement

The one-sample t-test was performed to determine the effectiveness of solutions for reducing cost premiums and improving the cost performance of green building projects. Because a five-point scale was used, the test value is three. The ranking of the solutions is shown in Table 9.

According to the test results, the mean values for the solutions S1 (3.7), S5 (3.83), S6 (3.80), and S8 (3.47) were statistically greater than the test values of three because all p-values were below 0.05. Moreover, all solutions except S2 and S3 could be considered relevant for reducing cost premiums and improving the cost performance of green building projects because their mean values were statistically equal to or greater than the test value.

"Tax relief," which was ranked as the most powerful solution, is a more flexible and feasible solution. It can be given to both businesses and individuals who make the effort to use green products and systems (Bourgeois, Breaux, Chiasson, & Mauldin, 2010). This was confirmed by the post-survey interview for this study. The interviewees agreed that tax relief was a specific solution that can directly benefit shareholders.

"Availability of skilled and experienced project team" was ranked second, which is consistent with Jiang's (2010) study. Green building projects generally have a more complex design as compared with traditional building projects (Hwang et al., 2017; Johnson, 2000). With a skilled and experienced project team, both lower cost premiums and better cost performance can actually be achieved because the right green design features and materials can be correctly and efficiently adopted during the design and construction period (Hydes & Creech, 2000; Malin, 2000). Furthermore, if a project team has sufficient green building expertise, the cost performance of green buildings can be much improved because costs caused by unnecessary rework and changes can be avoided (Architecture Week, 2001).

"Incentives/subsidies for green building projects" and "subsidies for green building professional and specialist courses from the government" were ranked third and fourth, respectively. From a practical standpoint, incentives from the government are extremely important for attracting and motivating hesitant building professionals to build green (Popovec, 2006), which could enlarge the green market. Additionally, a good education on green products and systems can increase the productivity and improve the learning curve of using these products. Both cost premiums reduction and cost performance improvement could be achieved if the building players were more familiar with green products and

SN	Solutions to Reduce Cost Premiums	p-value	Mean	Rank
S1	Government to provide incentives/subsidies for green building projects	0.000	3.70	3
S2	Low-interest loans	0.242	2.83	7
S3	Financial institutions to introduce lending schemes customized for green building projects	0.173	2.77	8
S4	Government to provide subsidies for research and development of green building products, systems, and technologies	0.109	3.33	5
S5	Tax relief for developers and contractors for use of green building products, systems, and technologies	0.000	3.83	1
S6	Availability of skilled and experienced project team and contractors	0.000	3.80	2
S7	Government to provide green building educational courses for key building players so as to flatten the learning curve of green construction	0.116	3.30	6
S8	Government to provide subsidies for green building professional and specialist courses	0.038	3.47	4

Table 9: Ranking of the solutions to reduce cost premiums of green buildings.

systems (Nalewaik & Venters, 2010). The results also coincide with the view from Ong (2013), who pointed out that green courses and educational programs can be funded by the government.

Conclusions and Recommendations

Green buildings are becoming increasingly popular in Singapore; however, despite the benefits of green buildings and various efforts being made to promote a sustainable built environment, the delivery of green buildings is still hindered by the higher cost associated with "going green." As a result, this study aimed to investigate the current cost premiums of green building projects and identify the significant reasons for these cost premiums. In addition, the cost performance of green and traditional building projects was compared, and finally, some plausible solutions that can reduce cost premiums and improve the cost performance were proposed.

The first finding from this study was that the majority of the respondents perceived green cost premiums to be 5% ~ 10%, with green residential buildings having the highest cost premiums, followed by green commercial and green office buildings. Furthermore, it was proven that "project type" and "project size" were statistically significant variables that affected cost premiums. This study also identified that "high cost of green technologies and materials," "higher research and development costs for green building products, systems, technologies, etc.," and "lack of required green expertise and information" were the top three reasons for the cost premiums of green building projects. As for current cost performance, it was concluded that green building projects were generally over budget (4.5% ~ 7%), which was worse than traditional building projects. Finally, "tax relief" was identified as the most efficient solution that could have a significant impact on reducing cost premiums and improving the cost performance of green building projects.

Although the main objectives of this study were achieved, there are some limitations. First, caution should be given when the analysis results are interpreted and generalized because the sample size was relatively small. Particularly, the data for green office building projects were relatively small and thus might not fully represent the specific project type. Second, the data were mainly about the perceptions of the respondents rather than the exact cost figures as a result of some confidentiality issues. The subjective evaluation could be influenced by the experience and attitude of the respondents. Lastly, 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 the cost premium and control solutions in green building projects for both practitioners and researchers. Key building professionals can make better cost-related decisions right at the beginning of green projects, based on the findings from this study. In addition, although the findings appear to be geographically specific to green buildings in Singapore, they would not be limited to the context of Singapore, as Singapore has been globally recognized as one of the leading countries advocating sustainability of the built environment through green buildings. From this perspective, the findings from this study will have important implications to the existing body of knowledge as well as to the global construction industry.

Further studies can investigate green building projects performed in other countries in the sense of cost premiums and cost performance, and provide the results from comparisons of projects. In addition, because this study was focused on new green building projects, other kinds of green building projects, such as green retrofit or maintenance projects, can be studied further. It would be also interesting to examine other types of green building projects, such as schools and hospitals.

References

Architecture Week. (2001). *Barriers to building green.* Retrieved from http://www.architectureweek.com/2001/0822/environment_1-2.html

Asdrubali, F., Buratti, C., Cotana, F., Baldinelli, G., Goretti, M., Moretti, E., Baldassarri, C., Belloni, E., Bianchi, F., Rotili, A., Vergoni, M., Palladino, D., & Bevilacqua, D. (2013). Evaluation of green buildings' overall performance through in situ monitoring and simulations. *Energies, 6*(12), 6525–6547.

Barrett, P., Zhang, Y., Moffat, J., & Kobbacy, K. (2013). A holistic, multi-level analysis identifying the impact of classroom design on pupils' learning. *Building and Environment*, *59*, 678–689.

Bordass, B. (2000). Cost and value: Fact and fiction. *Building Research and Information*, *28*(5–6), 338–352.

Bourgeois, M., Breaux, K., Chiasson, M., & Mauldin, S. (2010). Tax incentives of going green. *The CPA Journal, 80*(11), 19.

Building and Construction Authority (BCA). (2009). *2nd green building masterplan.* Retrieved from http://www.bca.gov.sg/greenMark/others/gbmp2.pdf

Building and Construction Authority (BCA). (2014). *3rd green building masterplan*. Retrieved from http://www.bca.gov.sg/GreenMark/others/3rd_Green_Building_Masterplan.pdf

Building and Construction Authority (BCA). (2016). *Green mark manager/green mark professional/green mark facilities manager/green mark facilities professional*. Retrieved from https://www.bca.gov.sg/GreenMark/gm_manager.html

Building Research Establishment (BRE), & Cyril Sweett (2005). *Putting a price on sustainability*. Bracknell, England: BRE Electronic Publications.

Carpenter, S. (2009). Do green buildings really save energy? *Building*, *59*(2), 22.

Chan, E. H. W., Qian, Q. K., & Lam, P. T. I. (2009). The market for green building in developed Asian cities: The perspectives of building designers. *Energy Policy, 37*(8), 3061–3070.

Chandramohan, A., Narayanan, S. L., Gaurav, A., & Krishna, N. (2012). Cost and time overrun analysis for green construction projects. *International Journal of Green Economics, 6*(2), 167–177.

Chen, Y. Q., Zhang, Y. B., & Zhang, S. J. (2014). Impacts of different types of owner-contractor conflict on cost performance in construction projects. *Journal of Construction Engineering and Management, 140*(6).

Construction Industry Institute (CII). (2008). *Sustainable design and construction in industrial construction*. Austin, TX: Construction Industry Institute (CII).

Darko, A., & Chan, A. P. C. (2016). Critical analysis of green building research trend in construction journals. *Habitat International, 57,* 53–63.

Davis Langdon. (2007). *The cost and benefit of achieving green buildings.* Davis Langdon Management Consulting, Australia.

Deng, Y., & Wu, J. (2014). Economic returns to residential green building investment: The developers' perspective. *Regional Science and Urban Economics, 47*(1), 35–44.

Dodge Data & Analytics. (2016). World green building trends: Developing markets accelerate global green growth. SmartMarket report. *Design and Construction Intelligence*.

Dwaikat, L. N., & Ali, K. N. (2016). Green buildings cost premium: A review of empirical evidence. *Energy and Buildings, 110*, 396–403.

Fowler, K. M., & Rauch, E. M. (2008). *Assessing green building performance: A post occupancy evaluation of 12 GSA buildings.* Pacific Northwest National Laboratory Report number PNNL-17393.

Furr, J. E., Kilbert, N. C., Mayer, J. T., & Sentman, S. D. (2009). *Green building and sustainable development: The practical legal guide*. Chicago, IL: American Bar Association, Section of Real Property and Trust and Estate Law.

Goh, B. H. (2016). Designing a whole-life building cost index in Singapore. *Built Environment Project and Asset Management, 6*(2), 159–173.

Hendrickson, C., & Au, T. (1989). *Project management for construction: Fundamental concepts for owners, engineers, architects, and builders*. New York, NY: Prentice-Hall.

Houghton, A., Vittori, G., & Guenther, R. (2009). Demystifying first-cost green building premiums in healthcare. *HERD, 2*(4), 10–45.

Hwang, B. G., & Leong, L. P. (2013). Comparison of schedule delay and causal factors between traditional and green construction projects. *Technological and Economic Development of Economy, 19*(2), 310–330.

Hwang, B. G., & Tan, J. S. (2012). Green building project management: Obstacles and solutions for sustainable development. *Sustainable Development, 20*(5), 335–349.

Hwang, B. G., Thomas, S. R., Haas, C. T., & Caldas, C. H. (2009). Measuring the impact of rework on construction cost performance. *Journal of Construction Engineering and Management, 135*(3), 187–198.

Hwang, B. G., Zhao, X., & Tan, L. L. G. (2015). Green building projects: Schedule performance, influential factors and solutions. *Engineering, Construction and Architectural Management, 22*(3), 327–346.

Hwang, B. G., Zhu, L., & Ming, J. T. T. (2017). Factors affecting productivity in green building construction projects: The case of Singapore. *Journal of Management in Engineering*, 33(3), 04016052.

Hydes, K. R., & Creech, L. (2000). Reducing mechanical equipment cost: The economics of green design. *Building Research & Information, 28*(5–6) (403–407).

Jiang, Y. (2010). *Understanding the cost of green buildings: Evidence from Singapore.* Master's thesis, National University of Singapore, Singapore.

Johnson, S. D. (2000). The economic case for "high performance buildings." *Corporate Environmental Strategy, 7*(4), 350–361.

Kang, Y., Kim, C., Son, H., Lee, S., & Limsawasd, C. (2013). Comparison of preproject planning for green and conventional buildings. *Journal of Construction Engineering and Management*, *139*(11).

Kansal, R., & Kadambari, G. (2010). Green buildings: An assessment of life cycle cost. *The IUP Journal of Infrastructure*, *VIII*(4), 50–57.

Kats, G. (2010). *Greening our built world: costs, benefits, and strategies*. Washington, DC: Island Press.

Kibert, C. J. (2008). *Sustainable construction: Green building design and delivery*. Hoboken, NJ: John Wiley & Sons.

Kim, J. L., Greene, M., & Kim, S. (2014). Cost comparative analysis of a new green building code for residential project development. *Journal of Construction Engineering and Management, 140*(5).

Lam, P. T. I., Chan, E. H. W., Poon, C. S., Chau, C. K., & Chun, K. P. (2010). Factors affecting the implementation of green specifications in construction. *Journal of Environmental Management, 91*(3), 654–661.

Love, P. E. D., Niedzweicki, M., Bullen, P. A., & Edwards, D. J. (2012). Achieving the green building council of Australia's world leadership rating in an office building in Perth. *Journal of Construction Engineering and Management, 138*(5), 652–660.

Malin, N. (2000). The cost of green materials. *Building Research and Information, 28*(5–6), 408–412.

Menassa, C., Mangasarian, S., El Asmar, M., & Kirar, C. (2012). Energy consumption evaluation of U.S. Navy LEED-certified buildings. *Journal of Performance of Constructed Facilities, 26*(1), 46–53.

Nalewaik, A., & Venters, V. (2010). Cost benefits of building green. *IEEE Engineering Management Review, 38*(2), 77–87.

Ong, Y. H. (2013). Green building retrofit projects: Critical success factors, barriers and solutions. Undergraduate, National University of Singapore, Singapore.

Ott, R. L., & Longnecker, M. (2010). *An introduction to statistical methods and* *data analysis*. Belmont, CA: Brooks/Cole, Cengage Learning.

Popovec, J. (2006). Incentives assuage investor fears over green premiums. *National Real Estate Investor, 48*(11), 31.

Robichaud, L. B., & Anantatmula, V. S. (2011). Greening project management practices for sustainable construction. *Journal of Management in Engineering, 27*(1), 48–57.

Rosenow, J., Eyre, N., Bürger, V., & Rohde, C. (2013). Overcoming the upfront investment barrier—Comparing the German CO 2 building rehabilitation programme and the British green deal. *Energy and Environment, 24*(1–2), 83–103.

Sahamir, S. R., & Zakaria, R. (2013). Green assessment criteria for public hospital building development in Malaysia. *Procedia Environmental Science, 20*, 106–115.

Shrestha, P. P., Burns, L. A., & Shields, D. R. (2013). Magnitude of construction cost and schedule overruns in public work projects. *Journal of Construction Engineering*.

Singh, A., Syal, M., Grady, S. C., & Korkmaz, S. (2010). Effects of green buildings on employee health and productivity. *American Journal of Public Health, 100*(9), 1665–1668.

Son, H., Lee, S., & Kim, C. (2015). An empirical investigation of key pre-project planning practices affecting the cost performance of green building projects. *Procedia Engineering*, 37–41.

Tagaza, E., & Wilson, J. (2004). *Green buildings: Drivers and barriers to lessons learned from five Melbourne developments*. Report Prepared for Building Commission by University of Melbourne and Business Outlook and Evaluation.

Thatcher, A., & Milner, K. (2014). Changes in productivity, psychological wellbeing and physical wellbeing from working in a "green" building. *Work, 49*(3), 381–393.

Thomas, S. R., Macken, C. L., Chung, T. H., & Kim, I. (2002). Measuring the impacts of the delivery system on project performance–design-build and design-bid-build. *NIST GCR, 2*, 840.

UNEP. (2009). *Buildings and climate change—Summary for decision-makers*. Retrieved from http://www.unep.org/sbci/pdfs/sbci-bccsummary.pdf

UNEP. (2011). *Sustainable buildings and climate initiatives*. Retrieved from http://www.unep.org/sbci/pdfs/sbci_2pager_eversion_Feb2011.pdf

Wong, N. H., Tay, S. F., Wong, R., Ong, C. L., & Sia, A. (2003). Life cycle cost analysis of rooftop gardens in Singapore. *Building and Environment, 38*(3), 499–509.

WorldGBC. (2013). *The business case for green building—A review of the costs and benefits for developers, investors and occupants*. Retrieved from http://www.worldgbc.org/files/1513/6608/0674/Business_Case_For_Green_Building_Report_WEB_2013-04-11.pdf

WorldGBC. (2014). *Health, wellbeing and productivity in offices—The next chapter for green building.* Retrieved from http://www.worldgbc.org/files/6314/1152/0821/WorldGBC__Health_Wellbeing__productivity_Full_Report.pdf

Wu, P., & Low, S. P. (2012). Lean management and low carbon emissions in precast concrete factories in Singapore. *Journal of Architectural Engineering, 18*(2), 176–186.

Wu, P., Xia, B., Pienaar, J., & Zhao, X. (2014). The past, present and future of carbon labelling for construction materials—A review. *Building and Environment, 77*, 160–168.

Wu, P., Xia, B., & Zhao, X. (2014). The importance of use and end-of-life phases to the life cycle greenhouse gas (GHG) emissions of concrete—A review. *Renewable and Sustainable Energy Reviews, 37*, 360–369.

Xiao, H., & Proverbs, D. (2002). The performance of contractors in Japan, the UK and the USA: A comparative evaluation of construction cost. *Construction Management and Economics, 20*(5), 425–435.

Yoon, S. W., & Lee, D. K. (2003). The development of the evaluation model of climate changes and air pollution for sustainability of cities in Korea. *Landscape and Urban Planning, 63*(3), 145–160.

Zhao, X., Hwang, B. G., & Gao, Y. (2016). A fuzzy synthetic evaluation approach for risk assessment: A case of Singapore's green projects. *Journal of Cleaner Production, 115*, 203–213.

Zhao, X., Hwang, B. G., & Lee, H. N. (2016). Identifying critical leadership styles of project managers for green building projects. *International Journal of Construction Management, 16*(2), 150–160.

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