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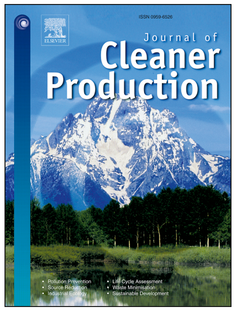

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Drivers for implementing green building technologies: an international survey of experts

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Abstract

In recent years, green building technologies (GBTs) have gradually been implemented to minimize negative impacts of the construction industry on the environment, economy, and society. In order to encourage widespread adoption of GBTs, a better and deeper understanding of the drivers for implementing GBTs is necessary. This study aims to identify the major drivers of GBTs implementation. The methodological framework used consists of a comprehensive literature review and a questionnaire survey of international green building (GB) experts, rather than experts in a particular country. The results of statistical analyses of 104 expert responses indicate that the top five drivers for implementing GBTs are energy-efficiency, reduced environmental impact, water-efficiency, occupants' health and comfort and satisfaction, and company image/reputation. Results from *t*-test analysis confirm that out of the 21 drivers examined, 13 are perceived to be significant. The Kendall's concordance test shows that though the experts were from different countries and with diverse backgrounds, a good consensus was reached in their rankings of the drivers. The Mann-

Whitney *U*-test also verifies the absence of significant differences among the experts in ranking most of the drivers. The findings of this study not only contribute to deepened understanding of the major factors that greatly drive GBTs implementation, but could also encourage the industry practitioners and stakeholders aiming at achieving better construction sustainability to further implement GBTs in the future. From the perspective of international GB experts, this study makes a contribution to the body of knowledge about GBTs implementation drivers, which is important for GBTs promotion.

Keywords: Green building technologies; Drivers; Construction industry; Sustainability; Sustainable development.

1. Introduction

The construction industry significantly impacts upon the natural environment, economy, and society. Globally, the construction industry consumes 40% of total energy production, 12-16% of all water available, 32% of nonrenewable and renewable resources, 25% of all timber, 40% of all raw materials, produces 30-40% of all solid wastes, and emits 35-40% of CO_2 (Green Building Council of Australia (GBCA), 2006; Son et al., 2011; Berardi, 2013). Green building technologies (GBTs) can be a solution to these negative impacts; hence, over the past few years, the construction industry has attempted to enhance the sustainability of its activities through the implementation of various GBTs (USGBC, 2003; Zhang et al., 2011a, b). Sustainability or sustainable development is necessary to "meet the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development (WCED), 1987). Ahmad et al. (2016) define GBTs as technologies that are incorporated into building design to make the end product sustainable, such as solar system technology, optimization of building envelope thermal performance, and green roof technology. GBTs aim at enhancing the environmental, social, and economic performance of buildings, which are three dimensions essential to address the need for sustainable development in the construction industry (Love et al., 2012; Zhang, 2015).

Despite the existence of barriers, such as high cost and a lack of information, to applying green building (GB) practices and technologies (Chan et al., 2016), there are many influences that drive the implementation of GB practices and technologies in construction, such as energy and resource conservation and environmental protection (Manoliadis et al., 2006; Ahn et al., 2013). A better and deeper understanding of these drivers is essential to encourage widespread adoption of GB practices and technologies, because such an understanding could significantly impact GB decision-making and help potential adopters to accept GB practices and technologies (Potbhare et al., 2009; Qi et al., 2010). In addition, the willingness of stakeholders to adopt GB practices and technologies could be increased, with a better understanding of the driving factors. Several studies exist on the driving forces behind the implementation of GB practices and technologies (e.g., Manoliadis et al., 2006; Love et al., 2012; Ahn et al., 2013); however, these studies primarily focus on analyzing GB practices and technologies implementation drivers in specific countries. Therefore, conducting an international study or survey is necessary to enrich the body of knowledge for GB. As GBTs implementation has grown to become an international strategic agenda (WorldGBC, 2016), a comprehensive international investigation and survey on GBTs implementation drivers is worthwhile.

There are several issues associated with GBTs implementation in the construction industry. With the objective to investigate and gain a comprehensive understanding of these issues, an international survey was conducted. The survey was conducted to gather and examine the perceptions of GB experts from different countries around the world to establish common set of drivers for, barriers to, and strategies for promoting the adoption of GBTs (Chan et al., 2016). The outcomes on the drivers are reported in this paper. This paper identifies and ranks the major drivers for implementing GBTs and then compares the perceptions of experts with actual GB project experience and those without actual GB project experience regarding the drivers. The findings of this study not only make a significant contribution to the existing research on GB by providing an in-depth explanation and understanding of the major factors that greatly drive the implementation of GBTs, but could also encourage the industry practitioners and stakeholders aiming at achieving better construction sustainability to further implement GBTs in the future. To effectively and efficiently promote and make informed decisions on GBTs implementation, advocates and stakeholders can focus and act based on the driving factors with high mean ranks or values and thus high importance. Furthermore, this research provides an opportunity for organizations and individuals attempting to enter the GBTs market to learn lessons from the perceptions of international GB experts who have had some years of experience in GBTs implementation activities, as to why GBTs must be implemented.

2. Literature review

In this research, the term 'drivers' is defined as the reasons why stakeholders decide to use GBTs. Previous studies have addressed various factors that drive the implementation of GB practices and technologies in construction. For example, the study by Love at al. (2012) found the drivers for deciding to use sustainable technologies in Australia to be improve occupant's health and well-being, marketing strategies, reduce the environmental impact of the building, reduction in whole-life cycle costs, marketing and landmark development, and attract premium clients and high rental returns. Low et al. (2014) showed that the important drivers for greening new and existing buildings in Singapore are return on investments, local and overseas competitions, rising energy bills, corporate social responsibility, and marketing/branding motive. In Greece, Manoliadis et al. (2006) identified the following as the most important drivers of change towards sustainable construction: energy conservation, resource conservation, and waste reduction. Several US studies have discussed the drivers of green or sustainable design and construction (Augenbroe et al., 1998; Augenbroe and Pearce, 1999; Vanegas and Pearce, 2000; Ahn et al., 2013; Mulligan et al., 2014). For example, Ahn et al. (2013) presented the major drivers as energy conservation, improving indoor environmental quality, environmental and resource conservation, waste reduction, and water conservation. The highest rank of energy conservation in Ahn et al.'s study reinforced the finding of the earlier study by Augenbroe and Pearce (1999). Zhang et al. (2011a) discovered that building up green reputation and good image, gaining competitive advantage, commitment on corporate social responsibility, reduction in construction costs, developing unique green products, and reduction in operation and maintenance costs are important factors driving the application of green technologies in the Chinese construction industry. Serpell et al. (2013) highlighted the main drivers for sustainable construction in Chile as corporate image, cost reduction, and market differentiation. Edwards (2006) revealed that green offices in the UK increase the productivity of employees by 2-3%, due to the improved workplace environment which in turn lessens employee absenteeism. Several other previous studies have investigated the drivers for implementing GB practices and technologies in different countries, such as in South Africa (Windapo, 2014; Windapo and Goulding, 2015), Turkey (Aktas and Ozorhon, 2015), and India (Arif et al., 2009).

The literature review above summarizes past studies related to the drivers for applying GB practices and technologies. These studies tend to primarily focus on analyzing country-specific drivers, which may limit their application to GBTs implementation in the global construction industry. As a result, the present study aims to examine the major drivers for implementing GBTs in the construction industry, as seen from the perspective of international GB experts and thereby enrich the body of knowledge for GB.

3. Methodological framework

3.1. Identification of GBTs implementation drivers

There are various drivers that influence and shape the implementation of GB practices and technologies in construction, which can be found in the previous studies (e.g., Manoliadis et al., 2006; Zhang et al., 2011a; Love et al., 2012). After a thorough review of previous studies, this study identified 21 potential drivers of GBTs implementation, as summarized in Table 1 with their corresponding literature sources. These factors are well documented in previous research and more applicable. For instance, energy-efficiency, water-efficiency, and reduced environmental impact are widely acknowledged in the literature as crucial factors that drive the GB market. Thus, the identification of this set of drivers focused mainly on factors that have received considerable attention in previous studies conducted in different countries. For a research study, Rowlinson (1988) suggests that well-known factors are more applicable, because respondents would be able to respond easily. As they are more applicable, examining them would be more useful (Cheng and Li, 2002) for gaining a deeper understanding of the factors driving GBTs implementation.

[Insert Table 1 about here]

3.2. Data collection

The questionnaire survey is a systematic method for gathering data based on a sample (Tan, 2011) and has been widely used in construction management research (Qin et al., 2016; Annunziata et al., 2016; Huang et al., 2016). For this study, a questionnaire survey was conducted to identify the main drivers for implementing GBTs. Based on a comprehensive literature review, a survey questionnaire was designed. The main questionnaire consisted of the following three sections: the first section communicated the primary objectives of the research and assured confidentiality and anonymity; the second section was intended to collect the respondents' background information, including their organizational position, profession, and years of GB experience; and the third section contained three questions about the opinions of the experts on: (1) 21 drivers for the adoption of GBTs; (2) 26 barriers to GBTs adoption; and (3) 12 strategies for promoting GBTs adoption. Note that only the question on the drivers is of interest to this paper and a sample of the relevant section of the questionnaire is provided in Appendix in order to have a better understanding of the survey. Prior to the main survey, a pilot study was adopted to test the comprehensiveness and relevance of the questionnaire (Li et al., 2011). The pilot study involved a team of three professors, a senior lecturer, and a postgraduate researcher who were experienced in this research area. They were asked to assess the questionnaire with regard to question construction, use of technical language/terms, whether the questionnaire covered all possible drivers, considering the background of GBTs implementation in the construction industry, and whether any factors could be added to, or deleted from the survey. The questionnaire was finalized based on feedback from the pilot study. It was then distributed via email to carefully selected international GB experts (both practitioners and academics), who were mainly identified through research publications and databases (member directories) of worldwide GB councils. An expert refers to someone with special skills or knowledge evidenced by his/her leadership in professional organizations, or someone holding office in professional organizations, or a presenter at national conventions, or someone who has published in recognized journals (Cabaniss, 2002). Hence, the experts in this study were selected based on their knowledge and understanding of use of GB practices and technologies in the construction industry, which was evidenced by their relevant GB research publications (to respect the anonymity of the experts, examples of the publications are not given) and/or registration as accredited green professionals with recognized GB councils (such as the USGBC, GBCA, UKGBC, Canada GBC, and WorldGBC).

The experts were emailed attaching a Microsoft *Word* file and a web link (to allow online responses). They were asked to express their professional opinions on the main drivers for implementing GBTs using a five-point Likert scale (1 = strongly disagree; 2 = disagree; 3 = neutral; 4 = agree; 5 = strongly agree). Likert scale is a popular method in construction management research for rating the relative significance or importance of individual factors based on experts' opinions (Zhang et al., 2011a; Qin et al., 2016). To encourage participation, it was communicated to the experts that the research outcomes can be shared with them (Li et al., 2011). Responses were received, including some incomplete responses. After eliminating the incomplete responses, a total number of 104 valid responses were received from 20 different countries (including the US, Canada, Australia, UK, China, Hong Kong, Malaysia, Singapore, Mexico, Brazil, India, Egypt, etc.). To meet the word-limit requirement, all of the countries and the number of responses received from each country, as well as background information of the experts are reported in full elsewhere (see Chan et al., 2016). As the exact number of questionnaires distributed is unknown, the response rate cannot be calculated (similar to Cheng and Li, 2002; Rahman, 2014). The exact number of distribution is unknown because the potential respondents were asked to forward the questionnaire to any other experts they thought suitable. However, more than 500 questionnaires were sent out and the resulting sample size of 104 has been deemed adequate and representative when compared with other similar international surveys reported in the construction management literature (e.g., Wang et al., 2000).

Analysis of the experts' background information revealed that the reliability and credibility of the study results are high, because most of them held top positions in their organizations, e.g., senior manager (26%), director/CEO (21%), and professor (19%). More importantly, all of the experts had been involved in activities related to adoption of GBTs before, such as actual GB projects implementation and participation in various types of meetings (e.g., business conferences) in support of GBTs adoption, with more than half

(59%) of them having been directly involved in GB projects. Furthermore, most (71%) of the experts had more than 5 years of experience in GB.

3.3. Data analysis

The research data collected were analyzed by using the SPSS statistical package. The data were first tested statistically for their credibility and reliability for the current study. To do that, the Cronbach's alpha coefficient (α), was used (Nunnally and Bernstein, 1994). The α value ranges from 0 to +1. The higher the value, the stronger the internal consistency and, hence, reliability of the data. Generally, an α value above 0.7 is considered acceptable (George and Mallery, 2003). In this study, the α value for the 21 GBTs implementation drivers was 0.863, indicating a good reliability of the data for further analyses.

To facilitate the intended analysis for this study, the experts were grouped into two main categories: experts with actual GB project experience and those without actual GB project experience yet have experiences in other activities related to the adoption of GBTs. It was reasonable to assume that these two groups may have different opinions on what drives the implementation of GBTs, because those two types of experiences (i.e., having and not having an actual project experience) are obviously different. To determine the relative importance of individual drivers, the mean value technique was used. The mean values of individual drivers were computed, ranked, and compared between the two groups of experts. Mean value analysis is considered a typical and effective method for identifying key factors amongst several individual factors (Moungnos and Charoenngam, 2003; Lam et al., 2015). At a significance level of 0.05, and against a test value of 3.5, statistical *t*-tests of the mean values were used to ascertain whether each driver was significantly important. In a study to analyze and rank the business reasons that drive GB, Chan et al. (2009) applied the Kendall's coefficient of concordance test (also known as Kendall's *W*) to examine the agreement amongst both Hong Kong and Singapore respondents on their rankings of the 'business reasons' factors. They further used the Mann-Whitney *U*-test to measure the degree of association of responses by the respondents from the two groups (i.e., Hong Kong and Singapore groups) concerning their rankings of different factors. A similar approach was adopted by Lam et al. (2015), Shi et al. (2013), and Lam et al. (2009) in their research. As such, in this study, the Kendall's *W* has been used to measure the agreement between the experts in each of the two groups (i.e., the groups with and without actual GB project experience) concerning their rankings of the different drivers for implementing GBTs. The Mann-Whitney *U*-test has also been applied to determine whether or not there was any statistically significant difference amongst the two expert groups on each of the drivers.

3.3.1. Kendall's coefficient of concordance (Kendall's *W*)

Kendall's *W* was calculated to measure the agreement and consistency of responses given by experts in a particular group in ranking the drivers of GBTs implementation based on mean values. Kendall's *W* is a coefficient index for ascertaining the overall agreement amongst sets of rankings. It represents the actual agreement amongst the rankings by different rankers. *W* has a value ranging from 0 to +1. Where a complete agreement amongst different groups of respondents exists, the value of *W* will be exactly or closer to +1, otherwise the value of *W* will be exactly or closer to 0 (Siegel and Castellan, 1988). Kendall's coefficient of concordance test does not assume any specific nature of data distribution. In conducting this test, the null hypothesis (H0) is that *'there is no agreement among the rankings given by the respondents'*. If the value of *W* turns out to be at a low significance ($p \leq 0.001$), the null hypothesis (H0) can be rejected, meaning that some degree of consensus exists amongst the respondents' scaled answers to a particular question. Kendall's concordance test is more suitable if the number of objects to be ranked (*N*) (21 drivers in this study) is less than or equal to 7. With more than 7 variables ($N > 7$) and large sample size (sample size > 20), Chi-square test is viewed as the best option for a near approximation (Siegel and Castellan, 1988).

Chi-square provides an approximate distribution with N-1 degrees of freedom (df) for determining the significance of an observed *W*.

The results of Kendall's coefficient of concordance and Chi-square tests are shown in Table 2. It can be seen that the coefficients of concordance are 0.194 and 0.182 for the expert group with actual GB project experience (group 1) and the group without actual GB project experience (group 2), respectively. Also, the critical values of Chi-square for the two groups are observed to be 236.159 and 156.221 (df = 20), respectively, with probabilities of occurrence under $p < 0.001$ (Asymp. Sig. = 0.000). These results indicate a good consensus between both the experts within group 1 and those within group 2 in expressing their opinions concerning the main factors that drive the implementation of GBTs, which is in turn reflected in the total sample.

3.3.2. Mann-Whitney U-test

The Mann-Whitney *U*-test has been conducted in this study to examine the degree of association of rankings of various GBTs implementation drivers from the perspective of experts within group 1 and experts within group 2 (Chan et al., 2009) (ranking results presented in Table 2). This test is suitable for identifying any statistically significant divergences or differences amongst any two independent groups answering a particular question on any continuous variable. When applying this method, it is not required to make any prior assumption on data distribution, and the sample sizes of various groups can be varied (Lam et al., 2015). Mann-Whitney *U*-test converts the scores given by the respondents on each continuous measure to ranks, across any two groups, and then assesses whether the ranks for the two groups significantly differ or not. For this test, the H0 is that *'there is no difference amongst two groups'*, which can be rejected if the *U* value exceeds its critical value at a significance level equal to or less than 0.05.

Table 3 summarizes the *U*-test results, showing the *z* value of each of the 21 drivers (D1-D21) and their corresponding significance levels of *p*. For example, the *z* value of driver 'D21' is -0.195 with a significance level of $p = 0.846$. As shown in Table 3, with the exception of drivers 'D1' ($p = 0.013$) and 'D11' (p = 0.029), the probability values (*p*) of all of the drivers are greater than 0.05. This means that aside from these two drivers (D1 and D11), the *U*-test results for all of the drivers are insignificant, indicating that there are no statistically significant differences in the ranks of 19 drivers out of 21 by the two expert groups (Table 2). This shows an optimistic result concerning the agreement between experts with and those without actual GB project experience.

4. Results and discussion

An overview was obtained from the survey data by computing the mean values of all of the 21 drivers of GBTs implementation assessed by experts from two different groups, as shown in Table 2. The relative rank of each driver was derived from the experts' opinions (mean values) in response to the survey question. Discussions are made based on the results within the two expert groups and the overall results (i.e., within the total sample).

[Insert Table 2 about here]

[Insert Table 3 about here]

4.1. Analyses based on the two expert groups

Different stakeholders may have different priorities for reasons why they decide to use green technologies in their buildings. In a real construction project, several confounding issues influence decision-making towards the adoption of certain technologies. As such, experts who have had hands-on experiences in GB projects may have very different preferences in identifying the most important influences that usually motivate efforts to implement GBTs, from experts who just follow developments relating to the adoption of such technologies, but are yet to test their experiences on a real project. Therefore, in this study, the views of experts with actual GB project experience and those without actual GB project experience on what drives the implementation of GBTs among construction stakeholders have been analyzed and compared. These insights are provided in Table 2, with group 1 representing the views of experts with actual GB project experience and group 2 representing the views of experts without actual GB project experience.

As discussed earlier, the Mann-Whitney *U*-test has been used to identify any significant differences between these two expert groups on their rankings. The test results in Table 3 show that these two drivers: "reduce the lifecycle costs of buildings" (D1) and "better rental income and increased lettable space" (D11) have significant differences among the two expert groups. Experts within group 1 regarded both of these two drivers as more important than experts within the second group. Especially with driver D1, the difference between the mean ranks across the two groups seems quite high: while the first group ranked D1 third with a high mean value of 4.25, the second group ranked it ninth with a mean value of 3.79. For the remaining 19 drivers, significant differences were not found between the two groups, because it can be seen that the data displays relatively close values of means and ranks across the two groups for those 19 drivers (Table 2). This verifies the homogeneity and acceptable quality of the collected survey data as well as a reasonably low degree of dispersion resulting in credible and reliable findings. However, it can still be observed that for all of the drivers for implementing GBTs, except D6 "reduce the environmental impact of buildings" and D21 "improve the performance of the national economy and create jobs", the first expert group tended to show bigger mean values than the second group (Table 2). This implies that experts with actual GB project experience attached more degree of importance to most of the drivers than the other expert group. This is reasonable because the experts within group 1 are more familiar with the multifaceted objectives involved in real GB projects. They know that most of the needs to be addressed in actual GB project situations are complicated, but highly important to achieve sustainable development.

4.2. Analyses bases on overall results on drivers for implementing GBTs

The left side of Table 2 displays the overall results of this study, i.e., results within the total sample. It shows a list of factors that drive the implementation of GBTs, with a ranked order that has been agreed by GB experts around the world. Thus, it demonstrates a good consensus of the perceptions on GBTs implementation drivers between experts with actual GB project experience and those without actual GB project experience yet have experiences in other activities related to the implementation of GBTs. From the results, it can be seen that the most important driver for deciding to use GBTs is “greater energy-efficiency of buildings” (D2) with the highest mean value of 4.57, followed by “reduce the environmental impact of buildings” (D6, mean = 4.25) ranked second, “greater water-efficiency of buildings” (D3, mean = 4.24) ranked third, “enhance occupants’ health and comfort and satisfaction” (D4, mean = 4.18) ranked fourth, and “good company image/reputation or marketing strategy” (D8, mean = 4.14) ranked fifth. Aside from these drivers, “better indoor environmental quality” (D7, mean 4.08, rank 6) is also deemed a good reason driving the implementation of GBTs. These drivers are considered effective to attract stakeholders’ interests in adopting GBTs for better construction sustainability. On the other hand, “efficiency in construction processes and management practices” (D20), “improve the performance of the national economy and create jobs” (D21), and “facilitate a culture of best practice sharing” (D19) are found to be the least important drivers among all the proposed ones. The results from *t*-test analysis verify that 13 out of the 21 drivers are significantly important for the implementation of GBTs.

It appears that the most important driver for implementing GBTs is ‘greater energy-efficiency of buildings’ (D2). This is echoed with previous investigations and it is not surprising, because energy-saving has become a high-priority all over the world and the building sector is considered as one of the biggest contributors to energy consumption in the world (Pacheco et al., 2012). Stakeholders are therefore realizing the need to reduce energy use in buildings. Manoliadis et al. (2006) and Ahn et al. (2013) also found that energy conservation is the most important driver influencing the implementation of green construction practices. Most of the energy consumed in buildings is for cooling, heating, and lighting purposes. The high levels of energy consumption in buildings can be attributed to the application of traditional electrical appliances and equipment. Moreover, almost all of construction operations, such as excavating, concrete casting, curing and finishing, and pumping and vibrating concrete, are energy consuming. The finding of this study suggests that replacing the traditional construction technologies with green technologies can help stakeholders to reduce the energy demand for cooling and heating, and for performing other functions in buildings. Through the utilization of GBTs, such as technologies that utilize natural resources of sun (e.g., photovoltaic panels and active western façade with automated louvres) and wind (e.g., roof mounted wind turbines), and active chilled beams, stakeholders can achieve a reduction in building energy consumption (Love et al., 2012). Adopting roof mounted wind turbines, for example, can result in the generation of about 36 MW/hr green energy (which may represent about 10% of the total building energy needs). A study by Wong (2012) pointed out that depending on the pattern of usage, the application of variable speed motors can help to reduce energy consumed by escalators (by around 10-15%) and air-conditioning systems (by around 20%). Moreover, the use of light emitting diode (LED) bulbs rather than incandescent light bulbs can save 70-80% of electricity. Air-conditioning systems are responsible for a sizeable amount of building energy use, however, the use of a water-cooled air-conditioning system in place of an air-cooled system can reduce electricity consumption by 20-30% (Wong, 2012). The reduced energy consumption and hence cost savings from implementing GBTs can be an important economic benefit for the stakeholder throughout the lifecycle of the building, and it is known that economic benefits are crucial for the business survival of every stakeholder (Chan et al., 2009). These merits could explain the reason why stakeholders implement GBTs to reduce energy consumption and achieve greater energy-efficiency in their buildings.

The second most important factor driving the implementation of GBTs is 'reduce the environmental impact of buildings' (D6). In fact, sustainability in construction has only become crucial because of the built environment's impact on climate change and natural resources, which affects the natural environment. Thus, environmental concern has triggered stakeholders to consider the advantages of sustainable options, such as renewable energy systems. It is not surprising to identify that reduction of environmental impacts is an important factor driving stakeholders in the implementation of GBTs. This concurs with the literature that stakeholder or managerial environmental concern is an important driver for the implementation of green technology (Qi et al., 2010; Wang et al., 2014). Most of the building sector's impact on climate change and, hence, the environment is attributable to its pivotal role in carbon emissions. The high energy consumption in the industry contributes to excessive CO_2 emissions, meaning that the application of energy-efficient technologies can reduce the environmental impact of buildings. Love et al. (2012), for example, demonstrated that the application of active chilled beams including floor by floor zoning and thermal zoning of airhandling units can reduce CO_2 emissions, because it minimizes energy consumption. It can save approximately 447.3/tne of CO_2 annually. Usually, building emissions are discussed in relation to the production of greenhouse gases and consumption of resources throughout the lifespan of the building. Building construction impacts upon the environment by excessively consuming notable natural resources, e.g., land and water, that are usually nonrenewable. The construction of buildings also pollutes the atmosphere in many ways. The same study by Love et al. (2012) showed that the adoption of renewable green technologies, such as wind turbines for on-site renewable power generation, can reduce demand for nonrenewable energy sources and consequent ecological impact. This study suggests that the implementation of green building technologies can reduce the environmental impact of buildings by favoring a transition to a low-carbon economy as well as developments that are less resource-intensive.

‘Greater water-efficiency of buildings’ (D3) is considered by the experts as the third most important driver for applying GBTs, implying that the need to reduce water use in buildings is a typical sustainability issue reinforcing the adoption of GBTs. In almost every well-known green building rating tool (such as Leadership in Energy and Environmental Design (LEED) and BRE Environmental Assessment Method (BREEAM)), water-efficiency is an important requirement that stakeholders that are developing GBs must satisfy. The application of suitable GBTs has been suggested to be critical for stakeholders to achieve this target, which is echoed with previous research by Zhang et al. (2011b) who identified that stakeholders adopt green technologies, such as permeable surface technology and on-site sewage treatment, to improve the water-efficiency of their buildings. Encouraging water-efficient design can bring about an added value that will benefit the end-user. A water-efficient building can reduce its lifetime economic costs (lower water bills), because of its lower water usage, and this can be more than a compensation for the higher initial investment. This economic benefit of cost savings can be well received by many stakeholders and thus encourage them to implement GBTs.

‘Enhance occupants’ health and comfort and satisfaction’ (D4) has been found to be the fourth important driver seeing through the implementation of GBTs. This is in contrast with Low et al. (2014) who found that ‘improve the wellbeing of employees’ is the least important driver for GB. It does not also support the finding of Chan et al. (2009) that ‘higher tenant satisfaction' is the least favorable factor for implementing GB. However, the finding echoes several other discussions in the literature that stakeholders are adopting GBTs, because they have realized the benefits of enhancing the health and comfort of occupants (Werna, 2013; Roseland, 2012). The reduced CO_2 emissions into the atmosphere from GBTs, for example, could be an essential social benefit that can make GBTs attractive to stakeholders.

'Good company image/reputation or marketing strategy' (D8) can also make GBTs attractive to market stakeholders. Stakeholders can gain good image and reputation by adopting green technologies. For instance, the application of technologies that have less impact on public health can help stakeholders increase their public reputation and gain a green image. This can help them differentiate their products and hence enjoy certain market advantages, such as high sale prices. The application of GBTs, such as efficient daylighting systems and solar shading devices, can further provide a 'better indoor environmental quality' (D7) for occupants, which has also been identified by this study as an important driver for stakeholders to adopt GBTs. These findings have been support by the literature as well-established benefits associated with GBTs and if they are favorable, can naturally arouse interests in the technologies.

5. Conclusions

GBTs have the greatest opportunity to reduce the negative impacts of the construction industry on the natural environment, economy, and society. To encourage widespread adoption of GBTs, this study identified the major drivers for implementing GBTs in the construction industry. This study contributes to the existing body of literature by focusing on the perspective of international GB experts, rather than experts in a particular country. A total number of 21 factors were identified through a comprehensive literature review and presented in a questionnaire. Afterward, a questionnaire survey was performed with GB experts around the world to identify the major drivers of GBTs implementation from these factors. The results from statistical analyses of 104 expert responses first showed that energy-efficiency, reduced environmental impact, water-efficiency, occupants' health and comfort and satisfaction, and company image/reputation were the top five drivers of GBTs implementation. This finding indicates that the implementation of GBTs needs consideration in order for stakeholders to realize sustainability benefits, such as developing buildings that are highly energy-efficient and have minimal environmental impacts. The analyses result also showed that 13 out of the 21 factors were significant drivers of GBTs implementation. In addition, although the experts were from different countries and with diverse backgrounds, they had a good consensus on their rankings of the drivers. Furthermore, there were no significant differences amongst experts with actual GB project experience and those without actual GB project experience in ranking most of the drivers.

As this study attempted to present major factors that greatly drive the implementation of GBTs, the empirical results have practical implications. The major drivers with high mean ranks or values can be focused on to effectively and efficiently promote and make decisions regarding the implementation of GBTs. GB advocates can widely promote these drivers in society in order to influence the interest industry stakeholders have in GBTs. For governments, they can take the lead to instigate policies, plans, and programs that can boost the energy and environmental consciousness of industry stakeholders and inform the public of the importance of and range of possibilities offered by GBTs implementation. The findings of this study can also help the industry practitioners and stakeholders make informed decisions as to whether to use GBTs or not, knowing the potential benefits.

Because this study was designed based upon the broad literature and GB experts in the global construction industry were engaged, the overall findings of this paper may be generalizable. The findings of this study can be beneficial not only for providing an in-depth understanding of the major factors greatly driving the implementation of GBTs in construction, but can also encourage the practitioners and stakeholders to further implement GBTs in the future for better construction sustainability. The organizations and individuals that intend to implement GBTs could learn lessons from the perceptions of international GB experts who have had some years of experience in GBTs implementation activities. They are advised to bear in mind that even though the initial investment may be high, benefits will be reaped in the long run, so they should be patient to see the return on their investments.

For the study reported in this paper, the necessary data were collected from GB experts from different countries having different experiences in promoting GB. This study compared the views of the experts with actual GB project experience and those without actual GB project experience on the drivers for implementing GBTs. However, because the extent of experience of different experts from different countries may differ as GBTs might be implemented to different degrees in different countries to meet different economic conditions and regulations, the future research work will consider and compare the views of the experts according to countries and/or continents/regions. For example, the perceptions of the GB experts from developed and developing countries on the GBTs implementation drivers will be compared in the future research to observe market-specific differences. Such a comparison will be useful to allow developing countries to learn from the experiences of developed countries where GBTs implementation has made considerable progress. For future research, it is also recommended to establish new models that will help to accurately investigate the links among the GBTs implementation drivers and their extent of influences on the implementation process, which would be more helpful and useful for GBTs promotion.

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Appendix A. Relevant section of the questionnaire

[Insert Table 4 about here]

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Tables

Table 1

List of potential drivers of GBTs implementation.

Code	Driving factors	Sources
D1	Reduce the lifecycle costs of buildings	Love et al. (2012), Arif et al. (2009), Serpell et al. (2013), Zhang et al. (2011a), Abidin and Powmya (2014), Aktas and Ozorhon (2015), Windapo and Goulding (2015), Windapo (2014), Zhang (2014), Bond (2011)
D2	Greater energy-efficiency of buildings	Manoliadis et al. (2006), Ahn et al. (2013), Low et al. (2014), Arif et al. (2009), Gou et al. (2013), Aktas and Ozorhon (2015), Windapo (2014), Mulligan et al. (2014), Tan (2014)
D3	Greater water-efficiency of buildings	Ahn et al. (2013), Aktas and Ozorhon (2015), Devine and Kok (2015), Boyle and McGuirk (2012)
D4	Enhance occupants' health and comfort and satisfaction	Love et al. (2012), Arif et al. (2009), Gou et al. (2013), Aktas and Ozorhon (2015), Windapo (2014), Devine and Kok (2015), Boyle and McGuirk (2012), Bhavani and Khan (2008), Tan (2014)
D5	Increase overall productivity	Edwards (2006), Dahiru et al. (2014), Gou et al. (2013), Windapo and Goulding (2015), Bond (2010), Bhavani and Khan (2008)
D6	Reduce the environmental impact of buildings	Love et al. (2012), Ahn et al. (2013), Manoliadis et al. (2006), Arif et al. (2009), Gou et al. (2013), Vanegas and Pearce, 2000
D7	Better indoor environmental quality	Ahn et al. (2013), Aktas and Ozorhon (2015), Windapo (2014), Bond (2011)
D8	Good company image/reputation or marketing strategy	Zhang et al. (2011a), Low et al. (2014), Love et al. (2012), Serpell et al. (2013)
D9	Better workplace environment	Edwards (2006), Li et al. (2013), Gou et al. (2014)
D10	Thermal comfort	Newsham et al. (2013), Van Tijen and Cohen (2008)
D11	Better rental income and increased lettable space	Love et al. (2012), Gou et al. (2013), Zhang (2014)
D12	Attract premium clients and enhanced property value	Love et al. (2012), Bond (2011)
D13	Reduce construction and demolishing wastes	Manoliadis et al. (2006), Ahn et al. (2013), Zhai et al. (2014)
D14	Preservation of natural resources and non-renewable fuels/energy sources	Vanegas and Pearce (2000), Manoliadis et al. (2006), Ahn et al. (2013), Arif et al. (2009)
D15	Set standards for future design and construction	Mondor et al. (2013), Li et al. (2013)
D16	Reduce the use of construction materials	Zhai et al. (2014), Gabay et al. (2014)
D17	Attract quality employees and reduce employee turnover	Bond (2010), Dahiru et al. (2014), Boyle and McGuirk (2012)
D18	Satisfaction from doing the right thing (commitment on social responsibility)	Zhang et al. (2011a), Aktas and Ozorhon (2015), Low et al. (2014), Gou et al. (2013)
D19	Facilitate a culture of best practice sharing	Mondor et al. (2013)
D20	Efficiency in construction processes and management practices	Mondor et al. (2013), Zhai et al. (2014)
D21	Improve the performance of the national economy and create jobs	Comstock (2013), Chua and Oh (2011), Li et al. (2013)

Table 2
Mean ranks within total sample and the two expert groups, and test of concordance.

	Total sample			Group 1		Group 2	
Label	Mean	Rank	Sig.	Mean	Rank	Mean	Rank
D1	4.06	7	0.000	4.25	3	3.79	9
D2	4.57	1	0.000	4.59	1	4.53	1
D3	4.24	3	0.000	4.28	2	4.19	3
D4	4.18	4	0.000	4.23	4[e]	4.12	4
D5	3.88	10	0.000	3.98	10[e]	3.74	10
D6	4.25	2	0.000	4.23	4[e]	4.28	2
D7	4.08	6	0.000	4.11	7	4.02	6
D8	4.14	5	0.000	4.18	6	4.09	5
D9	3.92	9	0.000	3.98	10[e]	3.84	8
D10	3.65	14	0.063[a]	3.69	14	3.60	14
D11	3.86	11	0.000	4.00	9	3.65	11
D12	3.98	8	0.000	4.02	8	3.93	7
D13	3.51	17	0.921[a]	3.59	16[e]	3.40	19
D14	3.79	12	0.001	3.90	12	3.63	12[e]
D15	3.67	13	0.060[a]	3.70	13	3.63	12[e]
D16	3.55	16	0.616[a]	3.59	16[e]	3.49	16
D17	3.49	18	0.913[a]	3.57	18	3.37	20
D18	3.61	15	0.248[a]	3.64	15	3.56	15
D19	3.45	19	0.564[a]	3.48	19	3.42	17[e]
D20	3.32	21	0.031	3.38	20[e]	3.23	21
D21	3.39	20	0.318[a]	3.38	20[e]	3.42	17[e]
Kendall's W^b	0.183			0.194		0.182	
Chi-Square	381.501			236.159		156.221	
df	20			20		20	
Asymp. Sig.	0.000			0.000		0.000	

Note: Group 1 refers to experts with actual green building project experience;
Group 2 refers to experts without actual green building project experience.
[a] Data with insignificant results of one-sample *t*-test ($p > 0.05$).
[e] Equal ranks wherein the next rank is skipped.
[b] Kendall's Coefficient of Concordance test on the drivers amongst the two expert groups.

Table 3

Mann-Whitney *U*-test on the drivers for implementing GBTs.

Test statistics[c]	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11
Mann-Whitney *U*	960.500	1245.500	1260.000	1221.500	1077.000	1309.500	1228.000	1217.000	1185.500	1251.000	1001.000
Wilcoxon *W*	1906.500	2191.500	2206.000	2167.500	2023.000	2255.500	2174.000	2163.000	2131.500	2197.000	1947.000
Z	-2.493	-0.507	-0.381	-0.652	-1.641	-0.014	-0.597	-0.676	-0.929	-0.428	-2.183
Asymp. Sig. (2-tailed)	0.013[d]	0.612	0.704	0.515	0.101	0.989	0.550	0.499	0.353	0.668	0.029[d]

Table 3 (*continued*)

Test statistics	D12	D13	D14	D15	D16	D17	D18	D19	D20	D21
Mann-Whitney *U*	1242.500	1168.000	1102.000	1242.000	1229.500	1157.500	1238.000	1258.000	1168.000	1283.000
Wilcoxon *W*	2188.500	2114.000	2048.000	2188.000	2175.500	2103.500	2184.000	2204.000	2114.000	3174.000
Z	-0.489	-0.987	-1.476	-0.483	-0.565	-1.076	-0.520	-0.376	-1.016	-0.195
Asymp. Sig. (2-tailed)	0.625	0.324	0.140	0.629	0.572	0.282	0.603	0.707	0.310	0.846

Note: [c] Grouping variable: actual green building project experience (1 = With; 2 = Without).
[d] Data with significant results of Mann-Whitney *U*-test.

Table 4

Drivers for the implementation of GBTs.

Code	Drivers	Level of agreement				
D1	To reduce the lifecycle costs of buildings	1	2	3	4	5
D2	For greater energy-efficiency of buildings	1	2	3	4	5
D3	For greater water-efficiency of buildings	1	2	3	4	5
D4	To enhance occupants' health and comfort and satisfaction	1	2	3	4	5
D5	To increase overall productivity	1	2	3	4	5
D6	To reduce the environmental impact of buildings	1	2	3	4	5
D7	For better indoor environmental quality	1	2	3	4	5
D8	For good company image/reputation or as a marketing strategy	1	2	3	4	5
D9	For better workplace environment	1	2	3	4	5
D10	Thermal comfort (better indoor temperature)	1	2	3	4	5
D11	For better rental income and increased lettable space	1	2	3	4	5
D12	To attract premium clients and enhanced property values	1	2	3	4	5
D13	To reduce construction and demolishing wastes	1	2	3	4	5
D14	Preservation of natural resources and non-renewable fuels/energy sources	1	2	3	4	5
D15	To set standards for future design and construction	1	2	3	4	5
D16	To reduce the use of construction materials (materials-efficiency)	1	2	3	4	5
D17	To attract quality employees and reduce employee turnover	1	2	3	4	5
D18	Satisfaction from doing the right thing (commitment on social responsibility)	1	2	3	4	5
D19	To facilitate a culture of best practice sharing	1	2	3	4	5
D20	For efficiency in construction processes and management practices	1	2	3	4	5
D21	To improve the performance of the national economy and to create jobs	1	2	3	4	5

Note: Experts assessed these drivers on a scale from 1 (strongly disagree) to 5 (strongly agree).

Highlights

- An international survey on green building technologies implementation drivers was conducted.
- The major drivers of green building technologies implementation have been identified.
- There was good consensus among green building experts' rankings of the drivers.
- There were no significant differences among most of the drivers.