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1 **Examining Issues Influencing Green Building Technologies Adoption: The United**  
2 **States Green Building Experts' Perspectives**

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26 **Examining Issues Influencing Green Building Technologies Adoption: The United**27 **States Green Building Experts' Perspectives**28 **Abstract**

29 Green building (GB) has been viewed as an effective means to implement environmental,  
30 economic, and social sustainability in the construction industry. For the adoption of GB  
31 technologies (GBTs) to continue to succeed and gain popularity, a better understanding of the  
32 key issues influencing its progress is crucial. While numerous studies have examined the  
33 issues influencing green innovations adoption in general, few have specifically done so in the  
34 context of GBTs. This study aims to investigate the underpinnings of GBTs adoption in the  
35 following areas: (1) the critical barriers inhibiting the adoption of GBTs, (2) major drivers for  
36 adopting GBTs, and (3) important strategies to promote GBTs adoption. To achieve these  
37 objectives, a questionnaire survey was carried out with 33 GB experts from the United States.  
38 Ranking analysis was used to identify the significant issues associated with GBTs adoption.  
39 Resistance to change, a lack of knowledge and awareness, and higher cost have been the most  
40 critical barriers. The major drivers for adopting GBTs are greater energy- and water-  
41 efficiency, and company image and reputation. The analysis results also indicate that the  
42 most important strategies to promote the adoption of GBTs are financial and further market-  
43 based incentives, availability of better information on cost and benefits of GBTs, and green  
44 labelling and information dissemination. The findings provide a valuable reference for  
45 industry practitioners and researchers to deepen their understanding of the major issues that  
46 influence GB decision-making, and for policy makers aiming at promoting the adoption of  
47 GBTs in the construction industry to develop suitable policies and incentives. This study

48 contributes to expanding the body of knowledge about the influences that hinder and those  
49 that foster GBTs implementation.

50 **Keywords:** Green building technologies; Barriers; Drivers; Promotion strategies; United  
51 States.

## 52 **1. Introduction**

53 The construction industry has a significant impact on the environment, economy, and  
54 public health. According to Yudelson (2007a), worldwide, buildings account for more than  
55 40% of all global carbon dioxide (CO<sub>2</sub>) emissions, particularly because they are a major  
56 contributor to energy consumption. In 2007, the World Business Council for Sustainable  
57 Development (WBCSD) reported that buildings account for 40% of total energy consumption  
58 (WBCSD, 2007). In addition, buildings in most developed countries, such as the United  
59 States (US), consume 68% of all electricity, 88% of portable water supplies, 12% of fresh  
60 water supplies, 40% of raw materials, and are responsible for 20% of solid waste streams (US  
61 Green Building Council (USGBC), 2003; Comstock, 2013). It is projected that the global  
62 carbon emissions of buildings will reach 42.4 billion tonnes by 2035, a 43% increase in the  
63 2007 level (US Energy Information Administration (US EIA), 2010). With the  
64 implementation of sustainable/green innovations, negative environmental, social, and  
65 economic impacts of the construction industry can be reduced. Thus, adopting green  
66 innovations in construction activities will result in high performance and minimize their  
67 environmental impacts (Love et al., 2012). Typical examples of green innovations in the  
68 construction industry include green specifications (Lam et al., 2009), green building (GB)  
69 guidelines (Potbhare et al., 2009), and GB technologies (GBTs) (such as wind turbines and  
70 solar panels) (Love et al., 2012).

71 Sustainable development is defined as “development that meets the needs of the present  
72 without compromising the ability of future generations to meet their own needs” (World

73 Commission on Environment and Development (WCED), 1987). GB has emerged as a  
74 widely accepted phenomenon to implement sustainable development, which considers the  
75 triple bottom line of environmental, social, and economic performance of buildings, in the  
76 construction industry (Sev, 2009; Son et al., 2011). It is part of a global response to growing  
77 awareness of the huge role buildings play in causing CO<sub>2</sub> emissions that drive global climate  
78 change (Yudelson, 2007a, 2008). GBs are buildings that “use key resources like energy,  
79 water, materials, and land more efficiently than buildings that are just built to code” Kats  
80 (2003, p.2). They are designed, built, and operated to boost health, environmental,  
81 productivity, and economic performance over that of conventional (non-green) buildings  
82 (USGBC, 2003). GB is considered as a form of technological and process innovation in the  
83 construction industry, because it revamps the non-green way of building by integrating a  
84 variety of special building technologies, techniques, practices, and materials to achieve  
85 sustainability (Yudelson, 2007b; Love et al., 2012). Beyond environmental benefits,  
86 employing green innovations offers many social and economic benefits, such as reduced  
87 lifecycle cost, job creation, and poverty alleviation (Ahn et al., 2013; Comstock, 2013), that  
88 are increasingly important for sustainable development. As a result, green innovations  
89 adoption has experienced significant progress in many countries in recent years (Yudelson,  
90 2008, 2009a).

91 GB technologies (GBTs) – an offshoot of green innovation – have evolved dramatically  
92 over the last decade. The promotion of green practices in building development has been the  
93 main impetus behind the development of various GBTs (Zhang et al., 2011a, b). Once rare,  
94 resource-efficient, environmentally friendly, and water- and energy-efficient technologies are  
95 now broadly recognized as mainstream. Innovative technologies, such as high efficient  
96 windows, green roof, solar shading devices, solar water heaters, gray water treatment plants,  
97 and high efficient HVAC systems, have all gained broad acceptance in the construction

98 industry (USGBC, 2003; Koebel et al., 2015). “Technologies are the building blocks of  
99 increased performance” (Sanderford et al., 2014, p. 37), which explains why GBTs are  
100 central to address the need for sustainability in the construction industry. It has been  
101 highlighted that in countries like the US, stakeholders’ use of GBTs is growing (Johnstone et  
102 al., 2010; Sanderford et al., 2014), suggesting that GBTs would displace many of the non-  
103 green technologies in the construction industry in the near future. However, for GBTs  
104 adoption to continue to succeed and become widespread and mature, a deeper understanding  
105 of the key issues influencing its progress is crucial (Love et al., 2012; Mao et al., 2015).

106 Despite the recognition of the importance of GBTs in achieving construction  
107 sustainability and the existence of many studies on issues associated with green innovations  
108 adoption in general, few have specifically examined barriers, drivers, and promotion  
109 strategies of GBTs adoption. As a result, with the intent to enhance GBTs promotion efforts,  
110 the primary objectives of this study are to investigate the: (1) critical barriers inhibiting the  
111 adoption of GBTs; (2) major drivers for deciding to use GBTs; and finally, (3) important  
112 strategies to promote the adoption of GBTs. In this research, the barriers, drivers, and  
113 promotion strategies of GBTs adoption are investigated through a questionnaire survey  
114 among GB experts from the US. The main reason for targeting the US GBTs market is that  
115 the US is one of the leading countries in GB development (Darko and Chan, 2016) and thus  
116 not only would this study pave a better way for further GBTs application and development in  
117 the US, but could also serve as a valuable reference for other underdeveloped markets (Chan  
118 et al., 2009).

119 The remainder of the paper is structured into the following sections. The next section  
120 presents relevant theories and draws on the extant literature to examine the issues influencing  
121 green innovations implementation. The motivation for this research is then presented. The  
122 next two sections describe the research methodology and data analysis. The section that

123 follows presents the findings and discussion. And the last section concludes the study. The  
124 research presented is expected to provide a valuable reference for industry practitioners and  
125 researchers to deepen their understanding of the major issues that influence GB decision-  
126 making as well as to help policy makers intending to launch policies and incentives to make  
127 GBTs adoption a mainstream practice in the construction industry.

## 128 **2. Literature review**

### 129 *2.1. Green innovation*

130 Innovation is “any idea, practice, or material artifact perceived to be new to the relevant  
131 adopting unit” (Czepiel, 1974, p. 173). In the adoption and diffusion of innovations theory,  
132 innovation is often viewed as a vital ingredient in the recipe for market differentiation and  
133 creating competitive advantage, and for creating new markets for products and processes  
134 (Christensen et al., 2004; Von Hippel, 2005; Chesbrough et al., 2006). GB is inextricably  
135 linked to innovation not only because it helps construction stakeholders (e.g., developers)  
136 gain competitive advantage through developing unique building products that have good  
137 market opportunities (Zhang et al., 2011b), but also because sustainability and in turn GB  
138 requires process changes, for instance, radical changes in the manner goods and services are  
139 produced, distributed and use (Fukasaku, 2000; Deering, 2000; Manley, 2008). For the  
140 purpose of this study, ‘green innovation’ is defined as “those products, practices,  
141 technologies, materials, and processes that either reduce the energy requirements of buildings  
142 and/or reduce the environmental impact of buildings” (Miozzo and Dewick 2004, p. 74).  
143 Thus, ‘GBTs’ is a branch of green innovation in the construction industry, whose adoption  
144 issues remain the main focus of this study. Ahmad et al. (2016) clustered GBTs into seven  
145 categories: indoor illumination technologies; control technologies; energy and water  
146 conservation technologies; renewable energy technologies; energy and water recovery

147 technologies; technologies to ensure air quality; and technologies to maintain comfort zone  
148 temperatures.

149 To conduct this study, it is critical to examine previous GB-related studies. The following  
150 sections present literature reviews on GB barriers, drivers for GB, and strategies to promote  
151 GB.

## 152 2.2. GB barriers

153 While the merits of green innovations considerably comply with requirements of human  
154 health and environmentally sustainable development, green innovations still face challenges  
155 in their market penetration; there are several concerns about their implementation. What are  
156 the stumbling blocks that prevent the GB market from growing and expanding? There is a  
157 need to better understand the barriers to the implementation of green innovations to help find  
158 ways and means to overcome them. Several researchers and practitioners have investigated  
159 the barriers hindering the use of green innovations in construction. For instance, cost,  
160 implementation time, and the shortage of knowledge and awareness of GB are well  
161 documented in previous research.

162 A crucial barrier to the adoption of green innovations is cost (Lam et al., 2009; Chan et  
163 al., 2009; Zhang et al., 2011a, b; Shi et al., 2013; Ahn et al., 2013; Dwaikat and Ali, 2016).  
164 Ahn et al. (2013) generically presented cost as the biggest barrier to sustainable design and  
165 construction in the US. A questionnaire survey by Lam et al. (2009) in Hong Kong showed  
166 that cost was the most dominant barrier to integrating green specifications in construction. By  
167 adopting the same factors examined by Lam et al. (2009), Shi et al. (2013) repeated a similar  
168 study on the adoption of green construction in China and identified that cost was also the  
169 most critical barrier in that part of the world. The questionnaire survey study involving  
170 building designers in Singapore and Hong Kong showed that higher cost was an undeniable  
171 barrier holding back GB survival in the construction market (Chan et al., 2009). Potbhare et



172 al. (2009) discovered that higher cost was the topmost barrier to adopting GB guidelines in  
173 India. As cost is widely recognized in the literature, it will be included as one of the potential  
174 barriers.

175 In construction, cost and time are closely related, as they are both essential in measuring  
176 project performance and success (Chan and Kumaraswamy, 2002). As a barrier to the  
177 adoption of green innovations, longer implementation time has been ranked second, just after  
178 cost in some studies. Lam et al. (2009) and Shi et al. (2013) showed that incremental time  
179 resulting from fulfilling green requirements was an inevitable barrier to the decision making  
180 of contractors, clients, consultants, and subcontractors, because it delays the project. A study  
181 by Hwang and Ng (2013) among project managers in Singapore revealed that longer time  
182 required during the pre-construction process ranked as the top challenge faced in GB projects  
183 execution. Another time-related issue is the lengthy approval process for new GBTs within a  
184 firm (Tagaza and Wilson, 2004).

185 The lack of knowledge and awareness of GB and its associated benefits is also pointed  
186 out by various researchers as a crucial barrier to the innovation adoption. In addition to cost,  
187 Ahn et al. (2013) highlighted the primary barriers to sustainable construction as long payback  
188 periods, tendency to maintain current practices and resist change, and limited knowledge and  
189 understanding. Other researchers (Williams and Dair, 2007; AlSanad, 2015) also found lack  
190 of knowledge and awareness of GB as a main barrier. This lack of knowledge and awareness  
191 can be linked to GB research and information gaps in the industry. The results of Rodriguez-  
192 Nikl et al. (2015) highlighted lack of information as the topmost barrier to adopting green  
193 innovations in general. Bin Esa et al. (2011) carried out a study to identify the obstacles to  
194 implementing GB projects in Malaysia. The major obstacles were found to be lack of  
195 awareness, education, and information on the benefits of GB. Researchers have also

196 identified lack of reliable GB research as an important barrier (USGBC, 2003; Hwang and  
197 Tan, 2012).

198 Furthermore, there are social and psychological barriers, such as stakeholders' attitudes  
199 and behaviors, and purchase intention, that affect the acceptance and progress of GB  
200 (Hoffman and Henn, 2008; Zhao et al., 2015). The unwillingness to change the non-green  
201 way of building as identified by Meryman and Silman (2004) has become a major barrier to  
202 the adoption of green specifications. This coincided with the finding of one study conducted  
203 in China, which found that deep rooted non-green ideas were the key barrier to sustainable  
204 construction (Chen and Chambers, 1999). A recent study by Du et al. (2014) confirmed that  
205 the reluctance of stakeholders to change is the main barrier to the adoption of energy-saving  
206 technologies in the Chinese construction industry. Häkkinen and Belloni (2011) contended  
207 that the resistance to sustainable building occurs because of the need for process changes,  
208 which entails the perception of possible risks and unforeseen costs.

209 Successful innovation adoption requires effective cooperation and working relations  
210 amongst different stakeholders within a specific project (Kumaraswamy et al., 2004).  
211 Therefore, a lack of interest and communication among project team members may affect the  
212 adoption of green innovations (Williams and Dair, 2007; Hwan and Tan, 2012; Hwang and  
213 Ng, 2013). Other barriers cited by researchers include:

- 214 • lack of interest and market demand (Hwang and Tan, 2012; Samari et al., 2013;  
215 Djotoko et al., 2014);
- 216 • lack of government incentives and regulations (Love et al., 2012; Zhang et al., 2012;  
217 Gan et al., 2015);
- 218 • distrust about GB products (Williams and Dair, 2007; Winston, 2010);
- 219 • unfamiliarity with green technologies (Eisenberg et al., 2002; Tagaza and Wilson,  
220 2004);

- 221 • lack of training and education (Djokoto et al., 2014; Luthra et al., 2015; Gan et al.,  
 222 2015);
- 223 • unavailability of approved green materials and technologies (Potbhare et al., 2009;  
 224 Aktas and Ozorhon, 2015);
- 225 • lack of GB expertise/skilled labor (Eisenberg et al., 2002; Tagaza and Wilson, 2004);
- 226 • lack of importance attached to GB by leaders (Du et al., 2014);
- 227 • lack of promotion (Zhang et al., 2012; Djokoto et al., 2014);
- 228 • lack of financing schemes (Potbhare et al., 2009; Elmualim et al., 2012; Gan et al.,  
 229 2015);
- 230 • lack of availability of demonstration projects (Potbhare et al., 2009); and
- 231 • lack of available and reliable green suppliers (Lam et al., 2009; Gou et al., 2013; Shi  
 232 et al., 2013).

233 After a careful examination of the existing literature relating to GB barriers, a variety of  
 234 factors that have the potential to hamper the adoption of GBTs were identified. Table 1  
 235 provides a list of 26 factors that are well documented and, hence, more applicable. Rowlinson  
 236 (1988) suggests that for a research study, well-known factors are more applicable, because  
 237 respondents could be able to respond easily. As they are more applicable, examining them  
 238 would be more useful for gaining a deeper understanding of the real barriers that inhibit  
 239 GBTs adoption (Cheng and Li, 2002). In this paper, these underlying factors will be  
 240 examined in terms of their criticality in preventing wider adoption of GBTs, as seen from the  
 241 perspectives of US GB experts.

242 **Table 1**  
 243 **Potential barriers to GBTs adoption.**

Code	Barrier factors
b01	Higher costs of GBTs
b02	Lack of GBTs databases and information
b03	Lack of GB expertise/skilled labor
b04	Lack of knowledge and awareness of GBTs and their benefits
b05	Lack of government incentives/supports for implementing GBTs
b06	Lack of reliable GBTs research and education

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b07	Fewer GB codes and regulations available
b08	Insufficient GB rating systems and labelling programs available
b09	Unfamiliarity with GBTs
b10	High degree of distrust about GBTs
b11	Conflicts of interests among various stakeholders in adopting GBTs
b12	Lack of interest and market demand
b13	Implementation of GBTs is time consuming and causes project delays
b14	Resistance to change from the use of traditional technologies
b15	Complexity and rigid requirements involved in adopting GBTs
b16	Lack of promotion
b17	Lack of importance attached to GBTs by leaders
b18	Risks and uncertainties involved in implementing new technologies
b19	Difficulties in providing GB technological training for project staff
b20	Lack of technical standard procedures for green construction
b21	Lack of available and reliable GBTs suppliers
b22	Lack of financing schemes (e.g. bank loans)
b23	High market prices, rental charges, and long pay-back periods of GBs
b24	Lack of availability of demonstration projects
b25	Limited experience with the use of non-traditional procurement methods
b26	Lack of tested and reliable GBTs

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244

245 *2.3. Drivers for GB*

246 A better understanding of GB drivers is necessary to encourage or lead potential adopters  
247 to accept and continue to use green innovations. This section presents a review of GB drivers  
248 addressed by previous studies. For example, Love et al. (2012) identified six key drivers or  
249 reasons why the client of the Western Australia's first six-star Green Star energy-rated  
250 commercial office building decided to use innovative green technologies. These were  
251 improved occupant's health and well-being; marketing strategies; reduce the environmental  
252 impact of the building; reduction in whole-life cycle costs; marketing and landmark  
253 development; and attract premium clients and high rental returns.

254 Gou et al. (2013) assessed Hong Kong's developers' readiness to adopt GB and found  
255 that the following issues motivated the developers to voluntarily adopt GB: low operation  
256 energy cost; environmentally friendly; reduced greenhouse gases; ability to differentiate in  
257 the market; lower vacancy rates; ease in re-sale; higher rents and/or sales prices; and  
258 improved comfort, health, and productivity. Low et al. (2014) examined the success factors  
259 and drivers for greening new and existing buildings in Singapore. The important drivers  
260 discovered included return on investments; local and overseas competitions; rising energy  
261 bills; corporate social responsibility; and marketing/branding motive.

262 Aktas and Ozorhon (2015) investigated the GB certification process of existing buildings  
263 in Turkey. Their findings highlighted the main drivers to include improved occupants'  
264 satisfaction and comfort; recycle materials; electricity, energy, and water savings; and  
265 commitment to environmental sustainability. Andelin et al. (2015) explored the GB drivers  
266 for investors and tenants in Nordic countries. Different sets of drivers were identified for  
267 investors and tenants, however, company image and reputation; and lower lifecycle costs  
268 were identified as the most remarkable mutual drivers.

269 Windapo and Goulding (2015) carried out another recent study in South Africa, which  
270 revealed that the drivers for adopting GB include good public image; competitive advantage;  
271 cost savings; and improved productivity. One of the widely cited studies on sustainable  
272 construction drivers in Greece is by Manoliadis et al. (2006), who found energy conservation;  
273 resource conservation; and waste reduction to be the most important drivers of change. Ahn  
274 et al. (2013) also identified that energy conservation; improved indoor environmental quality;  
275 environmental/resource conservation; waste reduction; and water conservation were the top  
276 six drivers for sustainable design and construction.

277 Chan et al. (2009) showed that the most important business reasons driving the GB  
278 market were lower operation costs, higher building value, lower lifetime cost, enhanced  
279 marketability, and higher return on investment. The literature further discusses that there is a  
280 job creation opportunity associated with GB adoption (Comstock, 2013). Chan et al. (2009)  
281 argued that investing in GB not only provide benefits for customers or buyers, but almost  
282 every stakeholder in the industry also benefits, because it provides many business  
283 opportunities. Furthermore, they opined that due to the increased marketability of new green  
284 products, new job opportunities may arise. Mondor et al.'s (2013) study demonstrated that:  
285 (1) investment in green systems can yield direct savings and improved sustainability  
286 operations and maintenance practices; (2) GB projects can accelerate broader organizational

287 sustainability efforts; (3) GBs can create major benefits for a region, including additional  
 288 commerce; and (4) GB projects can affect their industry standards by setting a standard for  
 289 future design and construction, and also by facilitating a culture of best practice sharing,  
 290 benchmarking, and peer comparison.

291 Serpell et al.'s (2013) study revealed that the main drivers for GB included company  
 292 image; cost reduction; and market differentiation. Vanegas and Pearce (2000) argued that the  
 293 sustainable construction drivers should focus on the impacts of the built environment on  
 294 human health, resource depletion, and environmental degradation. Augenbroe and Pearce  
 295 (2009) proposed 15 drivers for sustainable construction, e.g., indoor environmental quality;  
 296 waste reduction; re-engineering the design process; energy conservation; resource  
 297 conservation; adoption of performance-based standards; better ways to measure and account  
 298 for costs; and product innovation. Yudelson (2008) identified 14 benefits that build a business  
 299 case for GB, e.g., reduced operating and maintenance costs, marketing benefits, productivity  
 300 benefits, and increased building value. There are several other published studies addressing  
 301 the issue of GB drivers (Sayce et al., 2006, 2007; Falkenbach et al., 2010; Qi et al., 2010).

302 Following a detailed review of the literature, a large number of drivers for adopting green  
 303 innovations were identified and clustered, from which a list of 21 drivers found to have  
 304 received relatively considerable attention in the literature was compiled for this study (Table  
 305 2).

306 **Table 2**  
 307 **Potential drivers for adopting GBTs.**

Code	Driver factors
d01	Reduced whole lifecycle costs
d02	Greater energy-efficiency
d03	Greater water-efficiency
d04	Improved occupants' health, comfort, and satisfaction
d05	Improved productivity
d06	Reduced environmental impact
d07	Better indoor environmental quality
d08	Company image and reputation/marketing strategy
d09	Better workplace environment
d10	Thermal comfort (better indoor temperature)
d11	High rental returns and increased lettable space
d12	Attract premium clients/increased building value

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d13	Reduced construction and demolishing wastes
d14	Preservation of natural resources and non-renewable fuels/energy sources
d15	Set standards for future design and construction
d16	Reduced use of construction materials
d17	Attract quality employees and reduce employee turnover
d18	Commitment to social responsibility
d19	Facilitate a culture of best practice sharing
d20	Efficiency in construction processes and management practices
d21	Improved performance of the national economy and job creation

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308

309 *2.4. Strategies to promote GB*

310 There are a number of strategies to promote the adoption of green innovations. For  
 311 example, a wide range of rating systems and labelling programs, such as the UK's Building  
 312 Research Establishment Environmental Assessment Method (BREEAM), the US's  
 313 Leadership in Energy and Environmental Design (LEED), Australia's Green Star, and  
 314 Singapore's Green Mark Scheme, have been developed to improve GB development and  
 315 evaluation. These rating systems and labelling programs provide useful information and  
 316 guidance on GB to the general public and industry practitioners, and there are several studies  
 317 showing that they are essential for GB promotion (Qian and Chan, 2010; Windapo, 2014;  
 318 Murtagh et al., 2016).

319 It is also widely recognized in the literature that government's involvement is one of the  
 320 most crucial and effective ways to promote GB (Varone and Aebischer, 2001; Chan et al.,  
 321 2009). Research suggests that the most cost-effective means to promote the adoption of green  
 322 innovations are to impose mandatory regulations on market parties and introduce practical  
 323 financial and regulatory incentives (Qian et al., 2016; Olubunmi et al., 2016; Shazmin et al.,  
 324 2016) to increase the attractiveness of GB to stakeholders. Although regulations and policies  
 325 are helpful in promoting GB, it should be noted that their effectiveness is closely related not  
 326 only to their content, but also to their enforcement (Gan et al., 2015). Therefore, to effectively  
 327 promote GB, there is a need to ensure that GB policies and regulations are sufficiently  
 328 enforced following their launching (Qian and Chan, 2007; Zhang et al., 2011a, b).

329 Qian and Chan (2007) conducted a comparative study on government measures for  
330 promoting building energy efficiency in the US, UK, and Canada, and proposed a framework  
331 on these measures. Their framework contains several measures, such as implementation of  
332 further market-based incentives, product rating and labelling, subsidy, better enforcement of  
333 existing standards, investment incentives, and low-cost loans. Potbhare et al. (2009)  
334 developed a green implementation strategy to accelerate the adoption of GB guidelines in  
335 developing countries. Their study identified a number of crucial strategies to promote the  
336 adoption of GB guidelines, such as availability of better information on cost and benefits of  
337 GB guidelines, availability of institutional framework for effective implementation of GB  
338 guidelines, educational programs for developers, contractors, and policy makers related to  
339 GB guidelines, and the creation of environmental awareness by workshops, seminars, and  
340 conferences.

341 Häkkinen and Belloni (2011) argued that developing the awareness of clients about the  
342 benefits of GB is one of the most important actions to promote GB. As the attitudes and  
343 behaviors of consumers have a significant influence on GB promotion, strengthening  
344 publicity and education may be an efficient and effective way to enhance public awareness of  
345 environmental sustainability as well as customers' willingness to pay for GBs (Zhang, 2015).  
346 In their study on GB promotion in China, Li et al. (2014a) proposed the following strategies  
347 to promote GB: to enhance the awareness of the stakeholders, to strengthen technology  
348 research and communication, and codes and regulations.

349 Table 3 lists a total of 12 potential strategies to promote the adoption of GBTs. Although  
350 several studies were considered, these strategies were identified based mainly on the works of  
351 Qian and Chan (2007), Potbhare et al. (2009), and Li et al. (2014a), as they highlighted  
352 strategies that were relatively more important for the purpose of this study. Successful  
353 implementation of these strategies could help overcome most of the barriers summarized in



354 Table 1 to further promote GBTs adoption. Hence, this study will examine them to help  
 355 understand the most important strategies to promote the adoption of GBTs in construction.

356 **Table 3**  
 357 **Potential strategies to promote the adoption of GBTs.**

Code	Promotion strategies
p01	Financial incentives and further market-based incentives
p02	Mandatory GB codes and regulations
p03	Green labelling and information dissemination
p04	Better enforcement of GB policies
p05	Low-interest loans and GB subsidies
p06	Public environmental awareness creation through workshops, seminars, and conferences
p07	More publicity through media (e.g., print media, internet, and radio and television programs)
p08	Educational programs for developers, contractors, and policy makers related to GBTs
p09	Availability of better information on cost and benefits of GBTs
p10	Competent, active, and proactive GBTs promotion teams/local authorities
p11	Availability of institutional framework for effective implementation of GBTs
p12	A strengthened GB technology research and education, and communication of new technologies

358  
 359 The literature reviews above summarize past studies about the implementation of green  
 360 innovations in the construction markets of different countries worldwide. Most of the  
 361 previous studies focused more on the barriers to, drivers for, and strategies to promote the  
 362 adoption of green innovations in general (e.g., Chan et al., 2009; Häkkinen and Belloni, 2011;  
 363 Shi et al., 2013; Ahn et al., 2013; Li et al., 2014a; AlSanad, 2015). As such, most of the  
 364 findings and suggestions from these studies are generic for GB, requiring validation  
 365 regarding their applicability to the adoption of GBTs. Therefore, conducting a research that is  
 366 specifically focused on the adoption of GBTs, in order to validate the findings of the  
 367 literature review in this context is worthwhile.

### 368 **3. Motivation for this research**

369 Implementation of GBTs is very promising. GBTs have the potential to positively impact  
 370 environmental issues and help local governments achieve sustainable development goals  
 371 (Robichaud and Anantatmula, 2011). Hence, many countries have either already made the  
 372 promotion of GBTs adoption high on government agenda or have plans to do so in the near  
 373 future. Identification of the key issues associated with the adoption activity is essential for  
 374 effective promotion of GBTs. However, is it recognized that research on GBTs adoption

375 issues needs further efforts. Too general issues in previous studies present some limitations  
 376 when applied to the adoption of GBTs in practice. Therefore, the issues that are specific to  
 377 GBTs adoption need to be identified to be more applicable. As such, the most  
 378 critical/important issues also need to be identified and prioritized. When this initiative is  
 379 accomplished and fully documented, these issues can be focused on in GBTs promotion.  
 380 Thus, this paper identifies the major issues that influence GBTs adoption to help promote  
 381 GBTs adoption in the future.

#### 382 4. Research methodology

383 This study adopts literature review and a questionnaire survey as its main method of data  
 384 collection. The research approach is presented in Fig. 1. In order to achieve the research  
 385 objectives, this study also conducts ranking, *t*-test, and concordance analyses using the SPSS  
 386 20.0 statistical package.

387

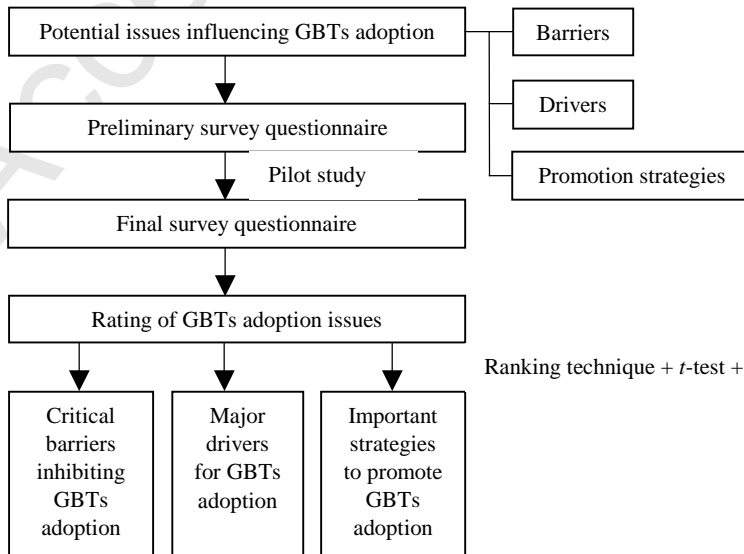
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391

392 Literature review



393 Survey

394 Pilot study

395 Final survey questionnaire

396 Rating of GBTs adoption issues

397 Data analysis

398 Critical barriers inhibiting GBTs adoption

399 Major drivers for GBTs adoption

Important strategies to promote GBTs adoption

Ranking technique + *t*-test + concordance analysis

400 **Fig. 1.** Research framework

401 *4.1. Questionnaire design*

402 As a systematic technique of data collection, the questionnaire survey method has been  
403 widely used to solicit professional opinions on the issues influencing the adoption of various  
404 innovations in construction management research (Rahman, 2014; Mao et al., 2015).  
405 Specifically, in the GB literature also, questionnaire survey has been a popular method to  
406 examine the issues influencing the adoption of green innovations (Lam et al., 2009; Andelin  
407 et al., 2015). Thus, to examine the issues influencing the adoption of GBTs in the  
408 construction industry, a questionnaire survey was carried out. Based on the literature review  
409 discussed above, a questionnaire was designed to solicit professional opinions from  
410 international GB experts. The questionnaire was composed of three parts. The first part  
411 explained the research objectives and presented contact details. The second part was designed  
412 to collect background information regarding the experts' position, profession, years of  
413 experience, nature of experience, country of origin, and whether they had been involved in  
414 activities related to the adoption of GBTs. The third part consisted of a list of potential  
415 barriers to the adoption of GBTs (see Table 1), a list of potential drivers for adopting GBTs  
416 (see Table 2), and a list of potential strategies to promote the adoption of GBTs (see Table 3).  
417 The experts were requested to evaluate the degree to which each factor was a critical barrier  
418 to GBTs application using a five-point scale (1 = not critical and 5 = very critical). In terms  
419 of the main drivers for implementing GBTs, the experts were asked to express their  
420 professional opinions using a five-point scale (1 = strongly disagree and 5 = strongly agree).  
421 Finally, the experts were asked to rate the importance of various strategies according to their  
422 roles in promoting the adoption of GBTs using a five-point scale (1= not important and 5 =  
423 very important). The five-point Likert scale was selected, because it gives unambiguous  
424 results that are easy to interpret (Ekanayake and Ofori, 2004). Prior to the questionnaire

425 survey, a pilot study was conducted to test the comprehensiveness and relevance of the  
426 questionnaire (Li et al., 2011). The pilot study involved three professors, a senior lecturer,  
427 and a postgraduate researcher who were experienced in this research area. The questionnaire  
428 was finalized based on feedbacks from the pilot study.

#### 429 *4.2. Data collection*

430 The questionnaire was distributed by email to carefully selected international GB experts  
431 (both practitioners and academics), who were identified mainly through research publications  
432 and databases (member directories) of worldwide GB councils. This study adopts Cabaniss's  
433 (2002, p. 42) definition of an expert: "an expert is someone with special skills or knowledge  
434 evidenced by his/her leadership in professional organizations, holding office in professional  
435 organizations, presenter at national conventions, published in recognized journals, etc."  
436 Therefore, the suitability of the initially identified experts was determined based on their  
437 basic knowledge and understanding of use of green innovations in the construction industry,  
438 evidenced by their relevant GB research publications (to respect the anonymity of the experts,  
439 examples of the publications are not given) and/or registration as accredited green  
440 professionals with recognized GB councils (such as USGBC, Green Building Council  
441 Australia, U.K. Green Building Council, Canada Green Building Council, and World Green  
442 Building Council). All questionnaires were sent out to the experts, attaching a Microsoft  
443 Word file and a web link (to allow online responses), and a request for them to forward the  
444 questionnaire to their colleagues or to other experts that they know also have basic  
445 knowledge of the issues to be assessed. Due to this approach to sample data collection  
446 (similar to Rahman, 2014), the exact number of distribution is unknown; however, more than  
447 500 questionnaires were sent out. In order to encourage participation, the experts were  
448 informed in the survey questionnaire that the outcomes can be shared with them (Li et al.,  
449 2011). Due to resource constraints, it was difficult to produce different language versions of

450 the questionnaire, so only an English version of the questionnaire was used for the survey  
451 based on the assumption that most of the selected experts could read, write, and understand  
452 English.

453 The survey collected 104 valid responses concerning GBTs application from GB experts  
454 around the world. Of these 104 responses, the majority (i.e., 33 responses) was received from  
455 the US. The current study is based on only the 33 responses from the US. These 33 responses  
456 were adequate compared with previous GB-related studies (e.g., 30 in Hwang and Ng (2013)  
457 and Zhoa et al. (2016), and 31 in Hwang and Tan (2012)). In the general construction  
458 management literature, with 25 experts, Mostaan and Ashuri (2016) determined and analyzed  
459 the major challenges and enablers for highway PPPs in the US. Moreover, as the central limit  
460 theorem holds true with a sample size higher than 30, statistical analysis could still be  
461 conducted (Ott and Longnecker, 2001; Ling et al., 2009).

462 The experts' profiles indicated that 13 (39.4%) of the experts were senior managers, 10  
463 (30.3%) were directors/CEOs, and the remaining 10 (30.3%) held other positions, such as  
464 professor, project manager, sustainability advisor, and senior technologist, in their  
465 organizations. With the professional background of the experts, those who identified  
466 themselves as architects (12, 36.4%) and engineers (12, 36.4%) formed the majority,  
467 followed by town planners (3, 9.1%). Of the total number of 33 experts, 13 (39.4%) had more  
468 than 15 years of experience in GB, 7 (21.2%) had 11 to 15 years of experience, another 7  
469 (21.2%) had 6 to 10 years of experience, and only 6 (18.2%) had 1 to 5 years of experience.  
470 Furthermore, all of the experts had been involved in activities related to adoption of GBTs  
471 before, with 25 (75.8%) of them having direct experience in GB projects.

472 In order to measure internal consistency among the various factors to assess the reliability  
473 of the five-point scales, Cronbach's alpha coefficient was used. The values of this study's  
474 tests were 0.912 (for barriers), 0.878 (for drivers), and 0.844 (for promotion strategies),

475 which were all greater than the threshold of 0.7, indicating that the measurements using the  
476 five-point scales were reliable at the 5% significance level (Nunnally, 1978). Hence, the  
477 collected sample can be treated as a whole, and suitable for further ranking, *t*-test, and  
478 concordance analyses (Mao et al., 2015) in the following sections.

#### 479 4.3. Data analysis

480 The mean score ranking technique has been widely used in previous GB-related studies to  
481 rank and determine the key factors among several individual factors (Manoliadis et al., 2006;  
482 Chan et al., 2009). It is a suitable method for testing the criticality and  
483 importance/significance of factors (Cheng and Li, 2002; Chan et al., 2003). There are papers  
484 that expound specific details about the method and its mathematical background (Holt, 1997;  
485 Ekanayake and Ofori, 2004). In this study, the mean score method is used to prioritize  
486 barriers, drivers, and promotion strategies of GBTs adoption, as perceived by the experts.  
487 Where two or more factors happen to have the same mean score, the factor with the lowest  
488 standard deviation (SD) was assigned the higher rank (Mao et al., 2015). The one-sample *t*-  
489 test was used to ascertain whether the mean score of each factor was significant or not (Zhao  
490 et al., 2016; Rahman, 2014).

491 The nonparametric test, Kendall's coefficient of concordance (also known as Kendall's  
492 *W*) is a coefficient index for ascertaining the overall agreement amongst sets of rankings  
493 (Chan et al., 2009). Before the statistical analyses, Kendall's concordance analysis was  
494 performed to check whether the experts were consistent or not in ranking the various factors  
495 in the survey questionnaire (Siegel and Castellan, 1988). The value of Kendall's *W* ranges  
496 from 0 to +1, where a value of 0 indicates "no agreement" within the group on the ranking of  
497 a particular set of factors, and +1 indicates "complete agreement". In this study, Kendall's *W*,  
498  $W_{\text{barriers}}$ ,  $W_{\text{drivers}}$ , and  $W_{\text{promotion strategies}}$ , were 0.269, 0.232, and 0.130, respectively (see Tables 4  
499 to 6). It is recommended that, since the number of factors ranked in all cases were more than

500 7 ( $N > 7$ ) and with large sample size ( $> 20$ ), the significance of an observed  $W$  should be  
501 determined by referring to the approximate distribution of Chi-Square ( $X^2$ ) with  $N-1$  degrees  
502 of freedom (df) (Siegel and Castellan, 1988). In the present study,  $X^2_{\text{barriers}} = 221.641$ ,  $df = 25$ ;  
503  $X^2_{\text{drivers}} = 152.940$ ,  $df = 20$ ; and  $X^2_{\text{promotion strategies}} = 47.260$ ,  $df = 11$ , all of which have  
504 probability of occurrence under  $p < 0.001$ , indicating that there exists a good agreement  
505 among the experts regarding the rankings of the barriers to, drivers for, and strategies for  
506 promoting the adoption of GBTs.

## 507 **5. Survey results**

### 508 *5.1. Ranking of barriers inhibiting the adoption of GBTs*

509 The experts were requested to rate the criticality of 26 factors in hindering the adoption of  
510 GBTs. The results of the experts' perceptions are shown in Table 4. The  $t$ -test of the means  
511 indicates that 15 out of the 26 factors were considered significant or critical in GBTs  
512 implementation. The first, as ranked by the experts, is "resistance to change from the use of  
513 traditional technologies" (mean = 4.24), which is thus deemed as the most critical barrier  
514 inhibiting the adoption of GBTs in the US construction market. It is also noted that this is the  
515 only barrier with mean score above 4.00. "Lack of knowledge and awareness of GBTs and  
516 their benefits" and "higher costs of GBTs" have the same mean scores. However, the SD of  
517 "lack of knowledge and awareness of GBTs and their benefits" is 0.740, which is lower than  
518 that of "higher costs of GBTs," which is 1.166. Therefore, "lack of knowledge and awareness  
519 of GBTs and their benefits" (mean = 3.88, SD = 0.740) is ranked second, and "higher costs of  
520 GBTs" (mean = 3.88, SD = 1.166) is ranked as the third most critical barrier. The fourth- and  
521 fifth-ranked barriers are "lack of GB expertise/skilled labor" (mean = 3.73) and "lack of  
522 government incentives/supports for implementing GBTs" (mean = 3.67), respectively. It is  
523 interesting to note that "implementation of GBTs is time consuming and causes project  
524 delays" (mean = 2.55, rank 24) was ranked very low as a barrier to applying GBTs. This is in

525 contrast with what has been previously reported by other researchers (Lam et al., 2009;  
 526 Hwang and Ng, 2013; Shi et al., 2013), that time is a crucial barrier to the adoption of green  
 527 innovations.

528 **Table 4**

529 Ranking of barriers inhibiting the adoption of GBTs, *t*-test, and test of concordance.

Code	Frequency of responses					Mean	SD	Rank	Significance <sup>a</sup>
	1	2	3	4	5				
b14	0	1	2	18	12	4.24	0.708	1	0.000
b04	0	2	5	21	5	3.88	0.740	2	0.000
b01	1	4	6	9	13	3.88	1.166	3	0.004
b03	0	3	6	21	3	3.73	0.761	4	0.000
b05	2	4	5	14	8	3.67	1.164	5	0.007
b22	2	3	6	17	5	3.61	1.059	6	0.002
b02	1	5	8	11	8	3.61	1.116	7	0.000
b18	0	6	10	12	5	3.48	0.972	8	0.002
b09	1	3	13	13	3	3.42	0.902	9	0.011
b12	1	5	13	8	6	3.39	1.059	10	0.040
b06	1	3	15	12	2	3.33	0.854	11	0.501*
b07	1	4	16	10	2	3.24	0.867	12	0.338*
b23	2	6	13	8	4	3.18	1.074	13	0.118*
b21	0	10	12	8	3	3.12	0.960	14	0.032
b11	2	8	8	14	1	3.12	1.023	15	0.474*
b25	3	7	9	11	3	3.12	1.139	16	0.545*
b15	2	11	6	9	5	3.12	1.219	17	0.609*
b17	1	9	12	8	3	3.09	1.011	18	0.572*
b10	4	6	12	7	4	3.03	1.185	19	0.521*
b19	1	8	18	5	1	2.91	0.805	20	0.013
b16	2	10	15	3	3	2.85	1.004	21	0.884*
b20	2	15	10	6	0	2.61	0.864	22	0.392*
b26	8	8	8	7	2	2.61	1.248	23	0.079*
b13	5	12	11	3	2	2.55	1.063	24	0.020
b24	8	8	12	4	1	2.45	1.092	25	0.007
b08	10	14	6	2	1	2.09	1.011	26	0.000
Kendall's <i>W</i> <sup>b</sup>						0.269			
Chi-Square						221.641			
df						25			
Level of significance						0.000			

530 Note: <sup>a</sup> ‘\*’ Data with insignificant results of one-sample *t*-test ( $p > 0.05$ ) (2-tailed); <sup>b</sup> Kendall's Coefficient of  
 531 Concordance test on the barriers among the experts.

532

### 533 5.2. Ranking of drivers for adopting GBTs

534 The experts were also asked to rank the major drivers for implementing GBTs. The  
 535 results are summarized in Table 5. The significance levels from *t*-test analysis show that only  
 536 one out of the 21 factors rated by the experts is insignificant. Moreover, the mean scores of  
 537 all the factors are above 3.00 (the average of the rating scale). These results suggest that,  
 538 overall, the factors considered in this study play important roles in driving the adoption of



539 GBTs in the construction industry. As shown in Table 5, “greater energy-efficiency” (mean =  
 540 4.64) is ranked first, suggesting that energy saving, along with reduced CO<sub>2</sub> emissions, was  
 541 perceived as the prime reason for deciding to apply GBTs. The experts agreed that the second  
 542 major driver is “greater water-efficiency” (mean = 4.33), followed by “company image and  
 543 reputation/marketing strategy” (mean = 4.18), “improved occupants’ health, comfort, and  
 544 satisfaction” (mean = 4.15), “reduced environmental impact” (mean = 4.12), “reduced whole  
 545 lifecycle costs” (mean = 4.09), “attract premium clients/increased building value” (mean =  
 546 4.06), “better indoor environmental quality” (mean = 4.03), and “high rental returns and  
 547 increased lettable space” (mean = 4.00). The least ranked driver is “efficiency in construction  
 548 processes and management practices” (mean = 3.09).

549 **Table 5**  
 550 Ranking of drivers for adopting GBTs, *t*-test, and test of concordance.

Code	Frequency of responses					Mean	SD	Rank	Significance <sup>a</sup>
	1	2	3	4	5				
d02	0	0	0	12	21	4.64	0.489	1	0.000
d03	0	0	3	16	14	4.33	0.646	2	0.000
d08	0	0	5	17	11	4.18	0.683	3	0.000
d04	0	0	4	20	9	4.15	0.619	4	0.000
d06	0	1	7	12	13	4.12	0.857	5	0.000
d01	1	2	3	14	13	4.09	1.011	6	0.000
d12	0	0	7	17	9	4.06	0.704	7	0.000
d07	0	0	10	12	11	4.03	0.810	8	0.000
d11	0	0	9	15	9	4.00	0.750	9	0.000
d09	0	1	7	17	8	3.97	0.770	10	0.000
d05	0	4	8	10	11	3.85	1.034	11	0.000
d14	0	4	7	19	3	3.64	0.822	12	0.000
d17	0	3	11	14	5	3.64	0.859	13	0.000
d10	0	2	12	16	3	3.61	0.747	14	0.000
d18	0	6	5	19	3	3.58	0.902	15	0.001
d15	0	7	7	13	6	3.55	1.034	16	0.005
d19	0	6	10	11	6	3.52	1.004	17	0.006
d21	0	9	8	9	7	3.42	1.119	18	0.037
d13	0	6	11	13	3	3.39	0.899	19	0.017
d16	0	8	7	18	0	3.30	0.847	20	0.048
d20	0	8	14	11	0	3.09	0.765	21	0.501*
Kendall's <i>W</i> <sup>b</sup>						0.232			
Chi-Square						152.940			
df						20			
Level of significance						0.000			

551

552 *5.3. Ranking of strategies to promote GBTs adoption*

553 Table 6 summarizes the results on the relative importance of strategies to promote the  
 554 adoption of GBTs among construction stakeholders. First, a total of 12 promotion strategies  
 555 were examined in the survey, and the *t*-test of the means indicates that all of the strategies had  
 556 significant importance. The experts believed that the six most important strategies are  
 557 “financial incentives and further market-based incentives” (mean = 4.30), “availability of  
 558 better information on cost and benefits of GBTs” (mean = 4.21), “green labelling and  
 559 information dissemination” (mean = 4.00), “mandatory GB codes and regulations” (mean =  
 560 3.97), “a strengthened GB technology research and education, and communication of new  
 561 technologies” (mean = 3.88), and “educational programs for developers, contractors, and  
 562 policy makers related to GBTs” (mean = 3.88).

563 **Table 6**  
 564 Ranking of strategies to promote GBTs adoption, *t*-test, and test of concordance.

Code	Frequency of responses					Mean	SD	Rank	Significance <sup>a</sup>
	1	2	3	4	5				
p01	0	1	1	18	13	4.30	0.684	1	0.000
p09	0	2	5	10	16	4.21	0.927	2	0.000
p03	0	2	7	13	11	4.00	0.901	3	0.000
p02	0	3	4	17	9	3.97	0.883	4	0.000
p12	0	1	7	20	5	3.88	0.696	5	0.000
p08	0	2	6	19	6	3.88	0.781	6	0.000
p05	0	5	9	9	10	3.73	1.069	7	0.000
p10	0	2	13	14	4	3.61	0.788	8	0.000
p07	0	5	8	15	5	3.61	0.933	9	0.001
p04	0	6	7	17	3	3.52	0.906	10	0.003
p11	0	4	13	11	5	3.52	0.906	10	0.003
p06	0	9	8	11	5	3.36	1.055	12	0.036
Kendall's <i>W</i> <sup>b</sup>						0.130			
Chi-Square						47.260			
df						11			
Level of significance						0.000			

565

## 566 6. Findings and discussion

567 GB represents a comprehensive mission in the construction industry that incorporates the  
 568 accomplishment of environmental stewardship, social responsibility, and economic  
 569 prosperity. To help accelerate the adoption of GBTs, this study identifies and examines the  
 570 major barriers, drivers, and promotion strategies of GBTs adoption by analyzing the

571 professional views of GB experts from the US. The ranking of these issues would enable  
572 stakeholders, especially policy makers, to understand key areas wherein future GB/policy  
573 initiatives are necessary to encourage wider uptake of GBTs. The following sections discuss  
574 the findings of the study. In this study, the promotion strategies work alongside the drivers to  
575 overcome the barriers. This study uses a pathway to examine the adoption activity, starting  
576 with the barriers and finally arriving at the promotion strategies, which is a more useful way  
577 to better understand the variety of issues influencing GBTs adoption than analyzing the issues  
578 individually (Aktas and Ozorhon, 2015). Due to the space/word limitation, the following  
579 discussions give priority to the top-ranked factors in the results highlighted in the previous  
580 sections. The findings are also compared with the findings reported in the broad literature  
581 concerning the adoption of green innovations.

#### 582 *6.1. Barriers*

583 There remain barriers to the successful and widespread adoption of GBTs in the US. The  
584 survey results indicate that ‘resistance to change from the use of traditional technologies’  
585 (ranked first) was perceived to be the most critical barrier. This finding is consistent with the  
586 previous study by Du et al. (2014) concerning the adoption of energy-saving technologies in  
587 the Chinese construction industry. Resistance from stakeholders can be detrimental to the  
588 ultimate success of GBTs implementation. By nature, human beings are resistant to change,  
589 and this can be particularly true in the construction industry wherein liability is a serious  
590 issue (DuBose et al., 2007). The US construction industry is often known to be an innovation  
591 laggard. Due to its size, fragmentation, diversity, and low investments in research and  
592 demonstration, the construction industry is characterized by relatively slow rates of  
593 innovation (USGBC, 2003). Whether due to exogenous or endogenous risks, construction  
594 firms in the US have traditionally resisted innovation (Sanderford et al., 2014). These issues  
595 may explain why resistance to change is considered the most critical barrier inhibiting the

596 adoption of GBTs in the US. Besides, it is true that it is difficult to persuade stakeholders  
597 who are accustomed to traditional technologies to change their mindsets, attitudes, and  
598 behaviors to use GBTs.

599 As a critical barrier to implementing GBTs in the US, 'lack of knowledge and awareness  
600 of GBTs and their benefits' occupied the second position. The high rank of this barrier  
601 supports the findings of previous research that lack of knowledge and understanding from  
602 stakeholders, such as contractors, subcontractors, clients, and structural engineers, is a major  
603 barrier to the adoption of green innovations in the US (Ahn et al., 2013; Rodriguez-Nikl et  
604 al., 2015). Bayraktar and Arif (2013) observed that there were no efforts in the US to create  
605 awareness programs that specifically target GBTs market opportunities among stakeholders.  
606 In practice, non-green thinking still prevails. While GBTs are increasingly capturing the  
607 attention of the construction industry, many stakeholders remain unaware of the wide-ranging  
608 benefits associated with them. The accumulation and sharing of knowledge is crucial to drive  
609 the sustainability agenda in the construction industry (Chong et al., 2009; Love et al., 2012).  
610 Therefore, a lack of knowledge and awareness of GBTs cannot provide sufficient confidence  
611 to encourage most construction stakeholders to adopt GBTs.

612 As expected, 'higher costs of GBTs' was ranked high amongst the barriers to  
613 implementing GBTs in the US; it was ranked as the third most critical barrier by the experts.  
614 The high criticality of cost in inhibiting the widespread adoption of GBTs is supported by the  
615 literature (Zhang et al., 2011a, b). Although many GBs can be built at comparable or even  
616 lower cost than non-GBs (Kats, 2003), GB demands the use and integration of new and  
617 innovative green technologies that usually cost more than their non-green counterparts,  
618 making stakeholders hesitant to implement them. The use of GBTs can increase project cost  
619 by 2-7% (USGBC, 2003). In the construction industry, almost every stakeholder shows  
620 concern about cost in the first instance when considering the application of new technologies

621 and new norms (Shi et al., 2013), which is a very obvious barrier in the field of green  
622 technology. The lack of knowledge and understanding of the real costs and benefits of GBTs  
623 might be one of the key issues exaggerating the concern about cost.

624 Another critical barrier is the ‘lack of GB expertise/skilled labor’ (ranked fourth),  
625 resulting from a shortage of GB education and training efforts in the construction sector. On  
626 the basis of this finding, it can be stated that the number of stakeholders who have expertise  
627 in GBTs in the US is limited. The finding agrees with the literature that lack of technical  
628 knowhow is a barrier to the implementation of green innovations (Tagaza and Wilson, 2004;  
629 Williams and Dair, 2007). Because of the complex nature of most GBTs, insufficient  
630 technical knowledge and expertise in them would greatly hinder their successful  
631 implementation and development. Li et al. (2014b) pointed out that GB knowledge and  
632 experience is the most important organizational factor to implement GBTs on construction  
633 projects. Hence, more technically competent stakeholders who are experienced and well  
634 versed with currently available GBTs are needed to move forward with the application of  
635 GBTs in the US.

636 The fifth ranked barrier was ‘lack of government incentives/supports for implementing  
637 GBTs’, which provides evidence that this barrier was emphasized by the experts, as they see  
638 insufficient support for the development of GBTs in the US. Lack of government incentives  
639 is reported as a major barrier to the implementation of green innovations in other studies as  
640 well (Love et al., 2012; Zhang et al., 2012). Stakeholders would like to see policy makers’  
641 and advocates’ direct intervention in the GBTs market in the form of more effective  
642 incentives to support their implementation of GBTs. Reasonable incentives can motivate  
643 market stakeholders to pursue GBTs. In the US, some states and local governments provide  
644 incentives, such as tax credit, expedited permits, and density bonus, to encourage the  
645 adoption of GBTs among construction stakeholders. These states and local governments have

646 tried to prove that even modest incentives can stimulate market interest in GBTs by offsetting  
647 the higher cost (USGBC, 2003). However, if stakeholders cannot receive sufficient  
648 government support, then it would be difficult for them to bear the higher costs of GBTs.  
649 Without sufficient government support, the expected economies of scale in GBTs are difficult  
650 to achieve in the current market mechanism.

651 An interesting finding is that the experts did not perceive ‘implementation of GBTs is  
652 time consuming and causes project delays’ (rank 24) as a highly critical barrier to  
653 implementing GBTs, which did not concur with previous studies, as indicated earlier. It was  
654 expected that time would receive higher criticality amongst the GBTs adoption barriers,  
655 because, for example, it is known that since most current GBTs have yet to be perfected, their  
656 implementation usually causes problems that lead to project delays (Hwang and Ng, 2013).  
657 Moreover, the consideration of GBTs could cause project delays, as more time is often  
658 needed to effectively incorporate all necessary technologies into the green design. This  
659 usually means more involvement, communication, and interactions between different groups  
660 of stakeholders with the requisite knowledge and experience, which could also delay the  
661 project. However, one possible reason why the time-related barrier was ranked very low may  
662 be that integrated design process which allows enough time for feedbacks and revisions on  
663 GB projects (Yudelson, 2009b) helps ensure that sufficient time is allocated for the green  
664 project so that GBTs could be implemented within project schedule, thus making the  
665 schedule delay or time overrun problem decrease in criticality.

## 666 *6.2. Drivers*

667 Despite the existence of barriers in the implementation of GBTs, stakeholders have  
668 several reasons for deciding to use GBTs. ‘Greater energy-efficiency’ was the highest ranked  
669 driver for applying GBTs. This result agrees with that of previous studies on sustainable  
670 construction drivers by Augenbroe and Pearce (2009) and Ahn et al. (2013) in the US, and

671 Manoliadis et al. (2006) in Greece. The finding also agrees with other researchers (Windapo,  
672 2014; Brotman, 2016), who found that rising energy costs is the most important driving force  
673 behind green innovations implementation. Energy efficiency is indeed a high-priority in  
674 many developed countries (Pacheco et al., 2012). In the US, the Department of Energy  
675 (DOE) is one of the well-known government agencies established to ensure the country's  
676 prosperity and security by addressing its energy, environmental, and nuclear challenges  
677 through transformative science and technology solutions (US DOE, 2016). The US DOE  
678 believes that energy efficiency is one of the easiest and most cost effective ways to mitigate  
679 climate change, improve the competitiveness of businesses, improve air quality, and reduce  
680 energy costs. As buildings account for a significant amount of energy use, improving  
681 building energy efficiency is a critical effort to dramatically reduce unsustainable energy needs.  
682 This study suggests that stakeholders place value on the application of GBTs, because it helps  
683 them achieve high energy-efficient buildings. Today, stakeholders are seeking ways to reduce  
684 their energy-related expenditures, recognizing that innovative solutions can reduce energy  
685 use by 25 to 40% (Vanderpool, 2011). Love et al. (2012) established that the most notable  
686 benefit from implementing GBTs is a reduction in energy consumption. Savings in energy  
687 costs of 20-50% are common through the utilization of energy-saving technologies, natural  
688 daylight and ventilation, renewable energy technologies, and light-reflective materials  
689 (USGBC, 2003), which means that stakeholders could reduce their utility bills and thus save  
690 money over a GB's lifecycle. It is true that such an economic benefit can substantially  
691 increase the motivation of stakeholders to take part in GBTs implementation, because  
692 economic benefits are the most essential issues for the business survival of every stakeholder  
693 (Chan et al., 2009).

694 GBs are commonly known to have reduced whole lifecycle cost. This reduced lifecycle  
695 cost can be attributed to savings on water and energy, typically 30 to 50% (Yudelson, 2008),

696 made possible through proper integration and performance of innovative green technologies.  
697 Therefore, just after greater energy-efficiency, ‘greater water-efficiency’ was ranked by the  
698 experts as the second major driver for implementing GBTs. GBTs such as permeable surface  
699 technology, water reuse and water-saving appliances minimize impacts on water quality to  
700 gain water efficiency (Zhang et al., 2011a).

701 The results of this study provide evidence that the third major driving force behind the  
702 adoption of GBTs is ‘company image and reputation/marketing strategy’. This finding has  
703 been supported by the literature (Andelin et al., 2015; Zhang et al., 2015). In this modern  
704 competitive business environment, establishing a good image and reputation has become  
705 crucial for companies’ survival. This study suggests that construction stakeholders see the  
706 adoption of GBTs as a wise decision to enhance their reputation and gain competitive  
707 advantages such as market differentiation. Employing GBTs could improve the public  
708 reputation and image of stakeholders, because it is a helpful way to develop GBs that  
709 contribute to improving public health. The good public reputation and image can translate  
710 into marketing benefits for the company adopting GBTs, especially when customers demand  
711 for green living environments and energy-efficient buildings. Thus, companies that build  
712 green can attract high-income buyers with higher sales price (Zhang et al., 2011b). Therefore,  
713 as most stakeholders, e.g., developers, act as “rational economic men” who pursue profit  
714 (Mao et al., 2015), GBTs could be attractive to them.

715 As ranked by the experts, other highly ranked motivations for engaging in the  
716 implementation of GBTs include ‘improved occupants’ health, comfort, and satisfaction’,  
717 ‘reduced environmental impact’, ‘reduced whole lifecycle costs’, ‘attract premium  
718 clients/increased building value’, ‘better indoor environmental quality’, and ‘high rental  
719 returns and increased lettable space’, all of which are commonly known benefits associated  
720 with GB and it is comforting to note that the industry appreciate that they could help drive the



721 adoption of GBTs. Advocates should take time to come up with strategies to widely promote  
722 these drivers in society in order to influence the interest people have in GBTs.

723 'Efficiency in construction processes and management practices' was ranked as the least  
724 important driver for adopting GBTs. This may be because the adoption of GBTs may not  
725 automatically improve the efficiency of the construction process; other management  
726 approaches may be required for process efficiency.

### 727 *6.3. Promotion strategies*

728 Various strategies are required to overcome the barriers affecting the adoption of GBTs,  
729 for successful and widespread adoption. This study has explored the most important  
730 strategies to promote the adoption of GBTs. The GB experts from the US perceived 'financial  
731 incentives and further market-based incentives' as the most important promotion strategy.  
732 This result agrees with Mulligan et al. (2014), who found that increased incentives was the  
733 greatest opportunity to increase the adoption of GB in the US. Incentive schemes are  
734 measures to promote green innovations and increase the motivation of stakeholders to meet  
735 higher standards (Qian et al., 2016). Financial and further market-based incentives are of  
736 great importance to GBTs adoption promotion, because of the compensation they provide to  
737 stakeholders who implement GBTs. Thus, as an economic support, incentives provided by  
738 local governments or financial institutions serve to compensate stakeholders for the  
739 additional cost and/or efforts that may be required to incorporate GBTs into their projects.  
740 Such an economic support can greatly influence GB project funding (Zhang, 2015) and thus  
741 can have a significant impact on the development of GBTs in a country. Given that most  
742 stakeholders are mainly concerned with profit, the higher costs of GBTs present a  
743 considerable loss of money. Therefore, cost reduction strategies or strategies to reduce cost  
744 burden for stakeholders could accelerate the adoption of GBTs. As cost is one of the main  
745 reasons for stakeholders to be reluctant to innovate, the provision of more attractive and

746 encouraging incentives could not only be a solution to the lack of incentives and higher cost  
747 barriers, but also to the resistance to change which has become the most critical barrier to the  
748 adoption of GBTs (see Table 4). The government and other public policy makers should pay  
749 a more careful attention to incentive programs in GBTs adoption promotion. The findings of  
750 this study suggest that the related incentives, allowances, and tax credits can stimulate  
751 demand for GBTs, but to speed up the adoption process, the government needs to reinforce  
752 incentive policies. More incentive schemes could be provided in every state to create a more  
753 supportive environment for GBTs implementation to flourish. Such incentives should apply  
754 to both residential and commercial markets and to all groups of stakeholders who patronize  
755 GBTs, ranging from developers to customers or tenants. If this is not taken into  
756 consideration, then widespread adoption of GBTs would remain a challenge.

757 The second rank of 'availability of better information on cost and benefits of GBTs'  
758 implies that the experts attached great importance to this promotion strategy, as information  
759 is essential for the acquisition of relevant knowledge and for the creation of public awareness  
760 and acceptance (Rogers, 2003). According to Potbhare et al. (2009), availability of better  
761 information on cost and benefits of GB guidelines was the most important strategy to catalyze  
762 the adoption of GB guidelines in India. In the construction industry, stakeholders who have  
763 easy access to information are keener on adopting energy-efficient technologies (Pinkse and  
764 Dommissse, 2009). This study confirms that the provision of relevant information concerning  
765 GBTs and their benefits to the public is crucial to create market demand. In the US, although  
766 information regarding GBTs exists within some states and local governments and federal  
767 agencies, it is often difficult to find. To catalyze the adoption of GBTs, advocates can  
768 develop stronger advertising and communication strategies that make good and maximum use  
769 of available research studies, fact sheets, and documentations demonstrating the 'big picture'  
770 benefits of GBTs. GBTs information should be disseminated more widely and released in

771 ways that are readily accessible and helpful. A comprehensive national database of GBTs and  
772 their benefits would be valuable for promoting GBTs adoption. An increased public  
773 awareness of the sustainability benefits of GBTs could help stakeholders overcome the  
774 concern about cost and be more willing to adopt GBTs.

775 'Green labelling and information dissemination' was ranked as the third most important  
776 strategy to further the application of GBTs in the US. This reinforces the argument of Qian  
777 and Chan (2007, 2010) that green labelling and information dissemination is an essential  
778 government measure to promote building energy-efficiency/GB. Aktas and Ozorhon (2015)  
779 asserts that it is nearly impossible for stakeholders to successfully implement green  
780 innovations without any guidance or support. They believe that a local rating system could  
781 help overcome this problem. Today, there are many GB rating systems and labelling  
782 programs in the US that provide useful information on GB to the public, including systems at  
783 the national, regional, and state levels, such as LEED, ENERGY STAR, Green Seal, and  
784 Green Globes. These rating systems have been instrumental in mainstreaming GB  
785 development, and the experts agreed that they are important to promote the adoption of  
786 GBTs. Sustainability in the construction industry is often measured by the level of, for  
787 instance, LEED certification issued by the USGBC. Hence, much of the popularity gained by  
788 GBTs in the US can be credited to the introduction of the GB concept by the USGBC through  
789 its LEED rating system in 1993 (Karakhan, 2016). Since its introduction, the LEED rating  
790 system has been applied increasingly on public and private projects nationally and  
791 internationally. One advantage of LEED is that it creates a brand that is attractive to  
792 stakeholders, helping make GBTs more attractive (Rodriguez-Nikl et al., 2015). Although the  
793 LEED program is a voluntary rating system, some states, local jurisdictions, and federals  
794 mandate its application on projects they fund. This mandate may explain the relatively high  
795 concentration of GBTs application in states like Washington (Center for Construction

796 Research and Training (CPWR), 2013). Therefore, mandating the use of LEED on more  
797 public and private projects would increase the rate of adoption of GBTs.

798 Having an efficient legal framework is a key factor in successful GBTs implementation.  
799 Gann and Salter (2000) argued that government regulatory policies have strong influence on  
800 demand and on the direction of technological innovations. Endorsement of a GBT by the  
801 government can accelerate its maturity in a country. Even though the high rank of ‘mandatory  
802 GB codes and regulations’ (ranked fourth) clearly shows that mandatory government policies  
803 play a crucial role in promoting the implementation of GBTs, it is surprising to find that this  
804 promotion strategy which forces GBTs adoption was not ranked as the most important  
805 strategy to promote GBTs adoption in the US. One possible explanation for this is that the  
806 respondents may have been GB experts who showed more concern about financial support  
807 (economic issue). This result is not consistent with Chan et al. (2009), who claimed that  
808 mandatory government regulation is the most essential means to promote the GB market. The  
809 study provides evidence that governmental initiatives in the form of policies and regulations  
810 are important to drive stakeholders to take relevant actions for GBTs adoption. In the US,  
811 while the federal government has played a critical role in promoting green innovations, much  
812 of the push for green innovations comes from state legislatures. Legislators from states  
813 around the US have considered using mandatory policies and regulation to promote green  
814 innovations. In the state of Michigan, for example, Mulligan et al. (2014) have recognized  
815 some of the recent GB policies. Korkmaz (2007) found that strict local codes and regulations  
816 are playing important roles in promoting green innovations in states like Washington and  
817 California. To further the use of GBTs, the government should regularly monitor, assess, and  
818 strengthen state policies to maximize their effectiveness at promoting GBTs implementation.

819 The results of this study also indicate that ‘a strengthened GB technology research and  
820 education, and communication of new technologies’ and ‘educational programs for

821 developers, contractors, and policy makers related to GBTs' are the fifth and sixth important  
822 strategies to promote the adoption of GBTs, respectively. These results suggest that greater  
823 GBTs research, education, and training efforts are pivotal for continuous promotion of GBTs  
824 adoption in the US. Increasing funding for GBTs research would help to further promote the  
825 adoption of GBTs. To help solve the high cost problem, robust scientific researches and  
826 analyses – based on lifecycle costing – can be conducted to quantify the real costs of and  
827 benefits resulting from implementing GBTs. Comprehensive and accurate economic tools can  
828 be adopted to assist this quantification, which should be capable of educating stakeholders to  
829 better comprehend the concept of 'total cost of ownership' over the lifecycle of a building  
830 and convince them that, although the initial investment may be high, investing in GBTs is a  
831 good and fruitful business practice. The presence of GBTs education and training champions  
832 who could help build the knowledge of stakeholders on current GBTs on the market, their  
833 system performance, and benefits can also catalyze the adoption of GBTs.

## 834 **7. Conclusions and future research**

835 It is projected that the adoption of GBTs in the construction industry will continue to  
836 grow in the future. This study investigates the major issues influencing the adoption of GBTs  
837 from the perspectives of US GB experts. Thus, given the limited empirical studies on issues  
838 influencing GBTs adoption, the present study contributes to the body of knowledge by  
839 identifying the issues that are primary for the US GBTs market stakeholders. It is concluded  
840 that several issues influence and shape GBTs implementation. A wide range of barriers,  
841 drivers, and promotion strategies of GBTs adoption were identified and examined by using a  
842 combination of research methods, including literature review and a questionnaire survey. The  
843 issues influencing GBTs adoption were further analyzed by using ranking technique, thus  
844 providing a clear understanding of the key issues that are worthwhile to pay more attention to  
845 in GBTs adoption promotion efforts.

846 This study examined 26 barriers, 21 drivers, and 12 promotion strategies from the  
847 perspectives of GB experts. 15 out of the 26 barriers were recognized as critical barriers to  
848 the use of GBTs, with the most critical barrier being resistance to change from the use of  
849 traditional technologies, followed by a lack of knowledge and awareness of GBTs and their  
850 benefits, and higher costs of GBTs. With respect to the GBTs adoption drivers, 20 out of the  
851 21 drivers were recognized as significant drivers, with the top three drivers being greater  
852 energy-efficiency, greater water-efficiency, and company image and reputation/marketing  
853 strategy. All of the 12 promotion strategies of GBTs adoption were recognized as  
854 significantly important strategies, with the most important strategy being providing financial  
855 and further market-based incentives, followed by availability of better information on cost  
856 and benefits of GBTs, and green labelling and information dissemination. The results of this  
857 study display a consensus of rankings amongst the GB experts, as verified by the Kendall's  
858 coefficient of concordance. While the identified barriers were cited in this study as barriers  
859 that inhibit the implementation of GBTs, most of them could be offset or otherwise overcome  
860 by taking advantage of the identified drivers and promotion strategies.

861 This study's results are expected to contribute information valuable for policy-making in  
862 the construction industry and in the implementation of GBTs in the future. The findings  
863 contribute to deepened understanding of the major issues that influence GBTs  
864 implementation. The results are relevant for the US GBTs market, but might also be useful  
865 for policy makers in other countries. Moreover, foreign entities attempting to develop GBs  
866 and thus use GBTs in the US could learn lessons from the opinions of local GB experts who  
867 have had some years of experience in the adoption of GBTs.

868 There are some limitations of this study that warrant future research attention. First,  
869 although the sample size was adequate to conduct statistical analysis, it is appreciated that it  
870 is nevertheless a relatively small sample. Future research is required to employ a larger

871 sample to see whether the results would differ from what have been reported in this paper.  
872 Second, future research could use more advanced statistical analysis techniques, e.g.,  
873 structural equation modelling, to verify the exact influences of the specific factors on the  
874 adoption of GBTs. Lastly, future study could compare the views of GB experts from different  
875 countries on the GBTs adoption issues to observe market-specific differences.

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1203 **Highlights**

1204  Critical barriers inhibiting green building technologies adoption are investigated.

1205  Major drivers for adopting green building technologies are investigated.

1206  Important strategies to promote green building technologies adoption are investigated.

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