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What are the green technologies for sustainable housing development? An empirical study in Ghana

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Abstract

The housing industry is a major contributor to global climate change, environmental pollution, and resource depletion. The adoption of green technologies in housing development is a way to realize sustainable development goals. This research aims to identify the green technologies that are important to achieve sustainable housing development, in particular Accra, Ghana. Due to differences in climate, focusing on Accra helps validate the findings of this study. To achieve the objective, 28 green technologies were identified from a comprehensive literature review, and a questionnaire survey was done with 43 professionals with green building experience. The results indicated that application of natural ventilation, application of energy-efficient lighting systems, optimizing building orientation and configuration, application of energy-efficient HVAC system, and installation of water-efficient appliances and fixtures were the five most important green technologies to achieve sustainable housing development. Furthermore, water efficiency technologies and energy efficiency technologies had the highest level of importance. The identified green technologies form a conceptual framework which can be used to guide the identification and selection of green technologies for sustainable housing development. The research findings would be useful for industry professionals responsible for decision making during the design stage of housing developments. Theoretically, this study adds to the literature by presenting one of the first studies in its kind focusing on green technologies for sustainable housing development within the Ghanaian context.

Keywords: Green technologies; Sustainable housing development; Sustainability; Housing industry; Warm climate; Ghana.

1. Introduction

It is widely accepted that the construction industry plays an important role in socio-economic development. For example, according to the United Nations Environment Programme (UNEP) (2009), the construction industry contributes 10–40% of the world's gross domestic product (GDP), and represents, on a global average, 10% of country-level employment opportunities. Despite its importance in the global economy, the construction industry has been noted for causing problems that have significant impacts on the environment, economy, and society. These include excessive energy consumption which has a profound impact on greenhouse gas emissions and thus climate change, the depletion of natural and non-renewable resources, the impact on land use and biodiversity, and the impact on human health (Zuo and Zhao, 2014; Fastofski et al., 2017). With a growing public concern about these negative effects associated with construction activities, the practice of developing sustainable or green housing projects has attracted considerable interest from the industrial practitioners and academics (Darko and Chan, 2016).

Because of its large environmental impacts, the construction industry has been considered a key battlefield to promote sustainability by adopting more sustainable building technologies and practices (UNEP, 2009; Zhang, 2014). The sustainability concept is most commonly known in relation to sustainable development (Manoliadis et al., 2006). The World Commission on Environment and Development (WCED) (1987) wrote that "sustainable development is development which meets the needs of the present without compromising the ability of future generations to meet their own needs". While conventional housing projects are featured with huge environmental effects, sustainable housing projects aim to minimize their effects on the environment, enhance the health conditions of occupants and the return on investment to local community and developers, and promote lifecycle considerations during their planning and development process (Robichaud and Anantatmula, 2011). Therefore, sustainable housing development is considered as an inevitable and helpful approach to meet the need for improved building efficiency and sustainability. Sustainable housing development offers a framework for integrating development strategies and environmental policies. It acknowledges that development based on environmentally responsible and efficient use of scarce resources is fundamental to satisfy human requirements and ameliorate life quality (Manoliadis et al., 2006). In short, sustainable housing development is about creating a built environment in which a proper balance is created between environmental, economic, and social objectives (Székely and Knirsch, 2005).

Green technologies are increasingly important to the achievement of sustainable housing development (Zhang et al., 2011a). There is consensus in the literature that employing green technologies in building projects provides a cost-effective option for developers, decision makers, and policy makers aiming to attain long-term building environmental, economic, and social performance improvements (Kingsley, 2008; Zhang et al., 2011b). Several green technologies, such as high efficiency windows, high efficient heating, ventilation, and air-conditioning (HVAC) system, and solar technology, have been introduced in housing projects and then studied in the literature (U.S. Green Building Council (USGBC), 2003; Koebel et al., 2015). Although it is easy to directly select from the pool of green technologies available in the global community, the identification and knowledge of green technologies that are appropriate for any country's context are necessary for the success and effectiveness of implementing and achieving sustainable housing development (Kahraman et al., 2009; Zhang, 2014). Hence, previous studies focused on identifying the green technologies to achieve sustainable housing development in specific countries and regions. For example, Roufechaei et al. (2014) identified the green technologies to achieve sustainable housing development in Esfahan, Iran; Ahmad et al. (2016) identified those to achieve sustainable housing development in Lahore, Pakistan; and Zhang et al. (2011a, b) identified those for sustainable housing development in China. However, as far as the comprehensive literature review is concerned, empirical studies identifying the green technologies to achieve sustainable housing development within the context of Ghana are lacking. It is worth noting that the green building approach is not identical worldwide. According to the World Green Building Council (WorldGBC, 2017), "different countries and regions have a variety of characteristics such as distinctive climatic conditions, unique cultures and traditions, diverse building types and ages, or wide-ranging environmental, economic and social priorities – all of which shape their approach to green building." Therefore, the lack of any green building related research in a particular country or region represents a significant knowledge gap that needs to be addressed.

Given the above background, this study aims to identify the green technologies that are important to achieve sustainability objectives in the design phase of housing developments, particularly in Accra, Ghana. As Koebel et al. (2015) indicated, climate has the greatest influence in decisions relating to the identification and selection of green technologies for sustainable housing development in a particular region – builders build to the local climate. Accordingly, given the differences in climatic conditions in different geographical areas of Ghana (Dickson and Essah, 1988; VIGS-GHANA, 2011), focusing on Accra helps validate the findings of this study (Roufechaei et al., 2014). Accra is the capital city of Ghana, as well as the capital of the Greater Accra Region. The region was selected primarily because vast parts of Ghana have tropical climates owing to their location in the Dahomey Gap, and Accra also has a year-round tropical climate. The tropical climate of Accra means plentiful sunshine (Chan et al., 2009), which causes hot and humid weather, leading to increased energy consumption in the city. Moreover, the Greater Accra region is the most urbanized region in Ghana (Songsore, 2016). In addition, as a coastal city, Accra is vulnerable to the effects of climate change, and rapid population growth exerts more and more pressure on ecological systems and scarce resources (Steynor and Jack, 2015). Furthermore, Accra is one of the largest cities of Ghana in terms of housing, infrastructure, and population (Central Intelligence Agency, 2017). Hence, it is considered that improving the sustainability of housing in Accra will have a significant impact on the Ghanaian construction industry's efforts to contribute to national sustainable development. The sustainability of housing in Accra can be improved through incorporating suitable green technologies into housing design (Assari and Mahesh, 2011). It is therefore crucial to help industry practitioners better understand how or what technologies can be applied to achieve sustainability in housing development. This study is focused on identifying the green technologies in the design stage of housing developments. It contributes to the literature by presenting one of the first studies in its kind focusing on green technologies for sustainable housing development within the Ghanaian context.

1.1. Why focus on housing and the design stage?

As stated by the USGBC (2014), "a home is more than just shelter: homes are the most important buildings in our lives. We think that every building should be a green building – but especially homes". Residential buildings account for a substantial portion of building energy consumption in the world (Kneifel, 2010; Pacheco et al., 2012). For example, in 2015, the commercial and residential sectors were responsible for 41% of the total energy use (including operation and maintenance of buildings) in the US, with residential alone responsible for 23% (US Energy Information and Administration (USEIA), 2016). Other available data show that while office and commercial buildings respectively account for only 1% and 7% of building energy consumption, residential buildings account for 11% (Koebel et al., 2015). Due to the large amount of non-renewable energy consumption, residential buildings also negatively impact the environment and society through significant carbon emissions. For example, in European countries, residential buildings account for 77% of the total carbon emissions from buildings (Petersdorff et al., 2004). On the basis of these facts, it can be said that the housing industry is the primary contributor to the environmental problems that are caused by the construction industry. Therefore, there exists a great potential to contribute to sustainable development by enhancing the overall environmental performance of housing projects using green technologies. The study focusing on the green technologies within the housing industry is thus important.

In Ghana, although the construction industry makes a valuable contribution to the national economic development by contributing approximately 8.2% to GDP per annum and providing employment for 2.3% of the active population (Owusu-Manu and Badu, 2011), it has detrimental environmental effects because of its poor and unsustainable use of resources such as water, energy, and building materials (Twumasi-Ampofo et al., 2014). National energy statistics indicate that during the period from 2005 to 2014, Ghana's residential sector consumed 43% of the country's total energy, higher than that consumed by any other economic sector (Energy Commission of Ghana (ECG), 2015). In addition, a report "Status of VRA's current and future power generation report" by the Volta River Authority (VRA) (the main generator of electricity energy in Ghana) revealed that 62% of the total energy generation is consumed by the residential sector (Owusu-Koranteng, 2015). Ghana has experienced many serious electrical energy supply challenges over the past four decades (1984, 1994, 1998, 2007, and 2012) (Agyarko, 2013), with the electricity sector burdened with challenges vis-à-vis power quality and supply security. Consequently, the country has suffered from massive load shedding from the beginning of 2013 till now (Gyamfi et al., 2017). The increased energy demand in the residential sector could be a main reason for the energy crises, because the Ghanaian electricity sector is characterized by relatively high total energy losses, unreliable, and inadequate supply to meet increasing demand (Gyamfi et al., 2017). To deal with the energy crises, the focus of the energy sector has been to increase the power production by installing additional power plants (Centre for Policy Analysis, 2007). However, the application and promotion of green technologies in housing developments in Ghana can offer a much more promising way of not only dealing with the energy crises, but also achieving a sustainable built environment. From this point of view, Owusu-Koranteng (2015) argued that it is high time for incorporation of green technologies and practices into architectural designs, and solutions to the energy efficiency and sustainability challenges in Ghana should target the housing industry, which is the main motivation for focusing this study on the housing industry.

There are numerous green technologies applicable throughout the whole lifecycle of a housing project, from planning and design to operation and management stages (Zhang et al., 2011a, b). This study is focused on identifying the green technologies in the design stage of housing developments. The sustainability performance of a building is heavily affected by decisions made at the design stage (Dhanjode et al., 2013). While the consideration of green principles is essential at every stage of housing development, the design stage has been recognized as the key stage to start integrating green strategies and technologies (Pacheco et al., 2012; Tsai and Chang, 2012). As Hodges (2005) advocated, it is during the design stage that the designer is well positioned to create a green environment. Hence, in considering environmental issues at the design stage of housing projects, it is crucial that appropriate green technologies are put in place. By so doing, residential energy conservation and overall sustainability can be enhanced and hence better sustainable housing development can be achieved. Therefore, conducting a study to investigate the green technologies to achieve sustainability goals from the early stages of housing development is worthwhile.

2. Literature review

Green technologies are defined as technologies that are incorporated into building design to make the end product sustainable (Ahmad et al., 2016). They include technologies that can help save and even generate energy (Lockwood, 2006; Mokhtar Azizi et al., 2014), those that are water-efficient, and those that are environmentally friendly, providing a good indoor environmental quality and possessing features for improving the economic, social, and environmental performance of a building (Building and Construction Authority of Singapore (BCA), 2016a, b). A better understanding of the green technologies that are important for sustainable housing development is useful both conceptually and to inform sustainable housing design within the industry.

There are various green technologies that have been introduced to achieve sustainability in housing development, and can be found in the literature (Zhang et al., 2011a, b; Roufechaei et al., 2014; Koebel et al., 2015; Ahmad et al., 2016). Some researchers focused on green technologies in the design stage (Roufechaei et al., 2014; Ahmad et al., 2016), whereas others focused on those in the whole lifecycle (Zhang et al., 2011a, b). Moreover, the classifications of green technologies for sustainable housing development in the construction industry vary depending on the views taken by different researchers. For instance, while Zhang et al. (2011a) classified green technologies based on various project objectives (energy efficiency, indoor environmental quality enhancement, materials efficiency, water efficiency, and operations and maintenance optimization), Roufechaei et al.'s (2014) classification was based on designer responsibility (architectural, mechanical, and electrical). After a comprehensive literature review on green technologies for sustainable housing development, this study identified 28 green technologies and, based mainly upon Zhang et al.'s (2011a) and Ahmad et al.'s (2016) classifications of green technologies, grouped them into five major categories, namely energy efficiency technologies (13 technologies), water efficiency technologies (3), indoor environmental quality enhancement technologies (6), materials and resources efficiency technologies (2), and control systems (4), as summarized in Table 1. Although all of these identified green technologies are considered important in the literature, it is certain that relative importance differs (Wong and Li, 2006). A questionnaire survey was performed in this study to obtain professional judgements on the relative importance of these green technologies.

<Insert Table 1 around here>

2.1. Energy efficiency technologies

Achieving energy efficiency is one of the main objectives for implementing certain green technologies in housing development. Constructing, operating, and maintaining a building entail the consumption of energy, which can generally be reduced by adopting energy-efficient technologies. As Yang and Yu (2015, p. 113) defined, "energy-efficient technologies refer to technologies that reduce the amount of energy required to provide goods and services". The comprehensive literature review revealed that the housing industry can achieve higher energy efficiency by applying technologies such as energy-efficient lighting, window, HVAC system, household appliances (e.g., energy-efficient refrigerators, dryers, and washers), renewable energy systems (e.g., wind turbines, solar panels, and ground source (geothermal) heat pumps), building orientation and configuration, and natural ventilation. For example, Zhang et al. (2011a) found that the use of low emissivity (low-E) insulation window technology and solar water heating technology allowed housing developers to achieve improvements in energy efficiency. The research results from Roufechaei et al. (2014) showed that the application of lighting sources to save energy, the application of natural ventilation, and integrative use of natural lighting (daylighting) with electric lighting system were effective technologies that contributed to reducing energy consumption in housing units. Chen et al. (2015) identified solar shading devices, the use of natural light and ventilation, and building orientation optimization as technologies that improve energy efficiency and thus reduce building energy budgets. Doherty et al. (2004), Lee et al. (2007), and Yunna and Ruhang (2013) identified the ground source heat pump as a technology for increasing building energy efficiency. Koebel et al. (2015) also indicated that high efficiency windows had an important impact on energy use in buildings.

2.2. Water efficiency technologies

The fact that sustainable buildings offer reduced whole lifecycle costs has already gained broad acceptance in the construction industry (Darko et al., 2017a, b), and that is most often credited to their potential benefit in energy and water saving. Water-efficient technologies are important as they help reduce the amount of water used in operating a building. Zhang et al. (2011a), Zhang et al. (2013), and Zhang (2014) pointed out that water-saving appliances, decentralized rainwater technology, and gray water systems (water reclamation and reuse) greatly helped to achieve water efficiency in buildings and in low-carbon communities. Ahmad et al. (2016) presented two key technologies for conserving water in sustainable residential buildings, which were rainwater harvesting technology and water-efficient appliances and fixtures. Bond (2011) studied the green technologies incorporated into the design and retrofitting of homes in Australia. The results showed that rainwater harvesting technology was one of the most common and client-preferred water-efficient technologies. Bond (2010) also identified that water-efficient fixtures and fittings were important in designing green buildings in Australia. According to Millock and Nauges (2010), rainwater tanks and the installation of water-efficient appliances (such as water-efficient shower heads and dual flush toilets) are effective technologies for water conservation in households.

2.3. Indoor environmental quality enhancement technologies

Indoor environmental quality enhancement technologies presented in this study refer to the green technologies needed primarily to efficiently complete a housing project which provides a good indoor environment for occupants. According to the literature review, these green technologies include ample ventilation for pollutant and thermal control, application of indoor CO_2 monitoring devices, application of low emission (low-E) finishing materials, optimizing building envelope thermal performance, application of solar chimney for enhanced stack ventilation, and use of efficient type of lighting (lighting output and color). The findings from Zhang et al. (2011a, b) showed that ample ventilation for pollutant and thermal control and optimizing building envelope thermal performance were two of the key indoor environmental quality enhancement technologies applicable in the design stage of sustainable housing development. Similarly, in developing an approach for sustainable housing design, Ahmad et al. (2016) highlighted that the application of solar chimney for enhanced stack ventilation, thermal insulation, and ample ceiling heights for naturally ventilated zones were three of the important technologies to maintain comfort zone temperatures. Moreover, they emphasized that the application of low-E finishing materials and indoor CO_2 monitoring devices also need to be considered to ensure better indoor air quality. According to Pacheco et al. (2012), the thermophysical and optical properties of the building envelope are important parameters of design that have effects on the indoor thermal comfort; hence, to ensure occupants' comfort, the overall building envelope thermal performance must be evaluated and optimized. Pacheco et al.'s viewpoint was supported by Chen et al. (2015) who argued that the indoor thermal environment is largely affected by the building envelope's thermal properties. They therefore mentioned that judicious use of thermal insulation, reflective surfaces, and heat storage capacity can enhance passive building thermal performance. The use of efficient type of lighting (lighting output and color), which can enhance the indoor environmental quality in terms of lighting, was among the green technologies for sustainable housing development identified by Tenorio (2007) and Roufechaei et al. (2014).

2.4. Materials and resources efficiency technologies

Materials and resources efficiency technologies help save scarce and non-renewable resources and materials. The materials and resources efficiency technologies for green property development identified by Zhang et al. (2011a) included underground space development technology and use of environmentally friendly materials for HVAC systems. Zhang et al. (2011b) reported similar results; they indicated that the application of underground space technology is beneficial for saving land resources. Through a questionnaire survey with 30 companies experienced in underground residential building projects, Shan et al. (2017) found that space or land saving was the most significant advantage of underground residential buildings. Several other previous studies suggest that the employment of underground space development technology in housing construction can effectively constrain the ever-increasing urban sprawl, and concurrently save space for the natural and heritage landscapes (Rönkä et al., 1998; Bobylev, 2009; Liu et al., 2015; Alkaff et al., 2016). Roufechaei et al. (2014) identified that the use of environmentally friendly materials for HVAC systems was among the top six technologies for sustainable housing development. Other researchers who identified use of environmentally friendly materials for HVAC systems as a technology for green property development include Zhang et al. (2013) and Zhang (2014).

2.5. Control systems

The control systems are those technologies for the management of occupants' preferences of aspects within a building environment, such as indoor air quality, thermal and illuminance comfort, and energy conservation (Dounis and Caraiscos, 2009). Generally, these control systems are integrated, centralized, software and hardware networks that are responsible for monitoring and controlling the indoor climatic conditions of a building. With these control systems, the building's operational performance alongside the occupants' security and comfort are normally ensured. Ahmad et al. (2016) presented six control systems for designing sustainable residential buildings, which were HVAC control, occupancy sensors, shading control, audio visual control, intercoms, and security control. After conducting a review on advanced building control systems, Dounis and Caraiscos (2009) identified that shading control is important for controlling the incoming natural light and solar radiation, as well as for reducing glare. As a technology for sustainable housing development, the goal of HVAC control is mainly to maintain the comfort of occupants with a minimal energy consumption (Guo and Zhou, 2009; Afram and Janabi-Sharifi, 2014). Garg and Bansal (2000) and Lu et al. (2010) also identified the application of smart occupancy sensors as an important technology for sustainable housing development.

3. Research methodology

3.1. Data collection

It is worth noting that green building has been used interchangeably with sustainable building or construction (Darko and Chan, 2016) in this study. In green building research, the method of questionnaire survey, which is a systematic method of gathering data on the basis of a sample (Tan, 2011), has been extensively used to collect professional opinions (Hwang et al., 2017a; Zhu et al., 2017). Thus, likewise, this study carried out a questionnaire survey to collect professional views on the importance of green technologies to achieve sustainable housing development. The advantage of conducting a questionnaire survey is that it helps to achieve "quantifiability and objectiveness" (Ackroyd and Hughes, 1981). The comprehensive literature review supported the development of the survey questionnaire; that is, based upon the green technologies listed in Table 1, the survey questionnaire was developed. The developed questionnaire was structured into two main sections. The first section sought background information of respondents, including their company types, their project types, their professions, and their experience in the construction industry as well as in green building. The second section solicited respondents' perceptions of the importance of each of the 28 proposed green technologies to achieve sustainable housing development, using a five-point rating scale (1 = not important, 2 = less important, 3 = neutral, 4 = important, and 5 = very important). The reason for adopting the five-point rating scale in this study is that it provides unambiguous results that are easy to interpret (Ekanayake and Ofori, 2014). Moreover, the five-point rating scale has been widely used in the previous studies to rate the relative importance of green technologies for sustainable housing development (Zhang et al., 2011b;

Roufechaei et al., 2014). Prior to the main questionnaire survey, a two-step procedure was adopted to assess the suitability and comprehensibility of the survey questionnaire. First, the questionnaire was reviewed by an international expert, a professor who had over 10 years' experience in green building, on question construction, ensuring that ambiguous expressions were not contained in the survey and that appropriate technical language/terms were used. Second, interviews were conducted with four professionals who also had over 10 years' experience in the local construction industry and possessed relevant experience in green building. They were requested to assess whether the questionnaire covered all potential green technologies, considering the Ghanaian local context, and whether any technologies could be added to, or removed from the survey. Based on the feedback, the questionnaire was finalized.

The questionnaire survey was conducted from January to July 2017 in Accra, Ghana. The target respondents for the survey were all industry practitioners with knowledge and experience in green building from contractor, consultant, and developer companies. Owing to the lack of a sampling frame for this study, the sample was a nonprobability sample (Zhao et al., 2014). The nonprobability sampling technique can be utilized to acquire a representative sample (Patton, 2001), and it is appropriate when a completely random sampling method cannot be used to select respondents from the whole population, but the respondents can rather be selected based on their willingness to partake in the research (Wilkins, 2011). Thus, a snowball sampling method was used in this study to obtain a valid and effective overall sample size. This method was also used in past green building studies (Zhang et al., 2011b; Mao et al., 2015), and it allows the gathering and sharing of information and respondents through referral or social networks. Local companies that have been directly involved in the construction of green buildings in Accra of Ghana were approached to identify the initial respondents. In the Ghanaian context, this study defines green buildings as buildings that have either obtained the South Africa's Green Star certification or the US's Leadership in Energy and Environmental Design (LEED) certification. Although the adoption of green technologies in Ghana has been slow and still in its early stages, Ghana remains one of the few developing countries that are making attempts to achieve major progress in the adoption and implementation of green technologies. For instance, Ghana has successfully launched the first LEED-certified green hospital in Africa, which is the Ridge Hospital (Bubbs, 2017), and the first green commercial office building in West Africa, which is the One Airport Square (ArchDaily, 2015). Various green technologies, e.g., solar water heating technology, rainwater harvesting technology, and natural ventilation technology were implemented in these projects. All of these green buildings are located in Accra. To identify the initial respondents for this study, local companies that were involved in the construction of these green buildings were approached, ensuring that the identified respondents had knowledge and experience in green building. For an overview of the current situation of the green building industry in Accra, the reader is referred to Darko et al. (2017c). The initially identified respondents were asked to share information regarding other knowledgeable participants. Using this approach, a total of 96 survey questionnaires were administered to qualified respondents. Finally, 43 sets of questionnaires with valid responses were returned, yielding a 44.8% response rate. Despite the relatively small sample size, statistical analyses could still be performed, because according to the commonly accepted rule, with a sample size of 30 or above, the central limit theorem holds true (Ott and Longnecker, 2010; Hwang et al., 2015). In addition, because green technologies have not been widely implemented in the construction industry of Ghana it is difficult to obtain a very large sample of experienced professionals. Moreover, the sample size was adequate compared with previous green building studies (e.g., 30 in Zhoa et al., 2016; 39 in Shen et al., 2016; and 40 in Hwang et al., 2017b).

The profiles of the respondents are shown in Table 2. Of the total number of 43 respondents, 16 (37%), 14 (33%), and 13 (30%) were from consultant, contractor, and developer companies, respectively. It is noteworthy that the respondents were experienced in developing different types of building projects, with all (43, 100%) of them experienced in residential projects development. Additionally, the respondents were of different professional backgrounds, including engineers, quantity surveyors, architects, project managers, and a contracts manager. The great diversity and heterogeneity of the panel of respondents helped to ensure the reliability and quality of the data collected (Harty, 2008; Shan et al., 2017). According to the respondents' practical experience in the construction industry, the majority of the respondents had more than 5 years of experience; only a few (14%) of them had 1-5 years of experience. Furthermore, all of the respondents had experience in green building development, with 24 (56%) having 1-3 years of experience, 11 (26%) having 4-6 years of experience, and 8 (19%) having more than 6 years of experience. In light of the respondents' industrial and green building experience along with their experience in residential construction, their views were representative for this study to guarantee the reliability and credibility of the findings.

<Insert Table 2 around here>

After collecting the research data, Cronbach's alpha coefficient was used for assessing the reliability of the five-point rating scale through measuring the internal consistency among the various green technologies (Santos, 1999). In this study, the Cronbach's alpha coefficient value was 0.910, which was much higher than the threshold of 0.70 (Norusis, 2011), indicating that the five-point scale measurement and thus the data collected were highly reliable for further analyses in the following sections.

3.2. Data analysis

To achieve the research aim, the respondents were requested to state the importance of the various green technologies to achieve sustainable housing development by using the five-point rating scale, as described in section 3.1. Various relevant statistical analysis methods including descriptive means, one-sample *t*-test, Kendall's coefficient of concordance (Kendall's *W*), and analysis of variance (ANOVA), were adopted in this study to analyze the data collected from the questionnaire survey. The mean value ranking method is a typical quantitative method which has been widely used in previous studies for ranking the relative significance of green technologies for sustainable housing development in specific countries and regions (Zhang et al., 2011b; Roufechaei et al., 2014). Thus, in this study, the mean values of responses from the respondents were used to derive the relative importance of each of the 28 green technologies. The higher the mean value of a green technology is perceived, the more important the green technology is seen to enable the achievement of sustainable housing development. The mean value of the importance of a green technology is computed by using the following formula (Hwang et al., 2017b):

$$B_i = \frac{\sum_{j=1}^{n} \alpha_{ij}}{n}$$

where n = the total number of respondents; α_{ij} = the importance of the green technology i rated by the respondent j; and B_i = the mean value of the importance of the green technology i. The SPSS statistical software (SPSS for Windows, version 20) was used in computing the mean values of the green technologies, and in ranking the green technologies, when two or more green technologies happened to have equal mean value, the highest importance rank was assigned to the green technology with the lowest standard deviation (SD) (Mao et al., 2015). Afterward, against a test value of three which is the average or middle value of the five-point rating scale, the one-sample *t*-test was conducted for testing the significance of the mean values of the importance of the green technologies. The null hypothesis, H_0, is that "the mean value is not statistically significant", while the alternative hypothesis, H_1, is that "the mean value is statistically significant". The one-sample *t*-test was conducted at a 95% confidence level with a 0.05 *p*-value. The null hypothesis for a green technology should be rejected if its *p*-value is lower than 0.05. Furthermore, Kendall's *W* was employed to investigate the agreement between different respondents' views on the importance of the green technologies (Siegel and Castellan, 1988). Without the assumption of any specify nature of data distribution, Kendall's *W* is a coefficient index for determining the overall agreement among sets of rankings. One-way ANOVA has been viewed as a suitable statistical method for examining the differences between mean values from three or more groups (Pallant, 2011; Chan et al., 2017). As such, in this study, since the respondents were from three different types of companies within the construction industry (i.e., consultant, contractor, and developer companies) (Table 2), the ANOVA technique was used to test whether the differences in mean values from the three respondent groups were statistically significant (Rahman, 2014; Chan et al., 2016). The analysis results are presented and then discussed in the following section.

4. Analysis results and discussion

There are various green technologies in the design stage of housing projects that need to be considered so as to achieve sustainable development. Table 3 shows respondents' importance assessment of the green technologies as well as the results of the relevant statistical tests. As the respondents were from different companies and of different professional backgrounds, it is necessary to first check whether significant differences exist among them. The ANOVA test results shown in Table 3 reveal that there exist no significant differences among the respondents from different companies in rating the importance of any of the listed green technologies, because the significance values of all the green technologies were greater than 0.05. Moreover, in this study, the Kendall's *W* test result of 0.171 with the small associated level of significance of 0.000 imply that there is a significant degree of agreement among the respondents in a particular group regarding the assessment of the importance of the green technologies to achieve sustainable housing development. The results of these two tests indicated that the importance assessments from the panel of respondents could be treated as a whole for analyses.

<Insert Table 3 around here>

As can be seen from Table 3, the mean values of the importance of the green technologies range from 2.51 to 4.53. From the results of one-sample *t*-test, the mean values of all the green technologies except "application of ground source heat pump technology" were statistically greater than the test value of three. The results indicate that these green technologies are significantly important to enable the development of sustainable housing projects. For the green technology "application of ground source heat pump technology", in addition to its mean value (2.51) which was less than three, its *p*-value (0.764) was also greater than 0.05, implying that the importance of this green technology was not perceived to be statistically significant. The negation of the importance of ground source heat pump technology in sustainable housing development could be attributed to the hot and humid weather conditions of Ghana that do not make the heating of homes an important issue. The research finding is consistent with existing empirical research by Roufechaei et al. (2014), who found that application of ground source heat pump was one of the three least important green technologies to achieve sustainable housing development in Esfahan, Iran.

From the results of mean, the top five green technologies (mean ≥ 4.40) that are of high importance to the achievement of sustainable housing development were "application of natural ventilation" "application of energy-efficient lighting systems", "optimizing building orientation and configuration", "application of energy-efficient HVAC system", and "installation of water-efficient appliances and fixtures (e.g., low-flow toilets)". These five green technologies are discussed as follows. The green technology "application of natural ventilation" was ranked first (mean = 4.53). This reflects that the practitioners within the current housing industry of Accra, Ghana, attach great importance to the adoption of natural ventilation in housing development as an effective means to bring about sustainability benefits. The importance of natural ventilation application was also demonstrated in Roufechaei et al.'s (2014) study in which one of the top five green technologies to achieve sustainable housing development was the application of natural ventilation. Zhang et al. (2011b) also identified the use of natural ventilation as one of the most effective green technologies for sustainable housing development in China. First, as a passive design technology, natural ventilation is much more inexpensive to apply than active design technologies, such as ground source heat pumps (Zhang et al., 2011a). For that reason, as cost remains a primary obstacle to taking up sustainable construction projects in developing countries like Ghana (Djokoto et al., 2014), the importance of natural ventilation application for sustainable housing development is high. Furthermore, because of the utilization of natural means, natural ventilation technologies have long been instrumental in increasing the sustainability of buildings. For example, the application of natural ventilation is a helpful method for reducing the energy consumption and cost associated with mechanical cooling and fan operation while also providing the expected level of building performance (Axley, 2001). Therefore, the application of natural ventilation is extremely important to the industrial practitioners in developing housing projects in terms of sustainability during the design stage.

"Application of energy-efficient lighting systems" received the second position (mean = 4.53). This confirms the finding of Roufechaei et al. (2014) that the application of lighting choices to save energy was the second most important or effective green technology to achieve sustainable housing development. As electricity consumption for lighting accounts for a substantial part of global energy use (Yang and Yu, 2015), the application of lighting systems that are more energy efficient to boost the efficiency of electricity consumption in lighting is highly important for sustainable housing development. Energy-efficient lighting systems have considerable potential for reducing the energy consumption for lighting and greenhouse gas emissions. For instance, fluorescent lamps are capable of reducing the amount of energy needed for attaining the same level of illumination compared to when traditional incandescent lamps are used. Also, solid-state lighting technology helps a building to use only 10% of the energy used by incandescent lamps for reaching the same level of illumination and even lasts 10 times longer (Yang and Yu, 2015). These merits may explain the reason why the application of energy-efficient lighting systems was considered as one of the most important green technologies to achieve sustainable housing development. According to the ECG (2009), lighting is responsible for the largest share of the total residential electricity load in Ghana, with the total lighting load estimated to be between 60 and 65%. A Ghanaian household survey of energy consumption by lighting types carried out by the Energy Foundation in 1999 showed that incandescent light bulbs accounted for 79%, linear fluorescent light bulbs 20%, and compact fluorescent light bulbs (more energy-efficient) only 1% (ECG, 2009). This further supports why the application of energy-efficient lighting systems was ranked very high.

"Optimizing building orientation and configuration" was ranked third (mean = 4.49), indicating that the importance of optimizing building orientation and configuration to achieve sustainable housing development was confirmed by most of the respondents in the survey. Optimizing the orientation and configuration of the building is another very important and effective passive design technology to achieve better sustainable housing development by increasing the building's energy saving potential. It is established that in the passive design of a building, the most important of the intervening parameters is orientation (Morrissey et al., 2011). There is a growing consensus that the southern orientation is the best and optimal option, with a general rule being to orient the longest wall sections toward the south (Littlefair, 2001; Mingfang, 2002). In line with this, the Passive Solar Handbook Volume 1 revealed that the building can obtain the greatest energy saving by optimizing its orientation through rotating the longest walls 30° to the south. Moreover, a research study substantiated that, especially in countries such as Ghana with hot and humid weather, if maximum energy saving is to be reached, then it is critical to orient the main glazing surface of the building to face south (Shaviv, 1981). Other specific benefits derived from optimizing building orientation and configuration, that make it highly important for sustainable housing development, include the following:

- it is not only applicable in the early stages of design, but it is also a comparatively low-cost technology;
- energy demand reduction;
- it prevents extensive application of sophisticated passive technologies;
- it improves the performance of other passive design approaches/technologies; and
- increment in the amount of daylight (Pacheco et al., 2012).

"Application of energy-efficient HVAC system" was ranked fourth (mean = 4.42). This finding was also supported by the viewpoints of previous studies (Wong and Li, 2006; Guo and Zhou, 2009; Ahmad et al., 2016), where the importance of energy-efficient HVAC was also stressed. With the growth in the demand for thermal comfort, HVAC system has nowadays become the largest energy end use in the residential sector. Pérez-Lombard et al. (2008) pointed out that in residential buildings, HVAC system consumes around 50% of the total electricity energy consumption, and plays a crucial role in fine controlling the indoor environment to fulfil occupants' comfort requirements. Hence, the application of energy-efficient HVAC system in sustainable housing development is very important to use less energy to arrive at a reasonable level of thermal comfort for occupants. In Ghana, HVAC system accounts for about 6.5% of the total energy use in households (Gyamfi et al., 2017). The finding of this study suggests that adopting more energy-efficient HVAC systems in housing development can be helpful for reducing this percentage.

"Installation of water-efficient appliances and fixtures (e.g., low-flow toilets)" was the fifth most important green technology (mean = 4.40). Water scarcity is a worldwide environmental problem. Owing to the contamination of water by pollutants, even water-abundant countries, such as Norway and Canada, face challenges in providing potable water. In a water-scarce country like Ghana, the installation of water-efficient appliances and fixtures, such as dual flush or low-flow toilets, water-efficient washing machines, and low-flow shower heads or water flow restrictor taps, has been considered an important green technology to develop housing projects that are sustainable in terms of water consumption. The installation of water-efficient appliances and fixtures is an important green technology for sustainable housing development for two main reasons (Millock and Nauges, 2010). First, a significant proportion of daily water use in households is accounted for by water consumed by outdoor as well as indoor appliances. Second, presently, there has been a growing recognition of the reduction potential of water-efficient appliances and fixtures. As examples, a water-efficient washing machine can use only one-third of the water used by a traditional model; while a traditional single-flush toilet can use up to 12*l* of water per flush, a dual flush toilet can use just a quarter of this; and whereas a traditional shower head could use up to 25*l* of water per minute, a water-efficient shower head may use as little as 7*l* per minute (Millock and Nauges, 2010).

In light of the above discussion, it can be summarized from the overall perception of various practitioners that the most important green technologies to achieve sustainable housing development mostly belong to energy efficiency category. However, all the green technologies identified to be significantly important demonstrate that the housing industry can achieve sustainable development through adopting these green technologies. Policy makers should take the initiative to design and implement good policies to promote the wider adoption of these green technologies in the housing industry.

If one calculates the average of the mean values of the green technologies to obtain a mean value for each green technology category, it can be stated that water efficiency technologies (mean, 4.19) and energy efficiency technologies (4.06) are the most important for achieving sustainable housing development, which are followed by materials and resources efficiency technologies (3.95), indoor environmental quality enhancement technologies (3.88), and control systems (3.81). The fact that water efficiency and energy efficiency are the most significant criteria for assessing sustainable building performance around the world (Shad et al., 2017; Illankoon et al., 2017) could explain this finding. The energy crises that make energy saving a high priority in Ghana might also support why energy efficiency technologies were considered as among the most important green technologies in sustainable housing development.

The findings of this study have practical implications. Therefore, to summarize the research findings, a three-level hierarchical conceptual model for the identification of green technologies to achieve sustainable housing development has been proposed in Fig. 1. Since the importance of the green technology "application of ground source heat pump technology" was statistically considered as insignificant by the survey respondents (see Table 3), it was excluded from the proposed model. That is, this model contains 27 green technologies that are significantly important, as confirmed and agreed upon by industry practitioners, for sustainable housing development. The top level is the identification goal, followed by the five main categories of green technologies. The third level comprises the green technologies expanding from the green technology categories. In this level, the various green technologies under each green technology category are presented in descending order of importance according to the survey results. Confronted with the problem to identify and select the most appropriate combination of green technologies to achieve sustainable housing development, decision makers can focus and act on the green technologies with high importance in individual categories.

<Insert Fig. 1 around here>

5. Conclusions and future research

Sustainable housing development is receiving increasing attention from the industrial practitioners and academics, since it is a way of implementing sustainability in the construction industry and particularly in the housing industry. Green technologies are increasingly vital to the achievement of sustainable housing development. This study identified the green technologies that are important to achieve sustainable housing development in Accra of Ghana. It did so by adopting a combination of research methods including literature review and a questionnaire survey to collect professional views on the importance of green technologies. The results of this study showed that 27 out of the 28 green technologies examined were considered to be important green technologies to achieve sustainable housing development, with application of natural ventilation, application of energy-efficient lighting systems, optimizing building orientation and configuration, application of energy-efficient HVAC system, and installation of water-efficient appliances and fixtures (e.g., low-flow toilets) identified as the five most important green technologies. In addition, the water efficiency technologies and energy efficiency technologies had the highest level of importance. The contributions of this study are in at least two ways. First, the research findings help industry professionals who are responsible for decision making during the design phase of housing developments improve their understanding of the important green technologies to achieve sustainable housing development, thus representing a good starting point to successfully implement sustainable housing development. Second, the identified green technologies form a conceptual framework which can be used to guide the identification and selection of green technologies for sustainable housing development.

The implication of this study for policy makers is that, because of the potential sustainability benefits, they should establish and implement policies aimed at promoting the widespread adoption of the identified green technologies in the housing industry. For example, they can provide incentives for practitioners who incorporate the green technologies in their housing projects. In addition, the government of Ghana has launched a national housing policy that aims to provide an enabling environment for housing development (Government of Ghana, 2017). To ensure sustainable housing development, it may be necessary to promote the adoption of the identified green technologies by incorporating them in this national housing policy. Moreover, businesses might consider the green technologies in their strategic business plans and adopt them in their construction projects as the adoption of green technologies could help them show their commitment to sustainable development and social responsibility (Zhang et al., 2011b).

Albeit the objective was achieved, this study was not conducted without limitations. First, the respondents' experience and attitudes could influence the importance assessment made in this study as it was subjective. Aside from that, because the sample size was not very large, cautions should be taken when interpreting and generalizing the analysis results. Moreover, the current proposed model is not complete as it does not show how it can be applied to aggregate all scores of each green technology to produce an integrated result for the evaluation of the combination of green technologies in a sustainable housing project. Further work is required to extend this model by evaluating the comparability of the green technologies and generating numerical weights that represent the relative importance of the green technologies with respect to the goal (identifying and selecting the most appropriate combination of green technologies to achieve sustainable housing development). In order to achieve this, the analytic hierarchy process (AHP) is proposed as it can help prioritize or rank the green technologies through pairwise comparisons to distinguish in general the more important green technologies from the less important ones. Upon completion, a decision support model could be developed allowing decision makers to reduce or increase the elements of the problem hierarchy regarding a sustainable housing project. The aforesaid work will be undertaken in the next stage of this study.

This study provides an in-depth understanding of green technologies that are highly important to achieve sustainable housing development. As the first of its kind to conduct such a study within the Ghanaian construction industry, the empirical results of this study add to the existing knowledge relating to sustainable housing development. Although the necessary empirical data for this study were collected from the housing industry of Accra, the identified green technologies could be useful for sustainable housing development in other locations having environment characteristics similar to that of Accra, Ghana. The data was strictly limited to Accra, particularly to help validate the findings of this study. Nevertheless, this study still forms a foundation for investigating the important green technologies for sustainable housing development in other cities of Ghana and beyond; thus, using the proposed green technologies, similar studies could be undertaken in different areas. Future research could also employ a larger sample and compare the green technologies for sustainable housing development in Ghana and other countries.

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Table 1

Summary of green technologies in the design stage of housing development.

Green technology categories	Code	List of green technologies	Key references: Zhang et al. (2011a)	Zhang et al. (2011b)	Ahmad et al. (2016)	Roufechaei et al. (2014)	Koebel et al. (2015)	Chen et al. (2015)	Lee et al. (2007)
Energy efficiency	EE1	Application of energy-efficient lighting systems	–	–	–	X	–	–	X
	EE2	Application of energy-efficient windows	–	X	X	–	X	X	–
	EE3	Application of energy-efficient HVAC system	–	–	X	–	–	–	X
	EE4	Use of energy-efficient appliances (e.g., energy-efficient refrigerators)	–	–	X	–	–	–	–
	EE5	Application of solar technology to generate electricity	X	X	X	X	–	–	–
	EE6	Application of rooftop wind turbines to generate electricity	–	–	–	X	–	–	–
	EE7	Integrative use of natural lighting with electric lighting technology	X	X	X	X	–	X	–
	EE8	Application of solar water heating technology	X	–	X	X	–	–	–
	EE9	Application of solar shading devices	–	–	X	–	–	X	–
	EE10	Application of ground source heat pump technology	X	X	–	X	–	X	X
	EE11	Use of wooden logs to provide structure and insulation	–	–	–	X	–	–	–
	EE12	Optimizing building orientation and configuration	–	X	X	X		X	–
	EE13	Application of natural ventilation	–	–	–	X	–	X	–
Water efficiency	WE1	Installation of water-efficient appliances and fixtures (e.g., low-flow toilets)	X	–	X	–	–	–	–
	WE2	Rainwater harvesting technology	X	X	X	–	–	–	–
	WE3	Grey water reclaiming and reuse technology	X	–	–	–	–	X	–
Indoor environmental quality enhancement	IQ1	Ample ventilation for pollutant and thermal control	X	X	X	X	–	–	–
	IQ2	Application of indoor CO_2 monitoring devices	–	–	X	–	–	–	–
	IQ3	Application of low emission (low-E) finishing materials	–	–	X	–	–	–	–
	IQ4	Optimizing building envelope thermal performance	–	X	X	X	–	X	–
	IQ5	Application of solar chimney for enhanced stack ventilation	–	–	X	–	–	–	–
	IQ6	Use of efficient type of lighting (lighting output and color)	–	–	X	X	–	–	–
Materials and resources efficiency	MR1	Underground space development technology	X	X	–	–	–	–	–
	MR2	Use of environmentally friendly materials for HVAC systems	X	X	–	X	–	–	–
Control systems	CS1	HVAC control	–	–	X	–	–	–	–
	CS2	Security control	–	–	X	–	–	–	–
	CS3	Audio visual control	–	–	X	–	–	–	–
	CS4	Occupancy/motion sensors	–	–	X	–	–	–	–

Table 2
Profiles of the respondents.

Characteristics	Frequency	Percentage
Company types		
Consultant	16	37
Contractor	14	33
Developer	13	30
Project types		
Residential	43	100
Commercial/office	34	79
Industrial	24	56
Educational	23	53
Professions		
Engineer	13	30
Quantity surveyor	11	26
Architect	9	21
Project manager	9	21
Contracts manager	1	2
Years of experience in construction industry		
1-5 years	6	14
6-10 years	17	40
11-15 years	10	23
16-20 years	3	7
> 20 years	7	16
Years of experience in green building		
1-3 years	24	56
4-6 years	11	26
> 6 years	8	19

Table 3

Summary of the survey results on the importance of green technologies to achieve sustainable housing development.

Green technology categories	Code	List of green technologies	Mean	SD	Rank	*p*-value	ANOVA
Energy efficiency	EE1	Application of energy-efficient lighting systems	4.53	0.702	2	0.000	0.525
	EE2	Application of energy-efficient windows	4.23	0.996	11	0.000	0.581
	EE3	Application of energy-efficient HVAC system	4.42	0.823	4	0.000	0.129
	EE4	Use of energy-efficient appliances (e.g., energy-efficient refrigerators)	4.35	0.783	6	0.000	0.803
	EE5	Application of solar technology to generate electricity	4.35	0.813	7	0.000	0.827
	EE6	Application of rooftop wind turbines to generate electricity	3.72	1.260	21	0.001	0.401
	EE7	Integrative use of natural lighting with electric lighting technology	4.28	0.882	9	0.000	0.128
	EE8	Application of solar water heating technology	3.81	1.139	20	0.000	0.576
	EE9	Application of solar shading devices	4.09	1.087	14	0.000	0.161
	EE10	Application of ground source heat pump technology	2.51	1.203	28	0.764[a]	0.751
	EE11	Use of wooden logs to provide structure and insulation	3.42	1.314	27	0.043	0.091
	EE12	Optimizing building orientation and configuration	4.49	0.631	3	0.000	0.759
	EE13	Application of natural ventilation	4.53	0.631	1	0.000	0.965
Water efficiency	WE1	Installation of water-efficient appliances and fixtures (e.g., low-flow toilets)	4.40	0.791	5	0.000	0.982
	WE2	Rainwater harvesting technology	4.28	0.854	8	0.000	0.246
	WE3	Grey water reclaiming and reuse technology	3.88	1.051	19	0.000	0.763
Indoor environmental quality enhancement	IQ1	Ample ventilation for pollutant and thermal control	4.12	0.956	13	0.000	0.688
	IQ2	Application of indoor CO_2 monitoring devices	3.56	1.053	25	0.001	0.615
	IQ3	Application of low emission (low-E) finishing materials	4.14	0.990	12	0.000	0.254
	IQ4	Optimizing building envelope thermal performance	3.88	1.028	18	0.000	0.519
	IQ5	Application of solar chimney for enhanced stack ventilation	3.51	1.242	26	0.010	0.931
	IQ6	Use of efficient type of lighting (lighting output and color)	4.07	0.936	15	0.000	0.550
Materials and resources efficiency	MR1	Underground space development technology	3.67	1.304	23	0.002	0.525
	MR2	Use of environmentally friendly materials for HVAC systems	4.23	0.895	10	0.000	0.081
Control systems	CS1	HVAC control	3.98	1.058	16	0.000	0.923
	CS2	Security control	3.93	0.961	17	0.000	0.241
	CS3	Audio visual control	3.65	1.193	24	0.001	0.081
	CS4	Occupancy/motion sensors	3.67	1.229	22	0.001	0.479

Note: [a] The one sample *t*-test result is insignificant at the 0.05 significance level (*p*-value > 0.05) (2-tailed). The sample size of *t*-test is 43. The Kendall's *W* for assessing the importance of the 28 green technologies was 0.171 with a significance level of 0.000.

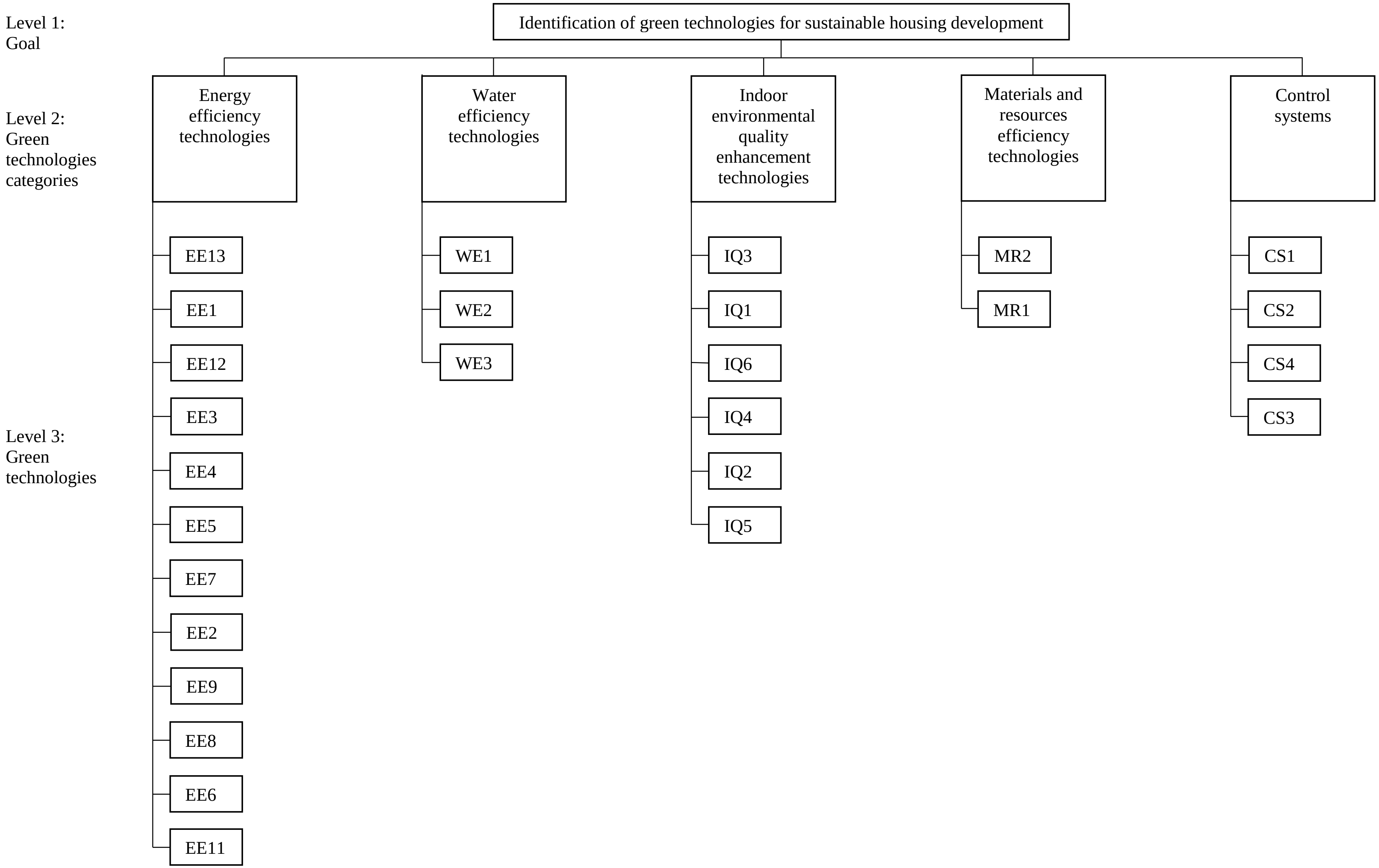

Fig. 1. A conceptual model of green technologies for sustainable housing development. The codes at the Level 3 correspond to codes in Table 1.