Green Energy and Technology

Zhonghua Gou *Editor*

Green Building in Developing Countries

Policy, Strategy and Technology

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Green Energy and Technology

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Foreword

For the past thirty years, green building has spread around the world, beginning first in the UK, then spreading to North America, then to Western Europe, Northeast Asia, Singapore, Brazil and Colombia, China, Eastern Europe, and, in the decade of the 2010s, to the entire world. In each country, it was necessary to put an entire "ecosystem" in place, consisting of rating systems, training of design and construction professionals, development of green products and systems, growth of green building consulting firms, development of a business case for commercial investors, etc.

With growing concerns over the rapidly developing twenty-first-century climate crisis, green building has moved away from simple improvement of various building features such as energy and water use, materials choices, and a better indoor environment, to encompass a broader and more ambitious agenda. Still, the need for a complete ecosystem in each country remains. The growth of green building in each country will be slow until the missing components of the ecosystem are put in place. This creates an opportunity for effective interventions by government, NGOs, and the private sector to accelerate green building growth.

With respect to climate change, it is now clear that in many countries, particularly those expected to build most of the new buildings in the next three decades, nothing less than a "zero net energy" building should be considered "green" in the near future. Growing recognition of the health impacts of poor building air quality and lack of views and connection with nature is spurring greater consideration of healthy buildings as the primary goal of "greening" the built environment.

These two aspects of low-energy and healthy buildings are beginning to be combined with new design and construction approaches. One might think that green building approaches in the developing world might lag behind those of the more economically advanced countries. But the essays in this book argue otherwise.

Many countries have skipped entirely the need to install millions of kilometers of copper wire to service landline phone systems, moving directly to a cellular network. These same countries have also been the leading adopters of mobile payment systems, eliminating the need to create branch-banking networks common to developed countries. Many developing countries will soon become reliant for servicing growth in electricity demand entirely on solar and wind power systems, reducing the need to build carbon-polluting coal plants.

In the same way, it is easy to imagine that architects, engineers, planners, and builders in developing countries will come up with ingenious ways to develop green buildings and certification systems that represent significant departures from the current paradigm at work in economically advanced countries. After all, most of the world's projected urban growth in the next thirty years will occur in the developing world, largely in the tropics and subtropics. Most of the buildings that we will occupy in the same time period have yet to be built.

From a viewpoint of both the climate crisis and the health of future populations occupying these buildings, it is critical that we move expeditiously toward assuring that we build low- to zero-net-energy buildings that provide a healthy physical and psychological environment in which all people can live, work, play, and learn. The essays in this book point the way toward that goal and deserve to serve as examples for future green building activities around the world.

Finally, green building needs to be incorporated into the "smart urban growth" or "eco-city" movement so that advocates for smart cities can help overcome barriers that work against the growth of green building in countries facing rapid urbanization.

Carlsbad, CA, USA

Jerry Yudelson, MS, MBA
LEED Fellow Emeritus

Introduction

Background: Published Books on Green Building

Although green buildings are defined in different ways, there is a common belief that the building design and construction industry should be more environmentally friendly. In response to this common environmental belief, many tools, techniques, and technologies have been introduced for the implementation of green buildings. Many books have been published on this topic to clarify the definition of green building, to introduce the best practice, to brand relevant green building certifications, and to inform investors and policymakers.

One of early books, "Green Buildings Pay" by Edwards [6] is an example of this. The book advocated that the green building should be developed in the context of market realities. It had been updated for the third edition by Edwards and Naboni [7]. Books on green building costs written by Malaver and Muller [13] and RSMeans [14] presented economic analyses and best practices for building green. Yudelson [16, 17, 18, 19, 20]'s book series reiterated the sense of marketing strategies and tactics for green buildings in developed countries. All cases studies in the books were drawn from the UK, Europe, and the USA, aiming for better implementation of assessment schemes such as Leadership in Energy and Environmental Design (LEED).

With the green building market growing, policy instruments and laws came out as corresponding supports. *Building an Emerald City: A Guide to Creating Green Building Policies and Programs* [4] is an early book aiming for policymakers and public officials. Furr, Kibert, Mayer, and Sentman [8], Adshead [2], and Howe and Gerrard [9] introduced regulations, legislation, and related practices in their books that could be used for business to benefit from the policy. Green building books can also be found for informing professionals to capture such opportunities. For example, Bauer, Mösle, and Schwarz [5], 7group and Reed [1], Kruger and Seville [11], Kibert [10], and Kubba [12] provided guidelines in their books for professionals to quickly understand and implement green building criteria.

In recent years, the green building research and dissemination is becoming more contextual and regional. For example, Schröpfer and Menz [15] focused on high-density urban context, using many cases from cities like Singapore and Sydney with compact urban form. Affolderbach and Schulz [3] published another urban-oriented book on green building, based on cities such as Brisbane, Freiburg, Luxembourg, and Vancouver.

Objective of This Book

This book for the first time introduces and showcases the green building status quo in developing countries. Although the green building development started late in developing countries, it is superseding, excelling in many respects, such as the mandatory green certification and the number certified green projects under the strong government advocacy and policy support. Particularly, the book contains examples from China, Indonesia, Malaysia, Thailand, Pakistan, Cambodia, Ghana, Nigeria, and some countries from the Middle East. Their policies, strategies, and technologies are disclosed in literature and policy reviews, case studies, empirical surveys, and so on. This book can be read in different ways. It is a collection of green building research focused on developing countries; it also contains different research methods which can be used for researchers and students who are interested in green building studies; furthermore, it provides policy guidance for government agencies. Above all, it is about developing countries and their showcasing of green initiatives.

Zhonghua Gou

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About the Editor

Zhonghua Gou is Senior Lecturer at Griffith University. His research focuses on green building design and technology. During his Ph.D. study (2008–2012), he surveyed more than ten green projects in China and conducted post-occupancy studies to find out the green building performance in uses; beyond that, he investigated green building assessment tools in different socioeconomic contexts. He has published more than 60 peer-reviewed journal articles that disseminate the knowledge on green building. His green building research is multidisciplinary, involving architecture, planning, interior design, project management, real estate, engineering, and social sciences. He is one of the most productive and highly cited authors on green building. He currently supervises Ph.D. students on this topic to educate next-generation green building designers and managers.

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The Shift of Green Building Development in China from a Voluntary to Mandatory Approach

Zhonghua Gou

Abstract The chapter is a systematic review of green building development and governmental interventions in China. A voluntary green building development approach led to a dramatic increase in green projects between 2008 and 2012. In 2013, green building development shifted to a mandatory approach. A central action plan with green building objectives was set out in the 12th Five-Year Plan, and a series of local implementation plans were published in support. This study carried out critical analyses of government policies and relevant data published by national and local governments over the period 2008–2013. The findings showed that the governmental intervention resulted in an exponential increase of green projects to meet national green building objectives by 2015, even though it was confined to government-invested projects and the commercial private sector had not been sufficiently involved. Incentives with monetary rewards were needed to motivate the private sector to strengthen green building development in the long run.

Keywords Green building · Policy review · China · Incentives

1 Introduction

Intergovernmental Panel on Climate Change (IPCC) identifies the building sector as having significant potential to cut down carbon emissions effectively [12]. Buildings, therefore, are an important part of environmental policies or strategies in response to climate change. The green building is emerging as a holist concept to reduce the overall impact of the built environment on human health and the natural environment [8, 39]. Although the concept is adapted in different countries, it usually encompasses three basic aspects: efficiently using energy, water and other resources; protecting health and improving employee productivity; reducing waste, pollution and environmental degradation [35]. In China, the gross floor area (GFA) of building stock has exceeded 40 billion square metres and it is increasing at the rate of two billion square metres per year [16, 41]. Green building is undoubtedly a sensible strategic approach

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for reducing building energy consumptions, while improving urban environments in the rapid modernisation and urbanisation of China.

Since the concept of the green building was first introduced in China's construction industry in the 1990s, numerous research has been conducted to produce a series of green building documents and regulations, such as Residential Green Building Elements and Technical Guidelines, China's Eco-house Technical Evaluation Handbook, Assessment System for Green Buildings of Beijing Olympic Games, Green Building Technical Guidelines (GBASBO) and Evaluation Standard for Green Buildings [7]. These efforts led to the official national Chinese Green Building Evaluation Standard (GB/T 50378–2006) released by the Ministry of Housing and Urban–Rural Development (MOHURD, former Ministry of Construction) in 2006 [19]. It covers residential buildings and public buildings (including offices, malls and hotels).

The standard has been officially used to certify the China Green Building Label (GBL) since 2008. Particularly, a label for the design stage is also known as the Green Building Design Label, which certifies buildings at the design stage mainly according to detailed design documents. The other label, the Green Building Operation Label, certifies buildings in the operation stage for a year or longer. Whatever the stage, one building can be evaluated as a one-star, two-star or three-star green building based on the following six aspects: land saving and outdoor environment, energy saving and utilisation, water saving and utilisation, material saving and utilisation, indoor environment and operation and management. More information about technical aspects of the standard and certification can be found in [38].

Under the current Five-Year Plan (2011–2015), China has explicitly stated that constructing green buildings is one way of meeting the target of reducing energy consumption by 16% and carbon emissions by 17% for every unit of gross domestic production (GDP) by 2015 [15]. The government, therefore, aims to construct green buildings across 1 billion square metres between 2011 and 2015 and to ensure that green buildings account for 20 per cent of all new buildings by 2015 [23].

The green building development still faces steep challenges globally due to its extra investment cost and risks and a push from the government is necessary [42]. However, in what way governmental policy can work in green building development is still debatable [4]. This chapter is a systematic review of the green building development and governmental interventions in China, aiming to provide a reference for the effect of governmental interventions on the green building development. The study involves critical analyses of government policies and relevant data about green building development published by the national and local governments over the period 2008–2013. With reference to this period, green building development in China is divided into two approaches: from 2008 to 2012 when the green building standard was voluntarily adopted, and from 2013 when the green building strategy shifted towards a mandatory approach to achieve the green building ambition of the 12th Five-Year Plan. This study looks at the current status of green building development, how it is shifting from a voluntary towards a mandatory approach under the influence of the government. China's environmental and energy policies have been receiving increasing worldwide attention; the greatest concern is that although there are well-intended environmental legislations promulgated by central government, there may not be effective implementation at the local level, especially in those less developed provinces or cities that are exceptionally lax in legislative enforcement [5, 33]. This chapter also examines the implementation gap to find out whether the green building goal of the national government is realised at local levels.

2 Materials and Methods

The research makes full use of three databases: the database published by the Building Energy and Technology Division of MOHURD, containing information (location, building type and GFA) of 742 certified green buildings from 2008 to 2012 [21]; annual GDP data and building industry data published in national and local statistic bulletins by National Bureau of Statistics of China [22]; and the incremental cost data published by the China Academy of Building Research (CABR) in its reports and research articles [18, 30–32], which include 17 green projects covering one-star to three-star labels. This research also reviews national and local governmental notices examining their plans and implementations for green buildings. The research approach covers quantitative data analyses of the three databases and qualitative analyses of the national and local governmental documents.

3 Results

3.1 A Voluntary Approach: 2008–2012

3.1.1 General Picture

Green building evaluation and certification officially started in 2008 when only ten building projects registered for the evaluation work. The number increased sharply in the following years. By the end of 2012, 742 building projects had been certified as green buildings. As can be seen in Figs. 1, 2, 3 and 4, certified buildings increased dramatically from 2008 to 2012. The number and GFA of green buildings in 2012 were approximately equal to the sum of the previous three years (2008–2011). By the end of 2012, the total GFA was over 75 million square metres.

Two-star green buildings are the largest group in the three classes. The three-star buildings are the smallest group. One important reason is that a three-star project might incur a higher extra cost than other projects. This is addressed later in this article. Another reason is the certification procedure. The overall certification procedure is the responsibility of the Centre of Science and Technology of Construction of MOHURD and the Chinese Society for Urban Studies (CSUS). All three-star buildings must go through the national-level approval, while one-star and two-star could be assessed at the local level. This policy largely encourages local promotions

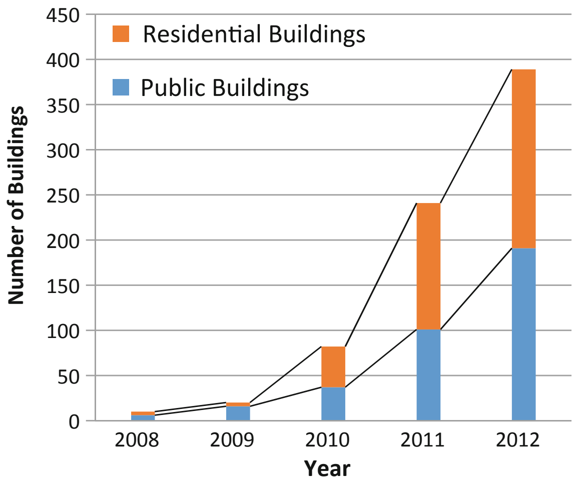

Fig. 1 Number of green projects by building types

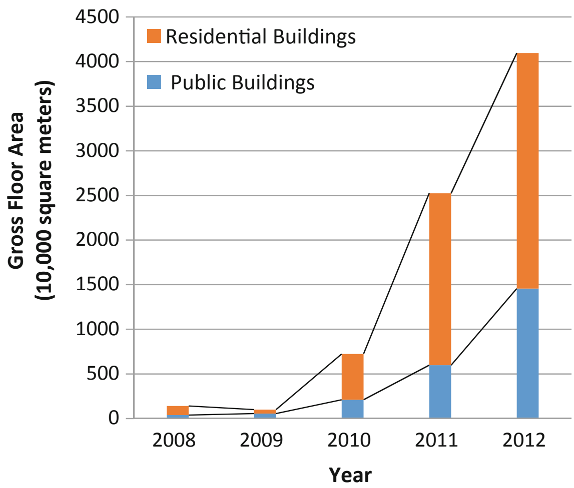

Fig. 2 GFA of green projects by building types

of green building development. By 2011, 30 local authorities had already been established to carry out the certification procedure for one-star and two-star buildings in their specific administrative regions. These local authorities play an important role in one-star and two-star evaluations, especially the two-star evaluation that is the highest level a local authority can endorse.

The dominance of the residential GFA of green building is evident in Fig. 2. A residential project contains several separate multi-family, multi-story or high-rise buildings and usually has a GFA larger than 50,000 m^2. Two types of residential projects can be identified in the green residential projects: private sector-invested and government-invested residential projects. Most certified private sector-invested resi-

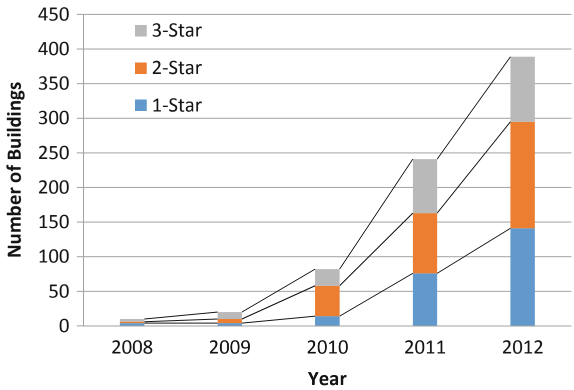

Fig. 3 Number of green projects by green classes

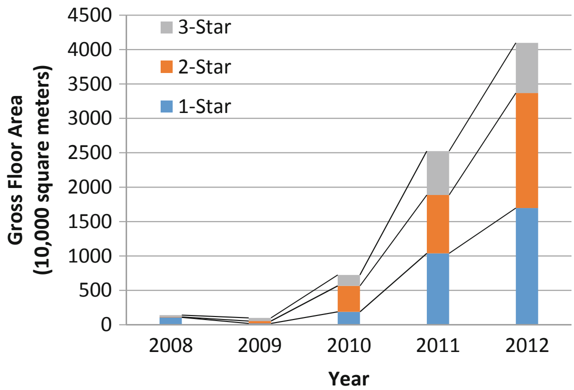

Fig. 4 GFA of green projects by green classes

dential projects are developed by top real estate developers in China such as Vanke and Landsea which were encouraged by the government to pursue two-star or above certification in their new residential developments from 2011. The government-invested residential projects mainly referring to social housing or affordable housing projects account for the other portion of residential projects. By the end of 2012, more than 40 social or affordable housing projects had been certified as green buildings, accounting for over 7.8 million square metres. The first governmental notice on green building, "Green Building Action Plan 2011," was published in May 2011 [25]. The plan targets government-invested social housing, as the government aims to build 36 million units by the end of 2015. However, the plan did not mention any mandatory policies.

Since the US LEED (Leadership in Energy and Environmental Design) was introduced in 2001, China has been one of the important markets for LEED in the world. By the end of 2012, in China, there had been over 1300 projects registered for or certified by LEED, accounting for more than 60 million square metres [36]. Although the number of LEED projects is much greater than that certified by the China GBL implemented only in 2008, the GFA of LEED projects is almost equal to that of

GBL projects. This is because most LEED projects are commercial office projects and the GFA of an office project is usually much smaller than that of a residential project. The residential sector is definitely the most important target for green building development.

3.1.2 Distribution of Green Building

Although LEED and GBL coexist in China, as this study considers the influence of Chinese governmental policies on green buildings, only the Chinese GBL-certified green buildings are included for analysis. As Hong Kong and Macau Special Administrative Regions mainly implement their own standards, they are excluded from the distribution analysis. Finally, 27 provinces and 101 cities that have green buildings are included in the distribution analysis. Figures 5 and 6 rank the number and GFA of green buildings among the 27 provinces. Jiangsu Province ranks first in terms of both GFA and number of projects. GFA of green projects significantly relates to GFA of total projects under construction (Fig. 7), which means that provinces that have a larger scale of construction tend to have a larger number of green buildings. Jiangsu Province has the largest number of construction and also the largest number of green buildings. Figure 8 further reveals that the GFA percentage of green projects is still very small and no province has more than 1% green buildings.

Figures 9 and 10 rank the top 10 cities in terms of number and GFA of green projects. The top 10 cities account for more than 38 million square metres and 50% of total green buildings in China. One important reason is that these cities have already published their incentives for green buildings [34] in response to the national "Green

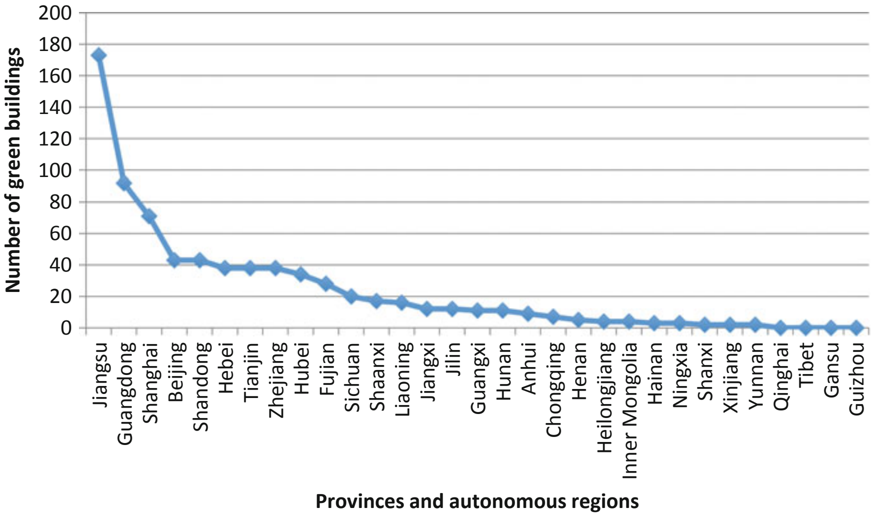

Fig. 5 Ranking in terms of number of green projects

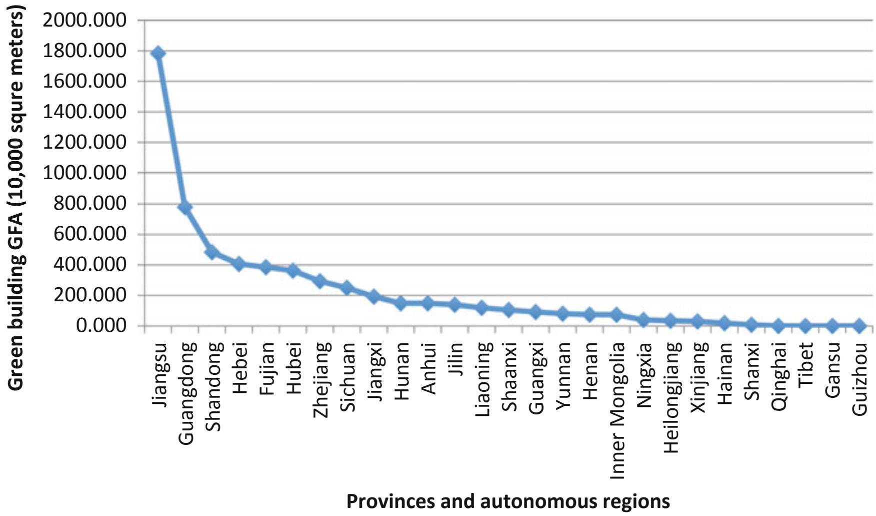

Fig. 6 Ranking in terms of GFA of green projects

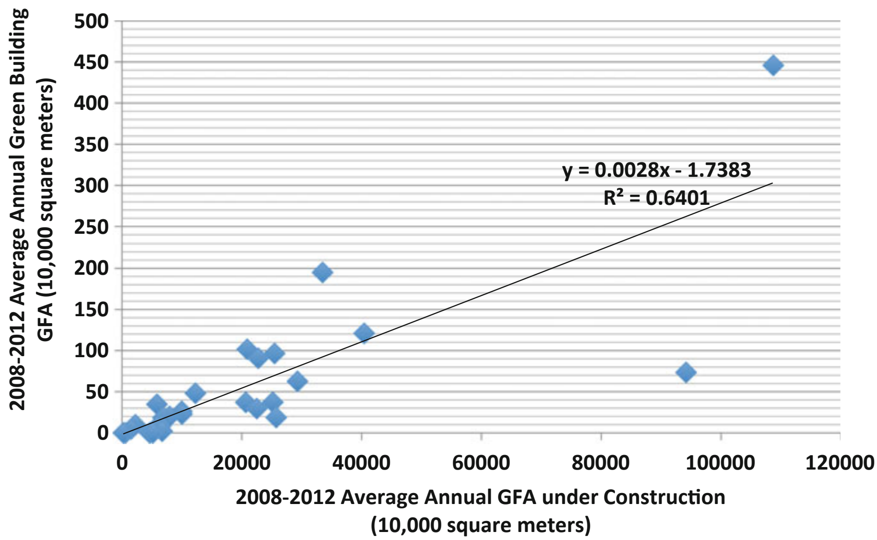

Fig. 7 Linear regression between green building GFA and all GFA under construction

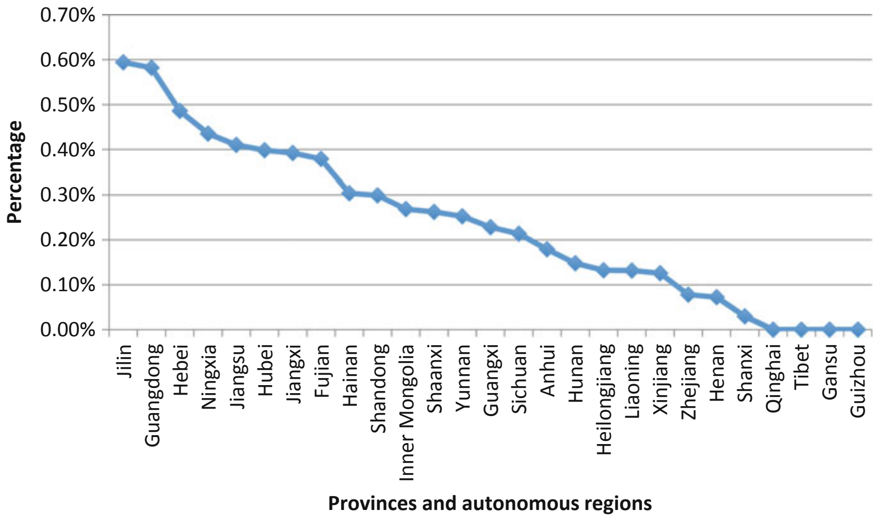

Fig. 8 Ranking in terms of percentage of green building GFA

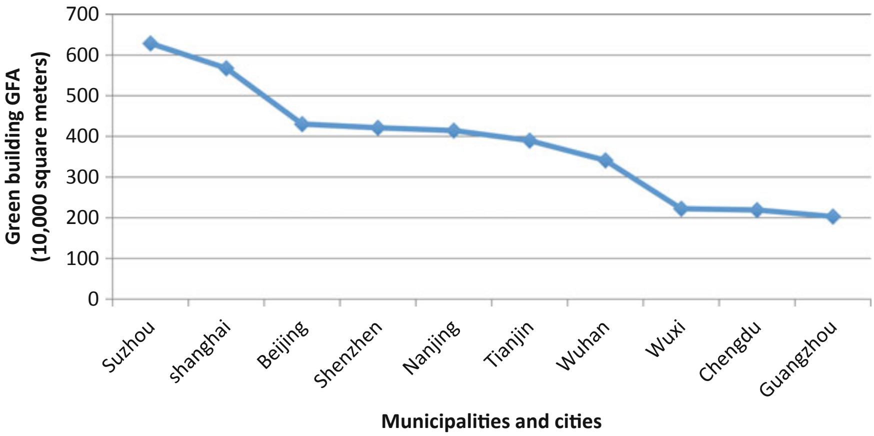

Fig. 9 Top 10 cities in terms of GFA of green projects

Building Action Plan 2011" mentioned above. For example, Shenzhen Government rewarded 500,000 RMB for each green building; Suzhou Government rewarded 1,000,000 RMB for each three-star building, 200,000 RMB for each two-star building, and 50,000 RMB for each one-star building; in Shanghai, the maximum monetary reward was 5 million RMB for each three-star building. However, these incentives did not differentiate building types and sizes and were not evidence-based.

The distribution of green buildings is obviously uneven. Provincial and civic GDP data are used to examine whether provinces or cities with higher GDP tend to have

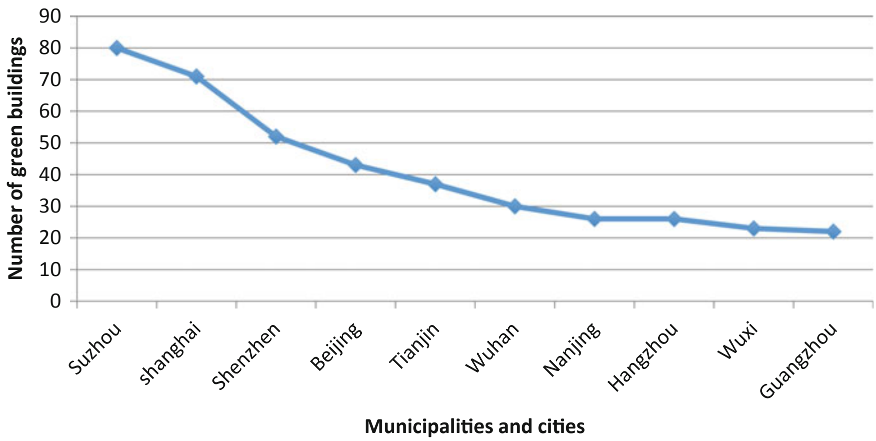

Fig. 10 Top 10 cities in terms of number of green projects

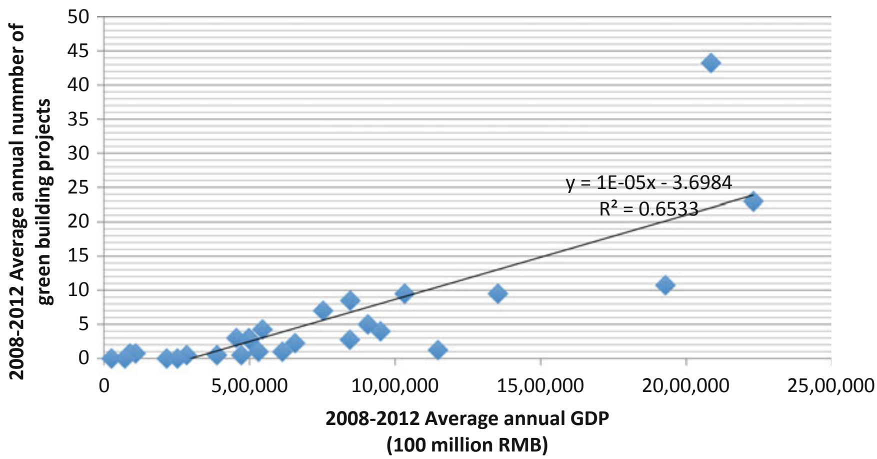

Fig. 11 Linear regression between GDP and number of green projects for the 27 provinces

more green buildings. Figures 11, 12, 13 and 14 show the regression analysis between GDP data and green buildings. All variables are significantly related to each other, and the significance is at the level of 0.000. These relationships through linear regression analyses show that provinces or cities with higher GDP tend to have more green buildings. The distribution also reflects the lax attitude of less developed regions or areas in terms of green building implementation.

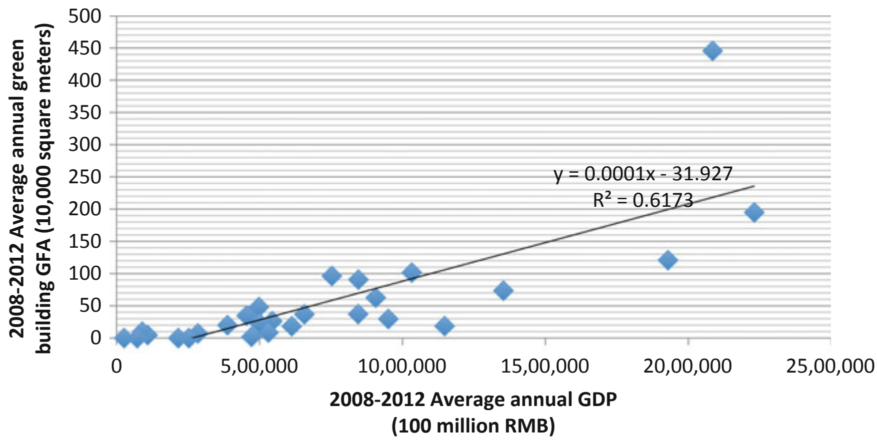

Fig. 12 Linear regression between GDP and GFA of green projects for the 27 provinces

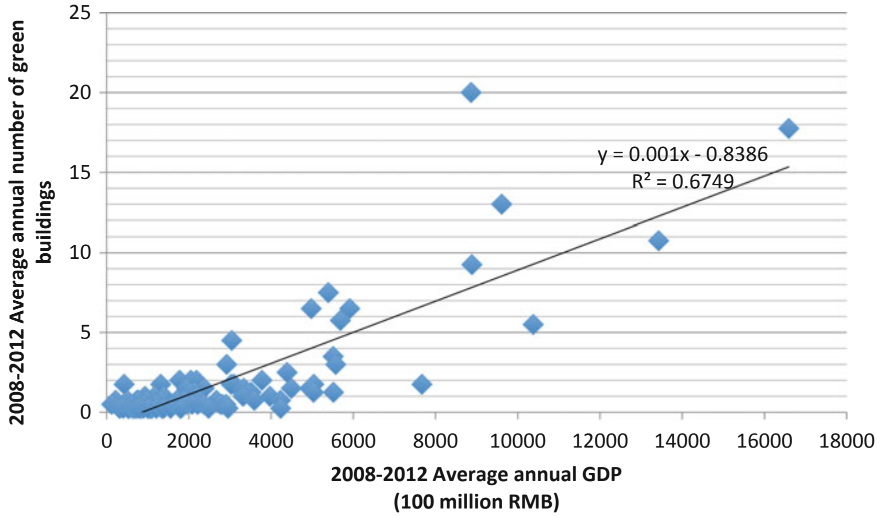

Fig. 13 Linear regression between GDP and number of green projects for the 101 cities

3.1.3 Incremental Costs

Green buildings are often perceived as having higher initial design and construction costs than conventional buildings, especially as they make use of energy-efficient products and low environmental impact materials [24]. The China Academy of Building Research collected the capital cost information of 17 green buildings in China. Compared with a conventional building, the incremental cost for a green building is usually spent on building envelopes (such as thermal insulation and double facades),

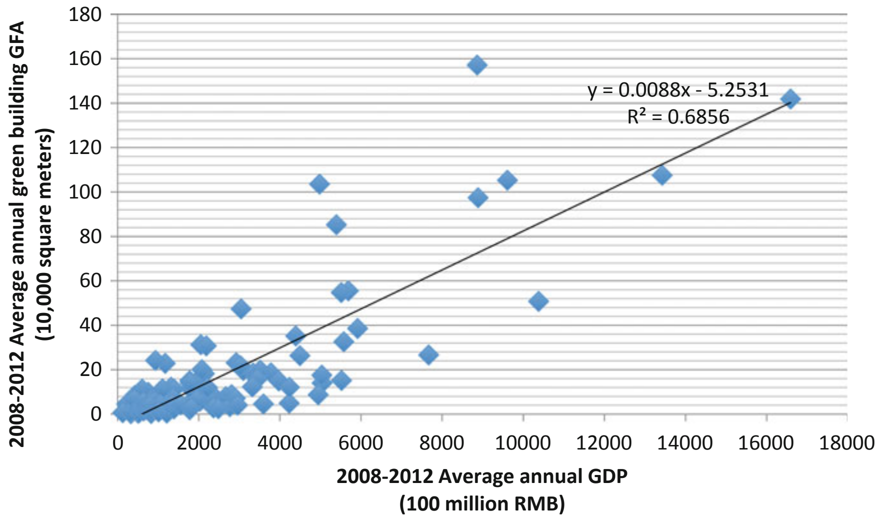

Fig. 14 Linear regression between GDP and GFA of green projects for the 101 cities

renewable energy (photovoltaic panels, heat pumps, wind tower, etc.), water strategies (such as grey water recycle and rainwater collection) and indoor environmental quality (air pollutants monitoring, increased fresh air for mechanical ventilations, etc.).

Table 1 shows examples of the incremental costs of regularly adopted green strategies. The cost even of the same green strategies is quite different between the two building types (residential and public buildings). Figures 15 and 16 are the linear regression analyses between incremental costs and green classes for the two building types. The incremental costs of residential projects are more linearly related to the class of green compared with that of public projects; in other words, the additional

Table 1 Incremental costs of green strategies

Items	RMB per square metre	Percentages (%)	
		Residential	Public
Energy-efficient envelope	70	4.6%	1.73
Heat pumps	100	6	2.35
Solar water	10–20	0.6	0.23
Solar panels	350–400	20	7.5
Rainwater recycle	35–40	2.6	0.98
Indoor air monitoring	100–250	8	1
Building intelligent control	Residential: 150 Public: 40	10	1

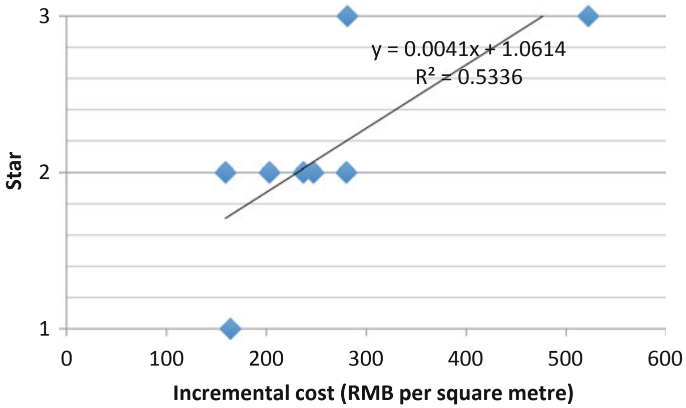

Fig. 15 Incremental costs for public buildings

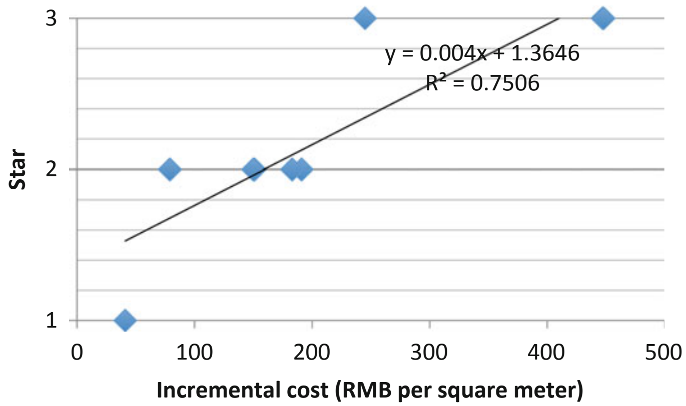

Fig. 16 Incremental costs for residential buildings

cost for a green residential project is more susceptible to which star it pursues. The average incremental costs for one-, two- and three-star green buildings are respectively 103, 207 and 360 RMB per square metre. They account for 2.7, 6.2 and 9.3%, respectively, of the total cost of construction. In the USA, Kats et al. found that the additional cost for LEED-certified buildings is on average 2% of the total construction cost, which is lower than that for GBL buildings in China.

The incremental cost data are useful to provide evidence of monetary incentives in the green building policy. However, the abovementioned incremental cost for a green building in China is actually calculated based on a concept of net present value that reflects a stream of current and future benefits and costs. For example, all energy-saving strategies used in a green building cost up to 405 RMB per square metre. After deducting the cost for thermal insulations and efficient water closets that are regulated in national building codes and also implemented in a conventional building, the cost is reduced to 317 RMB per square metre. After deducting the electricity and water cost saving, which is the benefit of using these strategies, the final incremental cost is 280 RMB per square metre. Obviously, the incremental cost calculation confused the initial cost and net cost from a life-cycle perspective. As in most cases commercial developers will sell the buildings and not receive any payback from future benefits, they only care about the initial cost. Such a deduction analysis is biased and might not provide correct information to policy makers and developers. The green building investment may incur more initial cost than the official statistics.

3.2 Shifting Towards a Mandatory Approach: From 2013

3.2.1 A New National Green Building Action Plan

The Five-Year Plans of the People's Republic of China (PRC) are a series of social and economic development initiatives to map strategies for economic development, setting growth targets and launching reforms. The plan is established for the entire country normally besides detailed development guidelines for all regions. Since China launched its first Five-Year Plan in 1953, the plans have been both a blueprint for the immediate future and a showcase of the political economy of the day. A new National Green Building Action Plan [23] was issued by the National Office on the first day of 2013 to show the green building ambition during the 12th Five-Year plan. During the 12th Five-Year Period (2011–2015), one billion square metres of green buildings will be built. By the end of 2015, green buildings will account for more than 20% of urban new constructions. To achieve this goal, the plan suggests that from 2014, government-invested public projects including governmental offices, schools, hospitals, museums, gymnasiums, etc. are mandatorily required to fully implement green building standards. The list of the Green Building Action Plan also includes social housing projects in municipalities directly under the Central Government (such as Beijing, Shanghai, Chongqing and Tianjin), cities specifically designated in the state plan (such as Shenzhen, Dalian, Qingdao, Fujian and Ningbo) and provincial capital cities. In addition to government-invested projects, from 2014, large public buildings with GFA exceeding 20,000 square metres per building in these cities and municipalities must implement the green building standard as well.

Following this plan, MOHURD published "The 12th Five-Year green buildings and green eco-city development plan" on 3 April 2013 [20]. This plan reiterates the green building action plan. In addition, it expands the action plan from single green buildings to areas or even cities by planning 100 demonstrative green eco-cities or areas where green buildings are densely concentrated (e.g. 100% green buildings). The government also recognises that the previous action plan did not fully engage the commercial sector, and in this new plan, it encourages developers to adopt green building standards especially in provincial capitals and eastern coastal cities. From the two governmental plans, we can see that green buildings become mandatory in government-invested projects and large-scale public buildings in specified cities and municipalities. However, the green building standard is still voluntary for the commercial private sector in most cities.

3.2.2 Implementation of the Action Plan

To implement the national action plan, local governments published separately their goals and strategies [3, 6, 9, 10, 13, 14, 27–29]. Considering their green building conditions in the previous approach from 2008 to 2012, their goals are quite different. As can be seen in Table 2, provinces that performed better in the previous stage tend to set higher targets. However, the strategies adopted by these local governments are quite similar. First, government-invested buildings must be green buildings. Second, public buildings with GFA of over 20,000 square metres per building must be green. Particularly, social or public housing projects are highlighted in each local implementation plan. In response to developing demonstrative green areas or cities where green buildings are concentrated, Fujian, Hunan and Jilin set their targets to develop demonstrative green areas or cities. However, few governments target private sector-invested residential projects that account for a large portion of green building GFA. Jiangsu Province and Shenzhen in Guangdong Province, forerunners of the initial stage, set the most ambitious goal: all new constructions shall implement green building standards and must be certified one-star or above. Furthermore, some provinces divide their goals among their cities (Table 3). In sum, the main strategies to develop green buildings locally are invariably focused on government-invested buildings especially social or public housing projects, while residential projects which receive investment from the private sector are largely ignored.

3.2.3 Incentives

The incremental cost is a significant barrier for green buildings. To subsidise developers, financial incentives are addressed in both the national action plan and some local implementation plans (Table 4). The national rewards account for a quarter of the average incremental cost. Some local governments such as Beijing and Fujian have additional monetary rewards. Fujian government further introduced its GFA concession rewards for green buildings. Shenzhen government is the only one that will punish developers who do not adopt the green building standard in their new developments. Compared with the old incentives mentioned in Sect. 3.2, the new incentive scheme is an important improvement due to taking into account the size of buildings. However, the incentive scheme does not show any difference between residential and public projects that have different incremental costs. In most cases, the maximum monetary reward for a green building is one-third of the net incremental cost. Because of the net cost from life-cycle perspective developers may have a biased view of the investment due to underestimating the initial cost. It is difficult to motivate these small private developers with limited financial resources to pursue green certifications.

Table 2 Local implementations for Green Building Action Plans

Regions or cities	Targets	Strategies	Government notices
Beijing	During the 12th Five-Year, the GFA of green buildings should be more than 35,000,000 m^2	All government-invested buildings, large public buildings with GFA of over 20,000 square metres per building should be designed and constructed as two-star or above green buildings	"Implementation for Green Building Action Plan in Beijing 2013" [3]
Jiangsu	By 2015, all new urban constructions should be designed and constructed to be one-star or above green buildings; by 2020, 50% of new urban constructions should be two-star or above green buildings	Social or public housing buildings, government-invested projects, provincial demonstration projects and large public buildings with GFA of over 20,000 square metres per building must be at least one-star green buildings	"Implementation for Green Building Action Plan in Jiangsu 2013" [13]
Fujian	By the end of 2015, more than 100,000,000 m^2 of green buildings should be added to the current green building stock; 20% of new urban buildings should be green buildings; two demonstrative green cities where all buildings are green should be built	Government-invested projects, large public buildings with GFA of over 20,000 square metres per building and residential projects with GFA of over 100,000 square metres per project should be green; social housing projects in Quanzhou should be green	"Implementation for Green Building Action Plan in Fujian 2013" [6]
Sichuan	By 2015, 32,000,000 m^2 of green buildings should be built; 20% of urban new constructions should be green buildings	Government-invested buildings and large public buildings with GFA of over 20,000 square metres per building should be green	"Implementation for Green Building Action Plan in Sichuan 2013" [29]
Hunan	By the end of 2015, more than 20% of urban new constructions should be green buildings; more than five demonstrative green areas should be built	From 2014, government-invested projects, large public buildings with GFA of over 20,000 square metres per building should be green; social housing projects in Changsha should be green	"Implementation for Green Building Action Plan in Hunan 2013" [10]

(continued)

Table 2 (continued)

Regions or cities	Targets	Strategies	Government notices
Jilin	During the 12th Five-Year Period, 10,000,000 m^2 of green buildings and three demonstrative green areas should be built; by the end of 2015, 20% of urban new constructions should be green buildings	From 2014, government-invested public buildings and large public buildings with GFA of over 20,000 square metres per building should be green; by the end of 2015, more than 20% of social housing projects should be green	"Implementation for Green Building Action Plan in Jilin 2013" [14]
Shandong	By the end of 2015, 50,000,000 m^2 of green buildings should be built; more than 20% of urban new constructions should be green buildings	From 2014, government-invested office buildings, projects, social housing projects, and large public buildings with GFA of over 20,000 m^2 should be green buildings	"Implementation for Green Building Action Plan in Shandong 2013" [27]
Hebei	By the end of 2015, more than 25% of urban new constructions should be green buildings; among all green buildings, three-star buildings should account for more than 10% of all green buildings	From 2014, government-invested public buildings, and large public buildings with GFA of over 20,000 square metres per building should be green	"Implementation for Green Building Action Plan in Hebei 2013" [9]
Shenzhen	By the end of 2015, GFA of green buildings in Shenzhen should be more than 40,000,000 m^2	All new constructions should be green buildings	"Measures to promote green buildings in Shenzhen 2013" [28]

Table 3 An example of sub-dividing green building targets: Fujian Province

Cities in Fujian	GFA of green buildings (m^2)	Number of green buildings
Xiamen	2000,000	2500
Fuzhou	2000,000	2000
Quanzhou	1000,000	1000
Zhangzhou	1000,000	1000
Longyan	1000,000	1000
Putian	1000,000	1000
Sanming	350,000	500
Nanping	1000,000	500
Ningde	350,000	500
Pingtan	1000,000	500

Source Fujian Provincial Government [6]

Table 4 Rewards and punishments

Governmental Notices	Measures
"National Green Building Action Plan" [23]	The monetary reward for a two-star green building is 45 and 80 RMB per square metre for a three-star green building
"Implementation for Green Building Action Plan in Beijing" [3]	The monetary reward for a two-star green building is 22.5 and 40 RMB per square metre for a three-star green building
"Implementation for Green Building Action Plan in Fujian" [6]	A 1% deduction in the bank loan rate can be applied to green building development. The GFA concessions for one-, two- and three-star green buildings are 1, 2 and 3%, respectively. The monetary reward for each green building is 10 RMB per square metre
"Measures to promote green buildings in Shenzhen" (Shenzhen Municipal Government, 2013)	Any new constructions that are not green buildings would be fined 50,000 to 200,000 RMB

4 Discussion

4.1 National Action and Local Implementation

As the world's largest carbon emitter and the world's largest building constructor, China sees the green building as a key solution to reducing energy consumptions, while improving living and working environments. China started much later in green building development, but has swiftly overtaken other countries by means of governmental interventions. Although the green building standards were voluntarily implemented during the period 2008–2012, the huge scale of construction made noticeable progress in green building development. The success demonstrates that governmental interventions are workable.

Since 2013, green building development had shifted to a mandatory approach because the goal of one billion square metres and 20% new construction market share was set out for green building development during the 12th Five-Year Period. A central action plan and a series of local implementation plans have been published. It is explicitly stated in the national and local plans that the green building standard is becoming mandatory for all government-invested projects. Since 36 million units of social housing will be built by the end of the 12th Five-Year Period, the mandatory policy is expected to produce more than 2 billion square metres of green buildings (averaging 60 m^2 for each unit). The green building goal can be easily met under the mandatory policy. The large-scale construction of social housing across the country by the government can also, to a large extent, balance the regional difference of the green building distribution.

The goal setting appears to be effective when combined with these plans, especially implementation intentions that spell out when, where and how a set of goals has to be put into action [2, 26]. The quantifiable goals and measures also increase the capacity of higher-level governments to monitor enforcement at local levels. The green building goal is primarily the responsibility of local governments that are supposed to draw on multiple resources to implement the green building plans. The local enforcement can be further strengthened by local authorities established to carry out the certification procedure for one-star and two-star buildings in their specific administrative regions.

However, when taking a closer look at the central action and local implementation plans, the commercial private sector is largely ignored. It seems that the national green building goal is fulfilled by way of autarky by government. At this point, it is doubtful whether green building development can go farther without actively involving the commercial sector.

4.2 Policy Instruments

The incremental cost of green building has been identified as a significant barrier that needs further governmental interventions. To incentivise the commercial sector to pursue green certifications, the national government and local governments jointly reward each two-star or above green buildings to offset approximately one-third of the net incremental cost at most. However, the monetary incentive may not be so attractive to private developers. The large commercial developers who have superior financial resources (such as Vanke and Landsea) could remain active in the green building development, while other smaller developers have little incentives to venture into green buildings construction. Even though the subsidies can, to some extent, encourage certain private developers to pursue green buildings, there are ineligible risks in green building development. Specifically, money can induce a mindset among developers in which the influence of social responsibilities or obligations on the building industry is suppressed [17]. It is, therefore, more important to consolidate the change due to any subsequent governmental intervention for a long-lasting effect.

Many studies assessed or reviewed policy instruments or measures to help exercise governmental power on building energy efficiency [11, 16, 37, 39]. The policy instruments can be classified into four categories: regulatory instruments (building laws, codes, regulations, legislation, etc.), market-based instruments (labels, etc.), fiscal instruments (financial rewards, etc.) and informative instruments (training, education, etc.). Governmental interventions are, it is suggested, geared initially and directly towards regulating the behaviour of the building industry via legislation and subsequently adapting attitudes and value priorities accordingly through market-based, informative and educational instruments [1]. Although China provides a successful case of initiating and gearing up the green building development by governmental interventions, the following educational, marketing or informative measures are seldom found in current green building action and implementation plans.

5 Conclusions

Given the serious environmental challenges the world is currently facing, it is worthwhile regulating the building sector through governmental interventions [40]. The green building policy in China sets an example for popularising green buildings in a short period of time through a top-down intervention strategy. Now green building development in China has explicitly shifted from a voluntary approach to a mandatory approach, which is evidenced in a series of action and implementation plans. To a large extent, the clearly articulated central action and local implementation plans improve the enforcement of the green building goal by accountability. Although the approach is increasing green buildings exponentially to meet the green building objectives of the 12th Five-Year Plan, it is confined to government-invested projects. The private and commercial sectors are less involved. Incentives by direct monetary rewards are the main policy instrument to motivate the commercial sector. However, the monetary reward incentive is short-lived.

Future development will be inclined towards encouraging the private commercial sector to foster the large-scale construction of green buildings in China. To this end, a combination of policy instruments is needed. In addition to financial support, the Chinese government could explore the further implementation of instruments such as marketing or informative measures, which could produce long-lasting effects on green building development.

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Analytical Review of Green Building Stakeholders in China

Xiaosen Huo

Abstract Green building is an essential part to promote sustainable development in the construction industry in China. In previous research, the green building development was studied from the general development progress, the benefits and barriers, the performance, and strategies. This research aimed to analyze the stakeholders of green building in the context of China. The stakeholders in green building were critical to the success of green construction projects, so the roles and relationships of the major stakeholders were also analyzed. It was shown that the importance of the government had been emphasized, while the roles of green consultants were overlooked. The research findings are helpful in promoting green building development from the perspective of management.

Keywords Green building · Sustainable construction · Stakeholder · China

1 Introduction

Sustainable development has been a development trend in China from the early twenty-first century. As defined by Brundtland [1], sustainable development refers to "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Among the overall energy consumption and greenhouse gas emission around the world, the construction industry accounts for more than 40% in energy use and around 30% in greenhouse gas emission [21, 39]. Especially in the context of China, the construction industry is a pillar industry, and the energy consumption is increasing rapidly. During the past decades, the growth rate of the energy consumption in the construction industry is over 10% [3, 9]. Therefore, promoting sustainable development in the construction industry is essential in reducing resource use and minimizing negative impacts of buildings on the environment. According to Kibert [13], the principles of sustainable construction include efficient resource use and ecological features conservation. In addition, sustainable construction aims to build a healthy built environment and to improve

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social productivity and overall health of the residents [14, 15]. Green building is regarded as an effective way to solve the global warming problem and improve our living environment. As an essential part of sustainable development, green building considers the energy conservation, water saving, waste reduction, and indoor environment improvement during the whole life cycle [12]. Though the prevalent trend of construction industry is sustainable development, green building is still an immature practice including immature green technologies, expensive green materials, and inadequate government supports [7]. The green building implementation still encounters many obstacles. Tam et al. [29] pointed out that the initial cost of green building is higher than traditional buildings due to the green requirements. Meanwhile, there are insufficient governmental financial incentives for green developers to get low risk and affordable financial resources [24]. As the initial cost of green building is higher, the investment of the developers is large, while the benefits of green building are mostly accrued by the occupants, such as the better indoor environment and lower energy consumption, which result in unequal benefit distributions [30, 38].

Various research studies are related to green building development, such as the general development progress, merits and obstacles, the performance of green buildings, stakeholders in green buildings, and green building strategies [12]. In this paper, the research on stakeholders of green buildings in China was comprehensively reviewed, and the roles of major stakeholders in green building development were summarized. This study contributes to better understanding stakeholders in green buildings and promoting green building development from the perspective of management.

2 Green Building Development in China

In China, the green building concept starts from the "Energy-Saving and Land-Saving Residential Building" developed by the central government, and defined by the Chinese national green building standard in 2006 as "Buildings that save resources (energy saving, land saving, water saving, and material saving) during the whole life cycle, protect the environment and reduce pollution, provide people with healthy, applicable and efficient use space, and build a harmonious coexistence with nature" [15].

In order to facilitate green building development, various green building rating systems (GBRSs) were developed and issued around the world. The aim of these GBRSs is to assess the green performance of a building and to evaluate the green level of the certification. Building Environment Establishment Assessment Method (BREEAM) is the first established GBRS by UK in 1990, followed by Building Environmental Assessment Method (BEAM) in Hong Kong, Ecology, Energy Saving, Waste Reduction, Health (EEWH) in Taiwan, Leadership in Energy and Environmental Design (LEED) in the USA, Comprehensive Assessment System for Built Environment Efficiency (CASBEE) in Japan, Green Mark (GM) in Singapore, and Evaluation Standard for Green Building (ESGB) in China [11, 20]. In China, the green building rating systems have been developed through a series of learning process, which was first issued in 2006 as ESGB and revised in 2014 as Assessment Standard for Green Building (ASGB), and assesses and certifies buildings at three levels based on seven categories [39]. Specifically, the number of green building standards at the country level is 17, and at provincial level, the number is more than 50 [36].

Zhu et al. [41] took an awarded green building in China as an example and displayed the higher performance of the building such as the lower costs and appropriate green technologies application. [38] investigated the motivations of developers to develop green buildings, which include lower costs during construction and operation, lower land prices, and various financial channels. Ying Liu et al. [19] emphasized that an important concern in promoting green buildings in China is to improve the public awareness and acceptance of the benefits of green buildings and green technologies. Through a questionnaire survey on green construction in China conducted by Shi et al. [27], it revealed that although the stakeholders would like to consider environmental requirements into green construction, it is still hindered by the higher costs and longer time, and lack of green suppliers. The cooperation of the government, industry association, and enterprises in the industry is highly suggested to promote the green construction in China. Shi et al. [26] evaluated the performance of green building policies in the context of China, and due to the limited effectiveness, the administrative supervision should be strengthened, the detailed technical standards should be issued, and the public awareness and knowledge should be enhanced. Zhou [40] also argued that except for the important position of the government in promoting green buildings in China, the popularization of green buildings needs the joint effort of various stakeholders. Meanwhile, the government power should be leveraged properly such as incentives to developers, support to the public, researchers, and market services. Specifically, by investigating the status of green roof development and research in China, Miao et al. [31] suggested that promoting the awareness of residents of benefits of green roofs, improving government support, and improving research investment were effective ways to promote urban roof greening. Similarly, Liu and Lin [18] also highlighted the importance of government encouragement, technology diffusion, and financial support for research in promoting energy-saving technologies in green construction industry. When concerning the risks of green buildings in China, the critical ones were regarded by Qin et al. [23] as the complicated governmental procedures, lack of maintaining green buildings, and inadequate experiences in green design. Pei et al. [22] conducted a comparison between green buildings and conventional buildings in China and displayed the higher performance of green buildings in thermal environment and indoor air quality.

To promote sustainable construction in China, researchers and practitioners have made great endeavor in green technology and standards application, and green management. The performance of green buildings has also been investigated and compared with conventional buildings, which revealed the efficiency of green buildings. Specifically, the previous research on stakeholders of green buildings in China was reviewed in the next section.

3 Green Building Stakeholders in China

The term "stakeholder" is defined as "any group or individual who can affect or is affected by the achievement of the firm's objectives" [5]. Previous studies have investigated the behaviors of stakeholders in green buildings, such as in the research conducted by Yang et al. [33] and Gluch et al. [7]; it was shown that in green buildings, there is a broader range of stakeholders who play influential roles. The stakeholders in green buildings include owners, occupiers, contractors, subcontractors, governments, suppliers, financial organizations, energy service companies, consultant companies, environment protection organizations, and researchers. Generally, stakeholders in green buildings focus more on the uncertainty and risks of the design and management. For instance, contractors normally feel that implementing a proactive environmental strategy will place their financial well-being at risk. Son and Kim [28] showed that prediction models are critical in helping stakeholders assess the potential performance of green buildings at the very beginning stage. Social network analysis (SNA) is an effective tool for analyzing the relationships among stakeholders. For instance, Shen and Yang [25] analyzed the effects of stakeholder relationship on the project and proposed a stakeholder management framework for construction projects based on the research results. Yang and Zou [34] analyzed the risks that exist when internal stakeholders are in a relatively central position in the project. Yang et al. [35] modeled the interactive networks of risks that affect different stakeholders and found that the central risks in Chinese green buildings are related to the behavior of the clients, the government, and the end users. Some researchers have focused on the behavior of participants in green buildings. For example, Xu et al. [32] developed a multi-objective model to buffer conflicts and balance gains between developers and contractors in a fuzzy environment.

In China, the green building promotion adopts top-down approach, i.e., the government developed and issued relevant standards and regulations and then implemented green buildings step-by-step [38]. Hu et al. [10] conducted a survey to investigate the willingness of occupants to pay for green buildings and found that comparing with energy saving of the buildings, the occupants concerned more about the living environment but unwilling to pay for the higher price green materials. Therefore, the application of green technologies and materials should be promoted by raising standards from the national level. Zhang [37] reviewed the development of green real estate in China and suggested that the role of the developers should be highlighted and the operation stage should be paid attention to. Zhu and Sarkis [42] highlighted the role of government in China in promoting green marketing by improving the public awareness. Based on interviews with stakeholders in green retrofit projects, Liang et al. [17] found that although the occupiers play an important role, their prioritization was surprisingly underestimated in the current situation. Li et al. [16] studied how the stakeholders influence the design and evaluation of sustainable buildings through interviews and Delphi analysis, which revealed that the government organization is the most critical part during the whole process of green projects, and the satisfaction of the end users is an important concern in assessing the performance of sustainable buildings. By conducting a questionnaire survey in the post-occupancy evaluation of green buildings in the context of China, Li et al. [14] investigated the roles of various stakeholders in green building performance and indicated that the most influential role is the government, whereas the least ones are the property management companies and NGOs. Deng et al. [4] took the Ningbo City as an example and found that the local government intervention is critical in promoting green building development; therefore, several policy improvement strategies were proposed such as the incentive mechanism and the coordination among green building development stages.

According to the situation in China, most of the researchers agreed that the government is a critical part in developing green building projects; meanwhile, the developers, designers, and occupants also occupy important positions in the development process. In addition, they stated that green building development in China is still immature such as lack of knowledge and awareness. However, green consultants who have professional green knowledge are rarely mentioned in previous studies and practice. Therefore, how do the major stakeholders play their roles in green buildings is illustrated in detail in the following section.

4 Roles of Major Stakeholders in Green Building Development

4.1 Government

The government, as decision makers and guides of green building policies and regulations, provides constraints and policy guidance for green building development. For instance, before the commencement of the project, some basic indexes including floor area ratio, greening rate, and building density are set by the government. To promote green building development, the government also provides several economic incentives. For example, for new buildings in Hong Kong, to promote green buildings development in private sector, incentives on gross floor area (GFA) concession and site coverage concessions are provided for private buildings which involve environmentally friendly features. To promote green building market, the government is helpful in developing green technology and green knowledge on a lower cost [2]. Meanwhile, during the process of green building projects, the government should guide the behaviors of other stakeholders. In public projects, the strong involvement of the government is a key for successful green building projects, which is also highlighted by Geng et al. [6].

4.2 Developers/Agent Construction Enterprises

In China, there are two basic building project types, i.e., public building projects and private building projects, in which the developers and agent construction enterprises are in charge of the projects, respectively. The developer is a dominant part in green building projects. In the context of China, there are three levels of green building certificates, i.e., one-star, two-star, and three-star. The developers can apply for subsidy according to their green building certification grade. For developers, they want to gain higher scores in green building evaluation and obtain green building label with lower costs. By considering professional information of green technologies from the consultants, developers will analyze the reasonableness of the green technologies in operation stage and their economic feasibility. Based on their own demands and understanding, developers will decide how to apply the suggested green technologies.

4.3 Consultants

Nowadays in China, although the consultants are independent parts as they work in green building consulting company, their roles in green building projects still depend on developers and occupy very little voice. In previous research, the importance of the consultants in green building development has been overlooked. The consultants provide professional and technical information of green building design and construction, and then, the developers consider green investment, construction technology, and the tax refund, and how to balance green requirements and construction costs. At the beginning of the building design, a series of evaluation will be conducted by the consultants to assess the construction site and to consider the targeted green building label level. As the popularity of green buildings in the coming future, the green consultants should be involved in a project as early as possible to reduce uncertainty and risks. In addition, in the future, the green consultation and green design should be integrated in the early stage of green building development, i.e., the designers in the future should have green consultation knowledge and reach a higher level.

Generally, the roles of green consultants in green building development should be links or bridges among major stakeholders. They make green requests in planning and design stage, which will be fulfilled by the designers, constructed by the contractors, urged by the developers, and supervised by the government.

4.4 Designers

In green building projects, the designers and architects conduct their design following the requirements of the developers. As the architects are unique-minded individuals, they have their own understanding of green features in building projects. Therefore, the degree to which the designers and architects will have green features in their design is also based on their understanding of green buildings. According to some experienced architects in China, it is said that when working as an architect in green building development, maybe there is no definite green standard during the planning and design stage, while the green conceptions will be beard in mind during their creative design process. Normally, in the context of China, the developers put forward their requirements to developers, and the consultants also have their suggestions from the professional green perspective.

4.5 Contractors

The contractors, as the implementers of the green building projects, need to meet the requirements and obey the arrangements of the developers in each process. Green construction is a vital process as many green technologies are applied in construction stage. To improve the understanding of the contractors on green technologies and materials is critical for a successful green building project. The efficiency of green construction can be highly improved if the contractors have better knowledge of green construction. In addition, the consultants suggest professional requirements in green buildings to developers, and the construction process should follow these requirements.

4.6 The Public and Occupants

The public are important participants after the green buildings are put into use, and they can propose their comments and suggestions during the whole development process. Especially in use stage, their feedback in green buildings can help to promote and improve green building development. Especially, the public is concerned as an important part in green building projects, as the people-oriented principle of green buildings. The requirements and needs of the public and the residents should be taken into consideration during green building design process. Occupants are critical parts of the green building operation stage; their perceptions and working and living experiences in green buildings should be highlighted for a better indoor environment. As the various regions and climates in China, green buildings and GBRSs should be developed and promoted according to local situations based on the feedback and

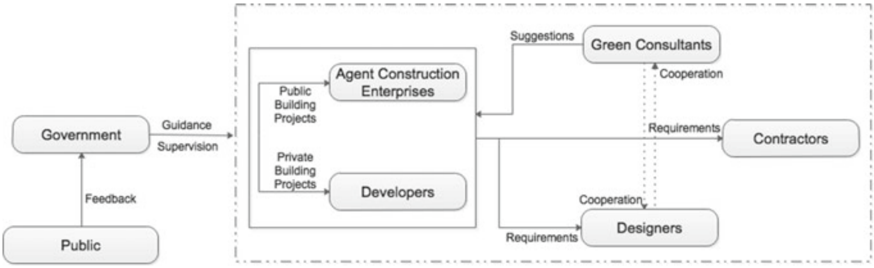

Fig. 1 Relationships among the major stakeholders of green buildings in China

demands of the occupants, which is in accordance with the research conducted by Gou et al. [8].

4.7 Relationships Among the Major Stakeholders

By analyzing the roles of the above major stakeholders, their relationships can be summarized as shown in Fig. 1. Within the relationships of developers/agent construction enterprises, green consultants, designers, and contractors, the solid line between the stakeholders represents that there are contractual relationships between the two stakeholders, and the dotted line means although there are no contractual relationships, they should cooperate and communicate with each other about the green information.

5 Conclusions

The importance of green building development has been highlighted in China. From the perspective of management, stakeholders are major participants in green building development and are key issues in successful green building implementation. This research reviews the green building stakeholders and development in China, and the roles and relationships of the major stakeholders are summarized. The research findings highlight the importance of green consultants which has been neglected in previous research. In future research, the relationships among these major stakeholders in green building can be analyzed quantitatively.

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Obstacles of Implementing Green Building in Architectural Practices

Xiaohuan Xie and Zhonghua Gou

Abstract This chapter looks at obstacles for implementing green building in design practices in China. A literature and document review is conducted to understand current situation of design process in China. An interview of experienced green building designers is conducted to identify the specific obstacles to designing green building in China. The research found that the conventional linear design process negatively affects the implementation. The specific obstacles mentioned architects are such as intrinsic mind-set, difficulties in performance assessment, unsuitable working patterns and doubts about green technologies. The study suggests that the measure to unblocking these obstacles and moving forward green building development is an integrated design process. The research also suggests at least three paradigm shifts toward the integrated design process: from descriptive to performance-based design, from personal experience to building simulation, and from individual to collective decision making.

Keywords Green building · Obstacles · Integrated design process · Architects · China · Design practice

1 Introduction

A green building revolution is happening around the world aiming to fundamentally change the current situation of the building industry by creating more environmentally friendly and more resource-efficient buildings [30]. Green building is also beneficial to the occupants' health and well-being [6]. This revolution is more essential in China due to fast urbanization and environmental degradation. The Chinese government launched Green Building Label (GBL) as the official green building certification to promote this movement and also provides many subsidies and incentives

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to the certified projects [2]. Furthermore, the government mandatorily requires that all large-scale public buildings and all social housing projects be certified as green.

The green building movement has largely affected the building industry since the 1990s. It has changed the way we design, construct, operate, and demolish buildings. A variety of terms are used to mean "green" in the construction industry. These terms include "green building," "sustainable building," "environment-friendly building," "sustainable design," "high-performance building," "energy-efficient building," "whole building design," and "integrated design" [21]. A single, widely accepted definition of green building does not exist. Representative definitions of sustainable or green building show that even though their implications may be slightly different, all definitions and concepts unanimously consider energy performance, resource efficiency, low-waste emissions, and indoor environmental quality [7].

In addition to identifying the definition of green building, another important point is distinguishing green building from conventional building by the implementation of green building rating or assessment systems from an independent third party. A number of third-party organizations or state administrations developed numerous types of GB rating systems, such as LEED in the USA, CASBEE in Japan, BREEAM in the UK, HKBEAM in HK, Green Star in Australia, and GBL in China. These systems offer a platform to rate and certify buildings. The rating system has an open process to allow the public to understand and identify green buildings. These rating systems are used to provide a recognizable framework that organizes a set of performance criteria with assigned points to evaluate the environmental impact of the building, covering site, water, energy, materials, environmental qualities and so on [3].

To meet the requirements, the design must be assessed in a series of energy and environmental studies, such as building heat island analysis, indoor and outdoor air ventilation assessment, day-lighting analysis, noise analysis, water consumption estimation, rainfall calculation, material calculation, and energy simulation. These assessments involve many building aspects such as heating, ventilation, and air-conditioning (HVAC), water, plumbing, structure, architectural design, interior design, landscape design, third-party commissioning and energy simulation. It is required that relevant professionals work together to discuss how to achieve corresponding certification credits. Even one single credit may require high levels of design collaboration and coordination and a specialized set of competencies and new simulation tools to assist design [25].

1.1 Green Building Obstacles and Integrated Design Process

The key to successfully promote green building is to reveal all the obstacles and seek for appropriate solutions to overcome these problems. Various researchers in different countries studied the obstacles of green building, and these obstacles can be classified into two categories: external factors, such as policy or market, and internal factors, such as design method or technology application. Most of existing literature on green building focused on the external factors, looking at policies and incentives to promote green building in building industry and real estate market [5, 10, 26]. This research focuses on internal factors. Because the internal effects significantly influence green building promotion, and the design process and working pattern are crucial to the successful design and construction of green buildings. Based on the literature, the barriers related to green building design, which are unchangeable by external factors and require urgent resolution, are summarized below:

- Late involvement of design team [29]
- Late adoption of simulation software [17]
- Isolation of disciplines [16]
- Insufficient time for architects [11]
- Lack of effective feedback on actual performance of buildings [4, 6]
- Lack of understanding of green building and related rating system [1]
- Lack of understanding of passive design technologies [24]
- Lack of database for green products [31]

These obstacles require a new design process and effective assistants to aid the design team in delivering green projects. A theory about integrated design process (IDP) was developed by actual practice of green projects to unblock the internal barriers for green building. This theory aims to overcome the obstacles of green building design and provide effective assistants to deliver green projects smoothly. A range of delivery models, roadmaps, guidelines, and standards has been utilized in the past decades to explain IDP theory and describe its benefits. Larsson [12] first proposed the concept of IDP based on the C2000 Program experience for delivering high-performance buildings in 1993. Evidence of this program showed that a suitable design process could balance the performance and cost. Lohnert et al. [16] developed the most important reference and principles of IDP from the Integrated Energy Agency (IEA) Task 23. It was based on the real cases of nine different countries involved in Task 23. This model compared different characteristics of IDP with the conventional design process and explored the working methodologies used by architects and engineers. Pearl [18] developed a circular model to describe IDP to provide a platform where the client, architects, engineers and other specialized consultants could be brought together to conduct an intensive design charrette and make sure environmental-friendly design direction. This model echoed Larsson [12] and Lohnert et al.'s [16] IDP models. Hansen and Knudstrup [9] proposed an IDP aiming to integrate knowledge from engineering and architecture to solve the complicated problems of sustainable building design.

These IDP models encourage early goal setting, cooperative working pattern, technical support from simulation tools, and assembling quality design team; these characteristics of IDP perfectly assist the projects that have quantitative environmental goals such as green building. However, IDP theory is confined to Western countries [20]. Despite an increasing interest in green building development in China, only few studies focused on overcoming the obstacles of green building design and implementing appropriate design process and design methods for green projects. Considering China is the leading global construction market, implementing the requirements of green building and successfully delivering green projects are crucial in reducing energy consumption and responding to the global warming issue. Further studies should be conducted to explore the effective measures in overcoming the obstacles and to seek for an appropriate green building design process that suits China.

2 Objective

This research looks at obstacles for green building design in China and the paradigm shifting toward an Integrated Design Process to better design green and high-performance buildings. The research is conducted in three consecutive steps. The first step is to understand the current situation of architectural design process and possible obstacles in China. The second step is to identify the specific obstacles from architects' perspectives. The final step is to take architects with experience in green building design as the main target to find out the major paradigm shifts that are needed toward an integrated design process in China.

3 Methodology

Figure 1 shows the research design for this study. First, a literature and document review is conducted to understand current situation of design process in China, based on which potential obstacles for green building were identified; second, an interview of experienced green building designers is conducted to identify the specific obstacles to designing green building in China; third, the interview also explores the paradigm shift from current design process toward integrated design process for green building. The literature and document studies are based on reviewing architects' practice guidelines and policies in China, as well as relevant theoretical and empirical studies.

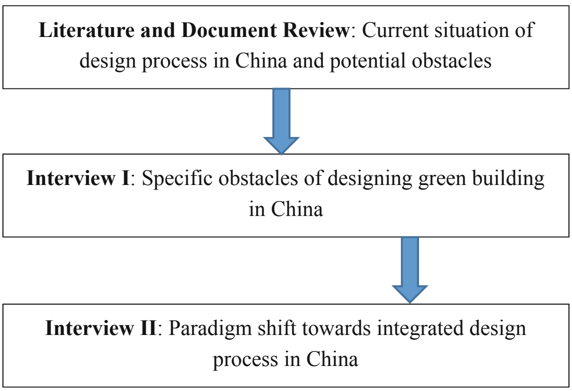

Fig. 1 Research design

For the interview, 20 experienced architects, who have participated in more than 10 green-certified projects, are interviewed to understand the design obstacles as well as to explore the paradigm shift toward integrated design process. The interviews and related information have been submitted to the Human Research Ethics Committee for Non-Clinical Facilities, the University of Hong Kong. The survey obtained Research Ethical Approval with Reference No. EA181211.

4 Findings

4.1 Design Process in China

The building design process in China generally includes seven stages, namely, the preparation, concept design, design development, construction document, construction, occupancy, and completion stages. Relevant government authorities examine different aspects of the building performance in every stage. The building design process in China can be understood as a linear process with sequential work routines and an isolated working pattern with different disciplines [13, 29]. Figure 2 shows a complete linear design process in China. The site is generally selected first by the developer without consulting the whole design team. The architect is then selected to develop a building plan for the site according to the requirements of the government authorities and developer. After the schematic design is finished by the architect, the developer dominates the selection and modification of the design concept that consists of a general massing scheme, orientation, fenestration, and general exterior appearance of the building [13]. After the initial plan is settled, the architect retains sub-consultants, including civil, structural, mechanical, electrical, and plumbing (MEP) and HVAC engineers to suggest appropriate systems [19]. The sub-consultants are then provided with the architectural schematics and requested to design their engineering subsystems conform to the schematics. Architectural, structural, mechanical, and electrical drawings and specifications are usually separately developed by professionals from different disciplines [13]. The drawings and specifications are then given to the general contractors to quote their price in a short period of time. Usually, the contract is awarded to the general contractor with the lowest price, who will then coordinate with all the sub-contractors of the construction works [19].

This linear working pattern allows all participants to focus on making full use of their expertise and minimizing the risk and negative consequences. On the other hand, it fosters the isolation of disciplines, for example, the structural design does not begin until the completion of architectural drawings, with both needing to be completed prior to mechanical systems design beginning [29]. This isolation coupled with increasingly fragmented design typically leads to costly changes, duplicated design efforts, and redundancies in the final design, which result in buildings that operate below their optimum potential [30]. This type of working pattern causes a lack

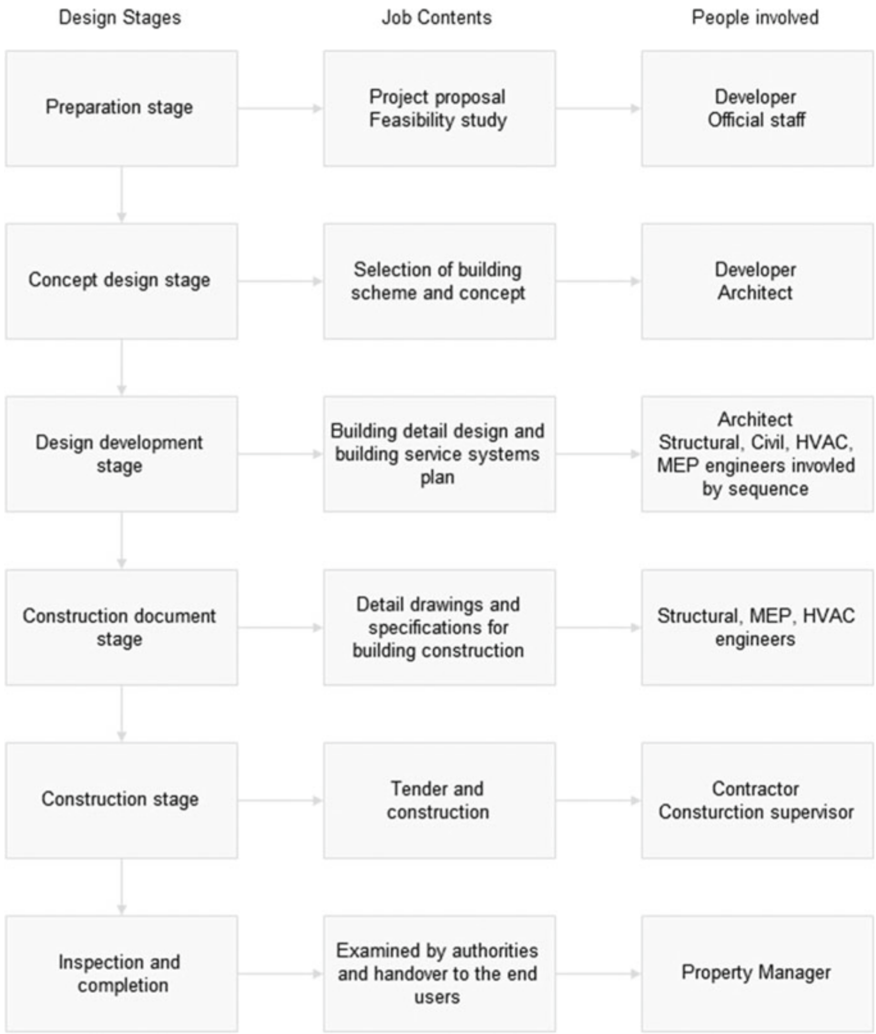

Fig. 2 Typical building design process and team organization in China

of shared objectives and hasty decision making due to insufficient communication. Obviously, the linear design process is not appropriate for green building practices.

Besides the linear design process, another significant barrier for the green building practice in China is due to the confined role of architects in the design process. Architects play a leading, important role in achieving high performance. They are supposed to be fully engaged in the whole design process for green buildings. Given the different rules for architects in different countries in terms of the design phase they can be involved in, rights and obligations given to the architects also differ from one another. Table 1 compares the involvement of architects in different phases. Chi-

Table 1 Architect's participation for all design stages in different countries

Design process	Architect's right for all design stages			
	USA	An ideal IDP	Hong Kong	China
Project inception	●	●	●	
Feasibility studies	●	●	●	
Conceptual design	●	●	●	●
Schematic design	●	●	●	●
Design development	●	●	●	●
Construction documents	●	●	●	●
Bidding and Construction	●	●	●	
Construction supervision	●	●	●	
Building operation		●		

nese architects' roles and responsibilities are narrow and limited only to the design stage, including concept design,schematic design,design development and construction document stage. In the first place, Chinese architects do not participate in communication and coordination with executive authorities and surrounding residents. Jiang [11] indicated that architects do not have the capacity to influence decisions because they do not participate in the project early enough. Many significant steps often occur before architects were brought in as consultants. The municipal zoning ordinance and developers are typically responsible for the site selection and determination of the project function in China [28]. In the second place, Chinese architects may not be fully engaged in the biding and construction supervision stages. In most cases, they are even forbidden to be involved in the building's cost, materials, and technologies to avoid conflict of interest. After architects complete the project design phase, the rest of the work will be handed over to the owners to conduct the project bidding. Architects in this condition become draftsman without guarantee of implementation of the project. The on-site construction has to develop functions and forms without the designers' monitoring; the construction supervisor on the field only focuses on the project quality rather than building design quality [11]. This mode limits the overall control of the architects for the construction project and also eliminates the functions of architects as the coordinator, collaborator, and problem-solver among different professionals.

To sum up, in the context of China, due to the isolated design process and limited involvement of architects in the whole process, the chance of designing high-performance building and the implementing the original architectural design in China is greatly reduced. All of these conditions may undermine the effectiveness of national green building policy.

4.2 Obstacles for Green Building Design

The barriers to green building design are explored from the perspective of these architects whose views are crucial in comparing green building and conventional building, as well as in determining the effect of green building on design themes, knowledge frames, and working sequence and patterns. The opinions of these architects can be summarized into the following four aspects: intrinsic mind-set, difficulties in performance assessment, unsuitable working patterns and doubts about green technologies.

4.2.1 Mind-Set

The overarching obstacle as mentioned by the interviewees is intrinsic: architects' mind-set. Architects are habitually concerned about the aesthetics of building forms, the requirements of building functions, and the space experience of occupants. Green building requires architects to satisfy the quantitative indicators of building performance and building utility, which cannot be directly perceived by visual building planning and cannot be easily predicted by experience.

These requirements of green building rating systems challenge architects. Their thoughts can be summarized as follows: "Most colleagues thought that the major duty of architects is to provide a creative form and the environmental concern of green building is essential but not the most important factor in architectural design." "Green building is a forward-looking movement and also the future trend of the building sector, which requires architects shifting from satisfying basic functions and achieving comfort to being concerned about the relationship between building and environment, resource and ecology."

This finding is supported by many studies. For example, Rydin [22] claimed that designers are confident in creating conventional buildings but not in creating green buildings. Häkkinen and Belloni [8] reported that architects couldn't depend on their experience in designing high-performance green buildings, which made architects feel that they had no control over the scheme design; thus, architects unconsciously resist the green building concept.

4.2.2 Performance

Energy and environmental performance are frequently mentioned by interviewees as the essence for designing green building. "Although every architect knows natural ventilation and daylighting, there is a lack of quantitative assessment during the scheme design phase to verify its effectiveness and optimize its performance." "Verifying the effectiveness of sustainable design strategies is important for the design team and the clients, and quantitative data present strong evidence to support the adopted technologies and persuade the clients to spend extra money and time on them. However, it is difficult to provide these results for the clients in conventional architectural practices."

The traditional design method in China described by interviewed architects relies on the architect's personal experience and intuition: Architects analyze a building master plan, sketch various spatial organizations, design the façade and sections of the building, and then finally draw a perspective view to illustrate the idea of the designer. However, building performance data required by green building rating systems is based on quantitative information [3]. Architects who want to successfully conduct a green building project must "translate" the quantified performance data into architectural symbolic design elements [14]. Which means, during the green building design process, architects are required to perform numerical simulation to predict the performance of the adopted technology and make the select decisions based on the quantitative data. However, many architects believe that numerical simulation is extremely complex and cannot be easily converted into a visual image. Therefore, architects have a negative attitude toward green building and relative evaluation systems. As a result, difficulties arise in implementing the green building concept.

4.2.3 Working Pattern

Working pattern appears as the third frequently mentioned obstacle by the interviewees. The green building working pattern relies on the collaboration and ongoing communication among the project team members, including architects, engineers, consultants, owners, contractors, and energy specialists. Many barriers mentioned related to working patterns by the interviewees are presented as follows:

> The green building design requires substantial knowledge from other disciplines, such as thermal comfort, lighting simulation, air ventilation assessment, and others. In the ideal process, the architects need to communicate with other professionals during the scheme design phase. However, in practice, they still follow the traditional way to deliver green buildings, which is purely linear with increasing information being added at each design stage. Simply put, structural design does not begin until the completion of architectural drawings, with both needing to be completed prior to the start of mechanical system design. The requirements of green building are usually considered after completion of the scheme design, and the green consultants often help to select the proper building components and equipment to obtain a passing score for certification.

Several Chinese researchers proved this point by claiming that the traditional linear processes in China increase the isolation of disciplines and layered project management during the building design process, thereby hindering the green building design [27]. Liu [15] indicated that the isolated working pattern coupled with increasingly complex requirements of green building typically leads to repeated modifications, low working efficiency, prolonged operations, and unnecessarily high cost. Xu et al. [29] criticized the lack of information and efficiency tools to support architects to design green building plans during the scheme design phase in traditional design because of the separate working pattern and fragmented personnel management.

4.2.4 Green Technologies

Green technologies and related products and materials are mentioned by several experienced green building designers. Some architects highly recommended green building technologies such as solar panels and smart control systems. In the meantime, they clearly described these barriers as follows:

> "These green technologies do not have enough data and evidence to support their efficiency and practicability, bring many risks to the clients, and also affect our design quality. An example is the application of recycled wastewater and rain harvesting system. Although these strategies can reduce the water consumption, they have difficulty in maintaining the water cleanliness standard and preventing bad odor." "The green material significantly increased the initial cost for the developers. However, there is a lack of life-cycle cost data as evidence to persuade them to accept the higher incremental cost."

Many green technologies need to be applied at the beginning of the design. They require a highly cooperative working style, which involves not only technical experts but also architects, different service engineers, green consultants, specialist consultants, energy modelers, even contractors and suppliers, who all need to work together to implement one single technology [8]. For example, the implementation of green roof requires the landscape designers to choose the suitable plants, the building structural engineer to calculate the weight capacity and design a proper structure, the MEP engineer to design a drainage scheme for the roof, the energy modeler to use the simulation tool to predict its effectiveness by reducing the building energy consumption, the quantity surveyor to estimate its upfront cost and life-cycle cost [12]. This innovative design process is not commonly used by many architectural firms.

4.3 Paradigm Shift Toward Integrated Design Process

The second part of the interview is about how to implement IDP model in China to unblock those barriers. The responses from the interview suggest at least three paradigm shifts: from descriptive to performance-based design, from personal experience to building simulation, and from individual to collective decision making.

4.3.1 From Prescriptive to Performance-Based Design

Architects usually applied the prescriptive approach to design building. They would compare the proposed design features with the standardized prescriptive requirements mandated by law, codes, and regulations. However, many green building rating systems propose quantitative, measurable performance targets, such as the building energy performance, indoor thermal comfort, lighting simulation, and outdoor and indoor air ventilation. These quantitative and precise goals provide measurable information for the design team to easily evaluate the success in achieving certain goals.

Performance target should be clearly set in the beginning of green building design process.

With respect to the transition from prescriptive to performance-based design, one interviewee stated, "We do need address these quantitative performance targets to draw architects' attention to the building performance during the design process, such as daylighting, indoor thermal comfort, air ventilation, and so on. Because of the market orientation and common architectural value, the architects' main focus is to design an eye-catching building shape or ideal façade, and the building performance is always ignored during the scheme design phase. These quantitative goals offer standardized evaluation criteria for assessing a building's performance, which can directly indicate the defects and merits of different buildings based on strong evidence." Another architect said, "These performance data also represented another important characteristic of the proposed building design. Even though the shape and function of the building design is good, there are defects in this design and more modifications need to be done by the architects if the building performance data are not good enough." According to another architect, "In my opinion, these performance targets have been developed mainly because they can provide measurable and clear goals for architects, which can help them to pay more attention to indoor comfort by adopting passive design strategies instead of relying on building service systems. Also, these performance targets can remind the architect that energy efficiency is an essential part of building design. The introduction of these data can significantly reduce the number of 'climate-averse' building designs because they can make the architects realize the awful performance data caused by inappropriate design."

4.3.2 From Personal Experience to Building Simulation

The traditional design practice is based on personal experience, making judgment without firm evidence. Architects speculate about how their design may influence the outcomes narratively. In recent years, building simulation is being used to estimate the building performance of a given design numerically. They are effective for meeting the quantitative performance requirements. Moreover, they aid professionals in decision making by helping them understand the consequences of different choices. Many performance targets proposed by green building rating systems can only depend on computer-aided simulations, including outdoor and indoor lighting simulation, sun path analysis, outdoor and indoor air ventilation assessment, indoor acoustics performance, indoor thermal performance, and whole-building energy simulation.

Architects who deliver many green projects highly recommend design support tools to aid architects in making scientific and environmentally friendly decisions. "The benefits of these simulation tools are reflected in the following two aspects. One is the creditworthiness of the project in the eyes of the clients because the simulation result is very convincing with the scientific simulation method, which is widely accepted. Moreover, the uncertainty between architects and the developers will be reduced with the help of simulation tools because architects always under the disadvantage side during their conversation with the developers. The final designs are always decided based on the personal preferences of the developer in normal situations, especially with regard to the building configuration, orientation, building envelope, and so on. However, with the help of simulation tools and solid data, the architects may have more confidence in their design plans … and may gain more power while negotiating with the developers. The other one is the simulation tools' role to help the architects in modifying the project plan. Architects have to make changes to the design plans to obtain better performance results. Through the use of simulation tools, the defects of the design plan, which cannot be found by qualitative judgments and the architects' own knowledge, will be revealed by the simulation results. For example, the indoor environmental performance, including thermal comfort, lighting, and ventilation situation, cannot be predicted by past experience; the implementation of simulation tools can clearly reveal this performance by quantitative data or simulation diagrams. This process can optimize the design plan, increase the architects' understanding of the indoor environmental performance, and improve their design quality in the future."

However, more than half of the interviewees mentioned that these simulation tools are time-consuming, have increased repeat modifications, and lack of simulation skills. In addition, simulation results are difficult to translate into useful guidance for the design plan. Another barrier is lack of skillful specialists in current architectural firms. Most architects are not capable of using simulation software because they are not included in the traditional architectural education; they also unable to translate the simulation results into useful guidance to aid their design. Therefore, the architects need technical support from simulation experts during the entire design process. Some interviewee said: "Skillful and competent experts are required in the architectural firms, or specific training courses for using simulation tools are needed by the architects, which are challenging and time consuming."

4.3.3 From Individual to Collective Decision Making

To satisfy the requirements of performance target setting and building simulation, building design is changed from a combination of design solutions developed by individual experts to a long-term negotiation process between multiple experts. In a traditional project, architects dominate the scheme design process, and the involvement of various team members is on an as-needed basis and with minimal opportunity to discuss the entire building design or how it will be operated. Communication only occurs in a linear process from architects to engineers and finally to contractors. This delivery mode often results in building a product without synergies between different building systems, optimum performance, and coordination among various disciplines. In green building design, many unconventional professionals should be involved to satisfy the additional requirements of green building rating systems, including energy modelers, commissioning authority, and special consultants. These extra professionals and conventional design team should be combined into a multidisciplinary design team at the early design phase to successfully integrate the green building principles and performance targets into the design plan. Design strategies must be developed through input from various experts, and solutions must be selected from solid data and sufficient information. Ideally, consultancy from different professionals is crucial during the entire green building design. It positively supports architects in developing attractive and high-performance buildings.

> One of the projects I was involved in achieved LEED Gold certification. The design method of this green building project is very different from conventional building design. Many seminars were held during the building design process, and these seminars continued until the end of building construction. The main participants in the seminars during the scheme design included the owner, architect, consultant, transportation expert, landscape architect, civil engineer, MEP engineer, and energy modeler. I completely understood the design target at the beginning of this project because the green consultant provided the requirements for green building and explained how the green building rating system may affect the design. During the scheme design, we closely cooperated with the energy modeler, and through the quantitative simulation we selected the best building plan from several proposals. Although this process took a lot of time, we had more confidence in the scheme, and it finally fulfilled the requirements of the LEED rating system and obtained a higher score.

Most of the interviewees confirmed the usefulness of guidance from multiple experts. They believe that consultancy from other disciplines is indispensable in obtaining green building certification. The opinions of green consultants, simulation experts, facility managers, contractors, and so on significantly affect the parameter selection of building components and equipment in the technical design phase. Most interviewees have argued that green building projects need more collaboration and cross-disciplinary workshops. "This collaborative work method is used not only for green building, but also for delivering conventional building." Because of the added contents and requirements of green building, one strategy or modification to the building plan may affect several other aspects of the building; therefore, more experts are needed in the seminars to discuss the solution. Another architect said that "In my opinion, the cross-disciplinary workshops are necessary for delivering the whole project because many aspects are not familiar to the architects, and professional support from other disciplines is common in architectural design, such as building services engineers, structural engineers, landscape architects, and so on. Especially in green projects, many green technologies are highly complicated and related to several specialized fields that demand more workshops or seminars involving multiple experts. Such cooperation is helpful during the technical design process."

5 Discussion and Conclusion

The green building movement had gained momentum on policy, standards and demonstrative projects in China. However, it is far from a final triumph in the building industry. Changing design process is the key toward a real green building industry and practice. Focusing on China, the research found that the conventional linear working pattern largely affects the green building design. The specific problems mentioned by architects such as intrinsic mind-set, difficulties in performance assessment, unsuitable working patterns, inefficient timelines, and doubts about green technologies, significantly block the way for green building development in China. These obstacles echo the findings from other studies and could be found in other countries or areas. The measures to unblocking these obstacles and moving forward green building development are an integrated design process (IDP). The integrated design process is featured by performance, building simulation, and multidisciplinary collaboration. These features should become the start point to shift the conventional design process into an integrated design process. In sum, the authors propose importing an IDP model into China for improving the linear and fragmented design process. The future green building development should address the design process that can help to change the whole architectural practice and industry culture.

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Integration of Low-Carbon Eco-City, Green Campus and Green Building in China

Bao-Jie He, Dong-Xue Zhao and Zhonghua Gou

Abstract Sustainable development has been a consensus of our world, where low-carbon eco-city, green campus and green building are three significant concepts, corresponding to urban, community and building scales. However, many issues and challenges delay the process to effectively implement above three concepts. Considering their co-aims and inner relationships in urban scope, this chapter is designed to examine how these initiatives can be integrated so as to holistically accelerate sustainable development. To meet this end, primary work of present study focuses on interpretation of sustainability at different scales, development of sustainable projects in China and integration of low-carbon eco-city, green campus and green building. Through the analysis, following conclusions can be drawn: (i) green building receives its best development among three sustainable concepts; it can be a micro-driver to promote low-carbon eco-city and green campus development, while much work is needed to understand how they can be linked; (ii) developments of low-carbon eco-city and green campus are still restricted, and their assessment tools require further definitions, revisions and localizations; (iii) there are many similarities in terms of resource, environment, economy and society, and an emphasis of common points in constructing sustainable projects should be a cost-effective way to realize the whole sustainability goal; (iv) low-carbon eco-city, green campus and green building can experience their co-development and developing interrelated projects can help promote our society towards sustainability much easier.

Keywords Sustainable development · Low-carbon eco-city · Green campus · Green building · Urban scale · Similarities and differences

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1 Introduction

The current world is confronting the rapid urbanization, meaning a large population of people are migrating into urban areas. This requires more infrastructures, resources, services and space to maintain human life, safety and development. However, the dilemma is that the shortage of resources and energy cannot accommodate all human beings over several generations. It is estimated that fossil resources like oil will be used up in 40 years, and 67 and 164 years for natural gas and coal, respectively. Only from the energy supply aspect, it has been a worldwide energy crisis issue. More severely, rapid urbanization has also aggravated the environmental problems. For instance, anthropogenic activities such as energy supply for electricity generation, transport, residential and commercial buildings, industry, waste, agriculture, land-use and forestry change, have increased the emission of greenhouse gas (GHG) [1].

At the same time, accompanied with the urbanization and industrialization, the earth has undergone constant temperature increase and higher frequency of extreme weathers in the past 200 years. It is reported by Intergovernmental Panel on Climate Change (IPCC) that during the period from 1905 to 2005, the temperature worldwide had increased by 0.74 ± 0.18 °C [2]. Alarmingly, the speed of temperature increase has accelerated in recent decades. The climate change has obviously led to a series of disasters such as storms, blizzard, hurricanes, floods and drought, and some other potential threats and crisis, e.g. glaciers melting, sea-level rising, animal extinction, vegetation damage, agricultural disasters and other unpalatable impacts. Statement from United Nations Human Settlements Programme mentioned that the above two issues, urbanization and climate change, are working in a combining way, posing severer threats to the environmental, economic and social stability of the world [1].

Considering the unprecedented deterioration in energy and resource crisis, environmental pollution, higher frequency of natural disasters and social inequity, the term of "sustainable development" has been repeatedly underlined in almost all professions and countries. "Sustainable development" was initially defined in Our Common Future (Brundtland Report) by United Nations World Commission on Environment and Development (WCED) in 1987, to meet *the needs of the present without compromising the ability of future generations to meet their own needs* [3]. It is recommended that "sustainable development" could be a holistic method and temporal process that guides human being to achieve the final goal of sustainability [4].

China is one of the developing countries that undergo rapid urbanization and suffer from climate change. According to the National Bureau Statistics of China, the urban population reached 771 million, constituting 56.1% of the total population [5]. Because of the unsustainable developing pattern, the current urban population is confronting many environmental problems, such as unbreathable air ($PM_{2.5}$ and PM_{10}), polluted and undrinkable water, soil loss, heavy metal commination, apart from GHG emissions [6]. Meanwhile, the increasing number of urban inhabitants requires more buildings to accommodate and need more energy to serve the basic living quality. Until 2013, the total building area had surpassed 40 billion m^2, and now it is still rising at a yearly rate of 2 billion m^2. This consumes a large amount of raw materials like concrete, cement and steel. Meanwhile, energy consumption in building sector accounts for more than 30% of total energy usage; even it takes up above 46.7% of total energy use if embodied energy use is considered in the building lifecycle [7, 8]. In addition, China generates approximately 28% of the global GHG emission, and buildings should be responsible for 30–40% of the total GHG emissions [9, 10]. Therefore, it is imageable that if remaining 603 million rural residents moved into urban areas, urban system would deteriorate [11].

To deal with varieties of complex issues and some future uncertainties during process of enabling such large population to move into urban areas, the central, regional, provincial and city governments at all levels have realized the significance to promote "green" urban development [6, 12, 13]. In practice, innovative approaches such as low-carbon eco-city, green campus and green building that take future sustainability as future development model have been proposed to cope with great challenges in city, neighbourhood and building context, respectively. Considering relationships between city, neighbourhood and building at different urban scales, the authors of this chapter present that how these initiatives can be integrated to accelerate holistically the sustainable development in China, so as to enhance the social, economic and environmental conditions for present and future generations. This chapter, therefore, conducts critical literature reviews of the performance of the three concepts and approaches. Afterwards, the development, definition, utilization and implementation of these concepts in China have been investigated. It is obvious that the sustainable development cannot be achieved in a short term, and these projects are difficult to implement effectively [11, 14, 15]. Because of the collaborative goals of sustainability, the integration in practical projects of low-carbon eco-cities, green campuses and green buildings is analysed to present a better understanding of sustainable theories for sustainable development. Ultimately, some implications for the future development of low-carbon eco-city, green campus and green building are proposed within the context of China.

2 Sustainability at Different Scales

2.1 City Scale: Low-Carbon Eco-Cities and Sustainability

To enhance the contractiveness and competitiveness of urban conditions in terms of society, economy and environment, a large number of cities all over the world have commenced various initiatives, such as sustainable cities, green cities, liveable cities, garden cities, digital cities, smart cities, knowledge cities, information cities, intelligent cities, ubiquitous eco-cities and low-carbon eco-cities [16–21]. Although these ideas have been suggested capturing and conceptualizing the key aspects of sustainability, some differences of primary contents in these concepts can be noted when making closer examination [18]. Meanwhile, Liu et al. [17] comparatively investigated the definition, strategies, indicators and targets of sustainable cities within the context of China and found different concepts covered distinct contents. Only the terms of low-carbon eco-city could include all contents in social, economic and environmental aspects.

The generation of eco-city can date back to the foundation of urban ecology in 1975, which aims to balance the relationship between cities and nature, and particularly eco-cities are required to minimize the resource consumption in Eco-city Berkeley [16]. Afterwards, in more than 20 years' development, researchers and scholars had enriched the contents of eco-city theory, covering four aspects of environmental protection, energy efficiency, economic growth and social aspects [17]. Specifically, it includes ten principles as follows: building multi-purpose and mixed-use communities; creating non-fossil consumption and convenient transportation; rehabilitating damaged urban environments especially water system; creating affordable and mixed housing; ensuring social equity and opportunities; sustaining local agriculture, greening and gardening; promoting technologies to reduce pollutants and hazards; supporting ecological industrial activities; encouraging simple lifestyle to avoid excessive consumption; and increasing public awareness of ecological sustainability [22]. Later the connotation of eco-city was extended and clarified to cut down the consumption of energy, water and other resources while reducing the emission of wastes and pollutants [23]. Furthermore, eco-city is considered as a rural–urban transition process, to develop an integral system and concern about social, economic and environmental aspects. Rural issues should be also taken into account during this process, so as to improve the harmony and fairness among rural and urban residents [11, 24].

The proposition of low-carbon city is derived from the idea of low-carbon economy, issued in the British Government published the "Energy White Paper" entitled "Our Future Energy: Creating a Low-Carbon Economy" [25]. It emphasizes the transformation of production models and the enormous business opportunities of innovative technologies [26]. Four years later, the Japanese government launched the project of "low-carbon society", aiming at altering inhabitants' consumption habits and lifestyle, and then adopting low-carbon technologies to lower carbon emissions [20, 27]. The concept of low-carbon city combines advantages of low-carbon economy and low-carbon society to balance low-carbon production and consumption, as well as maintain sustainability and ecology in urban areas [26]. This concept is mainly adopted to guide the research in the field of future energy consumption and carbon emissions, especially in developing countries with rapid urbanization [28–31].

Low-carbon eco-city combines both concepts by featuring energy-saving and environmentally friendly city symbolizing low energy consumption and low environmental impact [32], mainly consisting of carbon-efficient economy, environmental protection, energy efficiency, economic growth and social aspects [17]. Through the ELITE (eco and low-carbon indicator tool for evaluating cities), it is noted that the functions of low-carbon eco-city lie in energy and climate, water quality, availability and treatment, air quality, waste, transportation, economic health, land use and urban form, and demographics and social health [33].

However, the development of low-carbon eco-cities is still at the beginning stage, since many problems have been observed during its implementation. Especially when social and economic issues are included, cases and scenarios turn to be more complex. Many efforts have been made to technological and economic development rather than allowing community engagements [11]. For example, the upgradation of services and urban infrastructures of Sino-Singapore Tianjin Eco-city are mainly constructed by migrant labours, but these low-paid workers may never be able to afford to live themselves [34]. The dilemma depends on the fact that low-carbon eco-cities are a sustainable place to live in and many opportunities to work, while how to consider the social equity [35]. Likewise, through the analysis of eco-towns in Northern European countries, Netherlands, Sweden and Germany, Bayulken and Huisingh [15] pointed out that collective action with bottom-up participation and top-down commitment should be taken to create integrated eco-towns where citizens can experience, learn, participate and enjoy. However, to solve various problems, much more time is required to explore patterns to promote the holistic development of low-carbon eco-city [11, 15].

2.2 Community Scale: Green Campus and Sustainability

Schools and universities have been considered a kind of communities, not only to offer students and teachers places to study and work, but also to impart students and teachers with basic understandings of advanced ideas and trends [36, 37]. The concept of sustainability has been already incorporated into students' education, for the goal of improving their awareness of environmental protection and energy conversation [38, 39]. Meanwhile, many schools and universities have launched campaigns to create green campuses, so that all people in relation to education will be involved into real context of sustainable development [37, 40, 41]. Having been affected by a range of factors in school environments, from daily curricula to sustainable behaviours and living environments, students are more likely to enhance their consciousness of sustainable development. After their graduations, the long-term assimilation will make them be the main sector of behaving sustainably [42].

The quest of starting environmental protection education can be dated back to 1972, when a conference on human environment was held in Stockholm, Sweden [40]. Later, because of inequitable production and unsustainable consuming manners, all regions of the world underwent environmental changes in air pollution, natural resources depletion, energy shortage and greenhouse gas emissions, having the potential to further aggravate poverty. With these pressures, presidents from 20 universities signed the Talloires Declaration for the development of sustainability, in which there were ten points in how to practically incorporate sustainability and environmental literacy in teaching, research, operation and outreach at colleges and universities presented [43]. Until 2016, it is estimated that approximately 500 universities from 55 countries on five continents have signed the declaration to act their role as leaders in developing, creating, supporting and maintaining sustainability

[44]. The ideology of green campus was then put forward in an Ecological School Plan based on The Found of European Environmental Education (FEEE) in 1994, which aimed at enabling the disclosure of environmental education among primary and secondary schools via daily curricula [36].

In recent years, the campaign of green campus has been launched by almost all universities and schools around world. Many terminologies on green campus have been put forward and presented in previous literatures, such as green university, sustainable university, sustainable university campus, green campus, green school. Nevertheless, most of them have included the same meaning to enable our society to make the transition to sustainable lifestyle [45].

Moreover, previous studies have consistently indicated that all these activities at community level suggest the significant benefits in environmental, economic, societal and health aspects [46]. Concerning the health benefits of green campus, it is firstly reflected by widespread characteristics of green campus design. For instance, USGBC has launched assessment tools to support green schools for the young generation and has highlighted the importance in several perspectives, such as the improvement of indoor air quality, the removal of toxic materials from places where children learn and play, the improvement of classroom acoustics, the encouragement of waste management, etc. [36]. Additionally, BREEAM has tailored green campus evaluation system for pre-schools, general schools, colleges and universities, vocational colleges and institutions, and other facilities, in which health and well-being has been listed as an evidential requirement. In this item, visual comfort, indoor air quality, safe containment in laboratories, thermal comfort, acoustic performance, safety and security are required [47]. These have provided students and teachers with a cleaner and comfortable physical environment, which can enhance the levels of their health conditions and well-being.

The operation of green campus includes every sector in a university, such as classrooms and laboratories, accommodation, transportation and other facilities. Therefore, economic advantages of green campus could be firstly shown by its characteristics of energy-saving, water efficiency and natural resources [36, 37], especially when energy and water consumption intensities of universities are much higher than those of residential communities. Meanwhile, the economic quality has been set as a significant item in various green campus assessment systems [36]. Furthermore, its macro-effects on economic growth lie in social justness and increased efficiency in natural resources usage [46]. As for environmental benefits, all universities concern about their impacts on energy efficiency, water efficiency, greenhouse gas emission, the utilization of renewable energy, etc., through the upgradation of school or university facilities [37]. The green campus activities generate social benefits which not only promote students and teachers to form the habitats of environmental protection, but also strengthen creation of sustainable society in the long run. Additionally, it is an approach to eliminate poverty and inhabitants' deprivation, to improve societal fairness and to broaden the sustainable development concept to the whole society [48].

It is pointed out that local schools and universities can play many roles in promoting a society to move towards an eco-city [37]. However, how to practise the green campus remains questionable in many countries, although many educational institutions have attended some alliances of green campus. For instance, some universities are famous for its discipline of architecture and urban planning has witnessed the significance of green campus [40]. Meanwhile, many of them are currently exploring a reasonable green campus assessment system, and how to manage campus activities in relation to sustainability [49–51]. Therefore, how to link the development of eco-city and green campus are still blurring. It is therefore essential to examine the relationships between eco-city and green campus, for an integrative model on their future co-development.

2.3 Building Scale: Green Building and Sustainability

As a building is the minimum physical unit of a city, its construction, operation and maintenance seem to be a process of socioeconomic metabolism: consuming energy, water and materials, and then consequently producing a series of solid, liquid and gaseous wastes. In parallel, buildings are the most important sector to accommodate the rapid growing population, as well as to meet their rising living demands. In developed countries, it is estimated that building sector consumes about 30% of the national energy and exhausts about 40% of total GHG [52]. The percentages of both energy consumption and GHG emissions are much higher in developing countries [53]. In addition, it is pointed out the process of building construction, renovation, refurbishment and retrofitting causes a wide range of negative impacts, like noise, dust, traffic congestion and water pollution [54]. Confronted with the issues of environmental degradation and energy depletion, people proposed, developed and popularized the concept of green building for the pursuit of energy efficiency, ecology and sustainability [53].

The initial consideration of building as an approach to achieve sustainable develop was mentioned in Silent Spring published in 1962 [55]. Later, the terminology, Arcology, a combining form of architecture and ecology, that implied the emergency of green building was put forward by Soleri [56]. After about two decades, the topic of ‘green building’ was formally presented on the United Nations Conference on Environment and Development held in Rio de Janeiro in 1992 [57]. Generally, green building is firstly expected to provide human beings with healthy, comfortable and safe living, working and activity space, for realizing environmentally responsible and resource-efficient process throughout a building’s lifecycle [15]. It is pointed out that four aspects have been included in its definition, such as improving occupants’ health conditions, minimizing buildings’ impacts on environment, improving returns to developers and local community, and the life-cycle consideration [58]. Green building witnessed its dramatic development after the proposition of green building rating system, such as Building Research Establishment Environmental Assessment Method (BREEAM) in UK and Leadership in Energy and Environmental Design (LEED) system in USA. In recent years, many countries around the world have issued their own green building rating system in accordance with the geographical, economic and societal features [53]. In general, green building has been widely acknowledged by architects, engineers, developers, policy makers, etc.

There are many terminologies on using buildings to achieve the sustainable development of the society, such as energy-efficient building, low-carbon building, green building, ecological building, sustainable building, low-energy building, zero-energy building and even regenerative building. Energy-efficient building is a holistic concept, including all other concepts, aims to design low energy consumption buildings based on the climatic conditions and energy-saving techniques. Low-energy building, ultra-low-energy building and zero-energy building are a gradual improvement in energy performance. Meanwhile, the extra energy required should be covered by renewable sources produced on site and nearby [59]. Low-carbon building and zero-carbon building highlight the reduction in fossil fuel usage, the improvement of energy efficiency and the reduction on carbon dioxide throughout the lifecycle of building materials and equipment manufacturing, construction and building operation. Ecological building pays more attention to making use of local environment and natural conditions, so as to protect ecology and avoid destroying local environment. The concept of sustainable building is closely attached to sustainable development, where Berardi [52] summarized it *as a healthy facility designed and built in a cradle-to-grave resource-efficient manner, using ecological principles, social equity and lifecycle quality value, and which promotes a sense of sustainable community*. Nevertheless, green building is the most popular concept in both research and real practice.

The relationships between sustainability and green building lie in three pillars, including social, environmental and economic benefits, namely the triple bottom lines. For the environmental stewardship, green building can conserve natural resources, such as water, fossil fuel, as well as maintain and improve the quality of water, air, land, etc., reserving a better earth for the future generations. For example, the statistical data from USGBC has shown that LEED-labelled buildings witness 25% of energy reduction, 11% of water conservation and 34% of GHG reduction, when comparing to conventional buildings [60]. Moreover, it is projected that due 2030, LEED-labelled building can reduce 4.92% of the total GHG emission of American society. When it comes to the social sustainability, its scope mainly covers living quality, occupant health and safety, and future professional development opportunities, as indicated by Zuo and Zhao [54]. In office building, for instance, there are three kinds of illnesses disturbing workers' attendance, including sick building syndrome, asthma and allergies, and communicable and respiratory diseases [61]. A 35% higher in attendance rate has been evidenced when providing sufficient ventilation in offices (24L/s per person) when comparing to 12L/s per person [62]. Meanwhile, a higher hospital admission will be found in extreme weather conditions. The economic benefits could be reflected by reduced resource consumption and the lowered cost in dealing with air pollution. Meanwhile, the improved working attendance and productivity can benefit both occupants and owners.

Green building has been widely accepted by many professions of the society. Moreover, after several years' development, a large amount of experience in realizing green building has been achieved. The further development of green building could be the small unit to promote low-carbon eco-city development. To some extent, the creation of green building has been embraced by the development of low-carbon eco-city; in other words, green buildings are the one of the prerequisites of low-carbon eco-city [63]. However, few studies have been conducted to connect green building and low-carbon eco-city. Meanwhile, schools are physically composed by buildings. Therefore, the improvement in building resource efficiency and reduction in pollutions and wastes also means promoting the sustainability of schools and universities.

3 Projects for Sustainable Development in China

3.1 Low-Carbon Eco-Cities

Development of low-carbon eco-cities in China accompanies with the steady economic growth and rapid process of urbanization [17]. Since the adoption of Reform and Opening-up Policy in 1978, China has witnessed a dramatic increase in urbanization ratio, from just 17.92% in 1978 to 56.10% in 2015 (Fig. 1). In 2015, there were 771 million people living in urban areas. On the one hand, this society therefore requires more cities to accommodate the increasing urban population. It is illustrated that number of cities in China is 658 in 2013, which is approximately three times of the 193 in 1978. Although cities in China enter a relatively stable state in number [20], essential conditions, e.g. energy, water, houses, living space, to support citizens' daily life have generated significant burdens to the urban systems. The direct environmental degradation and its indirect impacts on economic and social development call for reasonable upgradation in urban management, for making cities more sustainable.

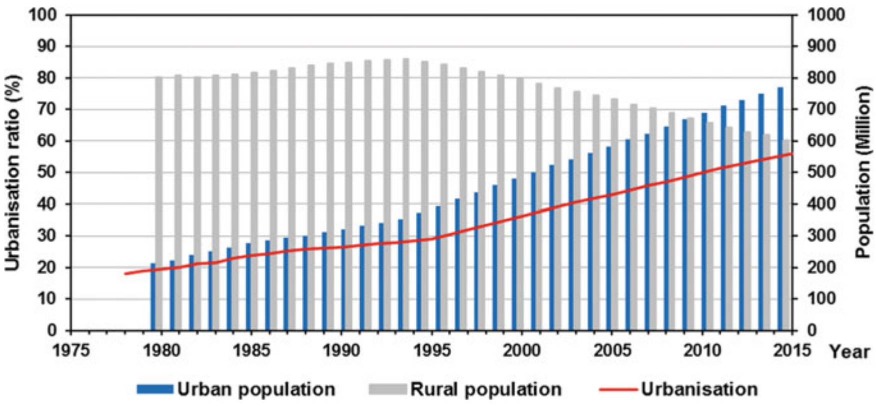

Fig. 1 Urbanization ratio, urban population and rural population in China from 1978 to 2015

In the context of Chinese traditional culture and custom, the concept of low-carbon eco-city has been proposed in the form of "building to unify heaven and humanity". Focusing on the harmony between the city and surrounding environment, this concept has affected the urban design and built environment for several thousand years [64]. In the modern world, the philosophy of low-carbon eco-city evolved after the proposition of eco-city by United Nations Educational, Scientific and Cultural Organization (UNESCO) in 1971. The issue of urban ecological environment was formally included in the Long-Term Plan for the Development of Science and Technology in 1978. Later, the urban issue and urban science had been emphasized. In 1982, National Sixth Five-Year Plan Key Scientific and Technological Projects included Beijing and Tianjin as two pilots to start investigating issues on urban ecosystems.

Given the increasing attention on urban environmental system, Yichun City in Jiangxi Province determined the goal of building an ecological city in 1986, which was implemented after two years. Afterwards, many concepts at city level were proposed. National Garden City was proposed in 1992 by Ministry of Housing and Urban-Rural Development (MOHURD), which was sustained by a series of standards in construction, evaluation and promotion [17]. During the period of National Ninth Five-Year Plan, the concept of National Environmental Protection Exemplary City was developed, aiming to establish healthy urban system from a variety of aspects, such as social, economic, environment, urban construction, health and garden. In 2003, the Ministry of Environmental Protection launched the indicators for eco-county, city and province construction, meaning the top-bottom promotion of this project. Later, the approaches that can encourage urban sustainability were considered as a national policy. For instance, Harmonious Society was proposed in the Fourth Plenary Session of the 16th Chinese Communist Party Central Committee in 2004. The eco-civilization was highlighted in the 17th National Chinese Communist Party, which promoted the proposition of Low-carbon eco-city by MOHURD in 2009 [65]. Although other concepts like national ecological garden city and new urbanization construction have also been put forward, the philosophy of low-carbon eco-city has been the most popular in China.

Before Singapore Prime Minister Lee Hsien Loong and Chinese Premier Wen Jiabao determined a framework agreement for Singapore and China to jointly develop Sino-Singapore Tianjin Eco-city in 2007, the development of low-carbon eco-city was in a state of slow development. However, after this milestone, many cities commenced on developing low-carbon eco-city in the form of MOHURD-province cooperation, MOHURD–city cooperation, and MOHURD pilot low-carbon eco-city [66]. According to the statistics by Chinese Society of Urban Studies (2016), there are 284 prefectural cities creating eco-cities. Around 79% of these ecological cities are in a healthy or very healthy condition, as indicated by ecological cities health index (Chinese Society of Urban Studies 2016). Meanwhile, National Development and Reform Commission of the People's Republic of China (NDRC) has listed 78 prefectural cities and five provinces as the low-carbon city pilots since 2010. It is also found that about 97% of the prefectural cities have expressed their intentions to build low-carbon city or ecological city, showing a great promise in China [11]. However, the national assessment system for low-carbon eco-city is still in a premature status, which should be further developed in the next few years.

3.2 Green Campus

Accompanied with large population of China, people who are educated in kindergarten, primary and secondary schools, and universities account for a dramatic proportion. According to report from Ministry of Education (MOE), school students at all levels reach 26 million, and students who are receiving higher education exceed 36 million [67]. Although teachers and students in colleges and universities have been well-educated with the significance of resource-saving and situations of resource shortage, still energy-use and water-use intensities of colleges and universities are much higher than those of residential communities. It is shown that energy and water consumption in universities were 17.9 million tons of standard coal and 3.32 billion m^3, accounting for 0.8 and 6.6% of national energy consumption and water supply in 2005. These digits are increasing rapidly due to increase in student number and living quality [68]. If energy- and water-use intensities could be reduced by 20%, a large city with 7.6 million citizens would survive. All these indicate the significant environmental benefits and economic benefits of sustainable university construction [68].

The concept of green university was introduced into China in 1996, aiming to integrate philosophy of sustainable development into teaching and curricula and to cultural atmosphere for comprehensively improving environmental awareness of teachers and students. At the very beginning, development of green university was promoted by a mix of national government, provincial and local governments, city council and universities themselves. In 1998, Tsinghua University was approved as the first green university pilot project by MOE, Ministry of Science and Technology (MOST) and Ministry of Environmental Protection (MEP), formally introducing the concept of green campus into the Chinese universities. In 2001, Shanxi Agricultural University was named green university by Shanxi Provincial Education Department. In 2002, Wuhan Municipal Environmental Protection Bureau and Wuhan Education Bureau collectively developed and Assessment Standard for Wuhan Green University, and Jianghan University was selected as the pilot university. Additionally, many universities spontaneously constructed green university, like Tongji University and Peking University.

In 2007, Tongji University built the first national conservation-oriented campus demonstration project. To promote the exchange and cooperation of colleges and universities in green campus construction, ten universities and academic institutions including Tongji University, Zhejiang University, South China University of Technology, Jiangnan University, Tianjin University, Chongqing University, Shandong Jianzhu University, Hong Kong Polytechnic University, China Architectural Design and Research Institute and Shenzhen Institute of Building Science co-sponsored China Green University Network (CGUN) in 2011. It is shown that this network has well achieved their goal in forming a platform of experience sharing and complementary resources for leading and promoting sustainable development of green university construction of in China. Many other institutions later applied for enrolment of CGUN.

Green university experiences a process of bottom-up development. In 2008, MOHURD and MOE emphasized the importance of university energy-saving and water-saving, and issued *Promoting the construction of economical campus in colleges and universities: Suggestions on strengthening the aim of energy-saving and water-saving*. It concretely pointed out that both energy consumption and water usage should be reduced by 15% until 2012, compared with situations of 2005. Many regulations were established by MOHURD and MOE in aspects of energy monitoring system, operation management, energy consumption audit and assessment indicators. At the same time, Ministry of Finance (MOF) launched special funds for energy-saving of office buildings and large public buildings to support green university construction. During promoting the energy efficiency of national office building and large public buildings, MOHURD issued *Twelfth five-year plan for building energy conservation*, in which 72 colleges and universities were selected as conservation-oriented campus demonstration projects. Therefore, green university construction was disclosed and spread to provincial and city levels through three stages. On this basis, to provide scientific evaluation standard for green university, MOHURD promulgated and implemented *Evaluation standard for green campus* (CSUS/GBC 04-2013) [69]. It is reported that more than 200 colleges and universities have been certified as green universities (Fig. 2).

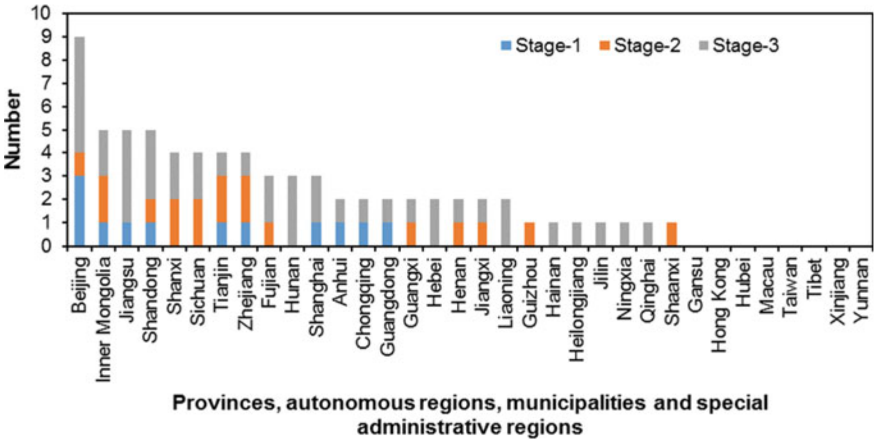

Fig. 2 Provincial distribution of conservation-oriented campus demonstration projects

3.3 Green Building

After the Reform and Opening in 1978, national population and economy of China have witnessed dramatic development, which is backed up by large energy demand. As indicated in Fig. 3, national energy demand increased from just 571 million tons of standard coal in 1978 to 4.3 billion tons standard coal. Moreover, a prodigious number of buildings are required to accommodate the large amount of national population. From 2001, yearly completed building area all exceeded 1 billion m^3, and increased to 4 billion m^3 per years between 2013 and 2015, as presented in Fig. 3. With improvements of living quality, energy consumption of building sector has kept increasing in the past decades, accounting for 27.8% of the national energy consumption in 2008 from only 10% in 1980 [70]. The large amount building energy consumption has encouraged all aspects of building-related staff to find effective approaches to reduce energy consumption.

Before the proposition of green building in 2004, China underwent more than 20 years' development in energy efficiency of buildings. This process was divided into three stages by Shui and Li [71] according to the release of energy-saving policies. Before 1986, energy situations of civil buildings were emphatically studied, and energy conservation design standard for new heating residential buildings (JGJ-95) was released to achieve 30% of reduction in energy consumption. Between 1987 and 1992, Ministry of Construction, State Building Materials Industry Bureau, Ministry of Agriculture, and Ministry of Land and Resources collaborated to promote energy efficiency through wall material innovation, after which Harbin in Heilongjiang Province and Chengdu in Sichuan Provinces were determined as piloting cities to provide guidance for provincial building energy efficiency development. Next stage from 1993 to 2005, standards, regulations and policies were established, providing political and legal supports. More importantly, energy-saving standards and energy-saving targets over different climatic zones and building types were determined, i.e.

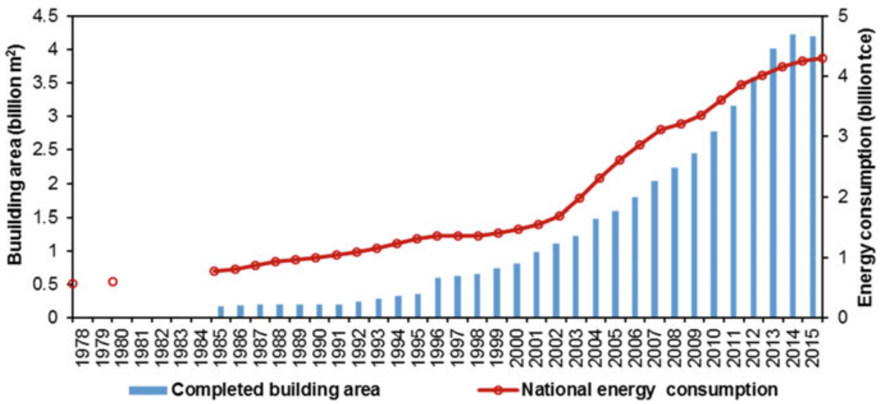

Fig. 3 Trend of China's building area increase and energy consumption between 1978 and 2015 (Summarized from: National Bureau of Statistics of China)

design standard for energy efficiency of residential buildings in hot summer and cold winter zone (JGJ 134-2001), design standard for energy efficiency of residential buildings in hot summer and warm winter zone (JGJ 75-2003). After these stages, people's awareness of energy efficiency has been improved, and governments at all levels have accumulated experience from technical, political and economic aspects.

Green building was formally introduced into China in the form of LEED green building in 2004, in which year only three buildings were registered for LEED. In the same year, the MOHURD released *National green building innovation award management measures* to encourage developers to voluntarily construct green buildings. In 2006, the first national green building standard titled "*Assessment Standard for Green Building*" (GB/T50378-2006) was announced by MOHURD, providing the green building construction with technical supports, although it was not mature and revised in 2014 as GB/T50378-2014 [72]. In progress, a series of technical and management regulations were issued. From 2005 to 2011, certified green building cases increased from only two cases in 2005 to 226 cases in 2010. In 2012, with the collaboration of MOF and MOHURD, economic incentive policies were implemented to upgrade quality of green buildings, where 45 and 80 Yuan RMB per square metre would be subsided to two-star or three-star green buildings. This promoted the application of national green building standard rather LEED, making it better follow current economic, social and technological situations of China. Since 2011, the number of certified Green building-labelled (GBL) green buildings has been more than that of LEED-certified green buildings. The GBL-certified green buildings reached 4515 cases due September 2016, as shown in Fig. 4.

In addition, based on the national technical and economic supports, many provinces and local cities established local standards and regulations for establishing local green buildings. It is shown that Zhejiang, Jiangsu, Beijing, Shanghai, Tianjin, Jiangxi, Hebei, Hunan, etc., have launched provincial green building assessment standards, and 25 provinces, municipal cities, autonomous regions have announced extra economic incentive policies on basis of national policies.

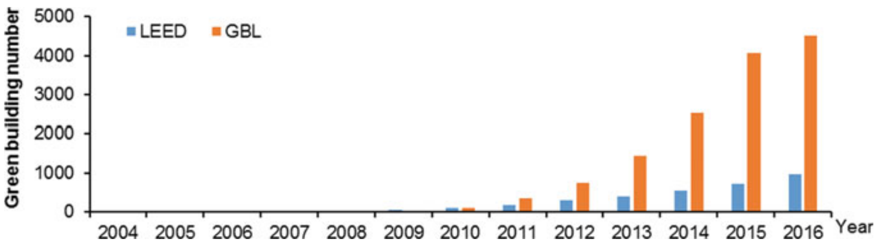

Fig. 4 Number of GBL-certified and LEED-certified green building projects in China (Due September 2016). *Note* The GBL-certified green buildings are mainly distributed in the mainland of China, because Hong Kong, Macau and Taiwan have already established, respectively, local green building evaluation systems, including EEWH (Ecology, Energy-saving, Waste reduction, and Health, Taiwan) and HK-BEAM (The Hong Kong Building Environmental Assessment Method, Hong Kong) [73, 74]

4 Integration of Low-Carbon Eco-City, Green Campus and Green Building

Under the background of sustainable development, various concepts like low-carbon eco-city, green campus and green building were introduced into China in 1980s. All of them underwent a long time of evolution and received great attentions around the year of 2010. Assessment standards for practically creating low-carbon eco-city, green campus and green buildings have also be issued and adopted. All levels of governments from national to local governments show their great activeness to the low-carbon eco-city, green campus and green building. Many departments such as MOHURD, MOE, MOF and MOST have provided technical, management and financial supports for building them. Meanwhile, many projects have been widely developed around the whole country; even many cities are developing low-carbon eco-city, green campus and green buildings with local characteristics. Nevertheless, construction of sustainable city, campus and building has been still independent with each other, while their inner connections in prompting sustainable development have been mostly neglected. The following section then examines the connections existing among low-carbon eco-city, green campus and green building.

4.1 Urban Sustainability

According to the constitution of urban form, development of urban sustainability should be achieved in three scales, namely city scale, community scale and building scale. Their relationship has been presented in Fig. 5, in which sustainable city stands at the highest position in the hierarchy, while sustainable building is the unit, standing at the lowest position. In the scenario of bottom-up pattern, functions and performances should be dominant, determining developments of green campus and low-carbon eco-city. On the contrary, achievements of both low-carbon eco-

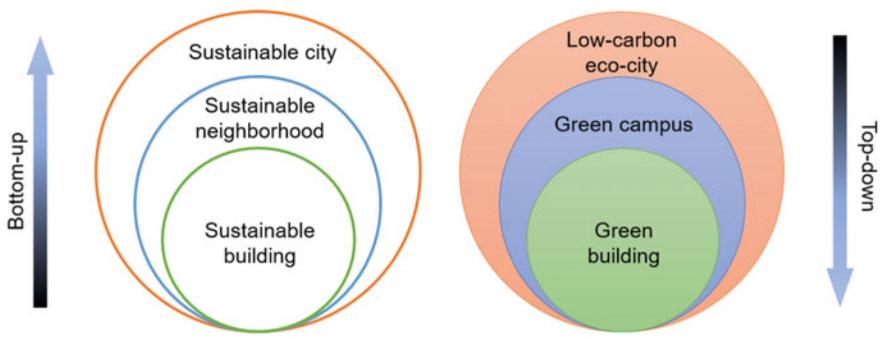

Fig. 5 Hierarchy of urban sustainability

city and green campus construction affect green building development in the top-down pattern [75]. The current context of sustainable development of China follows the bottom-up pattern, where low-carbon eco-city and green campus are developed based on energy-saving, water-saving and environmental protection, while green building that is mainly characterized energy-, material-, land- and water-saving, and environmental protection promotes developments of low-carbon eco-city and green campus in practice.

Although all three concepts are expected to promote resource-saving and environmental protection, there are some differences of roles they play. During realizing urban sustainability, low-carbon eco-city should guide and direct developments of green campus and green building. To start with, low-carbon eco-city does not only include environmental impacts and energy efficiency, but also consider economic development and societal harmony. Next, a master plan and management vision has the effects of connecting intrinsic elements. A low-carbon eco-city is a mix of artificial elements, such as commercial, institutional, educational uses as well as housing styles, sizes and prices, and natural elements like air, water, energy, land, etc. Community is the unit to serve citizens' basic living requirements, through a series of functions like dwelling, industry, entertainment, health care, culture, etc. Compared with low-carbon eco-city, it primarily highlights environmental, societal and healthy aspects rather than economic effects. Sustainable and liveable communities protect historic, cultural and environmental resources, while economic effects are embodied, in indirect relation to advantages of water-, energy-, land- and material-saving and carbon emissions. Green campus is one of several components of urban system, bridging green building and low-carbon eco-city. At the bottom of the hierarchy, building is the smallest unit. It achieves its main goals of environmental protection and resource-saving via technical approaches. However, the social and economic benefits are realized indirectly.

4.2 Connections Between Their Assessment Criterions

To develop low-carbon eco-city, MOHURD and MOF collectively launched a project of *Demonstrating Green Ecological Urban Built-up Areas* in 2012. It is indicated that *Sino-Singapore Tianjin Eco-City* should be the best one among all eight cases [11, 66]. To implement new its philosophy of ecological economy, ecological society, ecological environment, ecological culture, an indicator system consisting of 22 control indicators and four guiding indicators was proposed, based on national sustainable requirements of two countries, international and local Tianjin situations [76]. Meanwhile, to promote development of green campus and green buildings, two national standards denoted as CSUS/GBC 04-2013 and GB/T 50378-2014 were issued, respectively [69, 72]. In this section, the assessment criterions of low-carbon eco-city, green campus and green building are compared to examine their similarities and differences. Note that green campus standard CSUS/GBC 04-2013 includes assessment criterions for primary and secondary schools, and colleges and universities [69]. Hereafter, the colleges and universities version are adopted. According to possible benefits of three concepts, the comparison is carried out in four aspects: resources, environment, economy and society.

4.2.1 Similarities and Differences in Resource

Comparison of resource criterions was conducted in four aspects: water, land use, energy and material, as presented in Table 1.

Water: All three concepts have highlighted utilization of non-traditional water sources, where reclaimed water and rain water should be employed, while technology of seawater desalination is used to provide water source to the city when developing the low-carbon eco-city. Daily life on campus is appropriately served by municipal water, and non-municipal water is used for campus landscape. Distinctively, non-municipal water has been set as a compulsory indicator in residential, office, commercial and hotel green buildings, despite of differences in utilization rates. At campus and building levels, water-saving appliance and equipment, and water-saving design are required, indicating that green building and green campus construction more underline techniques. The water cooling technology is suggested to recycle water generated by air-conditioners, etc., in buildings. Embodied water for constructing buildings is also included in green building criterion. Low-carbon eco-city and green building formulated average daily water consumption, while green campus did not, which is a leak for water-saving.

Land use: Public green land for people's daily life is a common criterion in all three concepts, where green area per capita should exceed 12 m^3 in low-carbon eco-city and green university sets thresholds for greening rate. Green building combines green area per capita and greening rate as criterions for green land. On land use, the largest difference among them is that newly constructed buildings should be all green buildings in low-carbon eco-city. In order to save land, limits of plot ratio have been both provided in projects of green university and green building, respectively, while living area per capita should firstly meet requirements. During constructing green university and green building, the utilization of underground space has been regarded as an effective way to provide car parking space, saving over-ground space for other usage. Meanwhile, wasteland in campus and green building zones should be redeveloped and restored, and building's site should be reasonably designed for water collection. To protect urban ecology, land protection is a compulsory rule in creating low-carbon eco-city, green university and green building. In low-carbon eco-city, wetland that must be exploited for other use should be compensated via recovery and developing other lands, to maintain net loss of natural wetland zero. More strictly, universities and buildings cannot be developed over natural water bodies, wetlands, agricultural lands, forests and other reserves.

Energy: To cope with global climate change, China determined a goal that due 2020 renewable energy should supply 15% of national energy demand of China on *United Nations Climate Change Conference* in 2009. Therefore, the rate of renewable energy utilization should be higher than 15 percentiles in low-carbon eco-city area,

Table 1 Comparison of similarities and differences in resource criteria

Criterion	Similarities			Differences		
	Low-carbon eco-city	Green campus	Green building	Low-carbon eco-city	Green campus	Green building
Water	Non-traditional	Non-traditional	Non-traditional water	Seawater	Municipal water	Non-municipal water
		Appliance and equipment	Appliance and equipment			Water cooling technology
		Water-saving system	Water-saving system			Construction management
	Daily water usage		Daily water usage			
Land use	Public green land	Green land ratio	Green land	Green building		
		Plot ratio	Plot ratio			
		Underground space	Underground space		Wasteland redevelopment	Rainwater collection; Ecological compensation
	Land protection	Land protection	Land protection	Wetland	Water bodies, agricultural land, wetland, forests and reserves	Reserves
Energy	Renewable energy	Renewable energy	Renewable energy	Low-carbon operation; Carbon emission		
		Building and envelope	Building and envelope		Natural ventilation	Natural ventilation
		HVAC	HVAC			
		Lighting and appliance	Lighting and appliance			
		Energy recovery	Energy recovery			
Material		Material-saving design	Material-saving design			
		Material selection	Material selection			Local materials

and renewable energy use is recommended in campus and building scales, where different utilization ratio decides scores buildings can obtain. Generally, low-carbon eco-city is operated under low-carbon situations. More concretely, the construction of green university and green building is based on building and envelope design, HVAC, lighting and appliance and energy recovery techniques. In campus, buildings are required to be well-arranged to avoid winter prevailing wind and beneficial to the formation of outdoor natural ventilation. For green buildings, they should adopt natural ventilation to reduce energy consumption of HVAC system by settings of doors and windows.

Material: For low-carbon eco-city construction, although material-saving has not been proposed as an independent indicator, it is reflected by reduction of carbon emission, which synthetically considers effects of energy structure transition, green transportation and green material. For green university and green building, material-saving design and material selection have been especially listed as two individual items, where local materials should be reasonably employed when constructing green buildings.

4.2.2 Similarities and Differences in Environment

Urban environment covers a wide range of criterions, from quality of water, light, air and sound to waste produced due to anthropogenic activities, wind environment, infrastructures that support people's basic living quality, and local biodiversity, as summarized in Table 2.

Water: Quality and security of water affect directly healthy conditions of citizens. Considering current conditions of water pollution and water shortage in China, low-carbon eco-city, green university and green campus have all agreed that water quality should be a compulsory criterion. In addition, low-carbon eco-city commits to upgrading urban water environment from quality of surface water and centralized drinking water. Non-traditional water adopted in green campus should be monitored, avoiding generating adverse impacts on human health and surrounding environments. Water quality of rainwater collected should be maintained by ecological water treatment technology, in case of runoff pollution to landscape water.

Light: Urban construction has not yet clearly defined light environment, while campuses and buildings are required to create good indoor lighting environment. Light pollution in campus should be avoided, while outdoor vision should be unobscured.

Air: Air pollutants should be controlled in both in indoor and outdoor environments. For low-carbon eco-city, it is an approach to counterbalance the situation of atmospheric pollutions in most industrial cities where SO_2 and NO_X shall be strictly controlled. Outdoor natural ventilation is regarded to improve campus air quality, and dust reduction measures are required when constructing green buildings. Human thermal comfort is another important indicator of air quality, where relative humidity should be regulated by adjustable shading measures, while outside shades should be formed by building arrangement and shading devices installation,

Table 2 Comparison of similarities and differences in environment criteria

Criterion	Similarities			Differences		
	Low-carbon eco-city	Green campus	Green building	Low-carbon eco-city	Green campus	Green building
Water	Quality	Security	Quality	Drinking water; surface water	Non-traditional water	Runoff pollution control
Light		Indoor lighting	Indoor lighting		Lighting pollution	Outdoor vision
Air	Pollutants control	Pollutants control	Pollutants control		Natural ventilation	Construction management
		Thermal comfort	Thermal comfort			Relative humidity
		Urban heat island	Urban heat island		Landscape construction	Tree and cool material
Solid waste	Recycling	Recycling	Recycling	Garbage collection	Construction waste	Construction waste
	Waste control	Waste control	Waste control	Garbage production per person; waste disposal	Away from waste sources	Construction management
Noise	Noise control	Noise control	Noise control	City level	City and indoor level	City and indoor level
Wind		Natural ventilation	Natural ventilation			Comfort
Community	Public service	Public service	Public service	Available in 500 m radius;	University-communities' cooperation	Educational and industrial resources
Biodiversity				Local vegetation coverage		

to improve outdoor thermal comfort sustainably. Urban heat island that has not been mentioned in low-carbon eco-city concept, while campus and building construction should respond to UHI effects, through landscape construction, and greenery and cool material utilization respectively.

Solid waste: The solid waste generated in urban, campus and building operation are expected to be dealt with in a recycling way. To start with, citizens in low-carbon eco-city are encouraged to reduce garbage generation in their daily life. In low-carbon eco-city, solid waste recycled, including resource processing, should account for more than 60% of the totally urban waste, while only waste produced during construction period is considered by green university and green building. In order to provide people with healthy environment, hazardous waste and domestic waste should undergo harmless treatment. However, green campus selects to adaptively stay away from waste source and green building only focuses on reducing solid wastes produced by construction.

Noise: Noise at both urban, community and building level must be controlled, and the only difference between them is in relation to indoor or outdoor noise control.

Wind: At university and building level, natural ventilation has been an effective and low-carbon strategy to improve indoor and indoor air quality. Meanwhile, wind around buildings should be moderate to ensure pedestrian wind comfort.

Community: As a significant part of people's living, public services for entertainable, cultural, health care, etc., use and accessibility facilities should be offered in all three concepts. Low-carbon eco-city defines the service range of 500 m, and universities would like to share public infrastructures with citizens living in surrounding communities. Green building being a sustainable model aims to educate people with sustainable awareness.

Biodiversity: Low-carbon eco-city respects the local natural ecosystem, by keeping local vegetation coverage exceeding 70%.

4.2.3 Similarities and Differences in Economy

The economy pillar of urban sustainability has been analysed in employment, research and development and environmental impacts, as shown in Table 3. The environmental impacts have mainly caused indirect effects on economic development.

Employment: Low-carbon eco-city does not only consider the resource and environmental impacts, but also keeps economy development as its core. Providing citizens with sufficient job opportunity is an important criterion.

Research and development: Developments of a society are driven by technological development. Low-carbon eco-city through upgrading proportion of scientists and engineers promotes knowledge and innovations. Green campus draws on students' advantages to conduct research for utilization of green technology, while green building is the main part to utilize advanced technologies.

Environmental impacts: Low-carbon eco-city pays attentions to low-carbon operation through controlling carbon emission per GDP unit. Meanwhile, it pursues

Table 3 Comparison of similarities and differences in economy criteria

Criterion	Similarities			Differences		
	Low-carbon eco-city	Green campus	Green building	Low-carbon eco-city	Green campus	Green building
Employment	Employment			Workers		
Research and development	Sustainable technology	Green technology	Performance improvement and innovation	Scientists and Engineers	Students	
Environmental impacts	Carbon auditing		Carbon analysis	Carbon emission per GDP unit		Carbon emission intensity
	Circular economy		Economic analysis	Economic development of adjacent areas		Energy efficiency and building performance

circular economy, contributing to spur economic development of surrounding areas. Carbon emission intensity is required to be reduced in building operation, where carbon analysis is compulsory. Energy efficiency and building performance should be analysed to improve economic operation of green buildings.

4.2.4 Similarities and Differences in Society

The requirements of society highlight many aspects, such as transport, housing quality, culture, and their possible social influences, as shown in Table 4.

Transport: Sustainable construction at city, community and building scales all considers significance of public transport, where cycling is especially encouraged by low-carbon eco-city and green building concepts. It is provided that proportion of green transport in low-carbon eco-city should exceed 90%. Green campus and green building, however, mainly draw on reasonably selecting location of entrance and parking, connecting public transport and the places where people study or live.

Housing quality: Low-carbon eco-city has firstly considered providing people with place of residence; therefore, affordable housing ratio has been set as an independent criterion. Meanwhile, housing and income balance has been included. Green campus and green building emphasize the quality people live by regulations of land-use area per capita.

Culture: The item that urban development cannot be the price of destroying historical and cultural heritage is common considered by low-carbon eco-city, green university and green building.

Table 4 Comparison of similarities and differences in society criterions

Criterion	Similarities			Differences		
	Low-carbon eco-city	Green campus	Green building	Low-carbon eco-city	Green campus	Green building
Transport	Public transport, cycling	Public transport	Public transport, cycling	Public participation	Campus and gate location	Gate and parking location
Housing quality		Land-use area per capita	Land-use area per capita			
				Affordable housing ratio Housing and income balance		
Culture	Historical and cultural heritage	Historical and cultural heritage	Historical and cultural heritage			
Social influence				Surrounding area environment	Surrounding community	

Social influence: As sustainable models, low-carbon eco-city and green campus both exert their potentials to influence other areas, where the former one emphasizes surrounding regions and the latter one focuses on surrounding community.

5 Co-development of Green Building, Green Campus and Low-Carbon Eco-City

In previous several years, the eight-pilot low-carbon eco-cities have achieved many experiences that current sustainable city construction can draw on. One of them is the development of green building. It is indicated that green building has received its attentions, especially Sino-Singapore Tianjin Eco-city (SSTEC). The proportion of green buildings has to reach 100%, and the requirements of renewable energy usage, waste disposal and recycling, water-saving and carbon emission are quite strict [6]. Due September 2016, 68 green buildings have achieved their green building label, which accounts for more than one-third of all green building projects in Tianjin. When it comes to the quality of green building, 64 out of 68 are labelled with two-star or three-star. This indicates green building is a part of low-carbon eco-city,

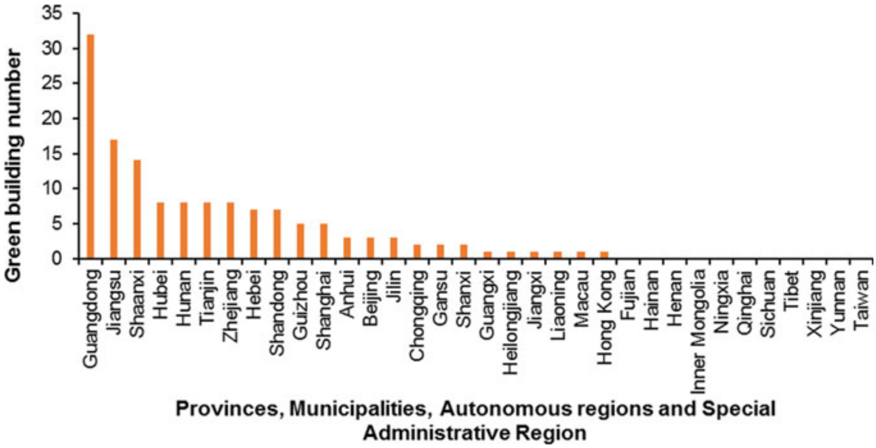

Fig. 6 Provincial distribution of 140 university green buildings in China (Due September 2016)

and construction of low-carbon eco-city is an opportunity that contributes to green building promotion. The benefits in resource, environment, economy and society of low-carbon eco-city and green building are sometimes consistent to promote urban sustainability.

Green buildings can be divided into several categories, such as residential, industrial, public and educated buildings. The green buildings that stand in universities have been studied and presented in Fig. 6. In total, more than 140 buildings have achieved their green building label around China, where universities in 22 provinces have built green buildings. However, compared with 4515 GBL-certified green buildings, university green buildings only account for 3%. Guangdong Province ranks at the first place with 32 green buildings, which accounts for 7.4% of its total green buildings. This high proportion mainly benefits from 15 buildings of Southern University of Science and Technology, which has been built with the concept of green and sustainable campus since 2011. Since many universities are currently retrofitting their old buildings and constructing new buildings, starting from creating green buildings will be an effective to achieve university sustainability.

6 Discussion and Conclusions

To promote sustainable development of present world, concepts such as low-carbon eco-city, green campus and green building have been introduced, corresponding to city, community and building contexts. Although many achievements have been obtained in the past decades, still urban sustainability requires significant efforts of all profession of our society. Based on co-aims and inner urban relationships of low-carbon eco-city, green campus and green building, this chapter settled the aim of examining how these concepts can be combined as a holistic way to accelerate sustainable development. Through interpretation of sustainability at different scales, development of sustainable projects in China and integration of low-carbon eco-city, green campus and green building, the following conclusions can be drawn.

Initiatives of low-carbon eco-city, green campus and green building date back to the same period of 1970s. Although they have undergone many years' development, many problems can still be found in their implementation. For low-carbon eco-city, it is characterized with carbon-efficient economy, environmental protection, energy efficiency, economic growth and social aspects, while the scope it covers still requires further definition. Low-carbon eco-city is a sustainable place to live in, but economic and social issues make cases and scenarios much complex, because how to realize social equity, i.e. balances of employment and housing of migrating labours, balances of urban–rural relationships, and participations of general public which determines environmental and energy-saving quality, is still in a dilemma situation. Schools and universities are special communities, having potential to propagate sustainable concepts and implement sustainable behaviours by current students after several years. For green campus itself, benefits in environmental, economic, societal and health aspects can be achieved no matter in direct or indirect way. However, campaign of green campus is still questionable, since it is shown that only universities with famous architecture and urban planning disciplines are shock troopers. In addition, green campus assessment system and management of green campus activities are still obscured. Green building receives its best development among three sustainable concepts, because of people's great demands and mature assessment tools around the world. Its benefits in environmental, economic and social aspects have been well-evidenced. As a minimum physical unit of community and city, therefore, green buildings development could be an important driver to promote low-carbon eco-city and green campus, while still much work is needed to understand how they can be linked.

Because of increasing population and rapid urbanization after The Reform and Opening of China in 1978, it is critical to cope with issues of energy shortage and environmental degradation. Low-carbon eco-city, green campus and green building were then introduced into China in 1980s. With a series of political guidance and incentive policies from MOHURD, MOE, MOST and MOF, these projects have been significantly pushed on. After the project of *Demonstrating Green Ecological Urban Built-up Areas*, most cities in China have shown their intentions to construct low-carbon eco-city. Green campus underwent the bottom-up development, after which governments paid attentions to spur its development by a 72 conservation-oriented universities demonstration project. However, development of green university is restricted, for it only accounts for 2.47% of total colleges and universities in China. Green building is well-developed in all provinces, municipalities, autonomous regions and special administrative regions. Currently, assessment systems for low-carbon eco-city, green campus and green building have been established; many provincial green building assessment systems have been developed. National assessment system for low-carbon eco-city and green campus should be further developed to guide local construction.

This study has investigated connections of low-carbon eco-city, green campus and green building from three aspects, namely scales of urban sustainability, similarities and differences of their assessment criterions and co-development of three projects. It is indicated that current development of sustainable projects in China is stipulated by green building, where low-carbon eco-city and green campus are developed on basis of requirements of green building. However, once all concepts are mature, low-carbon eco-city should play its in guidance because of its wide scope of functions, while green campus and green building can perform their roles in partially promoting low-carbon eco-city development.

Assessment criterions of low-carbon eco-city, green campus and green building have been compared in four aspects: resources, environment, economy and society. Generally, low-carbon eco-city assessment criterions set up indicators at a master level, comprehensively considering four aspects, while assessment criterions of green campus and buildings are considered in technical way, mainly in resources and energy aspects. For category of resource, non-traditional water, public green land, land protection and renewable energy have been all considered in low-carbon eco-city, green campus and green building. A series of technical criterions have been provided in green campus and green building assessment systems. For the category of environment, water quality, pollutant control, solid waste recycling, water control, noise control and public service are required by all sustainable projects, while urban heat island and natural ventilation have been only defined by green campus and green building. For low-carbon eco-city, local vegetation coverage is the most characteristic, different from green campus and green building. For scenario of economy, sustainable technologies have been required by all projects, and carbon auditing and economic development have been required by both low-carbon eco-city and green building. Most importantly, low-carbon eco-city emphasizes providing more employment opportunities and scientists and engineers' attendance of research and development. On society scenario, green transport and culture preservation are stipulated by all projects, while low-carbon eco-city more focuses on a target of improving public participation in green transport and green campus and green building technically suggest locations of entrance and parking. Generally, the emphasis of common points in constructing sustainable projects should be a cost-effective way to realize whole urban sustainability.

Low-carbon eco-city, green campus and green building can experience their co-development when other projects are constructing. Since green building itself is characterized by energy efficiency, water-saving, land-saving, material-saving, its development can promote upgradation of low-carbon eco-city. Sino-Singapore Tianjin Eco-city has been a successful case for green building development, since it specifies 100% green building as one of the compulsory rules. Meanwhile, green campuses constructed are also attempting to reduce consumption of water, energy, land and material, and recent built projects account for a higher proportion of the university green buildings. Therefore, a stricter retrofitting or newly constructing requirement for buildings not only helps promote green building development, but also benefits to green campus construction. Since the MOHURD has launched Thirteenth five-year plan for energy efficiency and green building development, in which goals of constructing green building, green campus and low-carbon eco-city have been set, respectively. Therefore, developing green building, green campus and low-carbon eco-city can help achieve goals much easier, considering the hardship in promoting our society towards sustainability.

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From Green to Healthy Buildings: A Comparative Study of the USA and China

Xiaohuan Xie and Zhonghua Gou

Abstract This paper presents an in-depth comparison of the items and detailed assessment criteria of US' WELL Building Standard System and China's T/ASC 02-2016 Assessment Standard for Healthy Buildings (ASHB). Classification and statistics are made on each item of the two standards separately to analyze their different emphases, different weights, and different quantitative criteria. It is obvious that the two systems are identical with what should be a healthy building. A healthy building should be human-oriented living and working environments where human's physiological and psychological needs are satisfied. However, they two systems show divergences on specific items and criteria, which are related to their social and construction practice. WELL is more performance-oriented, while ASHB is more experience-oriented. China ASHB could be improved from four aspects: Establish more performance criteria rather than one single measure; increase the demand for on-site inspection and testing; combine the concept of health into the consideration of whole life cycle of building design; and increase the impact of the standard on the post-occupancy stage of buildings.

Keywords Healthy building design · WELL · ASHB · China · USA

1 Introduction

In 1946, World Health Organization (WHO) defined health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" [20]. The new focus of the building industry has shifted from the construction of environmentally friendly buildings to the creation of healthy, comfortable, and efficient buildings. The concept of a healthy building has been mentioned frequently in recent years, with the emphasis on how the built environment can effectively reduce harmful effects on the human body, improve the comfort of space use, and guide

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people's healthy behaviors [2, 11, 13]. The study mentions that many major human diseases are associated with building environments [21]. Human mental health is also considered to be closely related to the building environment [2, 21]. In addition, indoor environmental quality also deeply affects the work productivity of employees [2, 11, 13]. After green building evaluation standards have been gradually recognized by the public and the market, healthy buildings now are emerging as a new direction for research institutions, designers, and builders. Both the USA and China have developed their own Healthy Building Design Standards.

The US standard, WELL Building standard, is developed by Delos Living LLC. It is the first comprehensive standard for human health and wellness in the built environment and is accredited by the International WELL Building Institute (IWBI) and the Green Building Certification Association (GBCI) through third-party certification. WELL has stipulated 100 performance metrics, design strategies, and policies [21]. The WELL Building standard was developed from the medical point of view, on the basis of the common diseases of human body and the research on 11 major physiological systems. The goal is to conclusively find the connection between well-being of occupants and the indoor environment so as to help the design and operation of buildings [9]. In March 2015, the GBCI and IWBI formally introduced the WELL Building standard into China [15]. China's healthy buildings are based on the strategic plan of The Fifth Plenum of the 18th CPC Central Committee, and the "Outline of Healthy China 2030" issued by the CPC Central Committee and the State Council on October 25, 2016, for the promotion of healthy construction in China [1]. To improve building health performance, the China Urban Science Research Association and the China Academy of Building Research in conjunction with relevant units have jointly prepared the "Assessment Standard for Healthy Building" T/ASC 02-2016 (hereinafter referred to ASHB) [17, 18]. Similar to the WELL standard, ASHB views human factors as the most fundamental considerations in building design and operation, sticks to the principle of interdisciplinary integration, explores the relationship between physical, mental health and the indoor environment of buildings, and attempts to use physical environmental conditions to guide users to lead a more healthy, comfortable, and efficient life [5]. This article compares the healthy building definitions and the specific design guidelines of WELL and ASHB, based on which we put forward the key points of healthy building design and future development direction.

2 Comparison of Scoring and Weighting Between the WELL and ASHB Standards

WELL standard is classified into eight major items, namely air, water, nourishment, light, fitness, comfort, mind, and innovation, including 105 subitems in total. China's healthy building standard is classified into seven major items, namely air, water, comfort, fitness, humanity, service and improvement, and innovation, including 102 subitems in total. The scoring system includes prerequisites and scoring items. Prerequisites are the criteria that must be met, and points are counted for each scoring item. Figures 1 and 2 show the weighting of sections in WELL and ASHB standards.

The comparison in Fig. 3 reveals that two standards are extremely similar in weighting of air, comfort, fitness, and mind (light is classified into the comfort category in the ASHB standard). However, in terms of water, the weighting of WELL standard is significantly lower than that of ASHB. This indicates that China pays more attention to water quality and safety, but this also indirectly reflects that there are lots of problems with water safety in our country. Meanwhile, since contents related to nourishment are evaluated based on the performance in the operating stage, ASHB

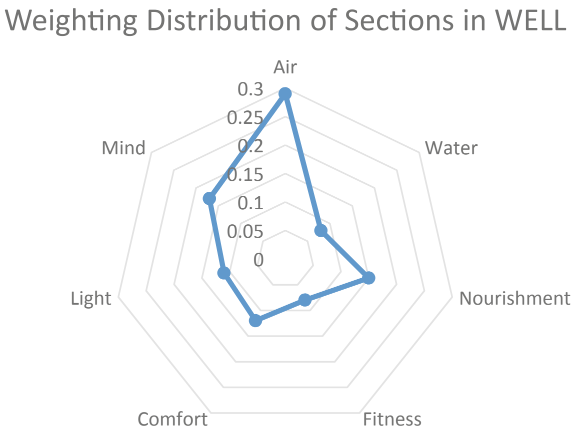

Fig. 1 Weighting distribution of sections in WELL

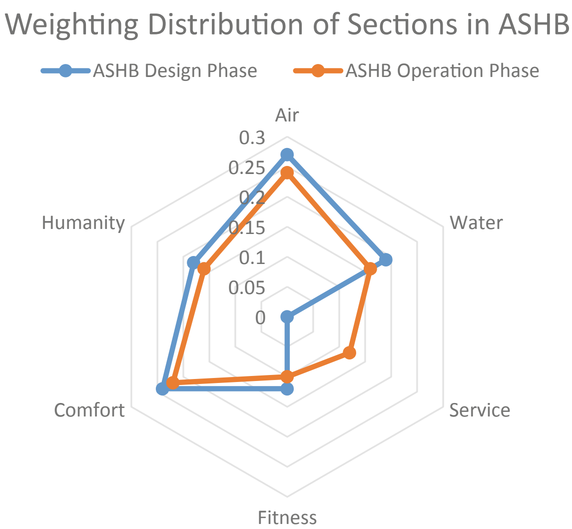

Fig. 2 Weighting distribution of sections in ASHB standard

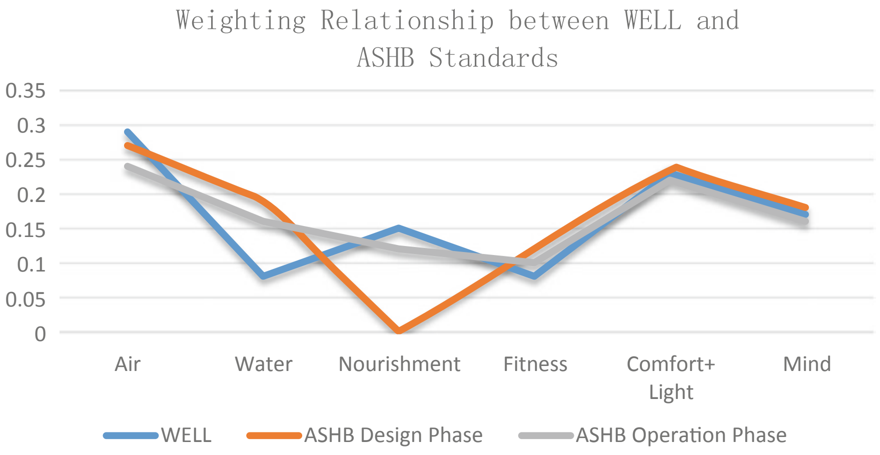

Fig. 3 Weighting relationship between WELL and ASHB standards

barely evaluates and guides contents of nourishment in the design stage, and its operation evaluation weighting is slightly lower than that of the WELL standard.

This study analyzes the ratios of the prerequisites (control items) to provisions in both standards. The statistical results are shown in Fig. 4. The ratio of control items in China's ASHB is far lower than that in the WELL standard. In addition, the ratio of control items in the ASHB standard is quite stable, accounting for about 24% of each section. One of four provisions is a control item. However, there are great changes to the WELL standard. In the weight of the water section, it is as high as 62.5%, and more than half of the requirements are mandatory. This means that requirements on water are closely related to the health and safety of users. WELL standard never compromises on water quality and safety requirements. Fitness requirement in both

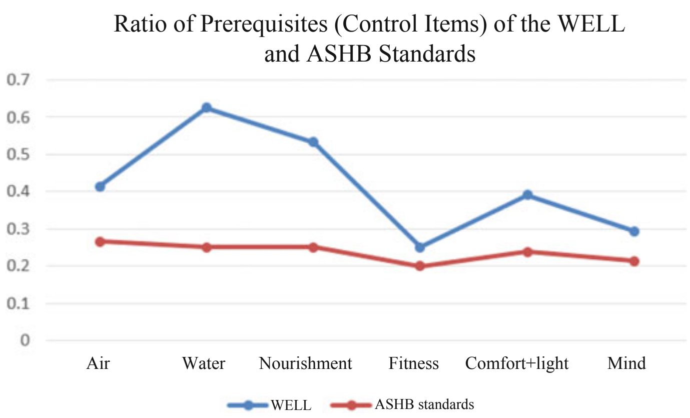

Fig. 4 Ratio of control items of the WELL and ASHB standards

standards reflects the common understanding that both standards encourage buildings to meet the demand for fitness activities so as to affect people's health positively and gradually.

This study also compares the similarities and differences between the provisions of the WELL and ASHB standards (see Figs. 5 and 6), comparing and categorizing the provisions of the two standards. Identical provisions refer to those with the same starting point, means of control, and implementation measures. Similar provisions refer to those with the same purpose but different implementation measures. Different provisions refer to those with different contents and design purposes. According to this classification rule, 44% provisions of the WELL standard are not absent in the ASHB standard, and the contents are mainly about nourishment and mind. In the

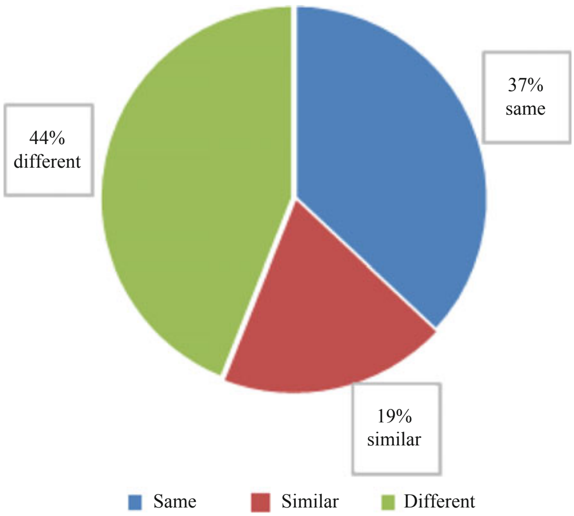

Fig. 5 Comparison of general provisions in the WELL and ASHB standards

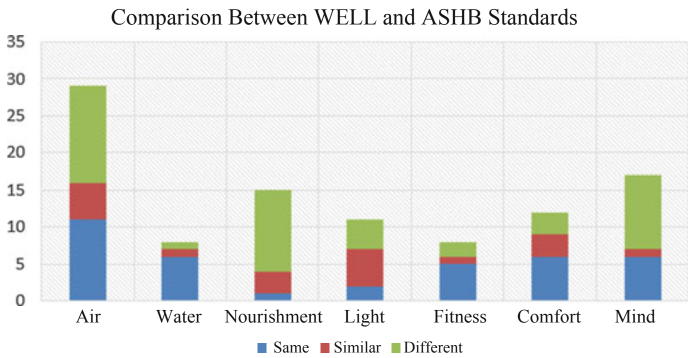

Fig. 6 Comparison of general provisions in the WELL and ASHB standards

water, fitness and comfort sections, the contents of the two standards are generally the same.

3 Comparison of Specific Items Between WELL and ASHB Standards

3.1 Air

The WELL standard has 29 air items, of which 12 are prerequisite items and 17 are scoring items. The ASHB standard has 15 air items, including 4 prerequisites and 11 scoring items. In terms of air control items in both standards, all four prerequisites of the ASHB standard correspond to the following three mandatory items of the WELL standard: 01. Air quality standard; 04. VOC reduction; and 11. Fundamental material safety. The WELL standard also requires that nine items should be mandatory. Two of the four control items of the ASHB standard are based on the total control amount, namely indoor volatile organic compounds (VOCs) and particle concentration (PM 2.5 and PM 10). The ASHB standard pre-evaluates the indoor VOCs and particle concentration in the design phase (according to the interior design, material selection, and fresh air volume). The other two items are focused on toxic and harmful substances in building materials (coatings, plates, and insulation materials), wood and plastic furniture. Metrics of air are classified into four categories (Table 1): air pollution source management, air purification measures, air operation, and air management in the construction phase.

Air pollution source management refers to the possibility of stopping indoor air pollution at the source. Both WELL and ASHB standards pay closer attention to this part. They have seven same metrics and two similar metrics. From the definitions and requirements of the two standards, the WELL standard is more comprehensive in managing pollution sources in home and office spaces in China. In the meanwhile, WELL standard considers more about the sick building syndrome (SBS), which can be resulted from indoor harmful ingredients and be avoided by adopting optimized design planning and building layout [5]. For example, Provision 17 Direct source ventilation of the WELL standard specifies the requirement on controlling indoor pollution sources. This includes cleaning and chemical storage rooms (removal of harmful gases), bathrooms (preventing mold production), and printer rooms (ozone isolation). However, in consideration of regional differences, the ASHB proposes the PM 2.5 issues that are caused by traditional Chinese cooking methods that are easily ignored by air pollution management personnel.

In the two standards, the same metrics include confirmation of indoor air quality standard, indoor and outdoor smoking bans, VOC reduction, pesticide management, fundamental material safety (excluding asbestos, mercury, and lead), air tightness of the building envelope, humidity control, and the independent ventilation system for spaces with indoor pollution. However, quantitative requirements in the same metrics

Table 1 Comparison of air-related metrics in the WELL and ASHB standards

Air item		WELL	ASHB	Similarity
Air pollution source management				
01	Air quality standard	√	√	Same
02	Smoking ban	√	√	Same
04	VOC reduction	√	√	Same
06	Microbe and mold control	√		
08	Healthy entrance	√	√	Similar
10	Pesticide management	√	√	Same
11	Fundamental material safety	√	√	Same
12	Moisture management	√		
14	Air infiltration management	√	√	Same
16	Humidity control	√	√ (Comfort section)	Same
17	Direct source ventilation	√	√ Kitchen ventilation	Same
24	Combustion minimization	√		
25	Toxic material reduction	√	√	Similar
26	Enhanced material safety	√		
27	Antimicrobial activity for surfaces	√		
Air purification measures				
03	Ventilation effectiveness	√	√ (CO_2 concentration)	Similar
05	Air filtration	√	√	Same
13	Air flush	√		
15	Increased ventilation	√		
19	Operable windows	√		
20	Outdoor air systems	√	√	Same
21	Displacement ventilation	√		
23	Advanced air purification	√		
Air operation				
09	Cleaning protocol	√	√ (Healthy building management regulation)	Similar
18	Air quality monitoring and feedback	√	√	Same
22	Pest control	√	√	Similar
28	Cleanable environment	√		
29	Cleaning equipment	√		
4.2.10	Linkage between the basement CO concentration and ventilation equipment		√	
4.2.11	Subjective satisfaction evaluation of air quality		√	

(continued)

Table 1 (continued)

Air item		WELL	ASHB	Similarity
Pollution management in the construction phase				
07	Construction pollution management	√		

of the WELL and ASHB standards are different. Using formaldehyde metrics as an example, WELL requires that the content of formaldehyde in the air must be less than 27 ppb (parts per billion) while the ASHB requires that the content of formaldehyde in the air is about 134 ppb. The required particulate matter (PM) 2.5 and PM 10 concentrations are also lower than those in the WELL. The ASHB requires that the annual soil radon concentration should not be higher than 200 Bq (becquerel)/m^3 (1 Bqm^3 = 0.03 pCi/L), namely 6 pCi/L. However, the WELL requires that the maximum radon concentration measured at the bottom of the building should not be higher than 4 pCi/L. Therefore, the air quality requirement of the WELL standard is much higher than that of the ASHB standard.

Similar metrics include toxic material reduction and a healthy entrance. Air pollutants including CO_2, fine particulate matter (PM2.5), volatile organic compounds (VOCs), and negative air condition such as inappropriate indoor relative humidity and temperature, pose threat on human health, which are supported by many findings [14]. It can even have some direct relationship with the childhood allergies [8]. The WELL defines more types of toxic materials than the ASHB. For example, the WELL requires that the upper limit of the urea-formaldehyde restriction should be 100 ppm, while the AHSB does not specify relevant limits. In the healthy entrance metrics, a healthy building only requires to set doors that can be closed at the entrance channel, and does not require any fixed entrance channel system. In the humidity control part, the requirements of the WELL are higher than those of the ASHB. The WELL requires that the indoor relative humidity be within 30–50%. The ASHB requires that the indoor relative humidity be within 30–70%. There are five items that are not considered by in the ASHB, including microbe and mold control, humidity management, combustion minimization, enhanced material safety, and antimicrobial activity for surfaces. For example, the WELL has the following requirements: mold and bacteria on the cooling coil should be removed using ultraviolet light, and regular mold checks should be performed. Indoor and outdoor liquid water and condensate must be managed, and moisture-resistant materials should be selected. All combustion equipment should conform to California's South Coast Air Quality Management District rules (time length of idling should not exceed 30 s).

The second part of the WELL standard describes air purification measures in eight aspects. The WELL and ASHB standards have three same or similar aspects, including air filtration, outdoor air system, and ventilation effectiveness. Both standards raise requirements for air filtration, in which the ASHB standard requires the use of various types of fresh air systems with the air purification function, but does not specify the filtration and purification techniques. The WELL standard classifies air purification into mandatory basic requirements and advanced air purification requirements. Basic air purification requires that a fresh air system should contain carbon filters and HEPA efficient filters (the MERV value is greater than 13), for the adsorption of volatile organic compounds and particulate matter. In terms of ventilation efficiency, the CO_2 concentration limits of two standards are slightly different. The requirements of the WELL standard are stricter than the ASHB standard. The ASHB standard requires that the daily average concentration should be no higher than 900 ppm, while the WELL standards require that the CO_2 concentration should not be higher than 800 ppm. If not, the fresh air system must increase the amount of fresh air. The remaining five items are not covered in ASHB standard, including air flush, increased ventilation, operable windows, displacement ventilation, and advanced air purification. For example, the WELL standard proposes the following requirements: a total air volume of 4500 m^3 of outdoor air per m^2 of floor area [14,000 ft^3 per ft^2 of floor area] prior to occupancy. The building ventilation rate should be 30% higher than the standard rate; windows can be opened only after the local outdoor air quality conditions are analyzed.

The third part describes air operation and covers seven aspects. The ASHB and WELL standards have three aspects that are the same or similar, including regular cleaning protocol, air quality monitoring and feedback, and pest control. Both the WELL and ASHB standards require indoor air monitoring and setup of air quality monitoring systems. However, the data storage time in both standards is slightly different. The data must be retained for three years according to the WELL standard and annually reported to the IWBI. While in the ASHB standard, the data must be kept for one year with no clearly specified report time. The cleanable environment and cleaning equipment are special items required by the WELL standard, but not included in the ASHB standard. The cleanable environment requires that high-touch surfaces should be smooth, corrosion resistant, and easily sanitized to maintain the cleanliness. The cleaning equipment must meet the requirements of EPA and relevant labels. The WELL standard also raises requirements on chemical storage. In the air operation part, the ASHB standard raises requirements on the linkage between the basement CO concentration and the air exhaust equipment, as well as the subjective evaluation for air quality satisfaction.

In China, there are a large number of vehicles on the road, and a large number of parking lots are built underground. These are relatively closed spaces and not favorable for the proliferation of air pollutants such as CO. Therefore, effective control of CO concentration becomes a term in the ASHB standard. However, the WELL standard does not specifically raise any requirements on CO concentration, perhaps because the US HVAC standard ASHRAE62.1-2013 has requirements on indoor CO concentration limit. The evaluation of subjective air quality satisfaction is proposed in the ASHB standard. Its main purpose is to evaluate indoor air quality in the light of the subjective feeling of users. Due to the complexity of indoor air pollutants, certain trace or unknown chemical substances cannot be accurately measured through instruments. However, smells or irritation from these substances can cause discomfort. As a result, the objective detection of indoor air pollutants cannot fully meet human body's requirements on indoor air quality. The ASHB combines subjective and objective evaluations, and considers indoor air quality acceptable when most people (over 80%) are not dissatisfied with indoor air quality and no known pollutants in the air are likely to produce health threats.

The fourth part describes the pollution management in the construction phase. The WELL standard proposes requirements on pollution management in the construction phase in four aspects, which include duct protection, filter replacement, absorption management of volatile organic compounds and dust containment and removal. Air pollutants introduced during the construction phase must be minimized. Construction management is difficult in China to a certain extent, because building inspections are based on drawing review or completion acceptance, and it is difficult to manage and implement intermediate construction processes. Therefore, this term is not included in the ASHB standard.

Generally, in the air part, the evaluation criteria of the WELL standard are more comprehensive and detailed than those of the ASHB standard. In addition to the requirements in the design and operation phases, the WELL standard also proposes requirements in the construction and commissioning phases. For example, construction pollution management and air flush are of the great referential values.

3.2 Water

The WELL standard has eight water items, including five prerequisite items, and three scoring items. The ASHB standard has 16 water items, including 4 prerequisite items and 12 scoring items. In terms of mandatory items in water section, the basic potable water quality requirements in the ASHB standard correspond to 5 prerequisite items in the WELL standard, which are 30 fundamental water quality, 32 organic contaminant, 33 agricultural contaminant, and 34 public water additive. Compared with the WELL standard, the ASHB standard has three additional control items: non-potable water quality, water storage tank cleaning and maintenance, and avoidance of condensation and leakage of the indoor water supply and drainage pipes. Metrics in the water part can be classified into four aspects (Table 2): water quality requirements, water system requirements, inspection requirements, and portable water promotion.

In the part for water quality requirements, both WELL and ASHB standards are concerned with water quality and raise requirements on water deposition, microbial, inorganic pollutants, organic pollutants, agricultural pollutants, and public water additives. However, the water quality requirements of the WELL standard are stricter than the ASHB standard. The WELL standard raises quantitative requirement on water quality, corresponding to the GB 5749—2006 Standards for Drinking Water Quality and CJ 94—2005 Water Quality Standards for Fine Drinking Water, as referenced by the ASHB standard.

In terms of basic water quality, the WELL standard requires that turbidity of water sample be less than 0.3 NTU and the ASHB standard requires that water sample turbidity be less than 0.5 NTU. In terms of microorganisms, the prerequisites of the WELL and ASHB standards require that the total number of coliforms in the water

Table 2 Comparison of water-related metrics in the WELL and ASHB standards

Water item		WELL	ASHB	Similarity
Water quality requirements				
30	Fundamental water quality	√	√	Same
31	Inorganic contaminant	√	√	Same
32	Organic contaminant	√	√	Same
33	Agricultural contaminant	√	√	Same
34	Public water additive	√	√	Same
36	Water treatment	√	√	Similar
5.1.2	Non-drinking water quality		√	
5.2.3	Centralized hot water system		√	
System requirements				
5.1.4	Avoidance of condensation and leakage		√	
5.2.4	Water supply pipe selection		√	
5.2.5	Piping and equipment identification		√	
5.2.6	Water distribution		√	
5.2.7	Shower constant temperature control		√	
5.2.8	Same-layer drainage for bathroom		√	
5.2.9	Kitchen and toilet shunt drainage		√	
5.2.10	Water seal affixing		√	
Later-phase operation and management				
35	Periodic water quality testing	√	√	Same
5.1.3	Water storage facility cleaning and maintenance		√	
5.2.12	Online water quality monitoring		√	
Drinking water promotion				
37	Drinking water promotion	√		

be zero. In addition, the ASHB standard has higher requirements on the total number of colonies in scoring items than national standards in China. Points are given as long as the total number of colonies is between 10 and 100. In terms of inorganic pollutants, there are more types of dissolved metals in the ASHB standard compared to the WELL standard. The WELL and ASHB standards require that the mercury content be less than 0.002 and 0.001 mg/L, respectively, and the nickel contents be less than 0.02 and 0.0012 mg/L, respectively. In terms of organic pollutants, there are more types of organic pollutants involved in the ASHB than the WELL standard. However, the quantitative requirements on each type of organic pollutants in the ASHB standard are lower than in the WELL standard. For example, the WELL and ASHB standards require that the styrene contents be less than 0.0005 and 0.02 mg/L, respectively, and the benzene contents be less than 0.001 and 0.01 mg/L, respectively. In terms of agricultural pollutants, there are more and different types of agricultural pollutants in the ASHB standard. This is perhaps attributed to the different ingredients of insecticides and herbicides used by the two countries, so chemical substances to be tested are different as well. In terms of public water additives, the WELL standard specifies the maximum values of chlorine and chloramines. For example, the residual chlorine content is less than 0.6 mg/L; however, the ASHB standard specifies the minimum values of chlorine and chloramines; for example, the residual chlorine content at the end of piping is greater than 0.05 mg/L.

Both the WELL and ASHB standards cover the requirements on turbidity, microbes, inorganic contaminants, organic pollutants, agricultural contaminants, and public water additives for water quality. In terms of turbidity and microbes in basic water quality, the requirements of the WELL standard are slightly higher than those in the ASHB standard. The requirements on organic pollutants in the WELL standard are much higher than those in the ASHB standards. As for inorganic pollutants and agricultural pollutants, the requirements in both standards are similar. It is worth mentioning that disinfectants added to the public drinking water are conducive to public health, but excessive intake may lead to adverse reactions. Therefore, the WELL standard requires that the residual chlorine and chloramine be smaller than certain values (0.6 and 4 mg/L, respectively). The ASHB standard requires that the residual chlorine concentration be higher than 0.01 mg/L at the end of pipes, and concentrations of chlorine, free chlorine, and chloramine be greater than 0.05 mg/L separately. The requirements in both standards do not conflict with each other. In terms of water treatment, the requirements in the WELL standard are much higher than those in the ASHB standard. The WELL standard requires that portable water and shower water can be treated through activated carbon filters, sediment filters, and UV disinfection. On the contrary, the ASHB standard only stipulates the minimum requirements on the water temperature of the centralized water heating system, encouraging the setup of sterilization devices, but which is not mandatory. The WELL standard classifies the water quality requirements into three categories: All water delivered to the project (including water not in direct contact with human body, such as water for flushing toilets, landscape irrigation, and washing road), water for drinking and showering, and water only for human drinking. The ASHB standard categorizes water into nontraditional water, landscape water, water for HVAC systems, hot water, water for swimming pools, and direct drinking water, and also puts forward the corresponding handling measures.

In the requirements on water system, the ASHB standard involves nine metrics, including avoidance of condensation and leakage, water supply pipe selection, piping and equipment identification, water distribution, shower constant temperature control, same floor drainage for bathrooms, kitchen and toilet shunt drainage, and water seal affixing. However, the WELL standard does not have mandatory requirements on water system. The metrics of water system show that the WELL is a result-oriented evaluation standard that brings forth requirements on the final testing results of water, without any stipulations on water system. The scoring mode of the ASHB standard is measure-oriented. The ASHB standard pays more attention to the measures used and does not require that water quality should be tested mandatorily. At present, the quality of main water supply in our country cannot meet the physical and mental health requirement of people, which is mainly resulted from outdated water supply pipeline and the pollution of water supply and storage facilities [3]. Designers can meet mandatory conditions of water and obtain approval through technical drawings.

With respect to operation and management in late stages, both the WELL and the ASHB standards have periodic water quality testing metrics. The WELL standard requires quarterly inorganic metal testing, listing all water quantity metrics in the testing standards, keeping the records for three years, and providing water quality reports to the IWBI every year. The ASHB standard requires property management departments to employ qualified third-party evaluation agencies to regularly perform water quality testing. Online water quality testing is a scoring point in the ASHB standard. It is required to monitor online the water quality of various types of supplied water in buildings in a continuous and real-time manner, to allow users to learn about water quality metrics at any time.

3.3 Nourishment

Nourishment in the WELL standard is mainly to advocate healthy food buying and consuming decisions, limit unhealthy ingredients in products, and encourage a good diet and production method. The WELL standard has 15 nourishment items, including 8 prerequisite items, and 7 scoring items. The ASHB standard does not have such requirements in this part and only involves four items in service, including development of kitchen cleanliness programs, food allergy labels, artificial ingredient labels, and food contamination prevention measures. Metrics in nourishment are classified as follows (Table 3): supplying healthy food, limiting unhealthy ingredients, and encouraging good eating habits.

The WELL standard raises requirements on supplying healthy foods to building owners, regulating the provision of foods containing too much sugar, and providing clearly identified organic and free-range agricultural products. They also stipulate the provision of a food storage space with a total volume of 20 L under temperature control per person, and providing a 0.1 m^3 gardening space per person (the maximum space does not exceed 70 m^3) as well as necessary planting materials. Such requirements are not involved in the ASHB standard. The causes of obesity are multifactorial and require multiple coordinated actions to address this important public health problem [19]. WELL points that lack of fruit, vegetable, and high consumption of added sugars are associated with obesity. Obesity constitutes an important threat to national and global public health in terms of prevalence, incidence, and economic burden [16]. The WELL standard requires that a canteen operating in the building should provide at least two kinds of fruits and two kinds of non-fried vegetables. Salad bars, vegetables, and fruits are to be placed in specified positions to encourage the consumption of fruits and vegetables. The WELL standard also requires that highly sugary beverages and foods should not be provided or sold in the buildings. In addition, foods containing trans fats are prohibited. All of these requirements are related to the operation and management of buildings, which are the most difficult tasks in China. The metrics cannot be promoted until domestic third-party regu-

Table 3 Comparison of nourishment-related metrics in the WELL and ASHB standards

Nourishment item		WELL	ASHB	Similarity
Supplying healthy food				
38	Fruits and vegetable	√		
39	Processed food	√		
49	Responsible food production	√		
50	Food storage	√		
51	Food production	√		
9.2.4	Development of kitchen cleanliness program		√	
Limiting unhealthy ingredients				
40	Food allergy	√	√	Same
43	Artificial ingredient	√	√	Similar
44	Nutritional information	√	√	Similar
45	Food advertising	√		
46	Special diets	√		
Encouraging good eating habits				
41	Hand washing	√		
42	Food contamination	√	√	Similar
46	Safe food preparation materials	√		
47	Serving sizes	√		
52	Mindful eating	√		

latory and testing institutions become mature. The ASHB standard proposes only a plan to clean kitchens on a regular basis in food safety. The food producers are required to take effective cleaning and disinfection measures and carry out microbiological monitoring in the food processing environment. Both the WELL and ASHB standards require relevant labels on food packaging, including food allergy labels, artificial ingredient labels, and nutritional information labels. The requirements on food allergy labels in the WELL and ASHB standards are the same. The labels must indicate eight types of the most common food allergens and glutens. With respect to artificial ingredient labels, the WELL standard requires that the labels should clearly specify all artificial colors, artificial flavors, sweeteners, preservatives, and so on. In accordance with "*National Food Safety Standards General Standard For the labeling of Prepackaged Food*" GB 7718-2011, the ASHB standard requires that the labels should specify the following contents: name, specifications, net weight, date of manufacture; ingredients or ingredient list; name of producer, address, contact method, expiration date, standard product code, storage conditions, common names of food additives used according to national standards, production license number, and other precautions that need to be indicated according to laws, regulations, or food safety standards. However, the ASHB standard does not require this information for meals supplied in buildings. Artificial ingredient labels are only required for prepackaged foods.

The requirements on nutritional information in the WELL standard are more stringent than those in the ASHB standard. It is required in the WELL standard that foods sold and distributed in buildings (no matter packaged foods or prepared foods) should be indicated with total calorie, constant nutrient content, complete ingredient list, as well as the levels of vitamins A and C, calcium, and iron. Based on the *National Food Safety Standards General Standard for the labeling of Prepackaged Food* GB 7718, the ASHB standard requires that only special dietary food and main and supplemental foods specifically for infants need to be marked with main nutrients and contents. In addition, the WELL standard also puts forward the regulations of food advertising. The promotion of unhealthy food advertising is prohibited. There must be at least three advertising points for promoting fruits and vegetables in public areas. For people with common food allergies or dietary restrictions, the WELL standard needs to provide them with foods containing on common allergens and vegetarian foods.

With regard to encouraging good eating habits, the WELL and the ASHB standards have similar metrics such as food contamination. The WELL standard requires that fresh food should be stored in a special cold storage space and affixed with clear labels. In addition, raw food and cooked food should be separated. The ASHB standard requires that appropriate separation or separation measures should be taken in the dining kitchen areas, food processing area, and sales area. The WELL standard also proposes the following metrics: sinks, soap, and paper towel dispensers are readily accessible in an appropriate place; safe cooking utensils and equipment are selected, and materials that affect human health are limited; reducing the size and caloric content of meals which can reduce the likelihood of overeating, thereby encouraging healthier eating habits. There should also be a suitable dining space and adequate facilities (including refrigerators, microwaves, sinks, etc.) provided for the staff.

3.4 Light

The WELL standard has 11 light items, including 4 prerequisite items, and 7 scoring items. The ASHB standard classifies light into the section of comfort. There are 6 light items, including 2 prerequisite items and 4 scoring items. According to the comparison of control items of the two standards, natural light environment and lighting environment in the ASHB standard correspond to the following mandatory items: 62 daylight modeling, 58 color quality, and 53 visual lighting design requirements. The mandatory light items of the WELL standard are more comprehensive. In addition to the quantitative requirements on visual lighting design, the WELL standard also has the mandatory items such as circadian lighting design, electric light glare control, and solar glare control. The light metrics are classified into four aspects (Table 4): natural light utilization, lighting control, circadian lighting design, and outdoor lighting.

Table 4 Comparison of light-related metrics in the WELL and ASHB standards

Light item		WELL	ASHB	Similarity
Natural light utilization				
58	Color quality	√	√	Same
61	Right to light	√		
62	Daylight modeling	√	√	Similar
63	Daylighting fenestration	√		
6.2.6	Natural light utilization		√	
Lighting control				
53	Visual lighting design	√	√	Similar
55	Electric light glare control	√		
56	Solar glare control	√	√	Similar
57	Low-glare workstation design	√		
59	Surface design	√	√	Similar
60	Automated shading and dimming controls	√	√	Similar
Circadian lighting design				
54	Circadian lighting design	√	√	Same
Outdoor lighting				
6.2.9	Outdoor lighting		√	

With respect to natural light utilization, both the WELL and ASHB standards have proposed relevant requirements, including color quality and daylight modeling. For example, both of the WELL and ASHB standards require that the color transmittance index (color rendering index) Ra of the lighting system should not be less than 80. The daylight modeling indicator of the WELL standard requires that 55% of the common space should receive at least 300 lx of daylight during at least 50% of the operating time in each year. The ASHB standard requires that the duration of at least 75% of the major functional space in a public building with a natural light intensity of no less than 300 lx should be no less than 4 h/day. In addition to the minimum lighting requirements, the WELL standard also limits the maximum lighting values. No more than 10% of the common space should receive less than 1000 lx of annual sunlight exposure (ASE) for at least 250 h every year. In the ASHB standard, light should meet requirements of the current *Standard for Daylighting Design of Buildings* GB50033, and the contents include the corresponding requirements on different types of buildings, such as sunshine, lighting coefficient, light color rendering, lighting uniformity and pollution of sun reflection.

Both standards encourage adequate access to natural daylight. Suitable daylighting design was recommended for classrooms or offices. It has positive effect on human health, even human mood, than the artificial light [4].The ASHB standard describes the natural lighting hours (equivalent to the spatial daylight autonomy (SDA)) through sunshine and lighting factors. The WELL standard specifies the upper and lower limits of natural light through the SDA and annual sunlight exposure (ASE). When satisfying the lower limit of indoor natural light, a building should avoid the exposure to too much high-intensity sunlight. In terms of color rendering metrics, the requirements in both standards are identical. In terms of indoor lighting uniformity, the WELL standard requires that the top lighting uniformity should not be less than 0.7 and the side lighting uniformity should not be less than 0.4. The lighting uniformity is usually calculated through simulation by software, mainly subject to window opening mode, window transmittance ratio, and indoor surface reflectivity ratio. The WELL standard does not have any requirement on indoor lighting uniformity, but it has the requirement on light reflectivity value (LRV) of internal areas of common spaces (such as ceiling, wall, and furniture).

The WELL standard creatively proposes the boundary separated windows based on the visual range (a height of 2.1 m). Windows are classified into lighting windows and viewing windows with different requirements, including visible light transmittance, shade facilitates, and window-to-wall ratio.

In addition, the ASHB standard also requires taking effective measures to fully utilize natural light for deep, underground, and windowless spaces, such as light pipe, reflector, or prism glass. The WELL standard has two additional metrics compared with the ASHB standard, including lighting right and window opening for natural light. Among the lighting right metrics, the WELL standard quantitatively specifies the minimum distance between a window and a common space, and requires that at least 75% of the common space should be in the range of 7.5 m from the viewing window.

With respect to window opening for natural lighting, the WELL standard specifies design parameters. For example, about 40–60% of the window areas should be 2.1 m above the floor. If the window-to-wall ratio is higher than 40%, shade facilitates or opaque glass should be adopted. The window's visible light transmittance and uniform color transmittance are also specified. According to the *Design Code for residential buildings* GB 50096, the window-to-floor ratio of windows for lighting in bedroom, living room, and kitchen should not be less than 1/7. The WELL standard proposes a window-to-wall ratio of 20–60%, and the purpose is to make sure that residents can receive enough light, which has a positive physiological impact. The upper limit is intended to avoid excessive glare and heat, to ensure no discomfort and distraction caused by strong light. Article proves that the appropriate illuminance setting makes significant contribution to overall staffs' productivity and well-being [4]. At present, most of the domestic standards ensure the full use of natural lighting by specifying the lower limit of the window-to-wall ratio. The upper limit of the window-to-wall ratio is determined according to the building energy-saving standards in different areas. For example, in an area of hot summer and warm winter, the window-to-wall ratio of the south and north windows should not be greater than 0.4, and the window-to-wall ratio of the east and west windows should not be greater than 0.3. This can prevent overheating caused by solar radiation in summer and resolve the problem of excessive cooling energy and discomfort. But fact is that the current statutory control may not fulfill or match user expectations. The window design framework should be a qualitative approach with the understanding of space function and user behavior in the sociocultural context in order to provide for a better living environment [10]. Compared with the ASHB standard, the WELL standard gives additional consideration to the window-to-wall ratio, which is a key variable affecting natural lighting. With respect to lighting control, both WELL and ASHB standards mention the visual lighting control, solar glare control, and automated shading and dimming controls.

For visual lighting design, the WELL standard has a quantitative requirement: the illuminance 0.76 m above the level of the workstation or desk should be kept at 215 lx. The background lighting system should be partitioned, and each independently controlled light loop covers an area of no larger than 46.5 m^2.

The ASHB standard proposes more comprehensive quantitative requirements, including space illumination distribution, color temperature, color rendering, color tolerance, strobe, and light biosecurity. Based on the different sensitivities of intrinsically photosensitive retinal ganglion cells (ipRGC) to different color temperature sources, the WELL standard requires converting the illumination into the Equivalent Melanopic Lux (EML) to measure the biological stimuli and effects of light on human body. The ASHB standard requires that the lighting system should be able to automatically adjust the color temperature, and artificial lighting close to the natural light color temperature (6500 K) should be adopted during the day. Because people have different color temperature requirements in different times and occasions, color temperature adjustment can satisfy this difference and further enhance the environmental quality of lighting. The two standards are consistent in terms of color temperature of light source. For indoor illumination at a certain height, the WELL and ASHB standards propose requirements separately according to the space functions and precision of activities. With respect to the glare control, the WELL standard proposes requirements in three aspects: For the electric light glare control, light fixtures of greater luminous intensity require a greater shielding angle to reduce the likelihood of creating direct glare on occupants. For solar glare control, a variety of shading designs, including user-controlled baffles and shade systems, dimmable glass, and microreflector film, are used to effectively manage the harmful glare from windows. For low-glare workstation design, glare and high luminance contrast between computer screens and the surrounding background should be minimized through the spatial orientation of occupant spaces. In the ASHB standard, the glare is only focused on solar glare control. The Daylight Glare Index (DGI) is graded for quantitative requirements based on the *Standard for Daylighting Design of Buildings* GB 50033. For the surface design, both the WELL and ASHB standard propose quantitative requirements on indoor surface light reflectance value (LRV). With respect to automated shading and dimming controls, the requirements of the WELL standard are more quantitative and rigorous. The WELL standard requires that windows larger than 0.55 m^2 should be provided with shades and light sensors. In addition, all non-decorative lamps should use human sensors and sunlight sensors for automatic adjustment. The ASHB standard also contains the similar requirement that lighting and shading facilities are linked together to adjust the luminance in time, and further control glare and utilize natural light.

The WELL standard brings forth a round-the-clock lighting design concept, which is similar to the physiological equivalent luminance concept in the ASHB standard. This concept is concerned not only with the luminance and the comfort of users, but also with the effects of light on human biology. Its purpose is to improve the working efficiency of indoor staff, and also guarantee a good rest for people at night. The WELL standard also proposes the EML concept (a value calculated based on the illuminance and wavelength of various types of light), and raises the quantitative requirement on EML at workplaces, namely that 75% workplaces should meet 250EML. The ASHB standard requires that the physiological equivalent vertical illumination in the main line of sight in at least 75% workspaces should not be less than 250 lx, which is the same as that specified in the WELL standard. The outdoor lighting is newly added to the ASHB standard. The color rendering index and glare limit for outdoor lighting are specified to ensure visual comfort for outdoor activities at night.

3.5 Fitness

The WELL standard has 8 fitness items, including 2 prerequisite items and 6 scoring items. The ASHB standard has 8 fitness items, including 2 prerequisite items and 6 scoring items. The ASHB standard is provided with two control items, including the requirement on total quantity control of fitness sites and fitness facilities, which is corresponding with the scoring item of the WELL standard, namely 68 physical activity spaces. The control items in the WELL standard are designed for indoor fitness requirement and corporate incentive plan of sports promotion. These two items of the WELL standard are intended to encourage physical activities, while the ASHB standard is mainly to furnish fitness facilities. This shows that the two standards vary in the inclination of fitness. Fitness metrics are classified into fitness sites and facilities, and fitness incentive plans (Table 5).

As for fitness sites and facilities, both the WELL and ASHB standards put forward a lot of quantitative metrics, with similar points of focus. The ASHB standard specifies the lowest requirement on outdoor fitness sites while the fitness space is a scoring item in the WELL standard. In addition, the WELL standard calculates the needed fitness space based on the number of building users, including indoor and outdoor fitness spaces. The ASHB standard calculates the needed fitness space for outdoor and indoor scenarios based on the total land area and ground floor area. Assume that the office building area is X, and the number of users is $0.1X$. According to the WELL standard, the needed space is $18.6\ \text{m}^2 + 0.1\ \text{m}^2/\text{user} = 18.6 + 0.01\text{x}\ \text{m}^2$. According to the ASHB standard, the needed space is: outdoor 0.008* land area $X/6/0.4$ (6 and 0.4 are maximum limit of floor area ratio and building density, respectively, in China), indoor area $0.005X$, totally $0.0083X$. Although the two methods of calculation are different, the fitness space expected in the WELL standard is slightly larger than that expected in the ASHB standard. Both standards have the corresponding requirements on the design of indoor staircase, trying to encourage users to take stairs with attrac-

Table 5 Comparison of fitness-related metrics in the WELL and ASHB standards

Fitness item		Well	ASHB	Similarity
Fitness sites and facilities				
64	Interior fitness circulation	√	√	Same
67	Exterior active design	√	√	Similar
68	Physical activity spaces	√	√	Same
69	Active transportation support	√	√	Same
70	Fitness equipment	√	√	Same
71	Active furniture	√		
Fitness incentive plan				
65	Activity incentive program	√		
66	Structured fitness opportunities	√	√	Same
9.2.12	Free physical examination activities		√	

tive designs. For example, the WELL standard proposes the following requirements on interior staircases: barrier-free staircases are designed with guides; the distance between staircase and building entrance should be no more than 7.5 m, and staircase should be located at a conspicuous position; the width of staircase should be no less than 1.4 m; and staircase should include the following elements: art, music, skylight lighting, and outdoor viewing window, with light intensity being not less than 215 lx. The staircase design requirements in the ASHB standard are similar: The distance between staircase and major building entrance should be no more than 15 m, with a logo guide. Staircase should be designed with natural lighting, a good field of vision and human body sensor lights should be set in the stairway. Both standards require service facilities for fitness or cycling. For example, the WELL standard requires that bicycle parking and basic bicycle maintenance tools should be placed within a distance of 200 m from the building entrance. This provides bicycle parking areas for at least 5% of regular users and 2.5% of visitors during peak hours. The ASHB standard requires that bicycle parking and basic bicycle maintenance tools are provided for 10% of the total users in the building. Both standards require that shower rooms with lockers are provided for users. The WELL standard requires one locker for every five regular users. For outdoor fitness sites, the WELL standard requires that parks with fitness equipment or free gymnasiums or playgrounds should be available within a walking distance of 0.8 km from buildings. The ASHB standard requires that outdoor fitness sites be no smaller than 0.5% of the total land area and at least 100 m^2 in size. In addition to drinking fountains, the WELL standard also requires offering outdoor convenience facilities, including benches, squares, parks, and public art. The ASHB standard requires that a dedicated fitness path with a width of no less than 1.25 m should be provided.

The fitness equipment requirements in the ASHB standard are more comprehensive. For example, the total number of fitness equipment in an outdoor fitness site should be no less than 0.5% of the total number of users in the building; and at least three types of equipment should be provided. The total number of fitness equipment apparatuses in an indoor site should be no less than 0.5% of the total number of users in the building, and at least three types of equipment should be provided. The WELL standard requires more fitness equipment than the ASHB standard. The WELL standard requires that indoor fitness equipment be able to serve at least 1% of the regular users. The WELL standard also proposes the active furniture concept, including offering treadmill desks, bicycle desks, steppers, and adjustable vertical desks to 3% of employees. The aim is to reduce the sedentary behavior during working hours and encourage a small amount of physical exercise during work.

The WELL standard also proposes an incentive program to encourage employees to exercise actively. It is suggested that a systems approach to health promotion and actions on inequalities in wider social determinants operating outside the health system are required to improve health and alleviate deprivation [12]. This is achieved through reimbursement of fees of fitness and other forms of physical exercise, and encourages employees to choose a healthier lifestyle. In addition, the WELL standard also requires enterprises to organize group fitness courses. On-site fitness or training programs should be provided on a monthly basis; and professional teaching should be provided once every three months. In the service section, the ASHB standard also proposes similar terms, including: fitness publicity, posting or distributing fitness information, and periodically organizing lectures and activities to promote physical and mental health. In addition, no less than once every three months, one free medical examination is provided for building users and the manager.

3.6 Comfort

The WELL standard has 12 comfort items, including 5 prerequisite and 7 scoring items. The ASHB standard has 21 comfort items, including 5 prerequisite and 16 scoring items. The comparison of their control items (Table 6) shows that they share the same focus in noise comfort, including outdoor noise isolation and indoor noise treatment. The difference is reflected in the fact that the WELL standard views the only two comfort-related items as control items, and the ASHB seemingly does not attach too much importance to it. The WELL standard independently proposes the olfactory comfort concept. Currently, it has only one term and will add more terms in the future. This content is categorized into the air section in the ASHB standard. In addition, the light environment comfort requirements are also incorporated into the comfort section of the ASHB standard, while the WELL standard separates it as an independent chapter along with air and water requirements. WELL standard regards the human well-being as defined target and sets key features refer to occupants' satisfaction and comfort, which fulfill the shortage of green building [12].

The first part in the comfort section describes human comfort in two aspects, namely indoor building planes and barrier-free design of facilities, as well as the ergonomic design of displays and furniture. Both the ASHB and WELL standards contain comfort requirements. The human comfort terms in two aspects are manda-

Table 6 Comparison of comfort-related metrics in the WELL and ASHB standards

Comfort item		WELL	ASHB	Similarity
Human comfort				
72	ADA accessible design standard	√	√	Similar
73	Ergonomics: visual and physical	√	√	Same
Acoustic comfort				
74	Exterior noise intrusion	√	√	Same
75	Internally generated noise	√	√	Same
78	Reverberation time	√	√	Same
79	Sound masking	√		
80	Sound reducing surface	√		
81	Sound barrier	√	√	Similar
Thermal comfort				
76	Thermal comfort	√	√	Same
82	Individual thermal control	√		
83	Radiant thermal comfort	√	√	Similar
Olfactory comfort				
77	Olfactory comfort	√	√	Same

tory control items in the WELL standard. In terms of indoor accessibility design, the requirements are based on the Americans with Disabilities Act (ADA), GB50763-2012 codes for accessibility design and GB50352-2005 code for design of civil buildings. Compared with domestic standards, the US standards are slightly more stringent and more detailed. Ergonomic design requirements are initially proposed as building-related requirements to regulate the interior decoration and post-procurement implementation. The WELL standard provides quantifiable requirements. The ergonomic compliance of tables and seats can be referred directly to the current US HFES100 standard or BIFMA G1 guidelines. The requirements of the ASHB standard and WELL standard are basically the same, but there is no detailed quantitative requirement or benchmarked furniture standard in China.

The second part describes acoustic comfort in six aspects. The ASHB and WELL standards are identical or similar in four aspects, including exterior noise intrusion, internally generated noise, reverberation time, and sound barriers. Both standards put forward requirements on indoor and outdoor noise levels. The difference is that the WELL standard requires a lower noise level. The WELL standard requires that the indoor noise level should be below 50 dB while the ASHB standard assumes that a full mark can be given if the indoor noise level is less than 55 dB. For indoor noise, the WELL standard only contains the requirement on noise generated from indoor noise sources in office buildings. With regard to other types of buildings, noise requirements are mentioned in the pilot standard. The WELL and the ASHB standards require the same limit of noise level, and the differences lie in the scope of room and site. The WELL has the more specific requirements. In terms of reverberation time, the WELL standard requires that the reverberation time for a conference room and an open office be 0.6 and 0.5 s, respectively. However, the ASHB standard requires that the reverberation time for a large crowded area only be less than 2 s. The ASHB standard also proposes requirements on voice clarity, not only related to reverberation time, but also including voice pressure level, background noise level, and system distortion. Considering the privacy of conversations and how easily people are distracted in a quiet environment, the WELL standard puts forward the requirements of a sound masking system that controls the noise in an open office space within a specific range. The sound masking system helps private office rooms provide optimal cognitive performance, better acoustic satisfaction, and less distraction for employees [6]. The ASHB standard does not have such requirements. The WELL standard proposes the noise reduction index of the ceiling and wall (material sound absorption properties) in the sound reduced surfaces terms. The ASHB standard does not have such requirements. In terms of sound barriers, the ASHB standard requires that the airborne sound insulation ($D_{nT,w}$) is no less than 55 dB, and the impact sound insulation ($L'_{nT,w}$) is no less than 55 dB. The WELL standard does not only require the Noise Insulation Class for closed office, conference room, and teleconference room (40, 53, and 53 respectively), but also refines the requirements in the wall construction specifications, sound insulation of doors, and specific construction of the wall. The aim is to fully satisfy the need of sound insulation between two rooms.

The third part describes thermal comfort, which covers three aspects: indoor thermal comfort, independent thermal control, and radiant heat comfort. The thermal comfort and independent thermal control in the WELL and ASHB standards are the same or similar. In terms of thermal comfort, both standards put forward thermal comfort requirements under natural ventilation conditions and manual control conditions. In a manually adjusted environment, the ASHB standard mainly proposes requirements on indoor PPD and PMV values, cooling sensors, vertical air temperature difference, and floor surface temperature. This is consistent with of the content required in the WELL standard.

But as for the specific metrics, the ASHB standard is less strict in comparison with the US ASHRAE 55-2013 standard referenced by the WELL standard. Similarly, the thermal comfort requirements under natural ventilation conditions are similar in both standards. In terms of independent thermal control requirements, both standards require that the indoor thermal environment should be adjustable, but the specific requirements are different. The ASHB standard requires users to control the indoor HVAC system based on the thermal comfort of the human body itself in an indoor environment. The WELL standard requires that users can freely choose the office space with the most appropriate temperature when the difference between different indoor spaces exceeds 3 °C. Users having other comfort requirements can use fans or other equipment to further adjust the temperature. Compared with the ASHB standard, the WELL standard provides more selective measures for users to adjust to the indoor thermal environment so they can enter the most comfortable environment more quickly. The WELL standard requires refrigeration and heating by means of a radiation temperature system. On the one hand, this system can realize the independent control of temperature and humidity, and on the other hand, radiation system can make users feel more comfortable than air supply system. This requirement is not mentioned in the ASHB standard.

The fourth part describes olfactory comfort. There is only one requirement that a series of measures are adopted to isolate odor from toilets, duty rooms, and restaurants. This is the same as Provision 4.2.1 in the air section of the ASHB standard. The ASHB standard requires the installation of automatic doors and independent mechanical discharge systems to achieve olfactory comfort. In addition, the WELL standard also proposes the use of gap rooms, vestibules, and corridors to isolate the smell to meet the standards.

3.7 Mind

The WELL standard has 17 mind items: 5 prerequisite items and 12 scoring items. This paper incorporates the humanity and service in the ASHB into this section as well. The humanity contains 14 items: 3 control items and 11 scoring items. The comparison of three control items in humanity reveals that the indoor and outdoor non-toxic and harmless green plant is a unique control item in the ASHB standard, and the other two items outstanding interior design and visibility as well as barrier-free design are basically corresponding with the two mandatory items in the WELL standard, namely 87 aesthetics and design and 72 barrier-free design standard. The service section has 20 items: 5 control items and 15 scoring items. The comparison of five control items in service reveals that formulating healthy building management system is the unique control item of the ASHB, and the other four are corresponding with the provisions of the WELL standard. For example, the requirement on appropriate separation or separation measures should be taken in the dining kitchen areas corresponds with 45 (food contamination), and the requirement for pest control and garbage collection corresponds with 22 (pest control). In this part, the WELL and ASHB standards have respective focuses and less overlapped content. The WELL standard places emphasis on the development of the enterprise's management strategies, while the ASHB standard pays more attention to the setting of an appropriate physical environment and conditions. In the health section, metrics are classified into four aspects (Table 7): physical environment design, mental treatment strategies, building operations quality assurance, and information disclosure and transparency.

The first part describes the design of the physical environment. According to the report of authoritative experts, excellent working and living environments can build a healthy mental state and reduce the possibility of mental illness to the greatest extent. The architectural and landscape design strategies and intentions for green, open space facilities targeting stress alleviation as well [7]. The WELL and ASHB standards have proposed similar provisions, including health and wellness awareness, adaptable spaces, and biophilia I—qualitative, and biophilia II—quantitative. In terms of health and wellness awareness, the WELL standard requires that design content with healthy building features should be communicated to users through a paper-based instruction. The aim is to enable users to maintain their health and wellness for a long time when

Table 7 Comparison of mind-related metrics in the WELL and ASHB standards

Mind item		WELL	ASHB	Similarity
Physical environment design				
84	Health and wellness awareness	√	√	Same
85	Integrative design	√		
87	Beauty and design I	√		
88	Biophilia I—qualitative	√	√	Same
89	Adaptable spaces	√	√	Similar
99	Beauty and design II	√		
100	Biophilia II—quantitative	√	√	Same
8.1.1	Non-toxic and harmless indoor and outdoor green plants		√	
8.2.1	Reasonable amount of outdoor communications spaces		√	
8.2.2	Reasonable provision of children's playgrounds		√	
8.2.3	Reasonable provision of an elderly activities venue		√	
8.2.4	Have public restaurants open to all building users		√	
8.2.5	Reasonably sized cultural activities venue		√	
8.2.9	Give full consideration to the safety and convenience of the elderly		√	
8.2.11	Provide convenient access to medical services and emergency services		√	
Mental therapy strategy				
90	Healthy sleep policy	√		
91	Business travel	√		
92	Building health policy	√		
93	Workplace family support	√		
94	Self-monitoring	√		
95	Stress and addiction treatment	√	9.2.10√	Same
96	Altruism	√	√	Same
9.2.13	Establishment of calligraphy and painting, photography, tea, dance and other interest groups		√	
Quality assurance of construction operations				
86	Post-occupancy surveys	√	√	Same
9.1.1	Development and implementation of the healthy building management system		√	
9.2.1	Property management agencies obtaining the relevant management system certification		√	
Information transparency				
97	Material transparency	√		
98	Organizational transparency	√		

occupying the building. ASHB standard only suggests the provision of additional health education materials (including books, magazines, and multimedia), instead of providing detail information for their own buildings. In addition, in terms of integrated design, the WELL standard emphasizes the need to continuously focus on the characteristics of healthy buildings throughout the design process to ensure that the expected health goals identified by the various stakeholders in the early stages of the project can be achieved. For aesthetic and natural design of healthy buildings, the WELL standard puts forward qualitative and quantitative requirements and regards them as control items and scoring items, respectively.

In terms of aesthetic design, the WELL standard hopes to produce a positive impact on users' mood and comfort through an intricate design of the room, including the appropriate room depth, height, and other scale relationships, the layout of artworks, lighting, furniture, unity of the visual elements of the floor, and adequate provision of an outdoor view.

The ASHB standard only proposes requirements on color coordination, partition of public and private spaces, and good outdoor view, which still remain at the level of control measures, and cannot be evaluated easily. In terms of natural design, the WELL standard requires creating an indoor environment that is associated with the natural environment as much as possible. This includes a certain area of outdoor landscape space, roof garden space, vertical green, and safe landscape water. This is basically in line with the ASHB standard. The WELL standard proposes the requirement on diversity spaces. Different work areas are divided to achieve different statuses such as independent work, coordinated work, and resting space, and meet requirements of floor area per capita, lighting, and sound insulation. The ASHB standard requires the provision of a room for psychological activities such meditation or psychological counseling, as described in Provision 8.2.8. The ASHB standard also puts forward requirements for children and old people, such as children's playground, elderly activities area, medical facilities, etc. The requirements of residential buildings have not been included in the current version of the WELL standard.

The second part describes the psychotherapy strategy. The WELL standard proposes seven requirements in this aspect, most of which are not mentioned in the ASHB standard. For example, the WELL standard pays more attention to sleep therapy and sleep time of employees in the healthy sleep policy and set a reasonable working time limit. The WELL standard also requires enterprises to reduce physical and mental stress caused by business trips through enterprise policies. In addition, the WELL standard also requires improving the satisfaction level of employees and their families for their health in terms of healthy building policies. In terms of workplace family support, the WELL standard requires enterprises to provide certain amounts of paid leave and maternity leave. In terms of self-monitoring, the WELL standard requires enterprises to provide employees with self-health monitoring equipment to accurately measure the health-related biological indicators. In terms of stress and addiction treatment, both the WELL and ASHB standards require adequate assistance and support in mental health. Altruistically, both standards also recommend building a greater social identity by participating in social welfare activities.

The third part describes the quality assurance of building operations. Both standards describe the quality assurance of building operations in detail. According to the requirements, in the later phase, a user satisfaction questionnaire (related to comfort and health feedback) can be distributed to further improve the building environment. The ASHB standard also requires that property management agencies need to obtain ISO14001 environmental management system certification and ISO9001 quality management system certification.

The fourth part describes information transparency. Material information transparency indicates that the information about building products and materials (including interior decoration materials, furniture, etc.) must be transparent. Organizational transparency refers to a series of methods to increase the employee's sense of belonging and satisfaction, and reduce work stress through open and transparent sharing of corporate policies and strategic decisions, the sharing of corporate values with employees, customers, sponsors, and organizations. This content is not mentioned in the ASHB standard.

4 Conclusion

Since its promulgation, the WELL standard has been closely linked with green building evaluation standards such as LEED, Living Building Challenge, and BREEAM [references].

(1) Compared with the ASHB standard, the WELL standard is developed on the basis of medical research and theoretical basis. Therefore, the provisions are more conclusive, and the content is reflected in performance metrics rather than a single measure. The ASHB standard is intended to provide more practical measures to guide the specific design, so it is relatively limited. For example, in terms of water, there are eight requirements in the WELL standard, and six of these are requirements on quantitative metrics that directly affect water quality and drinking water. In the ASHB standard, the water section is mainly concerned with requirements on the implementation of concrete measures, including materials of water supply pipes and hot water circulation system design.

(2) China's green building evaluation standards and healthy building standards should have higher requirements on-site inspection and testing, and strengthen the certification (after the initial certification) to ensure the achievements of performance requirements of healthy buildings. Similar to green building evaluation standards, the evaluation standard of healthy buildings is divided into design and operation certification. The design certification can be obtained by providing written documents, including drawings, design instructions, and calculation reports. If design changes or construction adjustments are made during the construction process, or equipment and facilities do not achieve the best operational state during the commissioning process, the overall performance of healthy buildings is likely to be affected. Therefore, the completion acceptance

process needs to be strengthened. Specific inspection and acceptance requirements should be proposed with respect to the healthy building design content and metrics, including expected performance upon building completion.

(3) More and more building standards are paying more attention to design process management, considering how to ensure people's health and comfort in the entire design process, how to integrate health elements into the building design, and how to use the design to guide healthy behavior. Generally speaking, the ASHB standard remains at the stage of proposing and implementing technical applications and design essentials. On the contrary, the WELL standard requires viewing unique conditions of a concrete project comprehensively, and continuously discussing the feasibility of each technical essential and how to gradually fulfill these technical essentials.

(4) Except for innovative items, the WELL standard contains a total of 100 provisions with specific content, among which 15 must pass the post-operation testing, and 45 must be inspected and sampled on site after the completion of the project. The WELL standard is only to objectively evaluate operations and uses of finished buildings. However, the ASHB standard proposes different requirements in the design and operation phases. After the construction drawings are reviewed in the design phase, a one-year certificate for the healthy building design phase can be obtained. This certificate can be used for marketing and promotion. If the evaluation of the operation phase is not carried out, it is difficult to ensure that the actual use of the building will reach the expected results. Therefore, it is not enough to only identify the significance of logo in the design phase.

In sum, obviously the two systems have agreements on what should be a healthy building. The healthy building should be human-oriented living and working environments where human's physiological and psychological needs are satisfied. However, they two systems show divergences on specific items and requirements, which are related to their own social and construction practice.

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Green Buildings in Makassar, Indonesia

Felix Kin Peng Hui, Putri Fatkhiyatul Ulya, Sally Wilson, Anna Meyliawati and Lu Aye

Abstract Indonesia has one of the world's largest populations, which creates a demand for buildings. Construction and operation of buildings have impacts on environment. To create sustainable cities, Indonesia applied the smart cities concept and selected Makassar as one of three role model cities. This chapter explores the current situation in Makassar with respect to green building adoption, the challenges faced and opportunities in market transformation. The Green Building Council of Indonesia (GBCI) in Makassar is heavily involved with market transformation for green building practices and has four main activities: market transformation, training and education, green building certification and stakeholder engagement. GBCI has developed the GREENSHIP rating tool, an assessment system covering categories associated with the green building concept as it applies to Indonesia. The embracing of the green building concept, however, is still low in Makassar. Market transformation is a challenging task, and there is still a lack of formal education programmes and courses available to architects, engineers and the construction industry to drive the transformation. The initial higher cost of green building presents as a major barrier to the uptake of green building even though these costs are mitigated after a period of 4–5 years through a reduction in operational costs. Government regulations that support green building practices and education of the community about the benefits of green building may support/improve uptake of green building.

Keywords Green building · Indonesia · Policy · Green certification

1 Introduction

Indonesia has one of the world's largest populations, and this is continuing to increase. It increased by 53% in the last 5 years alone [2]. This has an impact on Indonesia's

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need for housing, office space, commercial space and infrastructure required to support the growing population. Construction and operation of buildings and infrastructure need to have minimum environmental impacts as well as be cost-effective and efficient and allow people to work sustainably and effectively.

In response, the Indonesian government initiated the 100 Smart City Movement [34] to be spearheaded by BAPPENAS, the country's Ministry of National Development and Planning and Ministry of Communications and Information. "Smart cities" is a concept where cities or regional territories adopt the Internet of things (IoT) and other information and communications technologies (ICTs) to assist in the management of infrastructure and buildings.

In addition, three cities in Indonesia—Jakarta, Makassar in South Sulawesi and Banyuwangi in East Java—are proposed to be included in the ASEAN Smart Cities Network (ASCN) as role models for other Indonesian cities [23]. The concept of the ASCN was designed to achieve a shared goal of smart city development in the ASEAN network cooperation programme.

Green buildings are one of the key components of smart and resilient cities in the future urban concept of Indonesia. The hot and humid climate in Indonesia creates a demand for efficient cooling systems, which are the main contributors of chlorofluorocarbon (CFC) emissions and electricity consumption (leading to greenhouse gas (GHG) emissions). Buildings and infrastructure of the future urban economy need to be aligned with green initiatives, to deliver services at the lowest costs and minimum environmental burdens. Led by the Green Building Council of Indonesia (GBCI), plans to put in place components for innovative building solutions such as intelligence, automation, smart lighting and proactive maintenance will lead to reduced wastes and costs in building design, construction and operation. This calls for a balanced approach to productivity and sustainability. This chapter discusses opportunities and challenges for developing green buildings in Indonesia with a focus on Makassar. Current policies and regulations, certifications (currently voluntary), market transformation and barriers, incentives, and green building education in Makassar are reviewed. Future education needs and research opportunities are discussed.

1.1 Green Buildings in Indonesia

Buildings are responsible for a large part of GHG emissions, which may contribute directly to global warming. They generate 19% of GHG emissions and consume 40% of electricity globally [20]. In Indonesia, buildings account for 30% of the country's total energy consumption, and this is projected to grow up to 40% by 2035. By applying the green building concept, this will potentially reduce up to one-third of energy and water consumption [36].

Up until the end of 2018, The GBCI has issued/published certificates for green buildings with achievements as shown in Table 1 [16].

Table 1 Numbers of buildings certified

Status	Type	Number
Certified GREENSHIP	New building	22
Certified GREENSHIP	Existing building	11
Certified GREENSHIP	Interior space	2
Design Recognition	New building	31
Prospect in registration	–	39
Registration project	–	70

GREENSHIP = Indonesian green building rating tool

1.2 Green Building Implementation in Makassar

In Makassar, Indonesia, as of 2018, no buildings have yet been certified as green buildings by the GBCI. Currently, Nipah Mall, a shopping mall in Makassar, is the first development to undertake the process to complete the green certification scheme. Another proposed new building, an eye hospital, has recently finished the design and will release the tender for construction shortly, before registering with the GBCI to undergo the certification assessment. To support the implementation of green building (GB) certification, Makassar's city government is currently drafting the policy on green building for commercial and large-scale buildings [37], following the example of Jakarta and Bandung who have established public policy for green building at the regional level. Jakarta has, for instance, set the target that 100% of new buildings and 60% of existing buildings meet green building requirements by 2030 ([5, 22]). For the upcoming policy for Makassar, the type of certification that is being prioritised is that required for new buildings. Once the city mayor signs the law, it will become mandatory for new buildings to incorporate the green building concept in their design.

Green buildings have not been popular in residential buildings but are considered more acceptable for public spaces such as shopping malls, government offices, rental offices, hospitals and schools. Research conducted in Bone, a region in South Sulawesi, indicated that the implementation of green building in the design of school environments would raise the productivity of students, teachers and other stakeholders as users of the building, which would then have the potential to increase education quality [1].

1.3 Certifications

1.3.1 Green Building Council Indonesia (GBCI) and GREENSHIP

The GBCI is an established member of the World Green Building Council (WGBC). It was founded in 2009 by professionals in the design and construction industry who are concerned about green building practices. The focus of the GBCI is to pursue the social acceptance and market transformation of sustainable green principles, particularly in the building construction industry in Indonesia [11]. They believe that green building can contribute to the achievement of the Sustainable Development Goal (SDG) programme of the United Nations (UN). They aim to encourage industries and building owners to convert their buildings to become green and healthy buildings [15].

There are four main activities conducted by the GBCI: market transformation; training and education; green building certification; and stakeholder engagement. In terms of training and education, they conduct professional training (GREENSHIP Associate and GREENSHIP Professional) as well as socialisation in the form of network sharing, competitions, webinars, on-site visits, in-house training, seminars and workshops for the community. Up until December 2018, 2420 participants have graduated as GREENSHIP Associates and 994 participants graduated as GREENSHIP Professionals. As of November 2018, the GBCI in Makassar city has conducted two training programmes for GREENSHIP Associates: 27 participants have graduated as GREENSHIP Associates in Makassar to date.

The four main programmes of the GBCI are also undertaken by the representative office of the GBCI in Makassar city. They are actively promoting the implementation of the green building concept to the community, such as by giving public presentations. To raise awareness about the concept in the younger generation, the GBCI is currently preparing to organise targeted talk shows.

GREENSHIP is the rating tool initiated by the GBCI. It is an assessment system covering categories associated with the green building concept as it applies to Indonesia, which is valid for three years. Compared to LEED which is the most widely used green building rating system in the world (US Green Building Council, n.d.), the energy standard used in the LEED rating tool is more stringent than the one used in GREENSHIP. The energy calculation method used in LEED is more accurate than the one used in GREENSHIP [4]. GREENSHIP utilises the overall thermal transfer value (OTTV) to measure the efficiency of energy use of the building design, while LEED utilises the ASHRAE standard for baseline building. The OTTV only considers the building envelope, which leads to a less comprehensive assessment. The ASHRAE standard considers not only the building envelope, but also heating, ventilating and air-conditioning, water heating, lighting, power and other equipment. However, generally GREENSHIP and LEED have a similar structure and cover almost all energy conservation characteristics within the calculation.

There are five GREENSHIP assessment types that have been developed and published by GBCI, which have distinctive requirements and criteria.

New Building: The assessment of new buildings encompasses the design process up to the completion of the building construction. The construction projects that are included in new buildings are as follows [10]:

- New building in a vacant land;
- Renovation activity which accounts for 90% of the total load for mechanical, electrical or structural work, in a land with building;

- New building in a land within an integrated area.

Existing Building: This assessment type is intended for buildings that have been operating for at least one year after the completion of the construction process [14]. The implementation of the green building concept is related to operational management and building maintenance. Furthermore, it includes the implementation of retrofitting, which is the efforts to adjust a current utilised building to fulfil the requirements of green building [24].

Interior Space: GREENSHIP Interior Space is targeted to users who are generally a business entity as tenant management companies, which utilise part, or all the area within a building. The assessment scope covers the fit-out activity that serves to accommodate the company's activities, and management policy in selecting site-building and operational activities [9].

Homes: The unique thing about this GREENSHIP type is that people can conduct self-assessment through "www.greenshiphomes.org" to check whether the design of their homes/houses is categorised as green building or not.

The residential homes that have the potential to be assessed are as follows:

- Single land residential home;
- Design of new home, existing home and home that undertakes a redevelopment.

The advantage of this assessment type is the simplicity of conducting the assessment online, and the result can be downloaded free of charge. The assessment does not necessarily need to be answered by the building owner, but can be submitted by the architect or other submitters related to the building construction [12].

Neighbourhood: This assessment type is intended for embodying the sustainable neighbourhood that needs to be friendly for the tenants. It is not only scoping to the building, but also the interaction between buildings, its nature and the occupiers. GREENSHIP Neighbourhood is a tool for assessing: a housing, city business district (CBD), and industrial area, both on the small or large scale [13].

GREENSHIP has been developed by considering the conditions, natural character and regulations as well as standards that apply in Indonesia. Each category has criteria that hold certain value (credit points) and will be processed to determine the assessment outcome. GBCI has five types of GREENSHIP: new building; existing building; interior space; homes and neighbourhood. The categories (except for neighbourhood) are shown in Table 2, while the minimum credit points achieved to be certified as a green building in each level are shown in Fig. 1.

The indoor air health and comfort (IHC) category included in the GREENSHIP assessment relates to the quality of the indoor air and that the materials used are non-toxic, for instance, carpets, wallpaper and paint based on authors' observations. This category does not specifically mention the mental health and well-being of people who work within the building or the amount of natural light provided by the build which potentially impacts on psychological well-being of users of the building.

Table 2 GREENSHIP credit points for rating categories [9, 10, 12, 14]

Category	New building		Existing building		
	Design	As built	As built	Interior	Homes
Appropriate site development	17	17	16	5	13
Energy efficiency and conservation	26	26	36	5	15
Water conservation	21	21	20	3	13
Material resources and cycle	2	14	12	6	11
Indoor air health and comfort	5	10	20	12	13
Building and environment Management	6	13	13	3	12
Total	77	101	117	34	77

Fig. 1 GREENSHIP certification levels for new building design [15]

Unlike the four types of GREENSHIP assessment shown in Table 2, GREENSHIP Neighbourhood has different categories and associated credit points as shown in Table 3.

Table 3 GREENSHIP Neighbourhood rating categories [13]

Category	Credit points
Land ecological enhancement	19
Movement and connectivity	26
Water management and conservation	18
Solid waste and material	16
Community well-being strategy	16
Building and energy	18
Innovation and future development	11
Total	124

1.3.2 Green Product Council Indonesia (GPCI)

The GPCI is a non-governmental and non-profit institution that is concerned with environmental issues in terms of products used, particularly construction materials. GPCI is a part of the GBCI, initiated by professionals and corporate circle founders who were eager to raise the awareness of industrial actors to produce greener and healthier construction materials [17]. According to the Director of GBCI, who is one of the initiators, the establishment of GPCI is important, as Indonesia has not previously had any official certification institution focused on the use of environmentally friendly products. Meanwhile, government programmes still need to be developed [25]. GPCI aims to measure the industry capability to produce environmentally friendly products. In addition, it is also vital to protect domestic industries from exposure to imported products entering Indonesia.

They launched Green Label Indonesia, which is a certification for environmentally friendly products such as adhesive, cement, ceramics, tile and stone. For interior spaces, it is required to assess products such as carpet, insulator, board, textile, light bulbs, furniture and cleaning solvents.

2 Policy

2.1 Regulations

The regulation applied as a baseline for green building implementation is *Permen PUPR* Number 02/PRT/M/2015 issued by Indonesian Ministry of Public Works and People's Housing. It is aimed to achieve the efficiency of the natural resources and reduce GHG emissions by fulfilling green building requirements. The building performance should be able to be measured significantly in terms of efficiency in energy and water usage, healthiness, convenience and conformity to the environmental carrying capacity. There are requirements that should be fulfilled in each step, to be granted a green building certification, covering all stages of initial planning, technical planning, construction process, utilisation and demolition. Each stage has its own specified requirements that should be achieved.

Within the applied law, there is no detailed monitoring programme intended for controlling the implementation of the green building concept. According to the GBCI representative for Makassar, at this time, the monitoring programme has not been well executed and still needs to be developed to optimise the three-year period of certification.

The regulation covers the principles of green building, types of building, the requirements, implementation process, certification, incentives for those achieving green building and society's role. In terms of the effectiveness of policy implementation so far, there are some issues that need to be incorporated to better guide the implementation. A more detailed monitoring programme is necessary for better guidance of the building maintenance. In addition, the disincentives for not applying the green building concept also need to be considered.

The buildings that are subject to the requirements of green building are classified into categories as shown in Table 4. Meanwhile, the building codes applied in Indonesia, based on the regulation number 26/PRT/M/2008 by the Ministry of Public Works and People's Housing, categorises buildings into several classes (Table 5).

Table 4 Building classification [27]

<table>
<tr><th>Category</th><th>Building class</th><th>Further requirement</th></tr>
<tr><td rowspan="4">Mandatory</td><td>4, 5, 6, 7, 8 and 9</td><td>High complexity and moderate to high height</td></tr>
<tr><td>6, 7, 8, 9 a and 9 b</td><td>Two levels and floor area that are more than 5000 m^2</td></tr>
<tr><td colspan="2">High consumption of energy, water and other resources</td></tr>
<tr><td colspan="2">Considered urgent to apply the green building concept according to the regional government</td></tr>
<tr><td rowspan="4">Recommended</td><td>1, 2 and 3</td><td>Moderate complexity and moderate to high height</td></tr>
<tr><td>8, 9 a and 9 b</td><td>Low complexity, two levels and floor area between 500 and 5000 m^2</td></tr>
<tr><td colspan="2">Moderate consumption of energy, water and other resources</td></tr>
<tr><td colspan="2">Considered important to apply the green building concept according to the regional government</td></tr>
<tr><td rowspan="2">Voluntary</td><td>1, 2, 3, 4, 5, 6, 7, 8 and 9</td><td>Low-complexity building</td></tr>
<tr><td colspan="2">Considered important to apply the green building concept according to the regional government</td></tr>
</table>

Table 5 Building classification in Indonesia [26]

Class	Description
1	Common residential building
2	Residential building consists of two or more separated residential units
3	Residential building (excluding Classes 1 and 2) that is usually utilised temporarily or permanently by a group of people
4	Mixed residential building, which incorporates buildings in Classes 5, 6, 7, 8, and 9
5	Office building that is utilised for professional work, administration and commercial activities (exclude those that are in Classes 6, 7, 8 and 9)
6	Trade building, which is a shop or other buildings utilised for selling retail items or providing direct service to the community
7	Storage building that is utilised for storing goods, including parking area and warehouse
8	Building for laboratory/industry/factory, which is utilised for goods processing, manufacturing, modifying, packaging, finishing
9	Public building, for providing service to community
10	Non-residential building

2.2 Incentives

The green building scheme is voluntary, and there are incentives provided by regional (city/provincial level) government to encourage the implementation of green building. Incentives are in the following forms [27].

a. Reduction of building permits retribution and service fees;
b. Compensation: ease of obtaining building permits and additional of floor average ratio;
c. Technical support or experts supply in terms of pilot project;
d. Award (certificate, placard or other reward sign);
e. Other incentives such as publications or promotion channels.

2.3 Driving Investments for Sustainable Goals and Outcomes

Indonesia is set to become one of the world's top 10 economies by 2025 and within the top 6 by 2050. BAPPENAS, the Ministry of National Development and Planning, was tasked to coordinate the growth at a national level with instruments such as the RPMN (the medium-term development plan), PRNPN (long-term development plan) and the MP3EI, the economic masterplan [7].

In line with this, there are national plans to ensure these are in line with the UN's SDGs to which the Indonesian government has committed. At a tactical level, the National Action Plan for Reducing GHG Emissions, the Spatial Plans and the Environmental Law 32/2009 are important planning instruments [7].

This is also driven through the BAPPENAS Green Growth programme, which is the framework for sustainable development for both private and public investments. The goals are much aligned with the UN's SDGs (i.e. investments must curb GHG emissions), build resilience to climate extremes and long-term change, efficient use of resources and provide sustainable and equitable distribution of resources. The framework differentiates between works done at national, provincial and district as well as project levels. A set of indicators are used to measure green growth at each of these levels. Engaging with the private sector in this manner will ensure that key investments contribute to the green outcomes. The long-term strategic outcomes are that investments must include GHG emissions reductions, sustainable services, 600Mt of CO_2-e GHG emissions by 2020 and 9.86 million people gaining access to green energy by 2020 [8].

3 Discussion

Due to a combination of policy support, tax benefits, educational and awareness programmes, smart and green buildings in Indonesia are forecast to reach as high as

20–25% of the market by 2025. Most market players, even those from outside the traditional building automation market, have therefore already begun to introduce the cloud-based The Building Energy Management System (BEMS) platforms and services [32].

3.1 Challenges to Green Building Implementation

The main difficulty experienced in Makassar related to the implementation of the green building concept is market transformation. It is difficult to implement market transformation because of resistance by people due to the higher initial cost of implementing green building, which is 20% more expensive compared to traditional building. Even if the GBCI explains that a reduction in operational cost which is equivalent to the increased in initial cost can be recouped after 4–5 years with a green build, it is still hard to convince people that the initial investment will be worthwhile. The GBCI also needs to convince people that green buildings offer healthier working and living environments.

A separate issue is the skill of architects and engineers to implement green building. At this moment, green building is only offered as an elective at some universities in Indonesia, therefore not many architects major in this field. Discussion with the representative of the GBCI in Makassar indicated that there are no compulsory green building subjects as such in universities. There is clearly the need to provide further training related to green building within universities and in the construction industry.

In Australia, Holz and Sigler [19] surveyed green building stakeholders and found the challenges experienced in implementing green buildings as follows:

(a) Green building rating schemes do not consider the priorities of all stakeholders such as the embodied energy.
(b) The residential sector is not being catered for adequately by the available rating schemes which could impact green urbanism outcomes.
(c) The issue of unplanned expanded urban sprawl.

Climate: Makassar has a tropical monsoon climate (Köppen classification: Am) according to the Köppen–Geiger climate classification system [6, 30] with slight variations in climatic conditions over the year. Monthly average sunshine hours and monthly average solar radiations in Makassar are shown in Figs. 2 and 3, respectively. Hourly outdoor air conditions in Makassar generated by Meteonorm 7.3 [28] and plotted using Climate Consultant 6.0 software tool [29] are shown in Fig. 4. As can be seen, the outdoor conditions are outside the human thermal comfort zone. Year-round cooling is required for buildings in Makassar to make them thermally comfortable. It is also predicted that by 2050, the ambient air temperatures would be higher than current values (see Table 6). The IPCC emission scenario [21] selected for the prediction is B1 (a world more integrated and more ecologically friendly). The requirement of year-round cooling in Makassar necessitates more energy efficient and greener buildings.

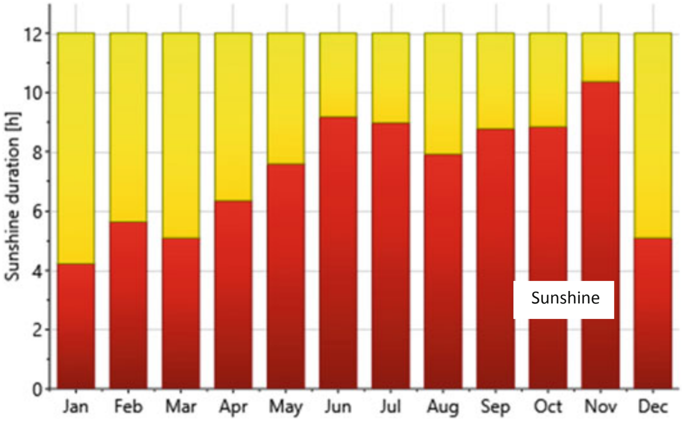

Fig. 2 Monthly average sunshine durations in Makassar

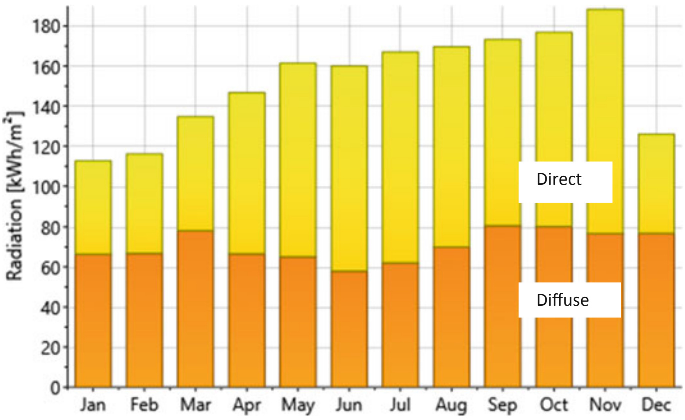

Fig. 3 Monthly average solar radiation in Makassar

3.2 Potential Benefits of Green Building Implementation

According to the representative from the office of the GBCI in Makassar, the implementation of the green building concept has the potential to lead to a healthier society because of better indoor air quality, better design of interior space and the use of non-toxic materials. This can result in an increase in the productivity of occupants. In the past few years, Makassar has often been subjected to flooding. By applying “Appropriate Site Development” requirements, this will assist to increase penetration of rainwater into the ground and decrease water run-off.

Broader considerations regarding health benefits arising from green building can be the consideration of the impact of green building on mental and physical health and

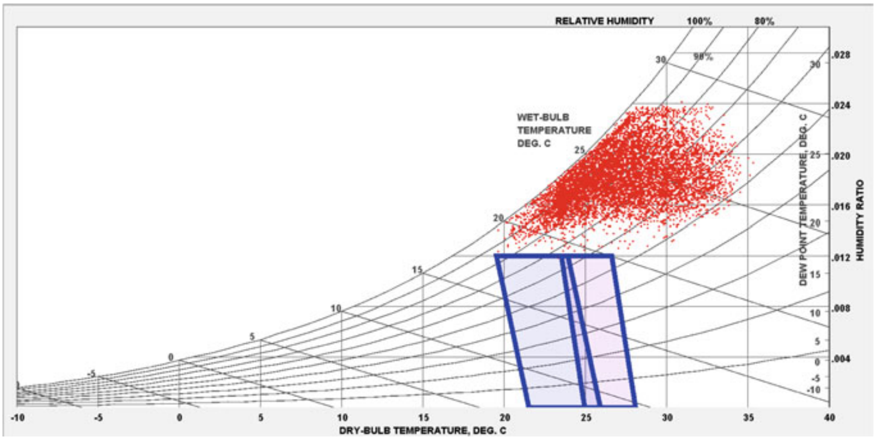

Fig. 4 Outdoor air conditions in Makassar

well-being of users of these buildings. In addition to the air quality and materials used for the build, the availability of natural light and access to the natural surroundings of the build and nature (biophilia) can support well-being and can, for instance, have a positive effect on recovery and healing of patients in hospitals. This principle has been incorporated in the build of some hospitals such as the Royal Children's Hospital (RCH) and Victorian Comprehensive Cancer Centre in Melbourne, Australia. In the case of the RCH, the design was planned to consider/incorporate the importance of nature and the environment to healing–linking the hospital to the nature and vegetation around the facility and bringing this into the facility [33].

Incorporating opportunity for physical activity, active transport and ease of access to buildings are additional features that can support well-being and health of users of the buildings: employees and visitors to the building. For the elderly and disabled people, ease of access to buildings and transport plays an important role in facilitating movement and limiting social isolation.

Green building therefore needs to consider the broader urban design considerations, such as transport, availability of "green spaces", seating, walkways and design that considers environmental factors which may impact both positively and negatively on the build. In tropical environments, creating open spaces which incorporate vegetation needs to balance this with ensuring that disease-carrying mosquitos or insects are not able to enter the buildings. Individual countries and regions therefore need to consider climate and regional differences when considering what is needed to develop their approach towards green building [38].

The green building concept can also be incorporated into the design of major infrastructure projects, for instance, in ports. The physical structures within ports can adopt green building principles, but ships that use these ports can also embrace these principles. For instance, the use of solar panels on ships to provide energy while berthed at the port can reduce the dependency on diesel which emits air pollutants.

Table 6 Monthly average ambient air temperatures (Ta °C), typical meteorological year (TMY) in Makassar

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Ta	27.4	27.4	27.5	27.6	27.6	27.1	26.8	26.9	27.7	28.1	27.6	27.1
Ta 2050	28.3	28.3	28.9	29.4	29.4	28.9	28.2	28.8	28.8	29.4	28.9	28.3
Ta rise	0.9	0.9	1.4	1.8	1.8	1.8	1.4	1.9	1.1	1.3	1.3	1.2

Ta 2050 = Predicted for 2050

3.3 Popular Certification Types

In Makassar, the implementation of green building is more popular for office and public spaces such as rental offices and shopping malls, while it is not popular for residential-type buildings. Of the five types of assessments for GREENSHIP, GREENSHIP homes (the self-assessment of green building for residential buildings) is considered harder to implement because of its higher requirements. To encourage people to apply green building principles, GBCI provides a simpler requirement called Excellent in Design for Greater Efficiencies (EDGE) certification, which is supported by the International Finance Corporation (IFC).

3.4 Skill Level of Engineers and Architects

There is currently no specialised course available in a university in Indonesia that offers a major in green buildings/sustainable buildings. However, in some universities, there is an elective subject related to green building, but not all universities provide this elective subject. Some of the universities that offer the elective are mentioned in Table 7.

Nonetheless, graduate architects are not sufficiently skilled to implement green building straight after finishing their study at university, even if they enrolled for a green building elective subject. To be adequately skilled, they need further training

Table 7 List of universities in Indonesia offering an elective subject related to green building

University	Location	Elective subject	Web site
Universitas Diponegoro	Semarang, Central Java	Green building	https://arsitektur.undip.ac.id/en/undergraduate-program/
ITB (Institut Teknologi Bandung)	Bandung, West Java	Green building	https://ar.itb.ac.id/program-sarjana/
UGM (Universitas Gadjah Mada)	Yogyakarta, DIY	Green architecture	http://archiplan.ugm.ac.id/en/programmes1/architecture/
ITS (Institut Teknologi Sepuluh November)	Surabaya, East Java	Green architecture	http://arch.its.ac.id/index.php?option=com_content&view=article&id=403&Itemid=95&lang=in
UNS (Universitas Negeri Surakarta)	Surakarta, Central Java	Green architecture	http://arsitektur.ft.uns.ac.id/

that is provided by the GBCI (train as GREENSHIP Associate and GREENSHIP Professional). The main goal of the training is to educate professionals in this field.

Currently, there is no research partnership between the GBCI's representative in Makassar with local universities related to green building issues. However, several academics at Hasanuddin University are considered experts in this field.

3.5 Capacity Building Aided by World Bank

The IFC, a member of the World Bank Group, has established a partnership with Green Business Certification Inc. to launch the EDGE certification programme to encourage green building implementation [36]. According to the Chairperson of the incorporation, EDGE is a quick, simple, and affordable way to convince developers to design better buildings. The EDGE certification system seeks to make building more resource efficient and helps builders and developers to identify "the most cost-effective ways to reduce energy use, water use and embodied energy in materials" [36]. Green Business Certification Inc. is the certification and credentialing organisation that administers project certifications and professional credentials within the green business and sustainability industry for WELL and LEED amongst others [18]. The press release mentioned that IFC and GBC Indonesia aim to turn 20% of new constructions projects (~80,000 housing units) into green initiatives in select cities by 2021. This level of penetration will help cut GHG emissions of 1.2 Mt CO_2-e per year, avoid 500 MWh of electricity use and save almost US $200 million per year by 2021 [31].

Mandatory green building codes have been adopted by pioneering city and national governments, with the support of the IFC. Furthermore, the IFC green buildings team in Jakarta has helped lay over 18×10^6 m^2 of new floor area, and it has reduced over 0.7 Mt CO_2-e in terms of GHG emissions [31]. Besides providing an advisory service and implementation support for the green building concept, IFC also facilitates access to finance for green building owners and developers.

3.6 Future Research

To fully leverage the green building opportunities to meet Indonesia's sustainability goals, market transformation must take place. This can only be done with a well-informed and well-planned implementation programme. It is recommended that research be undertaken to uncover the change readiness of the general population. Research should also be done to uncover the skill gaps in the education system covering the entire spectrum from primary schools to technical colleges to universities. Putting in place awareness programmes within the education system would be a long-term solution to addressing critical skill shortage in this area.

Secondly, it is recommended that researchers collaborate with international institutions to carry out case studies in green building implementation. This will help document problems, disseminate lessons learnt as well as showcase actual examples where green buildings have been successfully implemented in Indonesia and abroad.

Thirdly, given Makassar's hot and humid climate, universities can carry out cutting-edge research on how to best incorporate smart devices and sensors, automation and advanced materials in green buildings to better manage thermal comfort and energy usage with minimal costs. Possible outcomes can include simulation tools for building design and use of natural ventilation in green buildings in Makassar.

Fourthly, universities can also work with government planning agencies to study how to best integrate green buildings into the bigger picture of smart cities. This may include studies into integration of green buildings with road infrastructure, train and public transport networks, transit-oriented developments, ports and airports.

4 Conclusions

The GBCI office in Makassar and the City of Makassar have the vision to promote and educate the public about the green building concept in their region to help Makassar become a role model for smart cities in Eastern Indonesia [35]. The embracing of the green building concept, however, is still low in Makassar [3].

Market transformation is challenging, and there is a lack of formal education programmes and courses available to architects, engineers and the construction industry which incorporate green building principles. The initial higher cost of green building presents as a barrier to uptake of green building; however, these costs are mitigated after a period of 4–5 years through a reduction in operational costs.

Government regulations are a way to support green building practices and need to be considered where there is resistance to uptake of green building. Educating the community about the benefits of green building such as reducing GHG emissions, water savings, more efficient use of energy, improved work and living environments needs to be undertaken to improve buy-in. It is also important to make green buildings structurally robust and resilient to be able to cope with natural phenomena and take into consideration the variations in regional climates and needs.

Apart from reviewing the current situation regarding green buildings in Makassar and barriers for its implementation, the chapter also looked at potential opportunities for research that will lead to greater awareness and capabilities in this area. Some of the important areas include: developing the foundation of green building education in schools and universities; collaborative research on overcoming barriers to green building implementation; incorporation of smart devices and IoT to make green buildings function better; and finally research on how to widely integrate green buildings into Makassar.

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The Current State of Green Building Development in Nigerian Construction Industry: Policy and Implications

Abiodun Olatunji Abisuga and Tope Femi Okuntade

Abstract The negative impact of the construction activities on the economy and the environment has necessitated the need for a green policy formulation and framework in developing country like Nigeria. To ensure the development of green policy, it is necessary to evaluate the existing green building policy, barriers, and benefits of green practice, and the drivers of green building policy implementation. The chapter identifies Green Building Council of Nigeria (GBCN), National Building Efficiency Code, Nigeria Building Code (NBC), and National Adaptation and Plan (NASPA) as the existing green building policy in Nigeria. The findings of the chapter indicated that the existing green policy is not fully implemented due to the lack of government and leadership political will, policy compliance and enforcement, and lack of public awareness of green practice benefits among others. A green policy formation framework that can be adapted in Nigeria was also developed. It was concluded that for the policy framework to be effective, government, politician, and construction stakeholders should be involved in the formation of the green building public policy. Particularly, the government should champion the campaign for its enforcement within the Nigerian construction industry and the citizenry. If an enforceable green building standard is in place, the country-built environment will be set up for sustainable building.

Keywords Construction stakeholders · Green building · Green building standard · Green policy formulation · Nigeria

1 Introduction

The friendliest way to protect the environment is not to build. However, without any building activities, life can be hopeless and undermining. What is required is an energy balance without risks particularly to the environment. It is broadly acknowl-

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edged that the construction industry has destructive impacts on the environment and society [4, 37]. According to the reports [9, 24, 28], the construction industry consumes up to 40% of energy and 19% yearly greenhouse gas emissions. Additionally, the construction industry uses approximately 70% of cement and 25% of steel in numerous nations [24]. These have raised a series of concerns about the impact of these materials on the environment. The combination of these challenges gave birth to an unused concept in the design, construction, and operation of buildings incongruity with "sustainable buildings" known as green buildings (GBs). Bell and Cheung (2018) explained that green building is now seen as a sustainable development because it takes the obligation for balancing long-term financial and social health. It also offers an opportunity to form ecologically efficient buildings by utilizing a coordinated approach to reduce the negative effect of building on the environment and its inhabitants [5].

The adoption of green buildings concept recently is gaining tripartite academic, professional, and government concerns. The drive for green buildings concept has diverse perspectives due to its understanding, complexity, and usage. There is no single definition of what constitutes a green building. Green building can be freely characterized as one in which all the materials and frameworks are outlined with an accentuation on their integration, for the reason of minimizing their impacts on the inhabitants and their environment [16]. This incorporates such issues as building, materials choice, energy productivity, water preservation, indoor quality, and others. The word "green" alludes to a strategic plan and development that minimizes the burden on our infrastructure and the environment. Green building design does make a positive impact on public health and the environment; it decreases working costs, enhances the building and organizational attractiveness, and increases occupant efficiency [21]. Green buildings are energy proficient, water conserving, tough, and non-toxic, with high-quality spaces and high-recycled substance materials, which presents an arrangement for a large part of assets issues [6]. In addition, the green building combines energy and water productivity frameworks, daylighting techniques, indoor natural quality frameworks, and productive building envelope system to supply consolation and positive effect on the inhabitants and the environment [23]. It also developed a framework that can be utilized as a means of setting up feasible design priorities and objectives, creating fitting sustainable design strategies, and deciding environmental performance measures to direct the sustainable plan and decision-making forms [1, 40]. Furthermore, green building is now becoming a methodology that is moving forward the maintainability of the construction industry [36]. These paramount characteristics drive the popularity of green building concept in becoming recognized by researchers, policymakers, industry practitioners, governments, and other stakeholders around the world.

Despite all these benefits accrued to green building, there is a big question mark about whether developing countries are tapping into these new areas of sustainable building termed "green building"? In developing nations such as Nigeria, the concept of green has been slowly embraced and in its infant stage, even though some developing countries in Africa, like South Africa, Kenya, and Ghana, are prioritizing green building. Several studies have focused on the barriers [12], technology [13], and the promotion [12], of green building practice, but there is a lack of literature from the policy perspective [19]. Hence, it is an essence to explore the state of green building practice in Nigeria in relation to the barriers and policy that can encourage its adoption by construction stakeholders.

2 Developing a Green Agenda for Nigerian Construction Industry

Nigeria has an aggregate land territory of 923,773 comprising of abundant and differing renewable and non-renewable natural resources. These comprise energy, mineral, and organic natural resources. Tellingly, this natural endowment should transform into an industrialized developed country, with viable socio-economic development. Unfortunately, the reverse is the case: The nation is experiencing slow growth in technological advancement and increased in environmental degradation. The primary reason for this is lack of planning, execution, coordination, and monitoring in order to achieve the expected development drives. Recently, this challenge is being tackled by the government with the formation of different initiatives and environmental protection programs. But the attainment of the desired progress is far from success. Most of these initiatives to protect the environment in Nigeria are more focused on sanitation, oil pollution, and waste management. The initiative to go green also is attached to environmental protection with the view to manage waste production, disposal, and recycling. Green construction is not part of the large picture of the green initiative in Nigeria.

Green practice ideology is a strange phenomenon to a national system that even lacks maintenance culture. The challenges of the Nigerian construction industry go beyond the internal influencing factors to external factors. Suggestively, we listed some of the factors that inhibit green practices in the Nigerian construction industry as

i. Lack of government and leadership political will
ii. Lack of demand for green production
iii. Lack of sustainable practices and norms
iv. Lack of organization leadership commitment
v. Poor information sharing among stakeholders
vi. Lack of knowledge about environmental impact
vii. Lack of public awareness of green practice benefits
viii. Lack of green awareness
ix. Low green building policy and standard regulation
x. Inadequate green knowledge among professionals
xi. Poverty level in the country
xii. Lack of green building product production know-how
xiii. Cost implication of green product
xiv. Low development in design and innovation

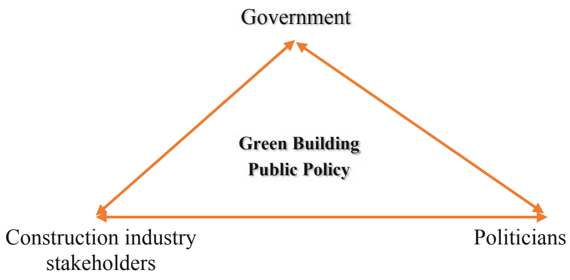

Fig. 1 Green building public policy formation circle

xv. Lack of interest of client and users
xvi. Lack of policy compliance and enforcement
xvii. Lack of green technologies.

Several researchers have investigated factors that affect the practices of green innovations in developing nations (see [12, 30]) and factors that can promote its implementation [12, 13]. Government regulation and policy has been indicated as the major driver of green building implementation. "Policy is a deliberate system of principles to guide decisions and achieve rational outcomes" [7, p. 120]. Government policy is an intended plan or course of action to influence and determine decisions relating to a purpose. Furthermore, policies are not legally binding but just plans and cause of direction. Hence, policies can only be enforceable legally when transformed into a law. Formation of green building policy is essential to be incorporated in the social, economic, and technological context of construction processes in Nigeria. This could only be done by the policymakers, after been influenced by the interested stakeholders. Passing policy to law involves lobbying of the politician by various interest groups. Therefore, construction practitioners need political influence to push some of their common goals, to get government public policy achieved. Green building public policy could be in fruition only if the construction stakeholders, politicians, and government share the same common interest to harness the benefits of greening. Green building public policy formation and implementation are within the circle of the government, politician and construction professionals and other stakeholders (see Fig. 1).

2.1 Green Building Policy Framework in Nigeria

One of few developing nations that have started the development and implementation of green building is Malaysia. Malaysia's green development started as early as 1976–1980 ([38]; Jomo and Syn, n.d; [25]). However, in 2009, Malaysia commenced the full development of green building policy by the introduction of the National Green Innovation Program (NGTP) and the Green Building Index (GBI) [35]. Nigeria, on the other hand, is still at an early stage of embracing and formulating a framework for green buildings [33]. Nigeria is slowly embracing the concept due to a few reasons such as design, innovation, and public awareness. Despite the progressively extraordinary climatic conditions, decreasing environmental resources, and all manners of contamination, African nations must go past the thought (or plausible excuse) that financial improvement and poverty annihilation is more of a need than sustainable advancement. Although during the last few years, the Nigerian government and experts within the built environment have started the development of policies for green buildings [33, p. 49]. As a matter of fact, in 2014, Nigeria was enlisted in the World Green Building Board (WGBC) on a probationary enrollment level after establishing the Green Building Council of Nigeria (GBCN) [41]. Studies have uncovered that nations and states that embrace green building have more prominent prospects of delivering a high-performance green building that reduces poor environmental condition, energy use, operational cost, and advance collaboration and innovation in the workplace [14, 33]. Such nations encounter circumstances where contractors and clients now pursue certification for their project development [14]. The weight behind the consistent call for green building policy in Nigeria is anchored on the rising proof that the building sector is a major customer of natural resources and energy use around the globe. For example, the building industry accounts for around 44% of total material usage with an expansive proportion of more than 50% of natural resources [29]. In Canada, UK and USA, for examples, energy consumption by buildings alone is about 30–50% of the country's total energy demand [29]. In Nigeria, about 50% of energy is utilized in buildings for occupant's comfort [15, 20]. A satisfactory and effective policy is required to control and cut energy utilization by buildings in Nigeria. Although in time past, Nigeria has created policies and programs that particularly target green building, these policies have not yielded a critical result. For example, based on LEED achievement of nations in a green economy, some developing nations have a total number of 5,785, 244 net square meters of certified and registered green building projects, whereas Nigeria has 317, 039 net square meters. The green building policy framework or organizations adopted or formed by the Nigerian government are discussed below:

2.1.1 Green Building Council of Nigeria (GBCN)

GBCN was enlisted in 2014 with the World Green Building Board (WGBC) on a prospective enrollment level [41]. GBCN has the duty of creating a rating framework for the economic evaluation of buildings in Nigeria. GBCN is directly in the process of creating a development framework for green buildings. However, the Green Building Chamber of South Africa (GBCSA) rating device (the Green Star) is being utilized to certify green buildings in Nigeria. The certification is called "Green Star SA-Nigeria." It is not clear whether Nigeria intends to adopt any further arrangements to advance green building due to some perceptible insufficiencies in Green Star SA such as the range of weighting standards specifically on energy proficiency, management, and advancements. The Green Star SA rating tool (Green Star SA-Nigeria) is based on nine major categories which are, management, indoor environmental quality, energy, transport, water, materials, environment, outflows, and innovations.

Despite that Nigeria has not made a significant improvement on environmental rating scheme, it has, in any case, enlisted almost 317,039 gross sq. of green buildings [39]. To improve the rating schemes, different motivating forces were established in form of policies and control such as National Policy on the Environment (NPE), Environmental Protection Organization Act 1988, and the National Environmental Guidelines and Regulations Enforcement Office (NESREA) to encourage the GBCN policies.

2.1.2 National Building Efficiency Code

Nigeria's launch its first Building Energy Efficiency Code formally on the August 29, 2017, by the Minister for Power, Works, and Housing, Babatunde Raji Fashola (SAN). The occasion was facilitated by German Development Agency (GIZ), Nigerian Energy Support Program (NESP), and the Federal Ministry of Power, Works and Housing. The Building Energy Efficiency Code (BEEC) involves the pertinence of energy productivity in buildings and on climate change. The Building Energy Efficiency Code (BEEC) will create opportunities for energy efficiency with respects to retrofitting, existing, and non-compliant buildings to sustainable improvement. Geissler et al. [17] explained that the BEEC is only applicable to new buildings and is prepared based on climatic conditions of different zones in Nigeria. According to [17], adoption of the BEEC is voluntary (at the starting stage) but will become permanent after 2 years which will include enforcement of all the BEEC requirement by a competent authority. The enforcement authority according to the BEEC must understand the following [10, p. 25]:

i. Building physic
ii. Usage of calculation sheet for minimum energy efficiency requirements
iii. Minimum energy requirements on drawings
iv. Types of equipment used
v. Tracking of progress and database, and
vi. Route and performance.

2.1.3 Nigeria Building Code (NBC)

The first edition of the National Building Code (NBC) was developed in 2006 by a team of professionals in the built environment to ensure a standard for professionals, materials usage, fire prevention, and competency among construction professionals. Despite the concerted efforts of the construction professionals towards the codes, the National Building Code (NBC) is yet to be approved by the National Assembly which makes the code inactive since 2006. The code was, however, revised in 2015 but still inactive due to the aforementioned challenges. The aim of the NBC is to set a "minimum standards on building pre-design, designs, construction and post-construction stages with a view to ensuring quality, safety and proficiency in the building industry" [26, p. 6]. Dahiru et al. [11] pointed out that the introduction of the building code to the building industry will help secure the built environment and ensure sanity among construction stakeholders. The NBC ([26], 2015) focuses on safety with respect to a sustainable building, but provisions were not made to key areas such as renewable building materials [11], sustainable design and construction, carbon emission, and energy preservation. The increasing emissions from building because of cement usage are not captured in the building code [32]. These gaps in the content of the NBC make it not enough to tackle green practice in the Nigerian construction sector.

2.1.4 National Adaptation and Plan (NASPA)

Most of the energy efficiency policy on green building and climate change are yet to be enforced by the National Assembly nor consented to by the executive. In 2012, the government adopted a scheme tag "vision 2020" which includes varieties of policy for climate change and sustainable development through the National Adaptation Scheme and Plan (NASPA). The overarching objective of NASPA is to advance low-carbon emission, high-growth financial improvement, and a climate-resilient society. According to Oribuyaku [32], the aim of NASPA is to promote renewable energy use and to create an adaptive measure of the greenhouse effect. In term of the greenhouse effect on the environment, the NASPA document traced the problem to poor infrastructural development that poses enormous challenges to the environment [27]. The report suggested that the government and relevant agencies should ensure a building is a design to adapt to green building models such as roofing requirement and alternative building materials that can ensure sustainability [27, p. 46]. Nevertheless, if the policy is not transformed into a law, it cannot be enforced to drive public decision making.

3 Major Drivers Essential for Green Building Practices in Nigeria

3.1 Research and Practice

Ordinarily, the thought of a green building would have been an unusual convention in developing nations. But with the climate change and high energy usage, nothing may be more alluring presently. A green building may be a structure that has been developed to join aesthetics, innovations, and materials that are ecologically friendly. Some school of thought believes that implementing green building in Nigeria would be confronted with challenges within the built environment primarily because most clients, investors, and engineers are not really concern of the practice. In addition, there is a tremendous disconnect between research and practice in Nigeria. For instance, the

Nigerian Building and Road Research (NBRRI) has done an extraordinary work in terms of research and systems improvement within the adoption of green building to produce sustainable buildings and infrastructure. The NBRRI has done a lot of investigation on the most excellent ways to utilize conventional building materials such as bricks, bamboo sticks, and alternative replacement of the concrete materials with local resources for the development of sustainable advanced architecture and buildings to drive the green building policy in Nigeria. Hence, the government should partner with other stakeholders such as the manufacturers, architects, clients/owners, construction units, developers, and so on, and thrust for more advocacies and the standardization of conventional building materials to guarantee quality, supportability, health, and cost-effective building.

3.2 Availability of Green Materials

Sustainability in development is approximately about an appropriate decision on the choices of materials, their sources, development techniques, as well as a planning logic in order to enable an improved performance, minimize waste and become ecologically friendly [1]. Green building materials utilize the use of low-carbon emanation with reusable and recyclable capacities. The challenges in many developing countries are that many of these green materials are not yet readily available locally, as the available ones are not strictly in use due to lack of enforcement, and awareness of their effectiveness. It has remained a major concern for the government in Nigeria due to the over-dependence on the imported sustainable building materials. Amal et al. [2] stated that building design and construction should endeavor to utilize locally made materials with renewable features. However, the major challenges of locally produced materials for green building in Nigeria are the lack of standardization.

3.3 Education and Training

Green building concept should be incorporated in the higher education curriculum, especially for built environment students. The National Adaptation Scheme and Plan [27] also suggested that information-based awareness on a sustainable building should be encouraged which will involve developing a skilled-based curriculum for every institution in Nigeria. In addition, a professional association within the industry should also organize seminars on the benefit of green building and how they can educate their clients on the benefits of consolidating green activities on infrastructural development. This will altogether reduce the operating cost over the lifetime of a building, whereas contributing emphatically to the environment and the individuals who utilize the building. There is enough proof that "green" feasible building is cost-effective and safe to live in. Experts advice could drive the green campaign if properly channeled.

3.4 Government Regulations and Enforcement

Every government should thrive to take the issue of sustainable building serious and should also be a priority. The government should lead in the green building implementation crusade. Government regulation and laws are the major drivers of green practice [3]. Green construction law and regulation need to be promulgated and enforced. Nigerian construction industry has been operating under less operational regulations. Even the proposed building code which reflects little or no items on green rating has not been signed into the federal law over the years. Few states like Lagos State have witnessed the promulgation of the building code at state level but confronted with enforcement challenges. The government must consolidate sustainable infrastructure into their environmental protection agenda. Approaches on greening buildings should be the government major agenda for a sustainable development. Such approaches should incorporate energy proficiency, sustainable building materials, indoor environmental quality, and advancement in design that consider the green building as a criterion. The government should introduce a certification for energy design and innovation to ensure compliance. The government needs to encourage regular audits on a green environmental standard of all construction industry activities. According to Arif et al. [3] green practice reflects the responsibility of the government because it is solely influenced by regulations.

The major challenge of enforcing, implementing, or promoting sustainable development faced by the Nigerian courts and policymakers is whether it is a moral or legal concept [31]. According to Okon [31], the legal status of green practices in Nigerian environmental law is still controversial. Nevertheless, the legality of green practices (i.e., sustainable development) in Nigerian environmental law depends on the judgment of the court [31]. Even the few policies on green building that have been formulated by the government are still inactive as the agencies to ensure compliance with green building measures are complicit. To achieve an effective implementation and enforcement of green practices in the Nigerian, there is a need for it to be directly integrated into the Constitution of the Federal Republic of Nigeria 1999. The major stakeholders for enforcement of the regulation need to energize the political will and capacity to encourage and foster the practice.

4 Green Building Policy Formation Process Framework for Nigerian Construction Industry

The Nigerian construction industry is regarded as a huge, energetic, and complex division that plays a crucial role in the economy. The industry accounts for more than 10% of most country's capital growth. Hence, if this growth is not controlled, it can pose a serious environmental challenge. For example, the building industry in Nigeria extensively utilizes resources such as water, timbers, and energy for its construction activities. But if all these resources are not put under control most especially materials that are energy intensive, they can erode the environment. It was reported that the construction industry consumes up to 40% of energy and 19% yearly greenhouse gas emissions majorly from air conditioning, water heater, and lighting. Likewise, the operation of the building also generates large chunks of waste materials into the environment about 48% waste generation and 50% air and water pollution [34].

Therefore, for the Nigerian construction industry to prevent energy emission of building and reduce the gap between energy supply and energy loss, "an effective green building policy framework" (EGBP) should be constituted on how to achieve environmentally friendly building in Nigeria. The building policy formation process would involve six interconnected activities/factors such as construction stakeholders, green rule standards, green building drafting policy, green policy presentation, public green building policy, implementations, and enforcement (see Fig. 2). The green building policy framework would aim at:

i. Constructing building to be self-sufficient and consume less energy and water during the whole building life cycle without altering the building standard;
ii. Reducing the impact of exploitation of our natural resources because of traditional method of building;
iii. Provide guideline for various construction stakeholders and organization with the aim of adopting the green building policy for new development;
iv. Encourage the use of energy efficient building materials;
v. Implementation of the existing energy efficiency code such as BEECC, NASPA, National building code (NBC), and National Building Efficiency Code (NBEC).

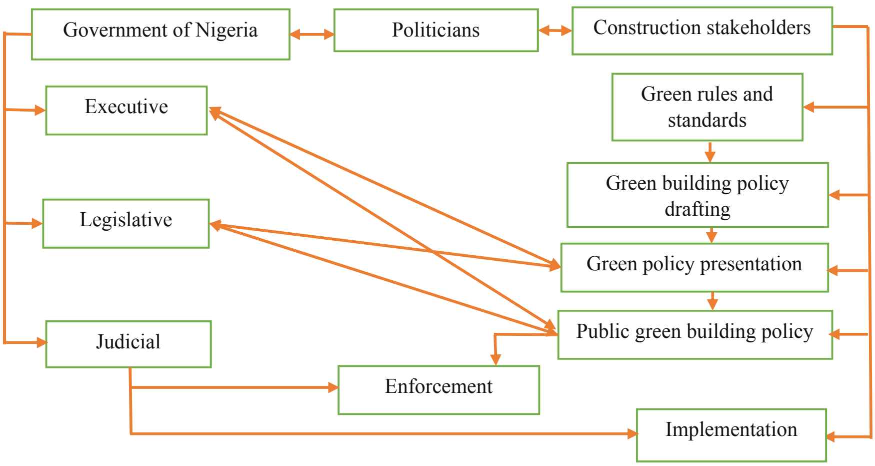

Fig. 2 Green building public policy formation process framework

4.1 Construction Stakeholders

The construction stakeholders involve the major players in the built environment. For a policy to become effective, all major stakeholders in the built environment must be involved in the policy formulation. The policy formulation is not only limited to construction stakeholders but also to politicians (lobbyists) that will act as the major drivers to the policy; the government which consists of the executive arm, legislative, and the judiciary is also key stakeholders in the policy formulation. The federal ministry of work and housing through the National Council of Housing can help organize a workshop on green building policy formulation before passing it to the Federal Executive Council for ratification. The construction stakeholders should also involve private organizations. Likewise, the interest of those who will be affected by the new policy on green building such as

i. Owner's representatives—Such as the owner's representatives that will be responsible for interpreting the green building policy.
ii. Supporting organizations—Those who may be responsible for funding the implementation of the green policy.
iii. End users—Users that will benefit from the implementation of the green building policy.

4.2 Green Rules and Standards

The construction stakeholders and other government representatives will make their input on the green rules and standards. The green rules and standards will consist of a set of ratings and certification that will act as a guide for delivering a sustainable building. The rules and regulations will be based on the input of all the construction stakeholders based on their areas of expertise and the international rating standards for building. Other stakeholders that will be involved in the drafting of the rules and standard are federal government agencies. The federal government agencies should create a consensus standard since other major stakeholders are involved to prevent a situation where a proprietary standard will be created for green building. The green rule and standard should also be subjected to public comments. More so, since there are international standards for a green building called the green star rating, all rules and standards should be subjected to the international green building standards in order to be in conformity with the known standard worldwide. Since international rating standard is based on nine major categories which are management, indoor environmental quality, energy, transport, water, materials, environment, outflows, and innovations, the green rules should be an improvement of these indices.

4.3 Green Building Policy Drafting

The green building policy drafting is the starting point for sustainable green building practice. The government can take the lead by drafting a unique policy based on the already prepared set of green rules and standard by the construction stakeholders. The purpose of the draft is to set a green building ordinance that will promote green building in Nigeria.

4.4 Green Policy Presentation

The green building policy is presented to the upper and lower assemblies in form of a proposal for first reading. After the first reading, a second reading date will be announced for the submitted policy document. At the second reading, the purpose of the "green building policy" is explained and debated by the house. A committee is set up to examine the details of the "green building document" for amendments and corrections which are made in accordance with the draft prepared by the construction stakeholders and suggestions. The "green policy document" is then presented by the committee set up by the house for third readings. At this time, the green policy document is subject to a vote by the house. If the bill passes through, a printed copy of the bill is signed by the clerk of work of both houses for consideration. If both chambers approve the green policy document (GPD), it is sent to the president for approval. Once the president signs the policy document, it then becomes a law, or otherwise an act in Nigeria for all construction industry.

4.5 Public Green Building Policy

Once the president signs the policy document, it then becomes a law, or otherwise an act in Nigeria for all construction industry. Should in case the bill is sent back to the house for amendment, the original copy is sent to the clerk for amendment and production of a new copy based on the amendment; it is then sent back to the president for assent and a seal of approval. Sometimes, if the public green building is not assented to by the president after 30 days due to some political reasons, the National Assembly can veto or overrule the president, and the public policy bill can be recalled and repassed by both chambers. At this stage, the public policy bill may require two-thirds in order to automatically become a law without the consent of the president.

4.6 Enforcement

The enforcement of green building will involve establishing and setting up an agency of the government involving a representative from the construction profession to ensure compliance during the construction of new building or retrofitting. The judiciary will also help in interpreting some part of the document to defaulters in the form of penalties or fine to prevent precedence. The police will also ensure a strict compliance by working with the established government agencies that oversee the adoption of green building in every construction development.

4.7 Implementation

The implementation will also involve the roles of the judiciary in ensuring compliance with the green building document. The implementation may involve monitoring the compliance of the green building policy through government-approved agencies and all the Nigerian built environment professional associations involved in the formulation of the policy. They would ensure that the manufacturers, contractors, suppliers, and other stakeholders operate with the directive of the green building policy. The implementation will involve ensuring control and proactive actions to ensure compliance.

5 Benefits and Reasons to Build Green in Nigeria

Green buildings join sustainable materials in their development (e.g., reused, recycled-content, or made from renewable assets); make sound indoor situations with negligible (e.g., decreased item emanations); and decrease water utilization (e.g., by utilizing local plants that survive without additional watering). The built environment includes an endless effect on the common environment, human well-being, and the economy. Green buildings are outlined to reduce the general effect of the built environment on human well-being and the characteristic environment through:

- Proficient use of energy, water, and other valuable resources
- Securing the inhabitant health and ensuring efficiency, and productivity
- Reducing waste, contamination, and natural debasement
- Green building is less expensive except in cases where retrofitting of existing buildings is carried out
- Less operating risk
- Low maintenance and replacement cost
- Consistent temperature and humidity
- High indoor air quality

- Low environmental impact
- Efficient waste management.

6 Implications of Green Building for Nigeria

Green innovations in Nigeria have the objective of moderating climate change and have impacts on different issues that incorporate social economic, political, and innovative advancements in Nigeria. It is basically for improving the developments of local practices and values, to improve the economy. There is no better time other than the present for Africa to seek green innovations to combat future challenges.

6.1 Economic Implication

Building materials generally constitute an expansive addition to capital project and add up to 80% of infrastructural development. Green technology utilizes locally made materials and building strategies to cut costs to its barest minimum. The effect of this is that house rent and cost of building that have been a major problem in the third world nation will reduce drastically. It will also optimize national domestic economic exhibitions. It will enhance multiple business and employment as well as occupational and regulatory efficiency, whereas poverty alleviation is upgraded. There will moreover be an expansion of market opportunities for green items, e.g., sales of locally produced energy efficient materials and higher exportation. Considering all factors, green technology would help in the areas of economic viability.

6.2 Political Implication

Green building technology ignites the legitimate issues pertaining to indigenous innovation by the government agencies. Government at different levels could formulate policies and monitor the performance at different jurisdiction to ensure open intrigued. These will also ensure that local materials and costs are controlled. By so doing, the objectives of green building technology can be realized. Government's activities will go a long way in implementing policies that are competent of advancing green technology. It will define a premise for controls and the application of policies that would lead to advancement.

6.3 Sociocultural Implication

Extemporizing green innovation in the Nigerian construction industry would lead to an advancement within the general quality of life of the populace. It would characterize the production of an occupant's wellness and the comfort of living in an eco-friendly building. Availability of green buildings, which take care of fundamental infrastructural needs, like clean water, solar powered (energy) electricity, and secure environment, is what society requires for sustainability. Green technology can change the social value system in Nigeria within the sense that the indigenous potentials will be sustained, approved, and compensated appropriately. Greener culture would have induced the consciousness of environmental protection and lean concept in the construction activities. Client organization awareness of green building practice would transform the construction procurement system. Formation and enforcement of building code for green innovation implementation in construction processes would imbibe green culture within the system, whereas awareness is improved as the Nigerian construction industry progresses in a profitable adventure bringing approximately efficiency through green indigenous innovation.

6.4 Technological Implication

Innovations in science have brought major advancements globally. Modern revelations in innovation would make tremendous commitments towards sustainability while making local assets necessarily in the improvement processes to encourage inventive thoughts in a developing country like Nigeria. Green innovation will advance discoveries and instructive values when given adequate supports; it would help improve innovative discoveries and revitalized industrialization in Nigeria and Africa at large.

7 Conclusions and Recommendations

This chapter viewed green building practice as related to developing economies such as Nigeria. It gives a brief insight into the issues of green policy adoption and formation in the country. Barriers and benefits of green practice in a developing nation like Nigeria were also highlighted. It was indicated that the government, politician, and construction stakeholders should be involved in the formation of the green building public policy. Particularly, the government should champion the campaign for its enforcement within the Nigerian construction industry. Education and training are also paramount to the success of its adoption. Availability of sustainable materials is essential for the attainment of the practice in the country. Nevertheless, it all should begin from somewhere either from the construction experts, private sector, or the government. What is paramount is that developing countries should endeavor to introduce a green building standard for all its future domestic and commercial buildings development. If an enforceable green building standard is in place, the country-built environment will be set up for sustainable building. Green building is frequently unreasonably blamed as being a hassle according to many academia in developing countries. What developing nations must know is that green building technology is not that cumbersome. At its most essential, green building is all almost making buildings more economical and eco-friendlier.

The unexpected thing is that most of the nations who will face the greatest impact of climate change are the third world countries that in fact are not contributing much to the greenhouse effect. We have seen how nature unleashes its wrath through tropical storms, typhoons, surges, and dry spell, making it a major catastrophe for third world nations. But building green requires a degree of moderation on the impacts of catastrophes on the building. Green building rewards individuals with energy efficient, secure and toxic-free residences and commercial space, and sustainability. Hence, it is of importance that developing nation should envision and thrust for the attainment of greening culture, develop a policy, make it a public policy, and enforce its implementation. Based on this vision, commitment to sustaining the green practice in Nigeria is a possibility.

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Attitudes of Cambodian Homebuyers Towards the Factors Influencing Their Intention to Purchase Green Building

Serdar Durdyev and Ali Ihtiyar

Abstract There is no doubt that green buildings (GBs) have a huge potential in the reduction of the built environment's impact on eco-system, which therefore needs to be promoted among the potential homebuyers. Thus, being the first in its kind, this research attempted to answer the question: What are the factors the potential homebuyers in Cambodia would consider to purchase GB? To answer this question, randomly selected potential homebuyers were administered a questionnaire survey (comprising 21 factors to be rated and demographics) seeking to evaluate the most significant factors, which were identified through a thorough review of the international context. It is noteworthy that the respondents are highly qualified, which reflected on the ranking of the awareness- and knowledge-related factors. Based on the results of data analysis technique utilized in this research, the consensus among the homebuyers is that the facilities that offer truly green features are of significance, rather than any means of financial support provided by government. In addition, neither marketing actions nor people around motivate the homebuyers towards purchasing GB. On the other hand, this paper could derive implications in terms of offering an eye-opener to home developers in the Cambodian real estate sector in focusing on the issues that drive the homebuyers' intention to purchase GB.

Keywords Green building · Cambodia · Purchase intention · Real estate

1 Introduction

Detrimental impact of the construction industry on the environment has forced decision-makers to implement greener/sustainable construction practices around the globe [15, 42, 48]. Several incentive schemes and initiatives have been introduced for

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further adoption of these practices; however, the uptake of sustainable/green practices is still moderate [45].

Despite the variety of definitions for green buildings (GBs), they can be defined as 'healthy facilities designed and built in a resource-efficient manner, using ecologically based principles' [34]. The consensus on the potential benefits of GBs is improvement in energy and water efficiency [3], health and comfort of human habitat [53] as well as save money [34]. In other words, GBs ethically and practically respond to issues of ecological impact and natural resource consumption [46]; hence, offer significant improvement over conventional project delivery methods, rather than providing radical departure from them [34].

The GB movement has been emerging across the world for more than two decades, which was sparked by mitigating the industry's impact on environment [34]. Since its introduction, the GB concept has become more popular, which has been driven by the advent of building assessment systems, namely BREEAM (Building Research Establishment Environmental Assessment Method) of the UK, DGNB (Deutsche Gesellschaft für Nachhaltıges Bauen) of Germany, the Leadership in Energy and Environmental Design (LEED) of the USA, the Green Star Rating of Australia and New Zealand, and CASBEE (Comprehensive Assessment System for Building Environmental Efficiency) of Japan [6]. Although these systems have been introduced in different countries, both provide a scoring system indicating the success of the facility or project in meeting the sustainability goals. It is worthwhile mentioning that the LEED is widely utilized assessment system in Cambodia.

Construction is one of the leading sectors of the national economy of Cambodia [20]. The sector has been attracting an attention of overseas investors, particularly real estate investors from China and from member countries of the Association of Southeast Asian Nations (ASEAN) [18].

Although the GBs adoption in Cambodia is still in its infancy stage, the concept has garnered lots of interest from both local and overseas investors. For example, the government of Singapore funded a centre for the provision of training on GB designs and delivery, which was established to be a model for building practices in the country [41]. According to The Green Building Information Gateway (GBIG), so far seven facilities in Cambodia have been certified by LEED [52]. Vattanac Capital tower is an example of the LEED-certified facility in Cambodia. Obviously, comparing to the countries in the region such as Singapore, Malaysia, Thailand and Vietnam, these are very few little steps towards the adoption of GBs concept. However, these examples show that Cambodia is trying to achieve a significant shift to much greener building practices, which put the country among the few countries with the same socio-economic status in the region (i.e. Laos, Myanmar) as well as worldwide.

Current body of knowledge suggests the variety of topics reported on GBs, such as drivers/benefits of GBs [5, 30, 32], barriers to GB adoption [12, 28], utilization of the GB assessment systems [4, 47], land-use efficiency [27, 51] and attitudes of the potential buyers and developers towards the adoption of GBs [31, 43]. However, research on the adoption of GBs in Cambodia has yet to receive the sufficient level. As every country has its specific regulatory and cultural environment, country-specific research is necessary for better understanding of the researched topic. Given to the variety of topics associated with GB, this study focuses on only one aspect of GB research. Therefore, being the first research conducted in its kind, this study aims at analysing attitudes of Cambodian consumers towards the factors influencing their intention to purchase GB.

2 Literature Review

The origin of GBs traced back to 1992, which were first introduced to increase the efficiency of resources (i.e. water, energy, materials) buildings consume and reduce the environmental and ecological impact for which buildings are responsible for [22]. As they have been commonly described, GBs provide healthy facilities for occupants, less harm on the environment as well as on national economy [45]. Thus, the idea of GBs has been considered to be an evolution of the construction industry worldwide. It has been receiving an extended attention (since its inception) from governments and academia, which have introduced various incentive schemes and developed legislation processes for further implementation of the concept of GBs. The above-mentioned assessment systems are clear examples of this evolution.

In addition to the actions have been taken by governments, the concept of GBs has received considerable amount of attention from academia, where researchers have focused on various aspects of GBs research. For example, Zuo and Zhao [59] reviewed number of studies on GBs and categorized those studies into three main areas, such as definition, evaluation of benefits and quantification of costs associated with GBs as well as practices for likelihood success in GBs. Several studies report environmental drivers of GBs, which are energy and resource conservation, improvement in the quality of water, air and indoor environment, and waste reduction [3, 31, 43]. From the project owners' perspective, Olanipekun et al. [43] highlight further significant drivers, such as government incentives, company image and reputation, market appeal, and persuasive influence. On the other hand, there are factors hindering the realization of GB benefits in the market [8, 25, 29]. The most common barrier is that the overall cost of GB is much higher than the traditional house, which is however, due to knowledge, skills, technology and planning required to execute a project. From the homebuyers' perspective, three main factors have been reported to reduce their intention to pay for GB, which are long payback period, institutional problems and visibility [7]. Hu et al. [29] report the findings from China, where the effect of various environmental and demographic factors on clients' purchase intention was investigated. The findings show that price, air pollution, commuting options and job accessibility were the most significant factors influencing the homebuyers' decision, rather than GB features of facilities. Similarly, other studies [9, 33, 50] buttress the findings, as homebuyers' decisions are predominantly due to the affordability and location of a house, as well as due to personal and cultural preferences.

3 Research Method

Being widely utilized method of the data collection [16], questionnaire surveys have been administered to the potential respondents aiming at collecting the primary data of this study, while the secondary data were sourced from the reported literature on the subject. Due to the absence of any publication on GB in Cambodia, as part of the secondary data collection, the international context had to be acknowledged, and hence, reviewed to identify potential factors influencing purchase intention. Thus, Table 1 presents the identified factors with their respective sources.

As the primary source of data for this study, being the most cost-effective and timely efficient method of data collection, the identified factors were presented in the questionnaire form [16] for further administration to respondents in Cambodia. Thus, the designed questionnaire comprised of two parts. While the first part sought to obtain demographics (education level, gender and age) of the survey participants, in the second part the potential homebuyers were asked to rate the factors provided in the survey. The questionnaire was originally prepared in English language; however, to overcome the language barrier it was also translated into Khmer language and proofread by an expert of GB area. As this study relied on the data collected through the questionnaire survey, the clarity and quality of the design and readability of the items provided are of strategic significance [23]. Therefore, to increase the number of responses, pilot test was carried out with randomly selected forty-three respondents, who were highly qualified (67% with postgraduate qualification). Cronbach's alpha (α) statistic has been widely used method of testing the reliability of the scales [19], particularly for the studies utilized a scaling method (i.e. Likert scale). The α was computed as 0.852, which indicates that the scales of the questionnaire are internally consistent [21]. Hence, the administration of the survey has commenced in February 2018 and ended up by April 2018, which was set as a cut-off date. Of 400 surveys distributed by hand, 253 of returned responses were valid, which was a sufficient sample size [37] and further used to perform statistical analyses of this study.

4 Results

4.1 Demographic Data

Demographics of respondents are crucial when analysing their purchasing attitudes. Therefore, as part of the questionnaire survey, the participants were requested to provide their level of qualifications, ages and genders, which are presented by Fig. 1. Analysis of the demographics shows that almost two-thirds of the respondents hold undergraduate level of qualification, while the rest hold postgraduate level. The vast majority of the responses (≈90%) were collected from the consumers with the age range of 16–25, which is considered to young consumers [57]. Slightly above 50% of the responses were received from male consumers, while females' responses

Table 1 Factors influencing consumers' intention to purchase GB from published literature

Code	Factors influencing consumers' intention to purchase GB	References
F1	Health and comfort in GBs	Ahn et al. [3], Maichum et al. [40], Paul et al. [44]
F2	Energy efficiency of GBs	Maichum et al. [40], Paul et al. [44], Durdyev et al. [22]
F3	GB provides safer environment	Whang and Kim [53], Maichum et al. [40], Paul et al. [44]
F4	Encouragement of family members	Maichum et al. [40], Liobikiene et al. [38]
F5	Encouragement of close friends	Maichum et al. [40], Zhang et al. [57]
F6	Encouragement of trusted/important people	Liobikiene et al. [38], Zhang et al. [57]
F7	Confidence in purchasing GB	Kim and Han [35]
F8	Capability in purchasing GB	Kim and Han [35]
F9	Financial conditions and willingness in purchasing GB	Portnov et al. [45]
F10	Awareness and knowledge on GB evaluation	Abidin [2], Durdyev et al. [22]
F11	Awareness and knowledge on a need for GB development	Abidin [2], Durdyev et al. [22]
F12	Awareness and knowledge on the advantages of GB	Abidin [2], Serpell et al. [49]
F13	Advertisements	Adapted from Durdyev and Ihtiyar [14]
F14	Exhibitions and other promotional events	
F15	Word of mouth	
F16	Concern on severe abuse of the environment	Zimmer et al. [58], Abdul Rashid and Shaharudin [1]
F17	Concern on limits to growth over that the industrialized society cannot expand	Hartmann and Apaolaza-Ibáñez [26]
F18	Concern on the harmony with nature to survive	Hartmann and Apaolaza-Ibáñez [26]
F19	Government incentives (i.e. tax) supplied for GB purchasing.	Diyana and Abidin [13]
F20	Direct grants supplied by government for GB purchasing.	Zhang et al. [56]
F21	A soft loan incentive supplied by government for GB purchasing	Zhang et al. [56]

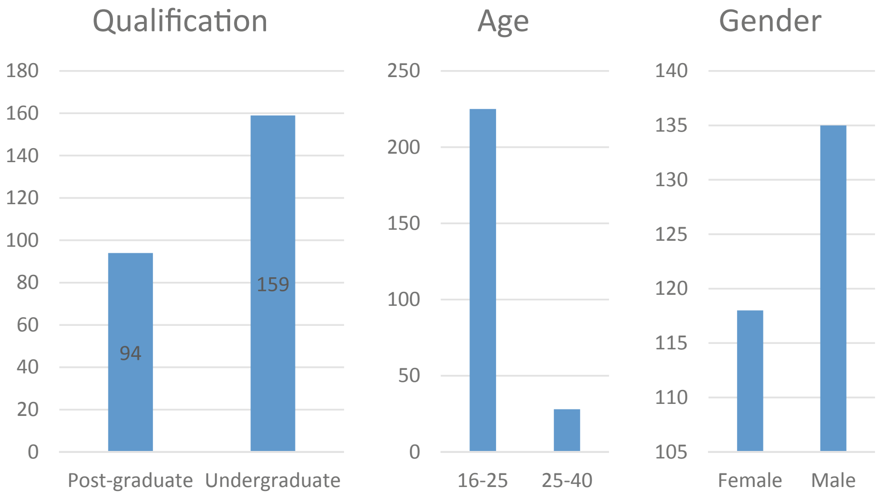

Fig. 1 The respondents' demographics

accounted for about 47%. It is worthwhile mentioning that the responses are biased towards the feedback of young consumers, which could be considered as a limitation of the study. However, highly qualified respondents added to the quality of the responses and hence, reliability of the research findings.

4.2 Data Analysis

To understand the potential homebuyers' attitudes, this study aimed at evaluating the factors influencing their intention to purchase GB. Addressing those factors would provide for GB developers a clear picture of homebuyers' attitudes towards purchasing GB in Cambodia. Following previously published studies, statistical methods were used including mean values to rank the factors according to their relative importance [17] and Kendall's W (W) to measure and ascertain the homebuyers' agreement on the rankings of the factors. In addition, Chi-square (χ^2) test was used to determine the significance of the calculated W [24]. For more comprehensive information (i.e. definition, formulae) on the utilized statistical techniques, the reader is referred to Fellows and Liu [24].

5 Discussion

Due to the shortage of studies on the subject in Cambodia, this study investigated the Cambodian homebuyers' attitudes towards the willingness to purchase GBs.

Their willingness is significant to ensure that they constantly show an engaging attitude towards the GB practices. Thus, based on five-point Likert scale ranging from 1—strongly disagree to 5—strongly agree, the potential homebuyers were asked to evaluate factors influencing their intention to purchase GB. The factors along with their mean values and other statistical indicators are presented by Table 2. Although the priorities may vary among different homebuyers, the results of W (0.187) indicate a good consensus among the potential homebuyers in providing their feedback on the factors that trigger their intention, while χ^2 (506.56) were also observed at the significance level $p < 0.001$ [24]. Thus, the following section discusses the outcomes of the statistical analysis, which were computed upon the feedback of the potential homebuyers in Cambodia and compared against the outcomes of previously reported studies in the area.

The most significant factor that triggers homebuyers' intention is '*energy efficiency of GBs*' (F2). The result aligns with the previous findings across the world [3, 53] as the GBs are proven to provide a significant saving in energy consumption. Ahn et al. [3] highlight the significance of the implementation of green/sustainable practices for the conservation of energy in buildings. The respondents' attitudes towards this factor are not surprising, because Cambodia is the energy-dependent country where the cost of electricity per average income (main source of energy for buildings) is much higher comparing to other countries in the region. Due to its typical Southeast Asian climate, which is warm to hot year round, a sizeable amount of energy in buildings consumed for air-conditioning systems as a main means of cooling. In his study Wong [54] point out that comparing to an air-cooled air-conditioning system, the utilization of a water-cooled system provides 20–30% reduction in energy consumption. Since 2010, annual electricity consumption growth in Cambodia has been increasing with an average of 20% and the rate of increase is expected to accelerate due to the rapid development in the national grid and improvement in average income [55]. In spite of the population growth and economic development, due to the growth in the energy demand, Cambodia is experiencing monetary instability. However, the improvements, which need to meet the growing demand do not seem to be at the desired level, and it is of highly strategic importance of meeting energy demand in the country. Thus, particularly for electricity demand savings, promotion of the efficiency in, and conservation of energy through the adoption of green practices in the building industry are vital.

The survey outcomes reveal that the Cambodian homebuyers' expectations from GBs are '*safer environment*' (F3), which is ranked as the second most significant factor driving their intention. The result is supported by Chen and Huang [11] who claim that apart from energy conservation and reduction in carbon emissions, green practices offer safer structures by incorporating high-tech materials and product applications. Although the common belief is that green and sustainable practices reduce the environmental impact and protect the eco-system [2], GBs are designed carefully to meet region-specific climate conditions, which provides a long-term durability of GBs [36].

'*Health and comfort in GBs*' (F1) ranked to be the third most significant factor drives the homebuyers to purchase GB in Cambodia. The significance of expected

Table 2 Mean ranks of the factors within total sample

Factor code	Total sample								
	Mean	SD	Rank	p-value	α	W	χ^2	df	Aymp. Sig.
F2	4.23	0.86	1	0.000	0.949	0.187	506.56	20	0.0000
F3	4.13	0.85	2	0.000					
F1	4.00	0.90	3	0.000					
F12	3.95	0.90	4	0.000					
F10	3.91	0.89	5	0.000					
F8	3.89	0.91	6	0.000					
F11	3.89	0.92	7	0.000					
F7	3.78	1.00	8	0.000					
F9	3.73	0.93	9	0.000					
F13	3.70	0.89	10	0.000					
F17	3.62	1.06	11	0.000					
F16	3.39	1.00	12	0.000					
F4	3.38	1.08	13	0.000					
F18	3.23	1.07	14	0.000					
F14	3.17	1.09	15	0.000					
F6	3.12	1.10	16	0.000					
F15	3.02	1.10	17	0.000					
F5	2.91	1.08	18	0.000					
F21	2.87	1.10	19	0.000					
F19	2.73	1.17	20	0.000					
F20	2.56	1.08	21	0.000					

health and comfort from GBs was evident in Whang and Kim [53], where the factor was ranked as one of the top drivers of green practices in the building industry. However, the result is in contrast with the findings of Chan et al. [10] and Low et al. [39], where the aforementioned factor was ranked as the least significant towards the implementation of GB.

'*Awareness and knowledge*' related factors (F12, F10, and F11) are ranked to be the fourth, fifth and seventh factors motivating the homebuyers to purchase GBs in Cambodia. The result is supported by Abidin [2], Serpell et al. [49] and Durdyev et al. [22], where the significance of awareness and knowledge is emphasized and reported to be a good catalyst for a widespread promotion of green/sustainable practices, particularly in developing countries . It is noteworthy to mention that homebuyers' confidence (F7), capability (F8) and financial condition (F9) were ranked within the top ten significant factors driving their purchase intention, while the government support (F19, F20 and F21), regardless of any means of support, received the least ranking. The results imply that the potential homebuyers are capable and willing to pay for GBs as long as the structure provides them healthy, safe and comfortable environment, which were perceived to be the top driving factors. Furthermore, the result perhaps reveals that the homebuyers neither seek nor expect for any governmental support. However, it is in contrast with other studies reported from developing countries, where the green/sustainable practices, due to their higher costs, are highly anticipated to be supported by government, particularly in developing countries [3, 22, 56].

6 Conclusion

Although the building industry makes a considerable contribution to human habitat, for example, basic infrastructure and residential facilities, it is responsible for the consumption of natural resources; hence, compromises the future generations. However, the detrimental impact could be reduced by implementing sustainable solutions (i.e. energy efficient equipment, eco-friendly materials) and more ethical approaches in the industry to ultimately save the eco-system. Undoubtedly, GBs, with their huge potential, can lead to remarkable reduction in the industry's impact on eco-system; however, the rate of adoption is yet to match their benefits. There has been a significant improvement in popularity of GB concept over the past two decades—uptake level will continue to improve simultaneously with its familiarity among the stakeholders. The domination of the GB concept within the majority of countries (i.e. the USA, the UK and Australia) worldwide has proved the significance of the concept to reduce the detrimental impact of the built environment.

Due to its proven significance, the GB concept has received broad attention from both industry professionals and academia, and various research topics have been reported in the literature pool related to the concept, which are highlighted in the aforementioned sections. However, the implementation of GB practices seems difficult owing to country-specific conditions where the construction industry is being operated. Thus, this research paper, being the first such to consider this scope in the Cambodian context, aimed at investigating the factors that drive the intention of the potential homebuyers to purchase GB.

A questionnaire listing the factors influencing the potential homebuyers' purchase intention of GBs identified through a comprehensive literature review was designed. Twenty-one factors were identified from the relevant literature, which were pre-tested through a pilot study prior to the administration among the respondents. The number of valid responses by the cut-off date was 253 (of 400 distributed surveys) comprising largely highly qualified young potential homebuyers in Cambodia. The demographics and opinions of the respondents towards the significance of 'awareness and knowledge' related factors coincide with each other. Mean value technique was utilized to analyse the opinions provided by the respondents and rank the factors according to their levels of importance. Furthermore, W was calculated to test the agreement on the rankings of the factors among the respondents as well as χ^2 to determine the significance of the calculated W.

Based on the survey outcomes, it can be inferred that neither any means (i.e. financial incentives, loans) of support by government nor marketing tools (i.e. advertisements, word of mouth) are the main impetus behind the Cambodian homebuyers' intention to purchase GB. These results contrast with the previous studies in the literature as the government support reported to be a significant driver of the implementation of green practices, while marketing actions influence consumer's purchase intention. In addition, encouragements of people close to the homebuyer do not play a significant role in motivating towards the purchase of GB. However, the most well-known benefits offered by GBs, which are health, safe and comfortable environment, are perceived to be the most significant factors stimulating the intention of homebuyers. It is worthwhile mentioning that the homebuyers are confident and financially capable of purchasing GB as long as it provides the better living environment for them.

Despite being a limited exercise in scope, this study provides a significant base for future GB studies on developing countries. Although a lack of information limited the authors in providing real data on the extent of GBs, the results have sufficiently provided an overall attitude of the Cambodian homebuyers' intention to purchase GB. Further, based on the research outcomes it is recommended that GB developers and real estate consultants should emphasize on the actual benefits offered by the introduced green facility rather than trying to attract the homebuyers' intention with marketing actions.

6.1 Implications of the Study

In the global GB context, the findings of this paper would enrich the knowledge on the factors triggering the purchase intention towards GB in a developing country. In the local context, the outcomes fill a significant knowledge gap by quantifying the significance of those identified factors based on the opinions of the potential homebuyers in Cambodia. Moreover, the findings provide insights for GB developers and real estate consultants on the factors influence the homebuyers' intention on which attention and resources need to be focused, for country-wide promotion of GBs. The outcomes imply that GB developers should focus on the environment, durability and long-term values GB offers to enthusiastic homebuyers while executing the residential facility. In other words, whether the built facility meets the required measures and performance and offers a truly green option for customers. Rather, investing on the marketing actions while trying to sell the facility. By doing so, it is believed that to provide impetus to promote homes that offer green features in the Cambodian context, subsequently help reduce the impact of the built environment on eco-system as well as to reduce, to some extent, the energy and resource consumption. Although the paper presents a snapshot of the factors motivating the homebuyers to purchase GB, these outcomes are not future proof. Owing to rapid changes in attitudes and/or financial and market conditions, developers may have to re-investigate the factors to stay up to date with new and emerging significant factors.

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Understanding the Green Building Industry in Thailand

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Abstract Promoting green building has become a global trend to improve resource efficiency and well-being of societies. The aim of this study is to systematically investigate the key aspects of the green building industry in Thailand (i.e., critical successful factors, key green technologies, and barriers) and to provide a sound basis for deeply understanding the drivers of the industry. Based on a survey of consultants, architects, and engineers, the results show that critical success factors of green building are mainly related to competence of project participants, integration of project team, technical and management innovation, external environment, and project characteristics. The analysis of green technical capabilities demonstrates that project participants should emphasize improving technical skills in green building, use of green materials, and familiarity with green building rating systems. Barriers to green building mainly arise from financial pressure, technical limitation, and inadequate promotion. The findings can help project participants to adopt appropriate strategies in boosting green building in emerging markets of developing countries. Future studies should focus on levering the demand of the market, integrated green technology innovation, and management measures at project, organizational, and industrial levels.

Keywords Green building · Thailand · Green technical capability · Leadership in Energy and Environmental Design (LEED) · Thailand's Rating of Energy and Environmental Sustainability (TREES)

Notes: This chapter has been developed based on the following papers: Shen et al. [17,18].

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1 Introduction

Green buildings (GB) have been globally adopted for sustainable development by enhancing resource efficiency, reducing operation cost, and improving the building environment for users [28]. With the rapid development of worldwide GB markets, various GB rating systems have been created and form the basis for designing, constructing, and maintaining and evaluating GB. Leadership in Energy and Environmental Design (LEED) is one of the most well-known and successful GB rating systems and has been widely adopted in over 140 countries around the world.

Green building in developing countries in Asia is especially noteworthy, which is an emerging market with fast development [5]. Thailand is an example of a developing country with fast-growing GB markets. Since the first GB project received certification from LEED in 2007, 219 projects have been registered with LEED up until July 2018. In addition to LEED, Thailand developed its own green building rating system in 2010, called Thailand's Rating of Energy and Environmental Sustainability (TREES), which is based on LEED but tailored to the features of Thailand. The number of green buildings applying for TREES is rising fast, demonstrating TREES' significant role in Thailand's GB industry [23].

With great growth potential in the green building market, Thailand, along with other developing countries in Asia will need strategies for delivering green buildings. However, existing studies mainly focus on developed countries and regions [8, 9, 20, 24], and a little research has systematically addressed and quantified some key factors on green building in developing countries. Thus, the aim of this study is to systematically investigate the key aspects of green building industry in Thailand (i.e., critical successful factors, key green technologies, and barriers) and to provide a sound basis for deeply understanding the drivers of the industry, thereby facilitating project participants' adopting optimal strategies in successful delivery of green buildings in emerging market.

2 Literature Review

2.1 Critical Success Factors of Green Buildings

Many studies have investigated the critical success factors (CSFs) for delivering construction projects (e.g., [14, 25, 26]). Specifically, Chua et al. identified that socio-political environment, relationships among stakeholders, and competences of project manager, designer, and contractor are critical to construction projects. Korkmaz et al. [12] explored the important factors for sustainable high-performance construction projects and found that the key stakeholders' early involvement in projects is one of the important indicators influencing project performance. Li et al. indicated that support from senior decision makers, innovative technological approaches, external environment, and project team motivation is the critical project management factors

Table 1 Critical success factors of green buildings identified from relevant literature

Success factors	References
Competence of project manager	Hwang and Ng [9]
Competence of GB consultant	Inayat et al. [10]
Competence of contractor	Kog and Loh [11], Inayat et al. [10]
Competence of designer	
Support from senior decision makers	
Relationships among stakeholders	
Innovative technological approaches	Chan et al. [5]
Early involvement of stakeholders	
Competence of project team	
Project team motivation	Kog and Loh [11], Chan et al. [5]
Communication among participants	Hwang and Ng [9]
Advanced machinery and equipment	Li et al. [13]
External environment	
Socio-political environment	Kog and Loh [11]
Type of the project	
Project size	Kog and Loh [11]

for Green Mark certified projects in Singapore. Kog and Loh [11] distinguished the importance of factors from different perspectives of stakeholders and pointed out that competence of stakeholders, project team motivation, socio-political environment, and project size are influential in project delivery. Chan et al. [5] suggested that innovative technological approaches and project team motivation are necessary to reduce possible cost in green building projects.

By reviewing the literature, it is evident that the most relevant CSFs differ from various perspectives. From a holistic view, this study extracts 16 critical success factors for developing green buildings on the basis of the above literature review, which is summarized in Table 1.

2.2 *Green Technical Capabilities and Barriers for GB Development*

Project stakeholders' performance in GB projects largely relies on their green technical capabilities. Specifically, the dimensions of green technical capability are related to aspects such as energy systems, ventilation, water use, natural light use, landscaping, green roofs and walls, low-emitting materials, and waste reduction [28]. Green building rating systems such as LEED and TREES can serve as a guide for incorporating best-in-class green strategies into project implementation and obtaining certification can raise the profile of industry participants. Thus, the experiences in meeting requirements and applying the certification of the rating systems are indispensable green technical capabilities [27]. Integrating the use of renewable energy sources (e.g., solar) with compatible designs and advanced technologies such as green materials to improve the energy efficiency in heating and cooling is a significant technological innovation direction of green building intensification [16]. Technological advancement is another fundamental driver to green building development.

There are still many barriers, such as higher cost, that prevent project stakeholders from adopting GB technologies and improving their green technical capabilities. Chan et al. identified 21 drivers and 12 promotion strategies for adopting GB technologies in construction [5]. According to their findings, among the promotion strategies for GB technologies adoption, "financial and further market-based incentives", "availability of better information on cost and benefits of GB technologies", "mandatory governmental policies and regulations", and "green rating and labeling" ranked in the top four.

2.3 Empirical Research Questions

Although there are many studies that have revealed the status, success factors, and rating systems of GB, the majority focus on developed countries and regions, and there is a clear need to learn the status of GB in developing countries. Thus, the objectives of this study are to systematically outline the overall picture of the GB industry in Thailand and provide a sound basis for revealing the drivers of the industry. Understanding the holistic status can help project participants adopt appropriate strategies to successfully promote GB in the emerging markets of developing countries. To achieve this, the relevant themes that need further investigation have been elaborated:

What is the importance of the critical success factors of green buildings in Thailand?
What is the importance of project participants' green technical capabilities in Thailand?
What are the barriers to green buildings in Thailand?
What are the actual performances of green buildings in terms of cost, time, and quality in Thailand?

3 Research Methods

3.1 Questionnaire Survey

A questionnaire was used as the data collection method. The questionnaire was divided into three parts. The first part related to the respondents' general information such as the role of work, professions, and experience involved in green buildings. The second part required the respondent to give a specific green building project's characteristics, including location, type of rating systems, project classification, type of owners, and delivery method. The third part asked respondents to evaluate on five-point Likert scale. The following part contained four groups of questions, which arose from the literature review, to estimate: (1) the importance of 16 critical success factors of GB in Thailand, (2) the importance of 14 indicators of green technical capabilities, (3) nine indicators of the barriers to green building, and (4) three indicators of project performance on a five-point Likert scale.

The number of the returned questionnaire is 38. The response rate is 54.3%, which is acceptable. There were 145 projects and 30 projects in Thailand that had successfully applied for LEED and TREES, respectively [23] by the end of June 2018. The questionnaires were sent to professional consultants and designers (architects and engineers) with experience in LEED or TREES projects in Thailand. There were a total of 70 questionnaires sent out, by email and personal delivery. Thirty-eight questionnaires were received, with an acceptable response rate of 54.3%. 52.6% of respondents have more than five years of work experience in the green building industry. More than 40% of the respondents are architects, while engineers and GB consultants account for 28.9%, respectively. Considering the total number of green building projects in Thailand, the distribution and green building experience of the respondents could, to a large extent, be taken to be representative of the whole green building industry in Thailand.

3.2 Data Analysis Techniques

The collected data from the questionnaires were analyzed using the Statistical Package for Social Science (SPSS 19.0). The survey results were analyzed by using: (1) a reliability test, (2) estimation of the sample population mean, and (3) rank cases.

Cronbach's alpha coefficient is used to assess the reliability and validity of the data [15]. The value of Cronbach's alpha between 0.6 and 0.7 can be considered as sufficient and the value greater than 0.7 is regarded as good. Spearman rank correlation results are tested by a significance level, with the hurdle of significance following the usual level of 0.05.

4 Survey Results

4.1 Descriptive Statistics of Sampled GB Projects

The characteristics of the 38 sample projects are summarized, which serve as the background for interpreting the following survey outcomes. The proportions of the investigated cases choosing LEED and TREES as their rating systems are 55.3 and 44.7%, respectively. As for GB certification level, certified level and gold level account for 36.8%, respectively, followed by platinum level (21.1%), and silver level (5.3%). When it comes to building type, the majority of projects are office buildings (52.6%), followed by commercial buildings, (21.1%) educational buildings (13.2%), and residential buildings (10.5%). Most of the cases used DBB project delivery approach (81.6%), while 18.4% of the investigated projects adopted design and build (DB) approach.

4.2 Critical Success Factors of Green Building

The respondents were asked to rate the importance of the identified CSFs in green building projects on a five-point scale, ranging from "1 = not important" to "5 = very important". The results are presented in Table 2.

As seen in Table 2, overall, competence of GB consultant, competence of designer, competence of project teams, and competence of contractor are the top four factors. These show that not only the competence of individual participant but also the integration of the project team is critical in fulfilling planning, design, and construction tasks of green building at different stages. It is notable that economic environment is ranked as the fifth important factor, which shows that external economic conditions can greatly impact the green building industry. Good global and local economic climates can create new demand and supply in a green building market. This will stimulate developers' investment in green building projects and relevant technical innovation, as the increased purchasing power can facilitate the investors in obtaining satisfactory paybacks.

4.3 Green Technical Capabilities

The respondents were asked to rate the importance of the identified technical capabilities related to green building on a five-point scale ranging from "1 = not important" to "5 = very important". The results are presented in Table 3.

Referring to Table 3, "experienced in LEED/TREES rating systems" ranked first, and "experienced in applying certification of LEED/TREES" also had a high rank of the third. These show that understanding and meeting the requirements

Table 2 Ranking of critical success factors in green buildings

	Overall	GB consultant	Architect	Engineer
Competence of GB consultant	4.42	4.91	4.25	4.18
Competence of designer	4.32	4.45	4.31	4.18
Competence of project team	4.32	4.55	4.19	4.27
Competence of contractor	4.16	4.36	4.13	4
Economic environment	4.13	4.36	4.31	3.64
Competence of project manager	4.08	4.09	4	4.18
Project team motivation	4.03	4.09	4.19	3.73
Support from senior decision makers	4	4.09	4.13	3.73
Communication among participants	3.92	4.09	3.88	3.82
Socio-political environment	3.89	4.09	4	3.55
Early involvement of key participants	3.76	3.91	3.75	3.64
Innovative technological approaches	3.74	3.64	3.81	3.73
Use of advanced equipment and materials	3.58	3.36	3.88	3.36
Type of the project	3.55	3.36	3.5	3.82
Relationships among participants	3.47	3.36	3.63	3.36
Project size	3.47	3.45	3.31	3.73
Average	3.93	4.01	3.95	3.81

Note: *M* mean; *R* rank; *Cronbach's alpha* 0.824

of LEED/TREES rating systems are critical capabilities for project participants to achieve the goals of green building. All of the ratings were higher than 3.6, and the average score of the green technical capabilities was 4.11, showing that all of the specific green technical capabilities were important in the delivery of green building projects.

4.4 Barriers to Green Building

To learn the status of barriers to green building in Thailand, respondents were asked to rate the relevant indicators on a five-point scale ranging from “1 = strongly disagree” to “5 = strongly agree”. The results are presented in Table 4.

As seen in Table 4, “lack of motivations from owners” and “high initial cost” are ranked as the first and the second barriers to GB, respectively, showing that financial pressure is the main concern of the owners. The results also demonstrate that a lack of government support, the high expense of preparing LEED/TREES documentation, and the lack of training and education in the industry are also the key barriers to GB in Thailand.

Table 3 Importance of green technical capabilities

	Overall	GB consultant	Architect	Engineer
Experienced in meeting requirements of LEED/TREES	4.55	4.73	4.31	4.73
Skilled in energy systems	4.42	4.64	4.44	4.18
Experienced in applying certification of LEED/TREES	4.37	4.73	4.31	4.09
Skilled in using ventilation methods	4.29	4.45	4.13	4.36
Skilled in using natural light methods	4.13	4.36	4	4.09
Skilled in using low-emitting materials	4.13	4.09	4.06	4.27
Skilled in water use	4.11	4.27	4	4.09
Skilled in low environmental impact techniques	4.05	4.27	3.94	4
Skilled in pollution prevention and waste reduction	4.05	4.36	3.94	3.91
Skilled in landscaping	4.05	4.27	4	3.91
Skilled in using renewable energy	3.97	4	3.88	4.09
Skilled in using green roof and wall	3.87	3.64	3.81	4.18
Skilled in using recycled materials	3.84	3.91	3.75	3.91
Innovation in using materials	3.68	3.64	3.63	3.82
Average	4.11	4.24	4.01	4.12

Note: *M* mean; *R* rank; *Cronbach's alpha* 0.933

Table 4 Ranking of barriers to green buildings

	Overall	GB consultant	Architect	Engineer
Lack of motivations from owners	4.39	4.45	4.38	4.36
High initial cost	4.21	4.27	4.06	4.36
Lack of government support	4.21	4.55	4.25	3.82
The high expense of preparing documents for LEED/TREES certification	3.92	4.09	3.75	4
Lack of training and education in the industry	3.82	4.18	3.81	3.45
Long payback period	3.79	3.91	3.69	3.82
Lack of green technologies	3.24	3.18	3.38	3.09
Lack of green products suppliers	3.21	3.18	3.44	2.91
Lack of skilled workers	3.11	3	3.25	3
Average	3.77	3.87	3.78	3.65

Note: *M* mean; *R* rank; *Cronbach's alpha* 0.721

Table 5 Green building performances

	Overall	GB consultant	Architect	Engineer
Quality	4.26	4.55	4.13	4.18
Schedule	3.79	4	3.75	3.64
Cost	3.24	3.36	3.43	2.82
Total	3.76	3.97	3.77	3.54

Note: *M* mean; *R* rank; *Cronbach's alpha* 0.607

4.5 Green Building Performance

To learn the ultimate GB performance in Thailand, respondents were asked to rate the performances of quality, schedule, and cost on a five-point scale ranging from "1 = very low" to "5 = very high". The results are presented in Table 5.

The results show that the overall rating of green building performances is 3.76, suggesting that there is room for the project participants to improve green building project delivery in Thailand. Specifically, the cost performance is rated the lowest, showing the difficulty in green building cost management.

5 Data Analysis and Discussion

5.1 Factor Analysis on CSFs of Green Building

To discover the underlying patterns of CSFs of green buildings, factorizing the CSFs above into a smaller number of groupings is necessary. The results of factor analysis are presented in Table 6. The KMO value of the CSFs is 0.592, and the significance level of Bartlett's test of sphericity is 0.000 ($p < 0.01$), indicating that the data were suitable for factor analysis.

Based on eigenvalues-greater-than-one [7], after Varimax rotation, five underlying components were extracted, and these components cumulatively explain 72% of the total variance. These five components are discussed below.

5.1.1 Competence of Project Participants

Competence of project participants consists of competences of project manager, GB consultant, contractor, designer, and project team, accounting for 16.78% of the total variance. GB consultants play a critical role in understanding owners' expectations and transforming them into specific requirements and objectives. Designers (including architects and engineers) need to conduct integrated building system design by considering sustainable site development, energy, and water efficiency, use of green

Table 6 Factor profile of CSFs for green buildings

Factor structure	Factor loading	Variance explained	Cronbach's alphas
Competence of project participants		16.78%	0.791
Competence of project manager	0.734		
Competence of project team	0.705		
Competence of consultant	0.693		
Competence of contractor	0.653		
Competence of designer	0.615		
Integration of project team		16.58%	0.805
Relationships among participants	0.858		
Communication among participants	0.814		
Early involvement of key participants	0.729		
Support from senior decision makers	0.533		
Technical and management innovation		16.13%	0.78
Project team motivation	0.793		
Innovative technological approaches	0.785		
Use of advanced equipment and materials	0.632		
External environment		13.23%	0.822
Socio-political environment	0.914		
Economic environment	0.824		
Project characteristics		9.43%	0.624
Type of the project	0.897		
Project size	0.737		

material, and indoor environmental quality. Accordingly, contractors execute and complete the works for the purposes of the green building. Each participant's competence is significant to fulfill the specific tasks in delivering green building projects. Compared to conventional projects, implementation of green building projects will encounter problems arising from the use of new technologies and materials [13]. This requires project participants to cooperate with each other in facilitating project team's capability, which significantly depends on the competence of the project manager. The project manager may face various challenges in a green building project, such as longer time, higher cost, and construction conflicts [8]. In dealing with these challenges, the project manager should be skilled in planning, organizing, leading, and controlling the processes of green building project, thereby enhancing the overall capability of the project team in problem resolution.

5.1.2 Integration of Project Team

Integration of a project team includes relationships among participants, communication among participants, early involvement of key participants, and support from senior decision makers. Green strategies increase the complexity of project delivery, requiring increased interdisciplinary interactions among participants to find optimum solutions [12]. Good relationships form the foundation to integrate diverse GB project activities by facilitating the resource inputs of participants. In integrating various resources, efficiently sharing project information in the team is critical, which is largely decided by the effectiveness of the communication among the participants. Open communication can not only help team members understand an owner's expectations and participants' specific requirements but also assist in the implementation of the generally interdependent processes of design, procurement, and construction.

Early involvement of the key participants is an important attribute of green team integration, which can greatly facilitate designers to seek cost-effective solutions by a value engineering approach with added information from the key players. Support from senior decision makers is also critical to integrate the project team. The team leader plays a role in facilitating inter-organizational cooperation, communication, and coordination by chairing a design charrette, value engineering, and seeking ways of resolving key project problems. Moreover, with the support from senior decision makers, necessary resources such as money, manpower, and equipment can be efficiently allocated and integrated in the implementation processes of green building projects. This is in line with the finding that continuous support by senior management of the owner is a critical success factor in green buildings [2].

5.1.3 Technical and Management Innovation

Technical and management innovation contains project team motivation, innovative technological approaches, use of advanced equipment and materials. After the contracts have been awarded, the project team can be assembled to achieve the goals of green building. However, the priorities of participants are different, which is attributed to the fact that each party tends to focus on its specific task [21]. Even if an alternative is suitable to one participant from an isolated perspective, it may not be an optimum option from a holistic viewpoint [3]. Therefore, owners need to motivate the project team to closely cooperate with each other through using incentives. Financial incentives may not only encourage participants to establish links across organizational boundaries, for efficiently sharing project information, but they can also ensure the participants have the necessary resources to continually seek better ways to achieve project goals with high performance [22]. The owner's willingness to allocate a higher budget in green building than in a conventional building can greatly encourage the project participants to use innovative green technologies and apply advanced equipment and materials. In the long term, good performance and technological advancement can help participants to win an owner's trust and to improve their industry image, thereby obtaining more business opportunities in the future. Most of the cases were based on selective biding/prequalification or negotiation in awarding contracts, showing that good reputation can assist designers and contractors to expand their share of the green building market in Thailand.

5.1.4 External Environment

External environment includes the socio-political environment and economic environment. These factors are closely related to society's attitude toward green products, government's involvement, and the status of the economy. The higher upfront cost can significantly affect a society's keenness for green building, as the public lack real knowledge on the improved performance of green building such as energy saving, increased water efficiency, and better indoor air quality. A society's preference largely decides the market demand which is the key driver for an owners' investment in green buildings. The economic environment can also have significant impact on development of green building. Good economic conditions can not only improve an owners' financial capacity in project development, but also enhance the purchasing power of the green building market. Notably, 73.7% of the surveyed cases were invested by private sectors, indicating that the green building market in Thailand can provide satisfactory products to consumers and create feasible financial return to investors.

Government can play an interface role in many aspects for promoting green building, such as public education, regulatory support for project development permission, tax deductions, and financial incentives for green technological advancement. For instance, the new City Planning Act in Thailand is an effective stimulus for green building, which provides the developers with incentives such as giving them more space for the construction.

5.1.5 Project Characteristics

Project characteristics contain the type of the project and project size. Different types and sizes of the project require different design and construction skills and different management strategies. 52.6% of the investigated cases are office buildings, which have the largest share in the green building market in Thailand. 86.8% of the investigated cases were new construction which is attributed to the fact that the green strategies can be cost-effectively executed from early stages. Nevertheless, renovation buildings account for 13.2% of total share, indicating that there is a considerable market need to change conventional buildings to green buildings in Thailand. The surveyed cases are medium to large in size, with many standardized units such as office, commercial, educational, and residential buildings. This enables green equipment and materials to be used on a large scale, which facilitates reducing the cost of green buildings.

5.2 *Factor Analysis of Green Technical Capabilities*

Factor analysis was conducted on the green technical capabilities of participants, with the results presented in Table 7. The KMO value of the green technical capabilities was 0.845 ($p < 0.05$), implying the appropriateness of factor analysis. Three underlying components are extracted, and these components cumulatively explain 74.4% of the total variance. These three components are discussed below.

Table 7 Factor profile of green technical capabilities

Factor structure	Factor loading	Variance explained	Cronbach's alphas
Technical skills in green building		33.82%	0.933
Skilled in pollution prevention and waste reduction	0.871		
Skilled in low environmental impact techniques	0.854		
Skilled in water use	0.818		
Skilled in energy systems	0.776		
Skilled in using natural light methods	0.767		
Skilled in using ventilation methods	0.620		
Skilled in landscaping	0.568		
Use of green materials		28.98%	0.911
Innovation in using materials	0.842		
Skilled in using low-emitting materials	0.809		
Skilled in using green roof and wall	0.798		
Skilled in using recycled materials	0.758		
Skilled in using renewable energy	0.709		
Familiarity with green building rating systems		11.65%	0.586
Experienced in meeting requirements of LEED/TREES	0.837		
Experienced in applying certification of LEED/TREES	0.815		

5.2.1 Technical Skills in Green Building

Technical skills in green building involve energy systems, ventilation, water use, pollution prevention, waste reduction, natural light use, landscaping, and low environmental impact techniques. “Skilled in energy systems” is ranked as the second most important green technical capability (see Table 3), which is attributed to the buildings consuming a large share of energy. Project participants should be good at not only energy efficiency techniques (such as whole building energy simulation, cooling, and heating applications), but also optimally combining these techniques with compatible building design and materials (e.g., the use of natural light and solar heating). “Skilled in using ventilation methods” is ranked as the fourth most important green technical skill (see Table 3), which can help improve indoor air quality and reduce energy consumption by using technologies such as natural ventilation. Although Thailand is not water-deficient, the respondents still consider “skilled in water use” to be important for green building, especially on indoor water use reduction. It is also important that participants are capable of reducing the negative externalities of buildings at both the construction and operation stages by applying low environmental impact techniques. Landscapes with the green feature can not only improve the attractiveness of the communities in which the buildings are located; they also play roles in reducing water use in irrigation and protecting the natural environment.

5.2.2 Use of Green Materials

The use of green materials is related to pollution reduction and energy efficiency. As many building materials create toxic emissions such as carcinogens, irritants, and odors, project participants who are skilled in using low-emitting materials can largely avoid indoor air pollution, which is critical to users’ health. Due to construction being intensively resource-consuming, designers’ applying environmentally friendly materials (e.g., recycled materials) to green buildings can effectively help reduce human activities’ pressure on the natural environment and avoid damage to natural resources such as forests and minerals, thereby decreasing greenhouse gas emissions [4]. The use of green roofs and walls is closely related to the utilization of renewable energy, especially solar power. Both architects and engineers can play an important role in integrating green roof and walls with using solar energy. For example, solar water heater/solar PV can be parts of roofs, and optimized building structures combining with thermal insulation materials can enable solar radiation heat and daylight to be efficiently received. It is necessary for project participants to continuously encourage innovation in green materials in order to reduce costs during the construction, operation, and maintenance stages.

5.2.3 Familiarity with Green Building Rating Systems

Familiarity with the green building rating systems includes "experience in meeting the requirements of LEED/TREES" and "experience in applying certification of LEED/TREES." These two green technical capabilities are ranked as first and third most important, showing the criticality for project participants to be good at LEED/TREES in delivering green buildings. LEED and TREES are recognized as effective green building assessment tools in Thailand. More than half (55.3%) of the investigated cases used LEED as their green building rating systems, showing that LEED is popular in Thailand. This might be because the application for the LEED can not only improve the value of the green buildings, and it can also raise the international profiles of investors. Considering that TREES were founded in 2010, 44.7% of the surveyed cases applied TREES, demonstrating that the native rating system incorporating local features has also diffused well within the green building industry of Thailand.

5.3 Factor Analysis of Barriers to Green Building

Factor analysis was conducted on the barriers to green building, with the results presented in Table 8. The KMO value of the green technical capabilities is 0.612 ($p < 0.05$), indicating that the data were suitable for factor analysis.

Table 8 Factor profile of green technical capabilities

Factor structure	Factor loading	Variance explained	Cronbach's alphas
Technical limitation		22.46%	0.707
Lack of green product supplier	0.791		
Lack of skilled workers	0.785		
Lack of green technologies	0.712		
Financial pressure		20.93%	0.674
Long payback period	0.841		
High initial cost	0.732		
High expense of preparing documents for LEED/TREES certification	0.698		
Inadequate promotion		17.66%	0.548
Lack of government support	0.778		
Lack of training and education in the industry	0.662		
Lack of motivations from owners	0.649		

5.3.1 Technical Limitation

Technical limitations include a "lack of green product suppliers", "lack of skilled workers", and "lack of green technologies". As Thailand is a developing country, its green building market is still immature. This leads to that some LEED/TREES-approved green technologies and products being unavailable in the locality.

5.3.2 Financial Pressure

Financial pressure includes a "long payback period", "high initial cost", and "high expense of preparing documents for LEED/TREES certification." High initial cost is ranked as the second (tied) major barrier to green building (see Table 4). This can be explained by the survey results of project performance (see Table 5), in which the cost performance is the lowest (score = 3.24) compared with quality performance (score = 4.26) and schedule performance (score = 3.79). Specifically, nine of 38 surveyed cases have very poor cost performance, showing that cost control is the major difficulty encountered by the project teams during project delivery. Due to the high upfront investment and uncertainty in cost control, it is not surprising to hear the owners' concerns about a long payback period in developing GB projects. Compared to conventional projects, applying LEED/TREES certification incurs extra costs in preparing complex documents and hiring LEED/TREES consultants, which can also be an obstacle to GB.

5.3.3 Inadequate Promotion

Inadequate promotion contains a "lack of government support", "lack of training and education in the industry", and "lack of motivations from owners". "Lack of motivations from owners" is ranked as the first barrier to GB (see Table 4), which is largely attributed to the high financial pressure on investment as mentioned above. "Lack of government support" is ranked as the second (tied) barrier (see Table 4), showing that the government's support such as promulgating relevant laws and policies, and providing financial incentives are critical in promoting GB. There are varying regulatory approaches employed by lawmakers and different levels of government (e.g., federal, state, county, and local) to develop green buildings, which can be categorized into three approaches [1]. The first one is to require all public construction projects to meet certain green criteria such as LEED. These laws, and their corresponding public projects, help to raise awareness of sustainable design practices and showcase the benefits of green buildings, especially to the private sector builders. The second approach is to create incentives for privately developed green projects, such as providing tax credits to developers and consumers and accelerated permits for developers. Authorizing expedited permitting for GB can particularly appeal to developers who have been overburdened by time-consuming and cumbersome permitting processes. The final, and most striking method of regulations, is to require that all new construction projects over a certain square footage, both private and public, meet certain green standards. Such laws have been enacted in several major cities such as Boston and Los Angeles. Thailand also has embraced this method to spur large-scale green development. In July 2017, the Department of Alternative Energy Development and Efficiency ("DEDE") has launched Thailand's first compulsory building energy consumption standards, namely the Green Building Energy Code ("GBEC") [6]. The GBEC established certain standards and specifications related to the building envelope, electrical lighting system, air-conditioning system, water heating, overall energy consumption, and renewable energy outfitting within the building, which all of the large buildings' design and construction must follow. It is estimated that 74 million units of electricity would be reduced if stricter standards were applied to energy consumption in larger buildings in Thailand [19].

As the green building development is still in its early stages in Thailand, training and education in the industry have much room to improve. Both professional training and public education are essential to make the whole society realize the long-term economic, environmental, and social value of GB. Previous studies have shown that social influence or social norms can significantly affect people's behaviors in energy use, suggesting that normative-based intervention can be an effective way to educate the public to change their attitude toward green buildings and their behaviors in energy consumption. For example, sending the occupants automated non-invasive personalized normative feedback and educational messages on their energy use and comparing it with the energy consumption in a green building could be plausible to help them realize the long-term benefit of GB in saving energy and protecting the environment.

6 Conclusions and Managerial Implications

Clearly, green buildings will become more and more mainstream in the future because of its advantages such as reducing greenhouse gas emissions and energy assumptions, especially in developing countries where environment pollution has become a serious problem. This study aims to systematically reveal the status of the GB industry in terms of the critical successful factors, the use of green technologies, and the barriers to GB in Thailand, from the perspectives of consultants, architects, and engineers. The major findings are as below.

Factor analysis shows that the CSFs of green building are mainly related to competence of project participants, integration of team, technical and management innovation, external environment, and project characteristics. Overall, competences of consultant, designer, project team, and contractor are the top four CSFs, showing that enhancing both competence of individual participant and integration of project team are critical in fulfilling tasks of green building. It is notable that economic environment can greatly impact green building industry, attributing to good global and local economic conditions can create new demand and supply of green buildings. The results demonstrate that, to transform green building business to a mainstream market, all project participants should continuously improve their competences via technical and management innovation for delivering affordable and sustainable products to the customers.

The analysis of green technical capabilities shows that project participants should emphasize improving technical skills in green building, use of green materials, and familiarity with green building rating systems. Specifically, project participants should be good at not only energy efficiency techniques (such as whole building energy simulation, cooling, and heating applications), but also optimally combining these techniques with compatible building designs and materials (e.g., use of natural light and solar heating). The results confirm that understanding and meeting the requirements of LEED/TREES rating systems are essential capabilities for project participants to achieve goals of green building.

Barriers to green building mainly arise from financial pressure, technical limitation, and inadequate promotion. "Lack of motivations from owners" and "high initial cost" are ranked as the top two barriers to green building, which is in line with the lowest rating on cost performance. In addition to financial pressure, unavailability of LEED/TREES-approved green technologies, products, and skilled workers in locality is also an obstacle, attributing to that green building development is still at the early stage in Thailand. "Lack of government support" is ranked as the second (tied) barrier, showing government's criticality in promoting green building. Government can boost green building by promulgating sustainable building criteria, providing favorable investment conditions, setting research grants and subsidies for green technical innovation, directly investing in green building projects, and supporting professional training and public education.

The above insights contribute to the body of knowledge regarding both theoretical and practical perspectives. Firstly, this study highlights the key issues regarding the GB industry in Thailand by identifying and empirically investigating the CSFs for GB, the green technical capabilities, and barriers to GB in Thailand, which helps practitioners learn the status of GB market. Secondly, the results collectively reveal that the market demand and technology advancement are the fundamental drivers to the GB industry, and the government, economic conditions, education, and corporate social responsibility are other stimuli to the industry. The findings from this research can be extendable to other developing countries and provide a valuable research and practical reference, especially for project practitioners and policymakers to make appropriate strategies to achieve better GB performance. Specifically, future policy emphasis should focus on investing the needed resources into stimulating the market and supporting the technology advancement, which is one of the most effective methods of improving GB infrastructure. Thirdly, regarding the green technical skills, the findings suggest that project participants should make efforts to improve their knowledge and skills in the use of energy, ventilation methods, natural light methods, and low-emitting materials.

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What is Stopping the Adoption of Sustainable Residential Buildings in Malaysia?

AbdulLateef Olanrewaju, Cheang Shi Min, Shalini Sanmargaraja and Vignes Ponniah

Abstract Researchers and the government have advocated for the delivery of sustainable building projects in Malaysia; however, the rate of demand and supply of the sustainable residential buildings has been low and the increase is slow. This research aims to examine the barriers towards the adoption of a sustainable residential building. This research conducted a cross-sectional survey using a questionnaire comprising 19 barriers to adoption of sustainable residential buildings administered on 110 professionals in the building industry. The research found that 89% of the responding housing professionals observed that there are barriers obstructing the adoption of sustainable residential buildings. The research found that a lack of experience on sustainable building projects by the industry, maintenance problems, lack of technology for the delivery of sustainable building projects, lack of competent labour in sustainable buildings, and the high capital cost of sustainable residential buildings compared with the conventional buildings are the five main barriers stopping the adoption of sustainable buildings in Malaysia. Based on the findings, it infers that the delivery of sustainable housing depends on the technological advancements, policies, competencies, awareness, homebuyers' experience, and costs. The research concludes by presenting a cycle of barriers for the rapid adoption of sustainable buildings. The findings provide feedback and feedforward information to the policymakers, design and construction teams, and manufacturers.

Keywords Green buildings · Technology · Developers · Whole life appraisal

1 Introduction

For a decade, the Malaysian government has initiated a number of measures to ensure that sustainable development goals are achieved in the construction industry. At the same time, there has been research that has established the need for the rethink-

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ing of strategies to implement sustainability in construction projects [9], examined the understanding of the concept of sustainability amongst property developers [18], assessed the readiness of the developers towards green home development [8], examined the barriers to adoption of sustainable buildings [14], evaluated the benefits of supplying sustainable housing [10], and investigated the reasons for the supply of sustainable housing [11] in Malaysia. In fact, Shari and Soebarto [14] described the multiple interests towards sustainable construction in Malaysia as 'top-down and bottom-up pressures'. Paradoxically, the rate of demand and supply of the sustainable housing has been low and slow, in both absolute and relative terms. For instance, there are six sustainable construction guidelines in Malaysia, and five of them are mainly for buildings projects. The number of certified buildings after completion and verification assessment (CVA) by Green Building Index (GBI) Malaysia which is considered as the most recognised by the industrial players and stakeholders for the last six years is less than 500 (Table 1). Whilst data for the previous years since the inception of the guideline in 2009 are not available, it is not difficult to argue that the total certified buildings are less than 200. However, whilst 2069 buildings have been certified to meet the design requirements, only 368 buildings have received the final certification after construction during the last six years. This represents less than 20%. Therefore, more than 6 million housing need to be upgraded to include green features.

Meanwhile, the total number of residential buildings in 368 buildings is only about 42%. Similarly, during this period, the certifications for the residential buildings are not renewed. It is also obvious that the increment rate is not fast. In fact, the Malaysian construction industry is entangled with sustainable practices and activities on account of numerous construction defects, delays, high costs and time overruns, increasing accidents on sites, volume of generated wastes, low productivity, pollution, labour exploitation and abuse, claims and disputes, and environmental degradation. A sustainable building is a building that is designed, constructed, operated, and maintained to address these problems. Consequently, from a research perspective, there is an urgent need to close this gap that exists between practice and research/theory. Therefore, this current research aims to investigate the barriers stopping the supply of housing. By so doing, it seeks to provide reference tools for government, industry, public, academic, and homeowners towards the provision and operations of affordable housing that is in compliance with the sustainability requirements in line with the global best practices. However, before moving on, we will make a clarification regarding the sustainable buildings. Some writers tend to distinguish between sustainable building and green building. Nevertheless, in this study, both terms and phrases are the same and they are used interchangeably.

Table 1 Summary of GBI-certified projects by year, on 15 December 2018

	2013		2014		2015		2016		2017		2018	
Sector	Total certified before CVA	Final certification after CVA	Total certified before CVA	Final certification after CVA	Total certified before CVA	Final certification after CVA	Total certified before CVA	Final certification after CVA	Total certified before CVA	Final certification after CVA	Total certified before CVA	Final certification after CVA
Total	190	17	265	30	335	51	377	66	435	86	467	118
Non-residential new construction	92	7	124	13	168	24	186	31	218	40	238	47
Residential new construction	84	5	122	11	138	17	158	25	178	36	187	59
Industrial new construction	2	2	5	3	9	4	9	2	11	2	13	4
Non-residential existing construction	7	2	7	2	10	4	13	6	13	5	13	5
Industrial existing building	1	1	1	1	3	2	3	2	3	2	3	2
Interior	–	–	–	–	–	–	–	–	1	1	1	1
Township	4		6		7	–	8		11	–	12	–

CVA Completion and Verification Assessment. *Source* GBI [5]

2 Theoretical Framework and Background

An extensive review of the literature revealed that sustainable development or sustainability has many interpretations but all the definitions have taken their roots from the definition and explanations put forward in a report of the Brundtland Commission [10]. The topical issues in the efforts towards sustainable development are the need to integrate economic, environmental, and social aspects in the decision-making [1, 4, 15] to increase productivity, enhance integration, reduce wastes, and increase well-being. The bottom line is that, in the current global scenario, we are currently consuming more than what the earth can productively support, and producing and discharging wastes that are far beyond what the earth can accommodate. At a practical level, sustainable development is a practice that integrates various criteria, including energy efficiency, community, waste minimisation, water efficiency, social impacts, good indoor environment, material control, ethic practices, zoning, pollution control, life cost, user-friendliness, and user comfort [12].

The impact of building construction and operation on sustainability issues is huge. For instance, buildings consume more than 40% of the world's energy, release one-third of the CO_2, use about 25% of harvested woods, release about 50% of fluorocarbons, produce 40% landfill materials, use 45% of the energy in operations, emit 40% of greenhouse emissions, and use 15% of the world's usable water. Olanrewaju et al. [10] explained that the production [brief, design, and construction] and use of sustainable buildings influence a variety of criteria, especially the materials, components, design, layout, and delivery process. The location, size, design, materials used, procurement strategies, maintenance, and operation of housing make the housing delivery threaten the fundamental aspects of sustainability. Sustainable buildings are cheap, efficient, attractive, pleasant, and satisfying because they help to (1) reduce water requirements; (2) use localised materials, components, and labour; (3) improve energy efficiently; (4) reduce traffic and transportation costs; (5) generate their own energy; and (6) contribute to the decarbonisation of the built environment. Because of the compelling benefits of sustainable buildings, many governments have made policies to increase the uptake of the supply and demand for sustainable buildings.

The Malaysian government and the construction industry recognise the need to increase the supply of sustainable construction projects (Government of Malaysia, 2010). In particular, in order to achieve the government's aim of incorporating green technology into the country's construction industry, policies and regulations have been established and green rating tools have been developed by the industry and government. The tools are the Green Performance Assessment System (Green PASS), Skim Penilaian Penarafan Hijau JKR (PH JKR), Malaysian Carbon Reduction and Environmental Sustainability Tool, (MyCREST), Green Real Estate (GreenRE), and Green Building Index (GBI). The Sustainable INFRASTAR, which aims to act as a design and measurement tool to ensure consideration of sustainable elements and is incorporated early on in the development of the project, was developed in 2018 [2]. The Sustainable INFRASTAR is specific to infrastructure projects other than the building portion. However, despite these efforts, the rates of supply and demand for the sustainable buildings have been low and slow. Corroborating this view, Olanrewaju et al. [10] found that the major impediment obstructing the adoptions, implementations, and practices of sustainability in construction project delivery is the lack of a concise and clear framework. Apart from the policies' formulations and implementations, and supported by the industry, research, which has been advocated for the adoption and implementation of sustainability in the construction industry, has been conducted [8, 14, 18]. However, despite the scientific activities and policies, and implementation with the support from the professional bodies, the adoption of the sustainable residential building is low and, further, the previous research is not specific to housing, but rather to the general buildings of the construction industry as a whole, and is qualitatively driven; and, hence, it is hindering the systemic decisions, generalisability, and applications. This research aims to fill this gap.

3 Research Design

The question that this research seeks an answer to is 'What are the barriers to the adoption of sustainable housing?' It is imperative to know the barriers in order to provide cogent measures to improve the uptake of sustainable buildings. The primary data collected were based on convenience sampling. Like other survey methods, it is inductive in nature. Convenience sampling is a data collection method where the survey is administered to available, accessible, and willing respondents. The method is appropriate where sufficient information on the population size and sample frame is not available. Its findings may not be generalisable; however, with a large number of respondents, the findings can be typical. Thus, its basic premise is that if sufficient data are collected and objectivity is maintained, the results will be a representative of the population.

The questionnaire consists of two sections, namely participants' demographic information and perceived barriers towards green building adoption in Malaysia. Thirteen questions were prepared for Section A, and thirty questions were prepared for Section B. The specific questions can be found in the following analysis.

The questionnaires were administered to the respondents through online surveys to the stakeholders in the building industry. The online survey was launched on 6 August 2018 and was open until 10 September 2018, but because of a low response rate, it was re-conducted on 1 November 2018 until 12 December 2018. The respondents were asked, based on their current evidence, to measure the extent to which the barriers obstruct the adoption of sustainable housing in Malaysia on a five-point Likert scale, where 1 = not critical, 2 = somewhat critical, 3 = critical, 4 = very critical, and 5 = extremely critical. The extent of the criticality of the barriers to obstruct the adoption of sustainable residential buildings was determined by the Average Relative Index (ARI) (Eq. 1).

$$\text{ARI} = \frac{\sum_{i=0}^{5} a_i x_i}{5 \sum_{i=0}^{5} x_i} \times 100 \quad (1)$$

where a_i was the index of a group; constant expressed the weight given to the group; x_i was the frequency of the responses; $i = 1$, 2, 3, 4, and 5; and described as below: x_1, x_2, x_3, x_4, x_5; the frequencies of the responses were corresponding to $a_1 = 1, a_2 = 2, a_3 = 3, a_4 = 4, a_5 = 5$, respectively. For interpretation, an ARI score of 1.00–20.00 was denoted as not critical, 21.00–40.00 was denoted as somewhat critical, 41.00–60.00 was denoted as critical, 61.00–80.00 was denoted as very critical, and 81.00–100.00 was denoted as extremely critical. There was a pooled difference of 1.0% between each of the scales. The barrier with the highest ARI score was the major barrier to the adoption of a sustainable residential building. All the constructs were positively worded. To ensure that the results would not be influenced by the authors, missing data were not replaced with either a mean or mode of the valid response. The mode technique was used to analyse the demography of the respondents. In order to test the hypotheses, whether each of the barriers could obstruct the adoption of sustainable buildings or not, one-sample t-test was conducted. The other statistical tests computed were the one-way t-test, Cronbach's alpha tests, validity, Kaiser-Meyer-Olkin Measure of Sampling Adequacy, Bartlett's test of sphericity, mode, standard deviation, or as the case may be. The mode was also used to determine the distribution of the respondents with respect to the scales. All data gathered adopted the SAS Enterprise Guide 7.1 for analysis.

3.1 Analysing the Results of the Survey

More than 3000 online survey forms were administered to the respondents; however, only 110 completed responses were received during the survey period, lasting more than three months. The results are presented in tables and figures and discussed in the following sections.

3.2 Demographic Profiles of the Respondents

Some 70% of the respondents obtained a minimum of B.Sc. degree (Table 2), and most (36%) of the respondents had their degrees in architecture and construction management (Fig. 1). The majority of those with Ph.D.s had their degree in architecture, and most of those with a B.Sc. had their degree in construction management. Most of the respondents held strategic positions (Table 3); more than 50% had more than 5 years of working experience (Table 4); approximately 12% had more than 20 years working experience. Most of the respondents worked with contracting organisations, whilst approximately 25% were with architectural firms (Table 5).

Table 2 Highest academic qualification

Qualification	Frequency	Cumulative percentage
PMR	1.00	0.91
SPM	22.00	20.91
Diploma	11.00	30.91
Degree	59.00	84.55
Master	6.00	90.00
Ph.D.	11.00	100.00

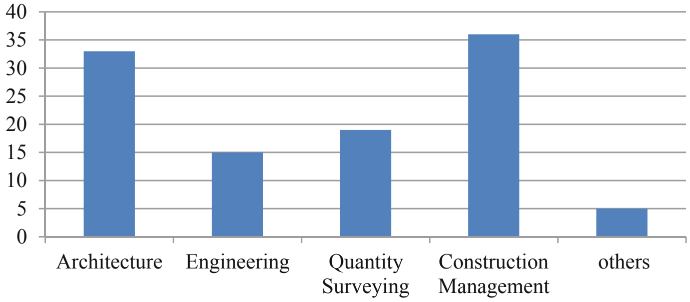

Fig. 1 Highest academic qualification

Table 3 Current position in the organisation

Position	Frequency	Cumulative percentage
Principal	5	4.545
Site coordinator	5	9.091
Architect	35	40.909
Engineer	17	56.364
Quantity surveyor	27	80.909
Project manager	6	86.364
Construction manager	8	93.636
Design manager	6	99.091
Plant manager	1	100.000

Table 4 Respondent’s working experience

Year	Frequency	Cumulative percentage
Less than 5 years	52	47.273
5–10 years	35	79.091
11–15 years	7	85.455
16–20 years	3	88.182
More than 20 years	13	100.000

Table 5 Respondent's type of organisation

Organisation	Frequency	Cumulative percentage
Property development	9	8.182
Contractors	37	41.818
Building material supplier	7	48.182
Bank	6	53.636
Architectural consulting firm	28	79.091
Engineering consulting firm	6	84.545
Quantity surveying consulting firm	17	100.000

The results revealed that most of the survey respondents were involved in the development of sustainable buildings at the design and construction phases (Fig. 2).

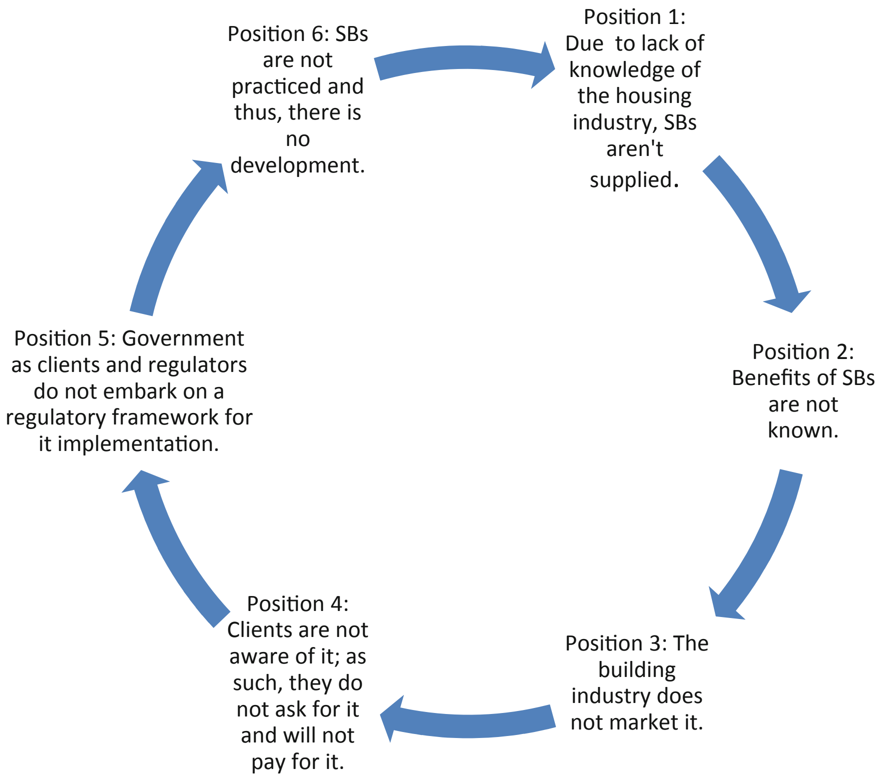

Fig. 2 Cycle of barriers

Based on their practical experience, close to 95% of the respondents confirmed that the price of sustainable buildings was higher than conventional buildings by more than 5% (Table 5). In fact, 15% of the respondents measured that sustainable buildings were expensive by more than 20% as compared to conventional buildings.

4 Survey Results

4.1 Analysis of the Barriers Stopping the Adoption of Sustainable Residential Buildings

The reliability test results indicate that the Cronbach's alpha for each of the barriers was 0.905, and the validity test, using the 'commonalities', returned a cumulative average of 0.689. Table 6 contains the t-test statistics to examine the measurements of the population with respect to each of the barriers. The null hypothesis was that each of the barriers will not stop the adoption of sustainable residential buildings (H0: U = U0) and the research hypothesis was that each of the barriers will stop the adoption of sustainable buildings (Hr: U > U0). U0 was the population mean. Two was set as the t-test level. Based on the results (Table 6), the significance (i.e. Pr > |*t*|) of each of the barriers (Hr: $U > U0$) showed that the all of the barriers was statistically significant. The degrees of freedom for all the factors were the same at 109. Furthermore, the small standard errors were close to zero. These suggest that the measurements of the respondents with respect to the barriers were reflections of the population. The KMO was very high (0.0852), and Bartlett's test significance is as follows: x^2 (171) = 1004.647, $p = 0.000$. These statistics suggest that the barriers will obstruct sustainable housing when drawn from a population with a similar background; hence, the information is suitable for the designed aim.

The average of the ARI values for all the barriers was 74.058, and the average standard deviation was 18.083 (Table 7). The standard deviation (SD) for the barriers, being less than 25, was also an indication of consistency. Furthermore, it is obvious that all the barriers based on the distribution of the ARI are very critical barriers in stopping the adoption of sustainable buildings because they fell within the ranges between 61 and 80. The plain interpretations of these statistics are that all the professionals in the housing industry measured that the barriers were those stopping the adoption of sustainable buildings. In particular, whilst 11% measured that the barriers were not critical or were somewhat critical in stopping the adoption of sustainable buildings, 23% agreed that they were actually critical. However, 66% knew that the barriers were very critical or in fact extremely critical in stopping the adoption of sustainable housing.

Table 6 One-sample test

Barrier	*t* Value	Pr > |*t*|	Mean difference	Lower	Upper	Std. error mean
High initial price of green residential buildings compared with conventional buildings	23.293	0.000	1.800	1.647	1.953	0.077
Research and development costs for green buildings	22.177	0.000	1.791	1.631	1.951	0.081
Longer construction time for green buildings	14.327	0.000	1.355	1.167	1.542	0.095
Lack of reliable cost and performance data	17.315	0.000	1.573	1.393	1.753	0.091
Lack of customer demand for green residential buildings	16.323	0.000	1.664	1.462	1.866	0.102
Technical difficulty during the construction process	16.403	0.000	1.509	1.327	1.691	0.092
Lack of relevant experience in green building projects	23.050	0.000	1.891	1.728	2.054	0.082
Lack of codes and regulations for green buildings	18.406	0.000	1.627	1.452	1.803	0.088
Lack of technology in green building projects	19.995	0.000	1.791	1.613	1.968	0.090
Lack of competent labour in green buildings	20.716	0.000	1.818	1.644	1.992	0.088
Lack of knowledge and training in green building projects	22.769	0.000	1.891	1.726	2.056	0.083

(continued)

Table 6 (continued)

Barrier	*t* Value	Pr > |*t*|	Mean difference	Lower	Upper	Std. error mean
Lack of quantitative evaluation tools for green performance	20.094	0.000	1.773	1.598	1.948	0.088
Low supply of green materials and components	19.651	0.000	1.709	1.537	1.882	0.087
Additional responsibility for construction maintenance	24.337	0.000	1.862	1.711	2.014	0.077
Divided interests; parties concerned with design and construction not associated with operators/users	19.070	0.000	1.600	1.434	1.766	0.084
Lack of enforcement	22.466	0.000	1.791	1.633	1.949	0.080
Lack of government support	20.274	0.000	1.745	1.575	1.916	0.086
Lack of public awareness	19.618	0.000	1.836	1.651	2.022	0.094
Weather conditions	11.248	0.000	1.182	0.974	1.390	0.105
Lack of strategy to promote green buildings	22.088	0.000	1.745	1.589	1.902	0.079

5 Discussion of the Findings

As previously stated, the degree of the criticality of the barriers to sustainable building delivery by the Malaysian housing market was based on the computation of the ARI. Therefore, the barrier with the highest ARI was the main barrier to the adoption of a sustainable building, whilst the barrier with the lowest ARI was the least of a barrier to sustainable building adoption. The research found the lack of experience of the Malaysian construction industry on the sustainable building as the main barrier. This finding seems to support Zainal Abidin [18] finding that the awareness of the sustainability/sustainable development by the Malaysian property sector was low. Although sustainable development has been around for many years, many industrial players are yet to fully comprehend its meaning, and in fact, many still cast

Table 7 Distribution of statistics

Barrier	Not critical	Somewhat critical	Critical	Very critical	Extremely critical	Reliability	Validity	ARI	SD
Lack of relevant experience in green building project	1	8	17	60	24	0.92	0.73	78.13	17.05
Additional responsibility for construction maintenance		6	25	56	22	0.93	0.48	77.38	16.04
Lack of technology in green building projects	3	9	17	60	21	0.92	0.74	76.64	17.91
Lack of competent labour in green buildings	3	7	19	59	22	0.92	0.76	76.64	18.32
High initial price of green residential buildings compared with conventional buildings	1	8	19	66	16	0.93	0.75	76.26	16.05
Lack of public awareness	3	7	24	47	29	0.92	0.76	76.26	19.64
Research and development costs for green buildings	2	5	26	58	19	0.92	0.75	76.07	16.81
Lack of enforcement	1	6	28	55	20	0.92	0.75	75.89	16.42
Lack of quantitative evaluation tools for green performance	3	9	17	62	19	0.92	0.69	75.70	18.43
Lack of government support	2	6	32	48	22	0.93	0.74	75.14	17.77
Low supply of green materials and components	3	9	21	61	16	0.92	0.70	74.77	17.66
Lack of strategy to promote green buildings	2	7	22	65	14	0.92	0.62	74.77	16.56
Lack of customer demand for green residential buildings	7	8	21	53	21	0.93	0.56	74.58	20.11

(continued)

Table 7 (continued)

Barrier	Not critical	Somewhat critical	Critical	Very critical	Extremely critical	Reliability	Validity	ARI	SD
Lack of codes and regulations for green buildings	2	13	24	56	15	0.92	0.73	72.71	18.51
Divided interests; parties concerned with design and construction not associated with operators/users	2	10	31	54	13	0.93	0.60	72.52	17.05
Lack of reliable cost and performance data	3	14	23	57	13	0.92	0.73	71.96	18.60
Technical difficulty during the construction process	3	14	31	48	14	0.92	0.67	70.28	19.30
Longer construction time for green buildings	6	13	37	44	10	0.93	0.57	67.85	19.38
Weather conditions	11	14	40	34	11	0.93	0.76	63.55	21.95

doubt on its purpose and whether it is achievable or not. However, this finding is compelling because it is only when the professionals in the building industry have gathered enough experience and are themselves convinced that they can 'market' the green buildings to home buyers and other stakeholders. Maintenance cost has been receiving serious attention lately as clients or homebuyers are now taking whole life appraisal of buildings instead of considering only the initial construction or purchasing cost. Therefore, it is not unexpected that the maintenance factor turned out to be the main barrier to the adoption of sustainable housing.

The sustainable buildings have different maintenance requirements, of which it seems the building industry is cognisant. The maintenance of the sustainable housing would be more challenging. A lack of technological resources to support the supply of sustainable buildings was cited as a major obstacle to the adoption of sustainable buildings. Examples of green building technologies for green housing include IBS, prefabricated concrete solar technology, and a rainwater harvesting system and recycle system. In order to promote the adoption of the sustainable buildings, there is a cogent need to have the technology that will supply the needed materials and components. In fact, it has been argued that to facilitate the adoption of green buildings, GBT must be embraced first [15]. One of the major reasons why sustainable buildings are expensive in Malaysia is because the cost of green materials and components is high since they are not available locally. To bring the cost of sustainable buildings down, a major area that needs attention is materials.

Normally, the cost of materials accounts for not less than 50% of the construction costs. It is interesting to find that the lack of competent labour in sustainable buildings comes next to the lack of technology and close to the lack of experience of building the industry on sustainable buildings. Green materials and components have different compositions as compared to conventional materials and components than the site operatives and professionals are familiar with; hence, a different set of skills and knowledge are required for the design, installation, and assembly of green materials and components. The housing industry will need to provide special training to site operatives on the construction of sustainable buildings.

Research and practice show that sustainable buildings are more expensive as compared to conventional buildings due to many causes, including the barriers discussed in this article. However, empirical evidence in countries including the UK, Australia, and the USA [12] suggests that the differential cost between sustainable buildings and conventional buildings is less than 5%. However, in Malaysia, more than 95% of the survey respondents measured that sustainable buildings were more than 5% higher to conventional buildings. In fact, 50% of the respondents believed that it was more than 15% more expensive than the conventional buildings. With this mind, it is not surprising that the high initial price of green residential buildings compared with the conventional buildings was also found to be a major barrier to the adoption in Malaysia. However, the high initial cost of green buildings as compared to conventional buildings was also found to be a major barrier in England [16]. Moving forward, the research found that homebuyers and home users are not aware of the sustainable buildings.

The general problems amongst the public are what sustainable buildings look like and how to define/describe them and how they benefit them. A lack of awareness of the benefits of green buildings was also a barrier in England [16]. To this extent, the building industry needs to promote and display sustainable buildings in order to create more awareness, especially on the success stories. Research and development costs turned out to be a major barrier to the adoption of sustainable buildings. In general, R&D in Malaysia is low. In fact, construction companies invest less than 1% of their turnover on R&D. This result is not different elsewhere. In Singapore, Hwang and Ng [7] also found the cost of R&D to be amongst the major barriers to green building adoption. For sustainable materials and components, which are mostly imported, it requires some research to examine their suitability and compatibility with the local contents. Some of the locally produced materials would require research to test their practicability and sustainability. This will require an investment in terms of time, expertise, and capital. Presently, there is no strict enforcement to promote or compel the building industry to implement sustainable materials and practices; as well, there are no regulations that compel a homebuyer or homebuyers to buy sustainable buildings. Needless to say, there are incentives for the housing industry and buyers to implement and practice sustainability, but penalties are not strictly enforced. Much of the research on sustainable construction has been qualitative. Consequently, many industrial players are not convinced regarding the benefits of sustainable housing.

One of the main motivators for the adoption of sustainable buildings is active government support. However, as the research indicates, government support is far from being enough. In fact, more than 50% of the respondents considered that government support was low. As previously explained, the technology is very critical for the supply of sustainable materials. Based on 63 in-depth interviews involving stakeholders in residential and mixed-use schemes, William and Dair [16] found that material shortages were a major barrier to green building adoption in England. These similar results were found in Singapore [7]. Therefore, it is not surprising that a lack or shortage of sustainable materials was found to be a barrier to the adoption of sustainable buildings. The research shows that the lack of clear strategies to promote the adoption of sustainable buildings was also a major barrier. The benefits of sustainable buildings need to be communicated to the potential homebuyers. It seems that the Malaysian government is yet to understand and promote the adoption of sustainable buildings. The government and the industry have much to benefit from if sustainable buildings are widely developed. For instance, in China, the government promotes sustainable building development more than the housing developers [4].

The CIDB Malaysia, the Ministry of Works, and other relevant agencies need to be proactive and aggressive in marketing the sustainable building development to organisations, architects, engineers, contractors, manufacturers, and suppliers. Workshops and training are required on the development process and operation of sustainable housing. Research shows that workshops/seminars, education/training, and periodical/magazines are the major sources of information for the active adoptions of sustainable [13]. Homebuyers and occupants need to be convinced of the benefits of sustainable buildings to heighten demand. Thus, it is not surprising to find that the lack of customers' demand for green buildings will stop its adoption. A recent research in Malaysia found that the main barriers to the adoption of commercial buildings were because clients did not require sustainable commercial buildings [14]. However, it is considered that clients are by nature inexperienced with the construction business and the benefits of sustainable buildings.

Hence, it is the responsibility of the industry to educate the clients and create the awareness. Clients will demand services or products once they are convinced of the benefits. Echoing the importance of regulations and codes, this research found the need for the availability of codes and regulations. This finding is consistent with the recent research that a barrier to sustainable construction in Malaysia was a lack of regulations [3]. Research also found that a lack of regulations, policies, and codes was amongst the barriers to green building adoption in Australia and Ireland [17]. Regulations that could be introduced for sustainable development include building energy codes, appliance standards, and land-use zoning. Through building codes, USD 1.1 billion was saved in 1998 in the USA and appliance and equipment efficiency standards led to cutting electricity consumption by 2.5% and carbon emission by 1.7% in 2000 [6]. A dominant problem in the construction industry is the fragmentation of the delivery process. Therefore, it is not surprising to find that the divided interests among the consultants, contractor, developers and buyers is a clear barrier to the adoption of sustainable buildings. In fact, the lack of consideration of sustainability by project team members was also found to be a major barrier to the adoption of green buildings [14].

To provide feedback and feedforward information to the design and construction teams and to convince stakeholders, especially the homebuyers, home users, and third-party agencies, data on the cost and performance of the existing sustainable buildings are required. In Malaysia, the 'success story' data seem to be lacking or not convincing. The design and construction teams are yet to be keeping such data. However, considering that more than 50% of the respondents measured that sustainable housing could be very expensive, it calls for concern. Difficulty in the construction of sustainable buildings is a problem for the adoption of sustainable buildings. This does not come as a surprise with the general lack of experience of the industry in sustainable buildings, lack of technology, and lack of performance data. There is no empirical research that suggests that sustainable buildings take more time to construct as compared to conventional buildings. Because of this, it is surprising that this research found that one of the main barriers to the adoption of sustainable buildings was the longer time required to construct sustainable buildings. A plausible explanation for this is due to the lack of supporting technology, lack of market, and the shortage of sustainable materials and lack of labour. It is equally surprising to find that the Malaysian weather is not friendly to sustainable building development. We are sceptical to interpret this finding. However, good weather may have a negative impact on the supply of industrialised building systems. For instance, because Malaysian is good and encourages site activities throughout the year, investment in IBS construction may not be encouraging.

6 Summary and Suggestions for the Construction Industry

It is extensively recognised that sustainability requirements need to be addressed, and government and stakeholders, including developers, contractors, and third-party agencies, have introduced measures towards these objectives. Yet, there is an apparent low demand and supply of sustainable residential buildings. This article has been able to identify and quantify the barriers stopping the adoption of sustainable residential buildings. Collectively, the reasons for the apparent low supply and practice of sustainable buildings on a greater scale can be summarised in the lack of knowledge and innovation in the construction industry, which could be summarised as the 'cycle of barriers' displayed in Fig. 2. The identification and analysis of the barriers can contribute towards developing a framework that supports and promotes the implementation of sustainable buildings in Malaysia. This study has both strategic and tactical implications because it provides feedback and feedforward information to the building industry and the government to achieve the sustainable development goals.

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Adoption of Green Building Practices in Pakistan: Barriers and Measures

Sana Azeem, Malik Asghar Naeem and Abdul Waheed

Abstract This chapter investigates the dimensions of green buildings observed in Pakistan along with the barriers inhibiting the adoption of green building in the local context as well as measures that could promote the uptake of this approach. Barriers and measures were identified and examined by using a combination of research methods, including literature review, a questionnaire survey, and in-depth interviews of construction industry practitioners working in Pakistan. Ranking and factor analysis were used to identify the significant issues associated with the adoption of green building practices. The survey results suggest that the most critical barrier is 'lack of awareness among people about the importance and advantages of adopting green building practices,' followed by 'lack of incentives from government' and 'lack of green building codes and regulations.' The analysis also indicates that the most important measure to promote the green building adoption is 'creation of public awareness toward green initiatives through seminars, workshops, and discussions,' followed by the 'availability of green building codes and regulations (mandatory to apply)' and 'financial incentives and penalties by the government (e.g., soft loans, taxes) for promoting green building practices.' The findings are expected to contribute valuable information to helping policymakers better understand some key issues and calling for more attention to the promotion of green building practices in Pakistan. The results are based on the perceptions of local stakeholders in Pakistan, while they might also be helpful for policymakers in other countries with similar conditions.

Keywords Green building · Barriers · Measures · Construction industry · Pakistan · Sustainable development

Notes: This chapter has been developed based on the following paper: Azeem et al. [4]

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1 Introduction

The construction industry makes up a significant proportion of GDP in the developed as well as developing parts of the world [6]. But at the same time, compared to sectors for any other infrastructural project or product type, the building sector alone is the largest consumer of electricity and natural resources. Global carbon emissions are expected to reach 42.4 billion tons by 2035, which is a 44.3% increase in the 2007 level [5]. Methods that are used to design and construct buildings today will not only have an impact on the present patterns of energy consumption and environmental degradation, but also have an immense direct and indirect impact on future generations [2]. To combat this situation, there is a need to construct buildings that have minimal effects on the surrounding environment and on human health. Currently, Pakistan is facing a number of environmental challenges (Sohail and Qureshi 2010). It has been a victim of severe energy crisis in recent years [1, 7]. Pakistan has a sunny, hot climate as it is situated on between 24°N and 35°N latitudes. Due to this climate, energy demands for cooling buildings are very high [10]. Pakistan is on the list of those countries that largely depend on thermal sources and generate most of their electricity from non-renewable sources. This practice is creating serious environmental problems, along with the rapid consumption of precious sources of energy [10]. To prevent a shortfall of electricity, there is a need to change current construction practices and move toward energy-efficient buildings, which has the potential to save up to 30% [1, 11]. Green design helps to reduce solid waste generation in construction by 70%, water consumption by 40%, and carbon dioxide emissions by 39% [3].

Unfortunately, in Pakistan, the green building approach suffers from many market barriers, despite its numerous benefits to society. The purpose of this research is to investigate the potential barriers inhibiting the adoption of green building and to explore measures that can be adopted to promote this approach in Pakistan.

1.1 Pakistan Green Building Council

Pakistan Green Building Council (PGBC) was founded in 2013. In Pakistan, green building practices are getting in stream of Pakistan construction industry through foreign industrial benefits or requirements. However, Pakistan Green Building Council took this initiative and provided a platform for national, international, and government bodies and organizations to gather on a single platform. Now, PGBC with the collective effort of nine bodies shown in Fig. 1 has developed country's first green building guidelines and the draft version of PGBG V-1 [8].

Currently, these practices are voluntary but believed to set sustainable building practices, standards, and awareness among masses. On the regulatory side, Pakistan has building code of Pakistan Energy Provision 2011 developed by National Energy

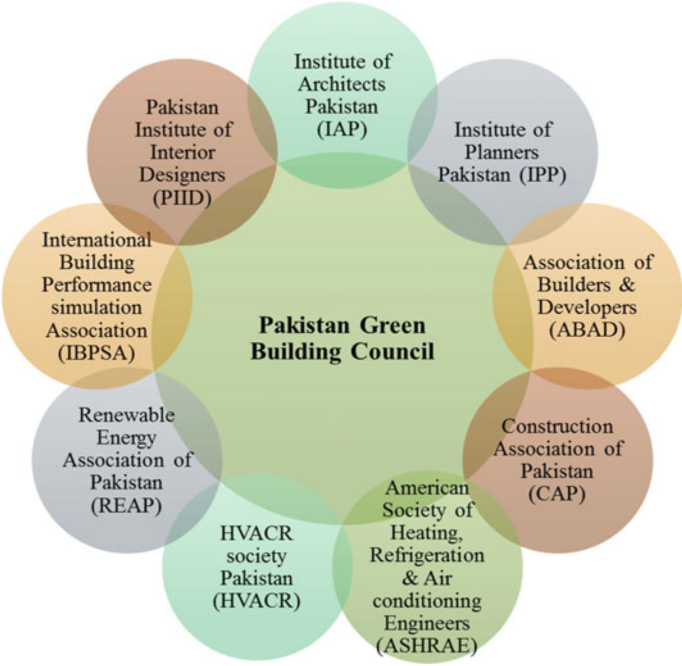


Fig. 1 Professional bodies of Pakistan

Conservation Centre (ENERCON) in collaboration with Pakistan Engineering Council.

1.2 *Pakistan Green Building Guidelines*

In Pakistan Green Building Guidelines, sustainability issues have been broken down into several environmental categories and further divided into key categories, and different credit points are allocated to these sections as shown in Fig. 2. In Pakistan Green Building Guidelines, energy and atmosphere section also got maximum points, i.e., 28 possible points.

1.3 *Green Buildings in Pakistan*

According to Green Building Information Gateway (GBIG), Pakistan contains 17 LEED-certified green buildings with 13 registered with US Green Building Council and 1 with achiever award, making a list of 31 total green buildings in the country.

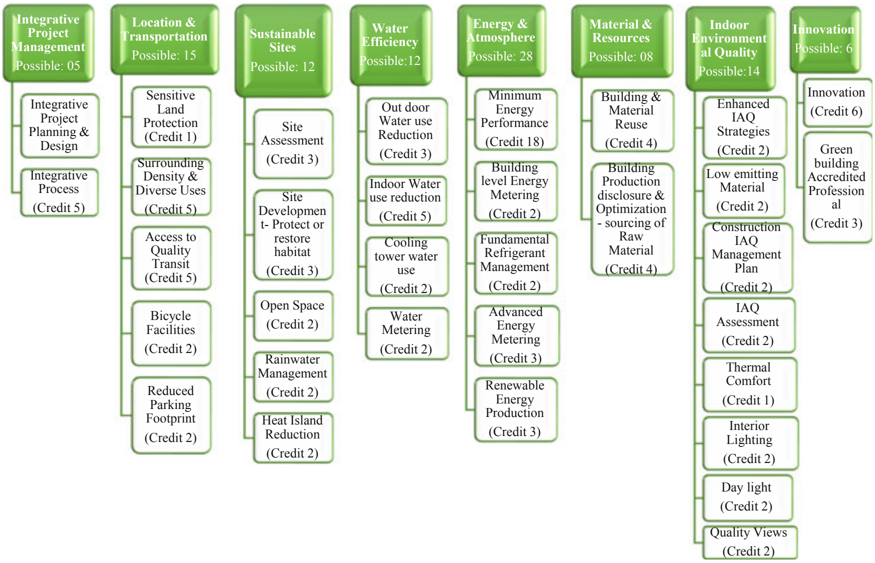


Fig. 2 Sustainability categories in PGBG

1.4 Dimensions of Green Buildings Observed in Pakistan

In order to examine the various dimensions of green buildings observed in Pakistan, five certified green buildings were selected, i.e., Artistic Garment Industries Pvt Ltd Karachi, Citibank Dolmen Karachi, Coca-Cola Icecek AS Multan Plant, British Council Library Lahore, and Artistic Fabric and Garment Industries Karachi. The data obtained from the building managers of all five buildings are discussed in this section.

- **Artistic Garment Industries (Pvt) Ltd** is an industrial manufacturing having an area of 14,837 m^2. It followed LEED for New Construction 2009 version and got 'Silver Certification' in 2016 by scoring 56 points out of 110. This building achieved 20% improvement in building performance by scoring 7 out of 35 points in energy and atmosphere section along with 5 out of 14 points in materials and resources, 6 out of 15 points in indoor environmental quality section, 19 out of 26 points in sustainable sites category, 100% points, i.e., 10 out of 10 points in water efficiency, 5 out of 6 points in innovation, and 4 out of 4 points in regional priority section.
- **Coca-Cola Icecek** is also an industrial manufacturing. This building has the largest covered area among all four buildings, i.e., 21,428 m^2. It followed LEED for New Construction 2009 version and got 'Silver Certification' in 2016 by scoring 52 points out of 110. This building scores 10 out of 35 points in energy and atmosphere section with 20% improvement on baseline building, 6 out of 14 points in materials and resources, 8 out of 15 points in indoor environmental quality section, 15 out of

26 points in sustainable sites category, 6 out of 10 points in water efficiency with half of reduction in total wastewater generation, 3 out of 6 points in innovation section, and 4 out of 4 points in regional priority section.

- **British Council Library Lahore** is a public assembly building having an area of 475 m^2. It followed LEED for New Construction 2009 guidelines and got 'Gold Certification' in 2017 by scoring 65 points out of 110 total possible points. This building scores 12 out of 35 points in energy and atmosphere section with 30% improvement on baseline building performance rating, 9 out of 14 points in materials and resources with 2.5% rapidly renewable materials, 11 out of 15 points in indoor environmental quality (two-third parts of building have accessed to daylighting with quality views), 18 out of 26 points in sustainable sites, 6 out of 10 points in water efficiency, 5 out of 6 in innovation, and 4 out of 4 in regional priority sections.
- **Citibank Pakistan** is having an area of 1347 m^2. It followed LEED for Commercial Interiors 2009 version and got 'Gold Certification' in 2016 by scoring 65 out of 110 points. This building scores 22 out of 37 points in energy and atmosphere section, 1 out of 14 points in materials and resources, 6 out of 17 points in indoor environmental quality, 17 out of 21 points in sustainable sites, 11 out of 11 points in water efficiency, 4 out of 6 points in innovation section and regional priority, respectively.
- **Artistic Fabric and Garment Industries Karachi** is Pakistan's first LEED existing building and highest LEED point scorer. It scores 72 total points out of 110 and got 'Gold Certification' in 2017. This building is having an area of 55,740 m^2, and it followed LEED v4 for Operation and Maintenance for existing building guidelines. This building scored 20/38 points in energy and atmosphere section, 8/8 points in material and resources, 7/17 in indoor environmental quality, 17/25 in sustainable sites, 11/12 in water efficiency, 5/6 in innovation, and 4/4 in regional priority section. This building is able to achieve 39.01% overall saving from baseline by analyzing the building performance in relation to envelope, lighting, process equipment, occupancy, and HVAC systems by using ENERGY STAR Portfolio Manager.

1.5 Barriers to the Adoption of Green Building Practices

As one of the critical components, this study reviews the previous literature on green buildings. This review helps to identify barriers and measures to promote green building practices. After an extensive review of literature on the barriers to green building, a list of 30 barriers was identified. These barriers, given in Table 1, have the potential to hamper the adoption of green building practices.

Table 1 List of barriers identified from the literature

Code	Barriers
B01	High initial investment, long payback period
B02	Lack of incentives from government
B03	Lack of green building codes and regulations
B04	Poor implementation of laws and legislation
B05	Disbelief regarding the benefits of green building
B06	Lack of availability of green building case studies
B07	Higher functioning costs and maintenance fees for green building
B08	Lack of awareness among people about the importance and advantages of adopting green building practices
B09	Lack of professional knowledge
B10	Lack of end-user support
B11	Unsustainable measures allowed by the regulator or statutory undertaker
B12	Lack of financial resources
B13	Lack of support and guidance from regulatory authority on green practices
B14	Lack of availability of environmentally sustainable materials and products
B15	Lack of indicators for evaluating how sustainable a building is
B16	Lack of demand for sustainable products
B17	Resistance to cultural change
B18	Lack of qualified staff
B19	Risk associated with implementation of new practices
B20	Weak market demand
B21	Technical level and innovation among architects, designers, and engineers are less than desirable in terms of environmental issues
B22	Improper communication structure to support green building practices
B23	Challenges of innovative equipment in design and construction methods
B24	Weak organizational structures to support green building practices
B25	Poor management and/or lack of staff time for implementing green practices
B26	Complexity of design needed to support green practices
B27	Lack of technology
B28	Lack of technical expertise
B29	Lack of technical training/education in green building design and construction
B30	Green building/material is aesthetically less pleasing

Table 2 List of measures identified from the literature

Code	Measures
M01	Promotion of successful green building practices through case examples
M02	Education on new green technologies should be a part of organizational training
M03	Easy access to green building rating/assessment tools
M04	Organizational belief in long-term benefits of green building practices
M05	Availability of comprehensive training and education in green building technologies for engineers, developers, and policymakers
M06	Availability of green building codes and regulations (mandatory to apply)
M07	Financial incentives and penalties from the government (e.g., taxes, soft loans) for green building practices
M08	Creation of public awareness toward green initiatives through seminars, workshops, and discussions
M09	More publicity of green building through television programs, Internet, newspaper, and radio
M10	Pressure from external and internal stakeholders toward green development
M11	Government should provide funding and regulatory incentives for green construction development
M12	Availability of institutional frameworks for the effective implementation of green building guidelines

1.6 Measures to Promote Green Buildings

As the green building approach faces above-mentioned barriers in the construction industry, researchers from all over the world have conducted a number of studies to identify the measures and strategies needed to promote green building practices. Table 2 gives a list of 12 potential measures for promoting green buildings identified through extensive literature review.

1.7 Design/Methodology/Approach

Barriers and measures were identified and examined by using a combination of research methods, including literature review, a questionnaire-based survey, and in-depth interviews with construction industry practitioners working in Pakistan. Ranking and factor analysis were implemented to identify the significant issues associated with the adoption of green building practices.

The questionnaire prepared for this study consisted of three major sections. The first part collected personal information about the respondents; the second part investigated potential barriers to adopting green practices; and the third part asked questions about the list of measures to promote them. It has both closed and open-ended questions. In order to ascertain the priority of individual barriers and measures (in a local context), participants were asked to rank barriers and measures on a scale of 1–5 based on their importance, where 1 = not important and 5 = very important.

Similarly, seven in-depth interviews were carried out with key stakeholders working with Pakistan Green Building Council, the National Energy Conservation Centre, the Pakistan Atomic Energy Commission, and a few private organizations working on green building projects as shown in Figs. 3, 4, and 5.

In the questionnaire, the experts were asked to rate the importance of the 30 barriers that were identified through the literature review. The results are given in Table 3.

The results from empirical analysis reveal that 'lack of awareness among people about the importance and advantages of adopting green building practices' (MV = 4.52; SD = 0.654) is one of the most critical barriers to the adoption of green building practices in the Pakistan construction industry. 'Lack of incentives from government'

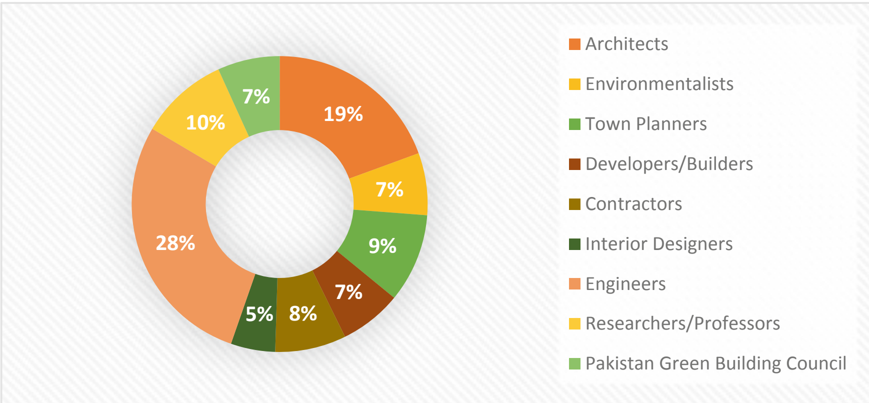
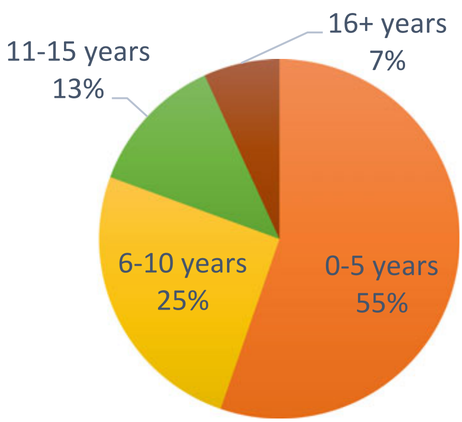


Fig. 3 Respondents' professions

Fig. 4 Respondents' length of experience in the Pakistan construction industry



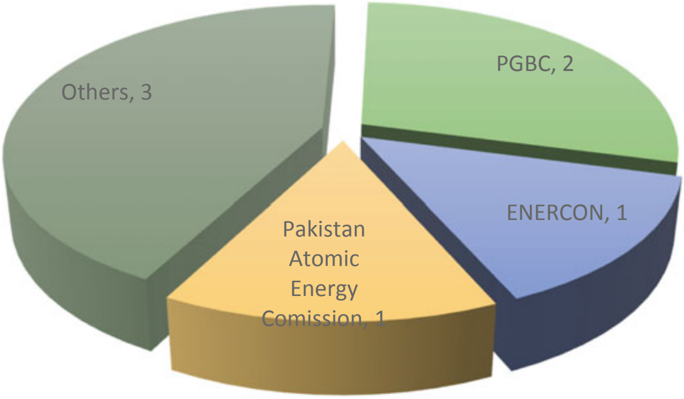


Fig. 5 Profile of interviewees

(MV = 4.32; SD = 0.770) is ranked second, and 'lack of green building codes and regulations' (MV = 4.20; SD = 0.964) is ranked third. 'Poor implementation of laws and legislation' (MV = 4.19; SD = 0.780) and 'lack of technical training/education in green building design and construction' (MV = 4.11; SD = 0.896) are ranked fourth and fifth, respectively.

The results on the relative importance of the measures needed to promote the adoption of green building practices are given in Table 4.

The mean values of all 12 measures were above 4, which indicates that all measures have significant importance. The results show that the five most substantial measures are the creation of public awareness toward green initiatives through seminars, workshops, and discussions (MV = 4.63); the availability of green building codes and regulations (mandatory to apply) (MV = 4.48); financial incentives and penalties from the government (e.g., taxes, soft loans) (MV = 4.47); the availability of comprehensive training and education in green building technologies for engineers, developers, and policymakers (MV = 4.44); and the availability of institutional frameworks for the effective implementation of green building guidelines (MV = 4.43).

Based on factor loadings, factor analysis enabled 17 barriers out of 30 to be grouped under five factors named as management/leadership barriers, governmental and sociocultural barriers, economical and innovative-related barriers, technical barriers, and regulations and resource-related barriers (see Table 5). Factors extracted through principal component analysis, having eigenvalues greater than 1, account for 65.46% of the variance, and the factor loading value exceeded 0.5. The result of factor analysis showed that factor 1 accounts for 18.856% of the total variances in the correlation matrix. Factor 2 explains 15.88% of the total variances, factor 3 accounts for 14.094% of total variances, factor 4 explains 9.15% of total variances, and factor 5 accounts for 7.48% of total variances in the correlation matrix.

Table 3 Ranking of barriers based on mean values and standard deviation

Code	Frequency					Mean values	Std. deviation	Ranking
	1	2	3	4	5	Statistics	Statistics	
B08	0	1	6	34	62	4.52	0.654	1
B02	0	2	13	38	50	4.32	0.770	2
B03	1	6	15	30	51	4.20	0.964	3
B04	0	3	14	46	40	4.19	0.780	4
B29	1	6	12	46	38	4.11	0.896	5
B13	1	1	14	58	29	4.10	0.735	6
B01	1	8	13	52	29	3.97	0.902	7
B06	2	20	25	35	21	3.97	1.004	8
B12	1	4	15	61	22	3.96	0.779	9
B09	1	10	11	55	26	3.92	0.915	10
B10	0	13	11	54	25	3.88	0.921	11
B24	1	11	15	51	25	3.85	0.944	12
B28	3	14	12	45	29	3.81	1.085	13
B22	0	11	17	57	18	3.80	0.856	14
B18	0	16	15	47	25	3.79	0.987	15
B17	3	12	19	40	29	3.78	1.075	16
B25	1	14	26	44	18	3.62	0.961	17
B23	1	15	23	49	15	3.60	0.943	18
B20	4	13	21	47	18	3.60	1.042	19
B21	4	17	15	50	17	3.57	1.072	20
B16	3	16	24	45	15	3.51	1.018	21
B05	2	8	17	40	36	3.51	1.083	22
B15	3	19	20	46	15	3.50	1.047	23
B27	6	15	20	45	17	3.50	1.110	24
B19	4	22	20	38	19	3.45	1.135	25
B11	1	9	59	25	9	3.31	0.792	26
B07	7	25	21	35	15	3.25	1.178	27
B26	6	30	30	28	9	3.04	1.075	28
B14	9	36	23	24	11	2.92	1.169	29
B30	40	31	19	10	3	2.08	1.109	30

Table 4 Ranking of measures based on mean values and standard deviation

Code	Frequency					Mean values	Std. deviation	Ranking
	1	2	3	4	5	Statistics	Statistics	
M8	0	0	2	34	67	4.63	0.524	1
M6	0	1	8	35	59	4.48	0.684	2
M7	0	3	3	40	57	4.47	0.698	3
M5	0	3	6	37	57	4.44	0.737	4
M12	2	0	8	35	58	4.43	0.800	5
M3	0	1	9	46	47	4.35	0.682	6
M1	0	2	13	46	42	4.24	0.747	7
M10	0	7	11	36	49	4.23	0.899	8
M2	0	4	8	54	37	4.20	0.746	9
M4	0	2	12	55	34	4.17	0.706	10
M11	0	5	15	48	35	4.10	0.823	11
M9	1	4	14	50	34	4.09	0.841	12

1.8 Findings and Discussions

In order to accelerate the adoption of green building practices, this research identifies and examines key barriers to its successful implementation and the measures needed to promote it by analyzing the professional views of Pakistan's construction industry. The following sections interpret the findings of the study, considering each of the five barrier factors and finally the measures for promotion.

Factor 1: Management/Leadership Barriers

This group consists of four critical variables: (1) poor implementation of laws and legislation; (2) lack of support and guidance from regulatory authorities on green practices; (3) the challenges of innovative equipment in design and construction methods; and (4) weak organizational structures to support green building practices.

Poor implementation of laws and legislation (mean 4.19) is the most important variable in this category. Interviewees said that the successful uptake of green building practices lies in the commitment of leaders and managers in developing and executing an efficient plan. Due to an inefficient legal system, leaders and managers have less interest in green building. Lack of support and guidance from regulatory authorities on green practices (mean 4.1) is another important variable in this category and was one of the barriers repeatedly highlighted by the interviewees. Interviewees found it difficult to start a project without the help of green building guidelines. They highlighted that in order to go green, internationally recognized green building guidelines and rating systems needed to be imported, which increases the cost to the client and so becomes a barrier to adoption in Pakistan. Adequate resources and support are also needed to manage the trial of innovative equipment in the design and construction processes.

Table 5 Factor matrix for barriers

Code	Statements	Factor loadings				
		Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
B04	Poor implementation of laws and legislation	0.647				
B13	Lack of support and guidance from regulatory authority on green practices	0.547				
B23	Challenges of innovative equipment in design and construction methods	0.586				
B24	Weak organizational structures to support green building practices	0.699				
B02	Lack of incentives from government		0.654			
B06	Lack of availability of green building case studies		0.626			
B17	Resistance to cultural change		0.594			
B20	Weak market demand		0.618			
B07	Higher functioning costs and maintenance fees for green building			0.716		
B14	Lack of availability of environmentally sustainable materials and products			0.570		
B26	Complexity of design needed to support green practices			0.524		
B27	Lack of technology			0.599		
B09	Lack of professional knowledge				0.669	
B18	Lack of qualified staff				0.681	
B28	Lack of technical expertise				0.717	
B11	An unsustainable measure is allowed by the regulator or statutory undertaker					0.736
B12	Lack of financial resources					0.624

Factor 2: Governmental and Sociocultural Barriers

This group consists of four variables: (1) lack of incentives from government; (2) lack of green building case studies; (3) resistance to cultural change; and (4) weak market demand.

The lack of incentives from government to implement green building practices is ranked as the second most significant barrier, as the survey respondents see insufficient support from government in the development of green building practices in Pakistan. Local stakeholders have a firm belief that green building practices will only be adopted if the government is devoted to doing so, because the government is the main stakeholder in the industry. Interviewees said that the construction industry of Pakistan has long been run in its traditional way because it is extremely difficult to change the construction practices and the building materials used. Due to the higher initial investment costs of green building, and the lack of financial incentives to adopt it, people are very hesitant to change their old and traditional construction habits. Due to the lack of demand for green products by clients and stakeholders, there is also a lack of building case studies.

Factor 3: Economical and Innovation-Related Barriers

This group consists of four variables: (1) higher functioning costs and maintenance fees for green building; (2) lack of availability of environmentally sustainable materials and products; (3) the complexity of design required to support green practices; and (4) lack of technology.

A major barrier cited by many researchers in the literature review is the extra financial cost that is needed to improve the sustainability of the built environment. One of the interviewees highlighted that some green building construction equipment requires highly trained management staff and regular professional maintenance and repair, which would increase the operational costs and difficulties of local stakeholders if they were to invest in green development. Lack of availability of locally sourced green building materials and products is another important barrier. In many cases, these have to be imported from elsewhere, which increases cost and becomes a hurdle to green investment.

Factor 4: Technical Barriers

This group consists of three variables: (1) lack of professional knowledge; (2) lack of qualified staff; and (3) lack of technical expertise.

Persson and Grönkvist [9] stated that the lack of common understanding about sustainability is a major hindrance to sustainable construction. Our interviewees believed that the green building approach is newer to our industry and that construction industry professionals who have experience and technical knowledge of it are limited in number. There are also shortages of platforms that provide technical training/education on green practices. Green building technologies are becoming more innovative and advanced, and so technically competent practitioners are needed for Pakistan to adopt and move forward in green building practices.

Factor 5: Regulations and Resource-Related Barriers

This group consists of two variables: (1) unsustainable measures are allowed by the regulator or statutory undertaker and (2) lack of financial resources.

The interviews revealed that in several cases, local stakeholders initially wanted to introduce green practices to their projects, but chose not to do so when local policies, regulators, or statutory undertakers permitted a less sustainable option. Unsustainable measures should not be allowed by regulatory authorities on any basis. If the authorities concerned were sincerely determined to take appropriate regulatory action, then this barrier to green building would be removed.

1.9 Framework for the Promotion of Green Building

On the basis of data analysis, literature review, and stakeholder's perception, the framework for the promotion of green building is shown in Fig. 6. The framework shows issues, dimensions, and measures to promote this concept at local level.

2 Conclusion

The objectives of the present study were to review dimensions of certified green buildings observed in Pakistan, to examine the barriers and measures for promoting green building in Pakistan, and to suggest a framework.

The first draft version of Pakistan Green Building Guidelines developed by Pakistan Green Building Council has been briefly discussed. In Pakistan, there are only seventeen certified green projects. Data from five certified green buildings were gathered and discussed.

This study also investigates the major issues influencing the adoption or otherwise of green building practices in Pakistan, based on the perceptions of local stakeholders. A wide range of potential barriers to adoption and measures to promote it were identified and examined using a combination of research methods, including literature review, a questionnaire-based survey, and in-depth interviews. The results were further analyzed by implementing factor analysis and ranking. These techniques are used to better understand the key issues for the adoption of green building practices in Pakistan.

This study examined 30 barriers and 12 measures. The survey results show that the most critical barrier is a 'lack of awareness among people about the importance and advantages of the adoption of green building practices,' followed by 'lack of incentives from government,' 'lack of green building codes and regulations,' 'poor implementation of laws and legislation,' and 'lack of technical training/education in green building design and construction.' In agreement with this, the interviewees confirmed that our local stakeholders are not yet fully aware of the long-term benefits

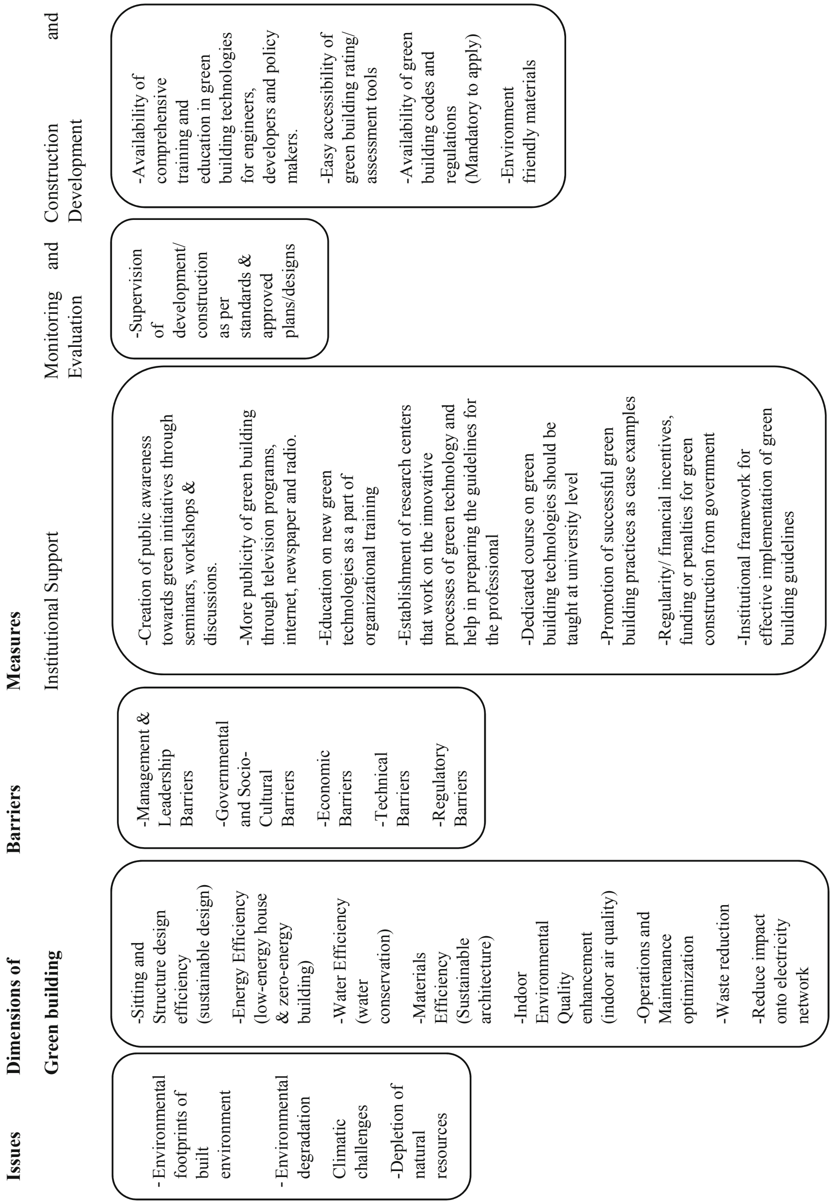


Fig. 6 Framework for promotion of green building in Pakistan

of green building. This suggests that the government and the respective authorities need to expend more effort in these areas to make green building approaches successful in a local context. Government must provide some monetary benefits to promote sustainable building designs in both commercial and residential communities.

Further investigation with factor analysis revealed five factors: (1) management/leadership barriers, (2) governmental and sociocultural barriers, (3) economical and innovation-related barriers, (4) technical barriers, and (5) regulation and resource-related barriers. The results also indicate that the most significant of these are management/leadership barriers. The interviewed stakeholders also highlighted the government's role in promoting green building practices in Pakistan.

All of the 12 measures were recognized as significantly important, with the most significant being the 'creation of public awareness toward green initiatives through seminars, workshops, and discussions,' followed by the 'availability of green building codes and regulations (mandatory to apply),' 'financial incentives and penalties from the government (e.g., soft loans, taxes) for green building practices,' 'availability of comprehensive training and education in green building technologies for engineers, developers, and policymakers,' and the 'availability of institutional frameworks for the effective implementation of green building guidelines.'

The findings of this study contribute to the understanding of the major barriers and the measures needed to promote green building practices in Pakistan. The results provide valuable information for policymaking, crafting of green building codes, and development of a mechanism for the implementation of green building practices in the construction industry. Although the results are based on the perceptions of local stakeholders, they can also be helpful for policymakers in other developing countries. Future studies could compare the views of green building experts from different countries on green building adoption issues to observe market-specific differences.

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Adoption of Green Building Technologies in Ghana

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Abstract This chapter aims at fostering a crystal-clear understanding of how to promote GBTs adoption in Ghana, a developing country in West Africa. To this end, the primary drivers for GBTs adoption have been discussed, with a focus on Ghana. Similarly, this chapter has analyzed the key barriers hampering the widespread adoption of GBTs in Ghana. Finally, strategies that can be used to overcome the current barriers in the industry and promote the GBTs adoption are presented. The value of this research lies in the fact that this research can help policy makers, practitioners, and advocates promote the GBTs adoption. The key strategies they could adopt for promoting the GBTs adoption include—more publicity through media; GBTs-related educational and training programs for key stakeholders; availability of institutional framework for effective GBTs implementation; a strengthened GBTs R&D; and financial and further market-based incentives.

Keywords Green building · Ghana · Technology adoption · Barriers · Drivers

1 Introduction

The construction industry has gained growing attention in international policies for sustainable development [12, 42]. Much of this attention could be accredited to the industry's energy consumption and greenhouse gas (GHG) emissions, which on a global level characterize over 40% each of the total energy consumption and GHG emissions [32, 33]. Through this large consumption of energy and emission of GHGs,

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the construction industry generates significant negative impacts upon the environment, economy, and society. The GHG emissions provoke climate change, which has been one of the world's most pressing issues for years [36–38]. The United Nations Environment Programme (UNEP) [63] argued that reducing the GHG emissions from the construction industry, which can be done by reducing the industry's energy consumption, would bring multiple sustainability benefits to the environment, economy, and society. It is urgent for the world's governments, policy makers, and decision makers to find ways to tackle the construction industry's energy consumption and GHG emissions. This is because it has been predicted that, if nothing is done, the construction industry's energy use and GHG emissions would rise by more than 50% by 2050 [13, 34]. The construction industry has also been said to be a resource-intensive industry [57] that consumes 40% of the global raw materials (sand, gravel, and stone), 25% of the global timber resources, and 12–16% of the global water available [9, 58]. As well, the activities and operations of the construction industry lead to the generation of huge amounts of solid waste, dust, smoke, noise, and wastewater [56, 59], which can be detrimental to the environment and human health.

The aforesaid issues emphasize the need for transition toward sustainability in the construction industry. As established by Berardi [12], the need to move toward sustainability within the construction industry is further justified by the contribution the industry makes toward the general economy. The construction industry accounts for 10–40% of countries' gross domestic product (GDP) and, on average, provides 10% of world employment, according to the UNEP [63]. Inside developing countries, the increasing importance of the construction industry also underscores the necessity for greater attention toward sustainability [12]. Likewise, owing to the fact that developing countries face numerous problems, such as rapid urbanization, environmental degradation, social inequity, and deep poverty, Du Plessis [22, 23] argued for embracing sustainability in the construction industry of developing countries. Accordingly, she designed an "Agenda 21" and a "Strategic Framework" for sustainable construction within developing countries. Moreover, as developing countries cause approximately 60% of the total GHG emissions of the global construction industry [30], it is highly important to implement sustainability inside the construction industry of these countries.

As much of the discussion in the present chapter refers to the Ghanaian construction industry, understanding the Ghanaian situation is valuable. The World Economic Situation and Prospects [68] classifies developing countries as those countries with gross national income (GNI) per capita of US$12,615 or less. As a developing country, Ghana had a GNI per capita of US$1380 in 2016 [67]. In addition, in 2016, the estimated GDP of Ghana was US$42.69 billion [61], with the construction industry accounting for US$667.35 million. Also, Owusu-Manu and Badu [49] indicated that in Ghana, the construction industry accounts for approximately 8.2% of GDP annually and provides employment for 2.3% of the population of nearly 29.5 million [74]. In spite of the construction industry's contribution to the Ghanaian economy, the industry also has harmful environmental, economic, and social effects upon the community, as a result of its poor and unsustainable use of resources such as energy, water, and construction materials [62]. In Ghana, buildings are responsible for over

54% of the total electricity energy consumption [10]. One of the key problems facing Ghana today is the energy crises. During the past four decades (1984, 1994, 1998, 2007, and 2012), Ghana has experienced many serious energy crises with the electricity sector faced with challenges concerning power quality and supply security [1]. This condition has not only caused Ghana to suffer from load shedding from the start of 2013 till now [28], but also costs the country an average of US$2.1 million in loss of productivity every day [41]. The high energy consumption inside the construction industry may be one of the key driving factors for these energy crises, particularly as the Ghanaian electricity sector is characterized by high total energy losses and unreliable, inadequate supply to meet high demands [28]. This underlines the urgency of accepting and implementing sustainability in the construction industry of Ghana.

Green building has emerged as the new way of building to address sustainability issues in the construction industry. While there exist various definitions of green building out there, the US Green Building Council (USGBC) [65] considered green building as a holistic and integrated concept that begins with the understanding that the construction industry could have significant impacts—both positive and negative—upon the natural environment as well as the people who inhabit buildings each day. The council further declared that green building represents an effort to amplify the positive and mitigate the negative of these effects all through the whole lifecycle of a building. Through amplifying the positive environmental, economic, and social impacts of the construction industry, while mitigating the negative ones, green building greatly contributes toward sustainable development. The WorldGBC [71] has comprehensively demonstrated how green building is contributing to achieving the United Nation's Sustainable Development Goals (SDGs). However, it is worthy to note that green building is not achievable without the adoption/use of green building technologies (GBTs) [17]. GBTs are defined as technologies, such as green roof technology, prefabrication technology, solar technology, and energy-efficient lighting systems, that are employed in building design and construction so as to hone overall sustainability and environmental performance [2].

Given that different countries and regions have various characteristics, such as unique cultures and traditions, distinctive climatic conditions, diverse building types and ages, or wide-ranging environmental, economic and social priorities, all of which shape their green building approach [72], it is necessary to understand how to promote GBTs adoption in specific countries and regions. Whereas many developed countries have made considerable progress in GBTs adoption and development [25, 43], developing countries such as Ghana are nowadays still struggling to emulate the developed countries' GBTs adoption and development progress. One reason may be that green building is fairly new to the construction market of developing countries [48], and accordingly, the green building policy of these countries is still underdeveloped. Mao et al. [46] and Darko and Chan [20] showed that GBTs adoption has been slower within developing countries than in developed countries. Stronger efforts are therefore needed in order to promote and accelerate the GBTs adoption in developing countries. As Zhang et al. [76] highlighted, the adoption of GBTs in buildings is an important step toward global sustainable development. Kumi et al. [41] also claimed that dealing with Ghana's energy crises requires a variety of actions, such as diversifying the energy generation mix through developing and using renewable energy sources and promoting energy efficiency programs. This supports that adopting GBTs, such as renewable energy technologies (e.g., solar panels) and energy-efficient technologies (e.g., energy-efficient lighting systems), has an enormous potential of helping Ghana to deal with the energy crises by improving energy efficiency [39]. In 2009, the government of Ghana introduced Ghana's Sustainable Development Action Plan [5]. However, it might be difficult to realize the sustainable development of Ghana in the face of the energy crises. The encouragement of the widespread GBTs adoption in Ghana is therefore critical.

The GBTs adoption in Ghana is slow and still in its infancy [21]. Consequently, GBTs adoption, and thus green buildings development, is still uncommon in Ghana. While the Ghana Green Building Council (GHGBC) was established in 2009 to lead the green building movement in Ghana [24], the government has yet to devise a roadmap to facilitate this movement. Also, only a handful of buildings in Ghana, e.g., the first LEED-certified green hospital within Africa, the Ridge Hospital [15], and the first green commercial office building within West Africa, the One Airport Square [8], have received green certification. This indicates that GBTs adoption is not widespread in Ghana, justifying the value of taking initiatives to promote the widespread adoption of GBTs to realize sustainability goals. This chapter attempts to contribute toward these initiatives through understanding three issues that are momentous to the successful adoption and promotion of GBTs in Ghana—drivers for the GBTs adoption; barriers to GBTs adoption; and strategies to promote GBTs adoption. This chapter is based on empirical evidence and was born from a larger research project aimed at promoting GBTs adoption in Ghana [19]. Because of the word/space restriction, this chapter has purposefully not entered into presenting the comprehensive reviews of the relevant literatures and detailed descriptions of the study methodology and data analysis, which can be found in Darko [19]. It is hoped that this study will assist the Ghanaian government and other policy makers, industry practitioners, and stakeholders, as well as green building advocates to formulate and apply proper and effective policies and strategies to promote the GBTs adoption.

2 Drivers for GBTs Adoption in Ghana

GBTs adoption provides numerous sustainability benefits that act as drivers for GBTs adoption. Due to different economic conditions and regulations within different countries, the drivers for adopting GBTs differ from country to country. A strong understanding of the drivers for GBTs adoption is useful for helping practitioners and companies (such as developer, consultant, and contractor companies) to understand the significant benefits the GBTs adoption can offer, and thereafter help them make more informed decisions regarding whether or not to adopt GBTs [21]. Such an understanding can also help policy makers and advocates in their GBTs adoption promotion efforts; they may identify and widely promote the key drivers in the society to impact the interest people have in GBTs. The key drivers of

GBTs adoption in Ghana are—setting a standard for future design and construction, greater energy efficiency, improved occupants' health and well-being, non-renewable resources conservation, and reduced whole lifecycle costs [21].

2.1 Setting a Standard for Future Design and Construction

Incorporating GBTs into construction projects today can serve as an empirical/practical benchmarking sustainability-focused practice for motivating the meeting of high, green standards in future construction projects via adopting GBTs. This has been a noteworthy driver for the GBTs adoption within Ghana at the moment. It is generally accepted that applying GBTs and practices in the construction industry can affect the industry standards via setting a standard for future design and construction [47]. This is particularly a unique GBTs adoption driver for those developing countries that are now trying to move their built environments in sustainability ways in order to emulate most developed countries. The Ghana Green Building Council has set its mission to "transform the built environment in Ghana towards sustainability through the way Ghanaian communities are planned, designed, constructed, operated, and maintained." So as to successfully carry out this mission, it is imperative for the council to encourage the widespread adoption of GBTs in the current construction industry of Ghana. Doing so to consequently achieve some green buildings may provide confidence for the implementation of GBTs in future construction projects, which may aid the green building movement in Ghana. Moreover, the adoption and diffusion of GBTs today is core to the future of GBTs adoption because the more diffused a particular technology inside the construction industry, the less risky it may be to implement it [51]. That is, existing green building projects might essentially offer concrete evidence about the practicality and feasibility of using GBTs in construction projects in Ghana, and thus help to inspire the widespread adoption of GBTs. Similarly, it is worthy to note that those companies and practitioners in the current construction industry of Ghana implementing GBTs to achieve green buildings are not only setting a pace for GBTs adoption and development, but might also be enjoying the competitive advantage associated with such action [78]. This competitive advantage may play an essential role in encouraging others to also go "green" by using GBTs as part of their portfolio and marketing strategies. A typical example of adopting GBTs in Ghana to set a standard for future design and construction was established in the One Airport Square project. The consultants of the project stated that the project was developed to "set new standards for sustainable developments in West Africa" [45], whereas the architects asserted that the project was designed with green technologies and measures "to become a point of reference and example for the new generation of commercial office buildings in West Africa" [8].

2.2 Greater Energy Efficiency

Being in line with and closely tied to the energy problems in Ghana, as explained before, greater energy efficiency represents another major driver behind the GBTs adoption inside Ghana. Energy efficiency is of high importance for sustainable development in both developed and developing countries [52]. It has been globally recognized as a low-cost, readily available resource that has great potential for ameliorating the electricity supply security and thus energy efficiency situation in a country [28]. As such, energy efficiency has emerged as a priority issue in Ghana and recently received considerable attention from the regulating agencies in charge of energy issues, e.g., the Energy Commission of Ghana, and Ghana Energy Foundation. One of the well-documented benefits associated with green buildings around the world is energy efficiency, which is associated with GHG emissions reduction. The WorldGBC [73] highlighted the benefits of green buildings in an attempt to facilitate a growing evidence base for verifying them. It indicated that, at a global level, through green building, the construction industry has the potential of making energy savings of 50% or more, together with emissions savings of as much as 84 gigatons of CO_2 ($GtCO_2$), by 2050. At a building level, green buildings inside India are shown to save 40–50% of energy compared to non-green Indian buildings [73]. GBTs adoption has a key role in securing this energy saving potential of the construction industry and buildings. For the Ridge Hospital in Ghana, the main reason for applying GBTs such as solar water heater was to limit the reliance upon electricity energy [15]. This implies that the desire for greater energy efficiency greatly influenced the decision-making process of adopting GBTs in this project. Ghana should take actions to promote and encourage the widespread use of GBTs in the construction industry to reduce energy consumption and so realize greater energy efficiency throughout the country. Achieving greater energy efficiency through GBTs adoption might have power in transforming the sustainability and sustainable development of Ghana, because it would significantly benefit the environment and climate.

2.3 Improved Occupants' Health and Well-Being

While the average person spends approximately 90% of his or her time indoors, the levels of pollutants indoors are usually higher than the levels outdoor [64]. Thus, ensuring that the indoor environment of buildings possesses a good quality is indispensable to the health and well-being of people who occupy buildings for various purposes, such as working and entertainment. In addition to setting a standard for future design and construction and causing greater energy efficiency, GBTs adoption can also help to ensure that buildings run in a way that improves and protects the health and well-being of their occupants. The improved occupants' health and well-being that GBTs adoption brings shapes and drives GBTs adoption within Ghana [21]. According to the World Health Organization [69], in Ghana, safe and healthy environment has weighty implications for the health and well-being of people, making the GBTs adoption to create a healthy and sustainable built environment necessary. Many studies have discussed the GBTs adoption benefits that are around the health and well-being of building occupants. The WorldGBC [73] indicated that compared to workers in non-green offices, workers in green, well-ventilated offices experience much better brain function. The American Academy of Sleep Medicine [7] studied the link among workplace daylight exposure and the sleep, physical activity, and quality of life of office workers. The study yielded some interesting findings. It was found that office workers who are exposed to workplace daylight slept an average of 46 min more per night, have much more physical activity and much better quality of life, compared to those without workplace daylight exposure. This finding seems to confirm Kats's [40] claim that applying natural lighting and ventilation as well as air quality enhancement technologies in buildings typically contribute to optimizing the health and well-being of occupants. In view of these occupants' health and well-being-related benefits GBTs adoption can afford, it may be justifiable and reasonable to support and promote the widespread GBTs adoption in Ghana. The One Airport Square adopted GBTs such as glass façade composed of a fixed and a movable bottom, central atrium, and spaces of circulation so as to promote natural lighting and ventilation in indoor environments [4]. This action might substantially benefit the health of the occupants, as deliberated above, and therefore may be rational for other Ghanaian building projects to replicate it.

2.4 Non-renewable Resources Conservation

This is another principal driver for GBTs adoption in Ghana. Taking non-renewable energy resources, for example, Ghana supports their protection, for a sustainable socio-economic development, by the development and deployment of naturally gifted renewable energy sources (such as solar, biomass, and wind) for electricity generation. Accordingly, the country enacted the "Renewable Energy Act"—Act 832—in 2011 to provide for the management, development, and sufficient supply and application of renewable energy for generating power and heat and for other related issues [53, 60]. Several studies confirm a positive correlation between renewable energy and sustainable development, including those that agree that making electricity from renewable energy resources can have a crucial part in electricity generation in Africa [6, 16]. Ghana is among the leading African countries with substantial renewable energy policies [54], suggesting that Ghana has all the potential for resolving its energy glitches if these renewable energy policies are properly optimized and used appropriately. One recommendation is to enforce the incorporation of renewable energy (green) technologies, such as solar water heating and electricity, in construction projects. Such a strategy would result in solar-powered, energy-efficient buildings that can help to combat climate change and its effects via the mitigation of the use of non-renewable energy resources (e.g., fossil fuel) that produce huge quantities of GHG emissions, the leading cause of climate change. Aside from helping to conserve non-renewable energy resources, adopting renewable energy technologies also makes a remarkable contribution to achieving the greater energy efficiency that is also driving GBTs adoption in Ghana. The WorldGBC [71] claimed that "energy efficiency coupled with local renewable sources improves energy security", an unavoidable factor for Ghana's sustainable development.

2.5 Reduced Whole Lifecycle Costs

GBTs adoption delivers economic/financial benefits too, which are also driving the GBTs adoption within Ghana in a notable way because they are relevant to a broad range of stakeholders [73]. In essence, adopting GBTs helps to deliver green buildings that, throughout their entire lifecycle, could be cheaper to operate and maintain than non-green ones. Green buildings that use renewable energy technologies, for instance, can be cheaper to run since they make use of free, renewable resources. Unquestionably, renewable energy could be cheaper than fossil fuel alternatives, for example. The International Renewable Energy Agency (IRENA) suggested that residential photovoltaic or solar technologies in Africa can offer households with electricity for as low as US$56 per year, which is much cheaper than energy from kerosene or diesel [71]. This may provide enough justification for Ghana to promote the widespread adoption of solar technologies and other GBTs that can result in additional long-term cost savings upon utility bills—via, for example, water efficiency (e.g., rainwater harvesting technology)—in the construction industry.

3 Barriers to GBTs Adoption in Ghana

Despite its many benefits, the GBTs adoption still encounters various barriers. Advantageous to the successful adoption and promotion of GBTs is a clear understanding of these barriers, which can help to find ways to address the barriers and thus promote the widespread GBTs adoption. Like several other countries, Ghana encounters barriers in GBTs adoption. These barriers are due to various reasons ranging from economic and local market conditions to human attitudes. The chief barriers to the GBTs adoption in Ghana, however, are: higher costs of GBTs; lack of government incentives; lack of financing schemes (e.g., bank loans); unavailability of GBTs suppliers; and lack of local institutes and facilities for GBTs research and development (R&D) [17]. As Berardi [12] substantiated, the most recognized barriers to the GBTs and practices adoption are economic ones. This is reflected in the Ghanaian setting.

3.1 Higher Costs of GBTs

As an economic issue, cost has been a long-standing major barrier to the widespread adoption of GBTs and practices [75]. Of course, even though the extra cost of adopting GBTs can be compensated for in a lifecycle perspective, the higher initial cost of GBTs could be a barrier to the GBTs adoption. GBTs typically cost significantly more than non-green building technologies. For example, Hwang and Tan [31] reported that, as a green substitute for conventional plywood, compressed wheat board costs around 10 times more than conventional plywood. Additionally, energy-efficient technologies may be more expensive. In essence, the higher costs of GBTs add to project cost and could be a major problem for project stakeholders as long as they remain sensitive to financial issues. Research has established that green building projects cost about 9.37% more than non-green building projects [66]. A remarkable part of this phenomenon could be attributed to the higher costs of GBTs. Some also trust that the use of GBTs can increase project cost by 10–20% [70]. In the light of these issues, the higher costs of GBTs may represent a main impediment to GBTs adoption in construction projects within especially developing countries such as Ghana wherein poverty is prevalent and entrenched [18].

3.2 Lack of Government Incentives

In fact, government leadership and role are vital for the adoption and promotion of GBTs, and this is particularly true in developing countries wherein the GBTs adoption practice is still in its early stages. Within such countries, the government needs to take a more proactive role in promoting the GBTs adoption by taking a variety of relevant actions, one of which is providing incentives—both financial and nonfinancial incentives—to stimulate the GBTs adoption. An incentive may be described as something that impacts people to act in some ways [50]. Essentially, in the green building context, government incentives impact people to accept and embrace GBTs in their construction projects because they help in many ways, including offering compensation for the extra cost and time that the GBTs adoption might require. However, unfortunately, Ghana presently has no government incentive schemes directed toward the use of GBTs in construction projects, a situation that is largely contributing to the slow pace of GBTs adoption in the country. While the lack of government incentives for the GBTs adoption does not help lowering the barrier of cost, this chapter will later discuss the strategies that can be used to address these barriers for the successful and widespread adoption of GBTs in Ghana.

3.3 Lack of Financing Schemes (E.G., Bank Loans)

For all stakeholders, raising money for projects always represents a challenge [75]. This challenge is more critical for those who need to raise money for green building projects which involve GBTs with higher costs. Thus, over the past decade, there has been an increasing number of third-party financing sources for investing in green projects and hence GBTs. While this holds true in developed countries such as the USA, UK, Australia, Singapore, and Hong Kong [55], the opposite situation exists in Ghana. So, Ghanaian practitioners have a difficult time trying to find financing sources for green projects that can defray the high costs of GBTs. Again, the lack of financing schemes also makes it hard to deal with the cost barrier in the GBTs adoption in Ghana. Bank loans, for example, are one of the most common financing schemes for green projects around the world [55]. Yet, within Ghana, it is arduous to find banks and other financial institutions that grant loans for green projects.

3.4 Unavailability of GBTs Suppliers

Suppliers have an important part in the successful adoption of GBTs. They are not only the vendors who serve the industry with the needed GBTs, but also the main source of information concerning the GBTs. But, the unavailability of GBTs suppliers that result in unavailability of GBTs in the local market has been a key barrier to GBTs adoption in Ghana. This barrier was encountered in some existing green building projects in the country. For instance, it was encountered in the Ridge Hospital project where the architect revealed that most of the infrastructure and technologies that support green building in developed countries such as the USA and Canada do not exist in Ghana [15]. This is mainly because most GBTs are not manufactured and sold locally in Ghana. A similar situation can be found in other developing countries, e.g., Turkey [3], implying that the current GBTs supply chain within developing countries remains immature with a shortage of suppliers. Often, Ghana imports the GBTs from other countries like the USA and Canada where the GBTs markets are more developed. While the global suppliers may offer innovative solutions, this move may come with "higher costs", which also greatly hinders the GBTs adoption in Ghana.

3.5 Lack of Local Institutes and Facilities for GBTs R&D

This is another important barrier to the GBTs adoption in Ghana. R&D is critical to the adoption and implementation of GBTs because it is helpful for developing innovating GBTs as well as for studying the benefits of these GBTs. Nevertheless, the GBTs adoption and development in developing countries lag behind that in developed countries, owing to that it is usually faced with a lack of R&D funds, institutes, and facilities [77]. The GBTs R&D requires a great deal of financial support for founding green technology research institutes/centers, educating/training, and recruiting qualified GBTs R&D experts, and this may be a large amount of money for developing countries such as Ghana to handle. As a result, Ghana has yet to establish accredited GBTs R&D institutes, resulting in a serious lack of GBTs R&D capacity in the country. Additionally, the GBTs education is still not better developed, leading to a lack of GBTs R&D experts in Ghana. In essence, the current GBTs R&D situation in Ghana proves to be a major barrier for Ghana in the adoption of GBTs.

4 Strategies to Promote GBTs Adoption in Ghana

After discussing barriers, it is reasonable and useful for this chapter to consider some strategies that can be rested upon in overcoming the barriers in order to promote the GBTs adoption. The key strategies to promote the GBTs adoption in Ghana are: more publicity through media (e.g., print media, radio, television, and Internet); GBTs-related educational and training programs for developers, contractors, and policy makers; availability of institutional framework for effective GBTs implementation; a strengthened GBTs R&D; and financial and further market-based incentives for GBTs adoption [20]. To promote the GBTs adoption, policy makers, practitioners, and advocates should pay special attention to and implement these strategies.

4.1 More Publicity Through Media

The media offers one of the most effective and efficient means to easily and swiftly communicate with the general public, whereas publicity, also called public relations, is a promotion strategy that can help create a positive image for a product, encourage people to use the product through conveying the benefits of the product, raise awareness, and boost demand for the product [11]. Thus, publicity through media can help in promoting GBTs in the public domain. Publicity through the electronic media of the internet and television, for example, capitalizes on innovative technologies to easily communicate with the public about GBTs. In order to promote the GBTs adoption in Ghana, the media should be used as a communication and marketing channel for advertising GBTs alongside their benefits. The government could sponsor media campaigns that draw attention and exposure to GBTs, as awareness of the public regarding GBTs and their benefits can help to breakdown the key GBTs adoption barrier of cost. With understanding and awareness of the full range of GBTs adoption benefits, people might be motivated to find the funds to adopt GBTs.

4.2 GBTs-Related Educational and Training Programs for Developers, Contractors, and Policy Makers

Developers, contractors, and policy makers are key players in adopting and promoting GBTs within the construction industry. The role of developers, for instance, has been generally acknowledged. Mao et al. [46] showed that developers are not only the chief decision makers in GBTs adoption, but their use of GBTs also impacts scholars' R&D activities, manufacturers' investment plans, and contractors' construction technique. Moreover, Hu et al. [29] indicated that developers are chief decision makers in GBTs and practices adoption because they are the investors. The research on the main drivers for innovation in construction [14] established that developers have massive capacity to influence companies and individual practitioners in the industry in a way that fosters innovation (such as GBTs) adoption. In Ghana, the Ghana Real Estate Developers Association (GREDA) is one of the most active construction industry associations that make recommendations to the government vis-à-vis ways to promote real estate development [26]. It is also active in seeking solutions to the problems, including sustainability problems, inside the Ghanaian property market [26]. These issues indicate that educating and training developers on GBTs would greatly help in promoting GBTs adoption in Ghana. Thus, Ghana needs to develop and implement effective GBTs-related education and training programs for enhancing developers' knowledge and awareness of and expertise in GBTs, so as to promote the widespread GBTs adoption. The GBTs education and training must also consider contractors and policy makers, who are also major stakeholders in GBTs adoption and promotion.

4.3 Availability of Institutional Framework for Effective GBTs Implementation

To promote the successful and effective implementation of GBTs inside Ghana, an institutional framework that clearly delineates the roles and responsibilities of all stakeholders is required. As indicated by the Global Water Partnership (GWP) [27], frameworks represent an important prerequisite for implementing sustainable practices, as they create the basis for successful implementation. Frameworks typically have two key components: legal framework and institutional framework. Whereas the legal framework is determined by local, provincial, and national policies, which constitutes the "rules of the game," the institutional framework consists the organizations and institutions with mechanisms and forums, data and capacity building, instituted to establish the "rules of the game" and to ease stakeholder involvement [27]. Hence, an institutional framework could be simply described as a set of formal organizational structures, rules, and informal norms for doing an activity [35]. In GBTs adoption, institutional framework may offer an aiding environment for adoption [44] by guiding stakeholders' behavior. To advance GBTs implementation, Ghana should establish an efficient institutional framework, which should comprise various bodies that could actively promote GBTs adoption at various societal levels. Governmental and nongovernmental bodies, industry associations, and community-based organizations are some bodies that may be considered in developing the institutional framework for GBTs implementation; the framework must clearly outline the roles and responsibilities of each body.

4.4 A Strengthened GBTs R&D

This GBTs adoption promotion strategy fundamentally assists in overcoming the "lack of local institutes and facilities for GBTs R&D" barrier. Having strong R&D base in GBT can be critical to promoting GBTs adoption. To promote GBTs adoption in Ghana, it is essential to strengthen GBTs research and communication. The R&D efforts could focus on studying the locally available GBTs, their application, applicability, and performance. They should also conduct proper analyses to show the lifecycle costs and benefits of the GBTs in real time. To support this agenda, the government can establish GBTs research institutes and centers and/or support academic institutions, e.g., universities, to undertake GBTs R&D. Once the research about GBTs and their costs and benefits has been done, good communication and marketing strategies, such as "more publicity through media," workshops, seminars, academic and industrial publications, and development tours, must be adopted to share the outcomes with the industrial practitioners and the public. This is necessary because having proper information on costs, benefits, and return on investment is important to keeping GBTs under consideration, rather than losing them to strictly financial considerations [75], thus overcoming the "higher costs of GBTs" barrier.

4.5 Financial and Further Market-Based Incentives for GBTs Adoption

In the context of Ghana, this promotion strategy may help to overcome three key barriers to the GBTs adoption: lack of government incentives, higher costs of GBTs, and lack of financing schemes. Giving incentives represents a very crucial strategy to promote GBTs adoption. To promote widespread adoption of GBTs in Ghana, the Ghanaian government should launch effective green building incentive schemes. It could provide financial and nonfinancial incentives for encouraging people to adopt GBTs within their construction projects. For the financial incentives, the government can adopt green building incentives such as free or subsidized development application fees, direct grants, tax reliefs, special loans, and density bonus, while for the nonfinancial incentives, it can adopt the gross floor area concession scheme, expedited permitting, etc. [25]. In order to ensure the promotion of GBTs adoption, these incentives should be offered to organizations and companies that support GBTs adoption; this can encourage and incentivize them and others to pursue GBTs.

5 Conclusions

Green building represents a construction approach that aims at contributing toward achieving the world's key sustainable development goal: decoupling economic development from climate change, inequality, and poverty. The adoption of GBTs is a necessity for successfully executing green building, and hence, every nation needs to promote the GBTs adoption in its construction industry to foster sustainable development worldwide. This chapter aimed at fostering a crystal-clear understanding of how to promote GBTs adoption in Ghana, a developing country in West Africa. To this end, the primary drivers for GBTs adoption have been discussed, with particular focus on Ghana. Similarly, this chapter has analyzed the key barriers hampering the widespread adoption of GBTs in Ghana. Finally, strategies that can be used to overcome the current barriers in the industry and promote the GBTs adoption are presented. The value of this research lies in the fact that this research can aid policy makers, practitioners, and advocates promote the GBTs adoption. The key strategies they could adopt for promoting the GBTs adoption include—more publicity through media; GBTs-related educational and training programs for key stakeholders; availability of institutional framework for effective GBTs implementation; a strengthened GBTs R&D; and financial and further market-based incentives.

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LEED in the MENA Region…Chances and Challenges of Change

Walaa S. E. Ismaeel

Abstract This chapter provides a critical overview of available opportunities and challenges of changes towards a sustainable green building industry in the Middle East and North Africa (MENA) region. The contribution of the LEED system as a third-party green building certification is acknowledged along with its applicability and adaptability to the local contexts of different principal LEED-adopting Arab countries. These are categorized into two groups for further analysis: the former includes countries rich in natural resources such as UAE, KSA, Qatar and Oman, while the latter includes countries with limited resources such as Egypt, Jordan and Lebanon. Hence, the type of complexities to comply with the system's requirements in the local context is demonstrated. This includes the dominance of the market-driven factors to adopt green building approach, lack of green materials according to the system's specifications and lack of practitioners' awareness. Likewise, pitfalls in the system itself have been highlighted which are related to the lack of clear guidelines to integrate the systems' requirements during the building process. The results provide a detailed clue about the performance of the LEED system in the region as well as for each principal adopting country.

Keywords Green building rating and certification systems · Greenmarket · LEED · MENA region-Arab countries

Nomenclatures

EA	Energy and Atmosphere
EPI	Environmental Performance Index
GBC(s)	Green Building Council(s)
GBRS(s)	Green building rating and certification systems
GDP	Gross domestic product
GHG	Greenhouse gas

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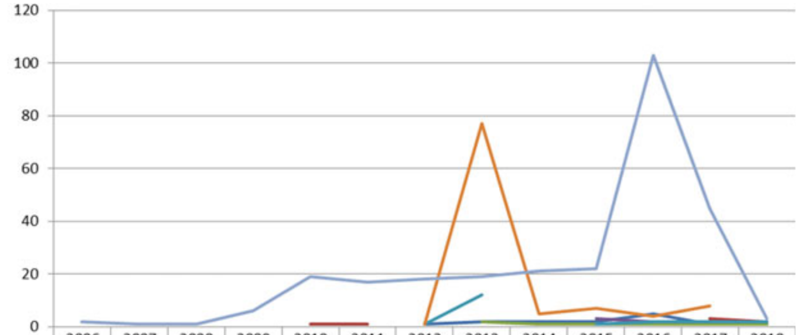
GNI	Gross National Income
IEQ	Indoor environmental quality
IN	Innovation in design
KSA	The Kingdom of Saudi Arabia
LCA	Life Cycle Assessment
LEED	Leadership in Energy and Environmental Design
LEED-AP	LEED Accredited Professional
LEED-CI	LEED for Commercial interior
LEED-CS	LEED for Core and Shell
LEED-EB	LEED for Existing buildings
LEED-NC	LEED for New construction
LEED-ND	LEED for Neighborhood Development
MENA	The Middle East and North Africa
MR	Materials and Resources
RP	Regional Priority
SS	Sustainable Sites
UAE	United Arab Emirates
WE	Water efficiency

1 Introduction

The MENA countries, responsible for around 5.2% of the world's GHGs, are the largest gas and oil exporting nations [1]. They share similar development goals and challenges with international commitments to reducing energy consumptions and emission releases. This has driven many countries to set out robust legislation for buildings' energy efficiency, including building codes, GBRSs, GBCs and green markets [2–4]. Accordingly, this has created a push for green-certified buildings and made ways for the diffusion of the LEED and other locally developed GBRSs to enable comparing building performance and create an added market value [2, 5]. Nevertheless, the lack of accepted and uniform assessment tools created the push for adopting the LEED system rather than locally developed GBRSs [6].

2 Chances

The LEED system has been applied in the MENA region since 2006 in the UAE and it has been diffused in other MENA countries ever since following the international version, since no local versions have been developed till the time of writing this section. It has been a reference to other locally developed rating systems which share common assessment criteria but demonstrate variations in the weighting assigned for each. Figure 1 shows the temporal diffusion patterns of LEED projects in principal



	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Egypt					1		1	2	2	2	5	1	1
Jordan					1	1			1	1		3	2
Lebanon								2	1	1	1	1	1
Oman										3	2	2	
Qatar							1	12		1	2	2	2
Saudi arabia				1			1	77	5	7	4	8	
UAE	2	1	1	6	19	17	18	19	21	22	103	45	3

Fig. 1 The temporal diffusion patterns of LEED projects for the principal LEED-adopting Arab countries [7]

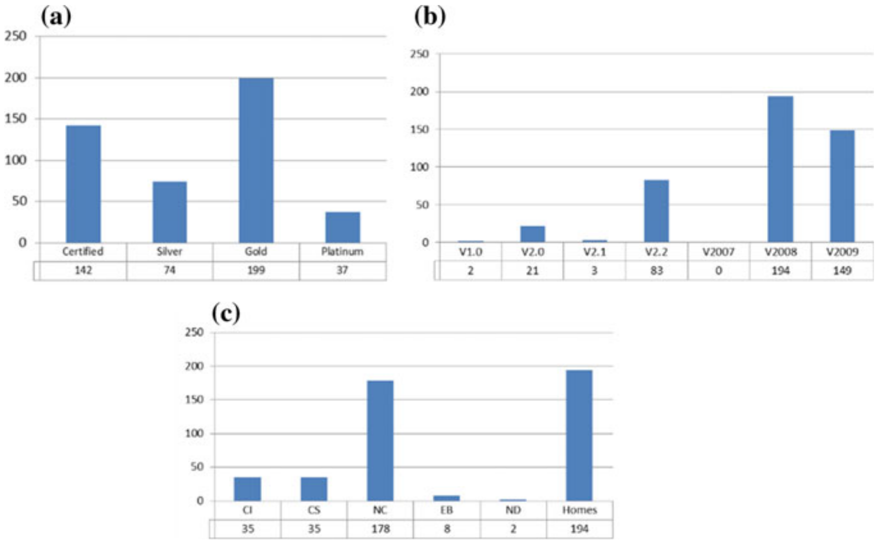


Fig. 2 The prevailing type of LEED certification level (**a**), version (**b**) and type (**c**) [7]

LEED-adopting Arab countries with an almost steady rate except for some booming in the UAE (the Bayti Home project in 2016) and KSA (The King Abdullah Petroleum Studies and Research Center project and The King Abdullah Financial District project in 2013) [7].

The analysis in Fig. 2 indicates that most projects have succeeded to obtain the 'Gold' certification level, the second highest LEED awarded certification level, which indicates the existing potentials in the area for promoting the green building industry. This indicates that the prevailing type of LEED certification and version is similar to the international status [5]. This is particularly true for new commercial buildings and small-scale housing projects. Nevertheless, it should be noted that more concerns should be paid for existing buildings which represent the greatest share of the existing building stock in the MENA region [7].

3 Challenges

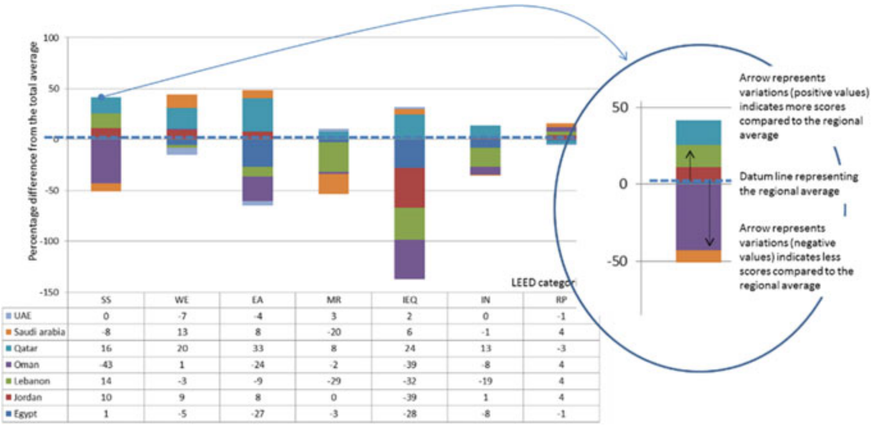
The success of the LEED system is subject to a number of challenges: those attributed with implementing the system (know-how) and others dependent on local contexts (where and why) as well as capacities of local practitioners (who). This can be discussed as follows.

3.1 Where and Why

Studies have indicated that the diffusion of the LEED system can be mainly attributed to political, economic, legislative, social and environmental factors [8, 9]. Ismaeel [7] has indicated that economic reasons play a major role in the MENA region due to the high capital cost required to implement and certify LEED projects. This explains its diffusion in countries with high GDP and GNI despite their increased energy consumption and CO_2 emissions [7]. Furthermore, the average adoption rates of LEED categories vary according to local conditions. Table 1 shows the percentage average adoption rates of LEED categories and Fig. 3 shows their variations compared to one another in respect to the regional average value. This shows that Qatar precedes all other principal countries in all categories that Egypt is less, particularly for the

Table 1 The percentage average adoption rates of LEED categories for principal LEED-adopting Arab countries [7]

	SS	WE	EA	MR	IEQ	IN	RP
Egypt	67	74	37	35	39	76	95
Jordan	73	86	51	36	36	83	100
Lebanon	77	76	43	28	38	69	100
Oman	46	79	38	35	36	76	100
Qatar	79	98	70	39	66	94	93
KSA	61	90	51	30	53	81	100
UAE	66	73	45	37	51	82	95



	SS	WE	EA	MR	IEQ	IN	RP
UAE	0	-7	-4	3	2	0	-1
Saudi arabia	-8	13	8	-20	6	-1	4
Qatar	16	20	33	8	24	13	-3
Oman	-43	1	-24	-2	-39	-8	4
Lebanon	14	-3	-9	-29	-32	-19	4
Jordan	10	9	8	0	-39	1	4
Egypt	1	-5	-27	-3	-28	-8	-1

Fig. 3 The difference of average adoption rates of LEED categories for principal Arab countries compared to the total average [7]

EA and that IEQ categories and the least adoption rates are seen for Oman. This study indicates variations among Arab countries to comply with LEED credits and score points under its main categories.

Similar insights can be deducted in relation to LEED categories. Both the RP and the IN categories achieve the highest adoption rates, 96 and 82%, respectively, which indicates precedence in employing innovative and regional sustainable solutions in building design and construction. This is followed by the WE and SS categories, of 78 and 66%, respectively. These high adoption rates are mainly attributed to the efficient use of water and sites' potentials. The IEQ and EA come next with 50 and 47%, respectively, and the least adoption rate is noted for the MR category. These low rates indicate the lack of experienced practitioners to carry out the required simulations and calculations as well as the lack of sustainable materials, services, and systems according to credits' requirements. Nevertheless, the total average adoption rate of categories is similar to previous international studies by Lavy and Fernández-Solis [10], Ismaeel [5] and Wu et al. [11] which indicate precedence in some sustainable criteria and pitfalls in others. This may be the result of variations in the local context and climate, as well as buildings' system design complexity and feasibility.

3.2 Who

It is also noted that the number of LEED professionals and member organizations is proportional to the number of LEED projects in one country as shown in Fig. 4. LEED accredited professionals holding the Fellow, AP or Green Associate accreditation levels acquire and spread knowledge about sustainable design and construction practices according to LEED credits' guidelines. They ensure a smooth and

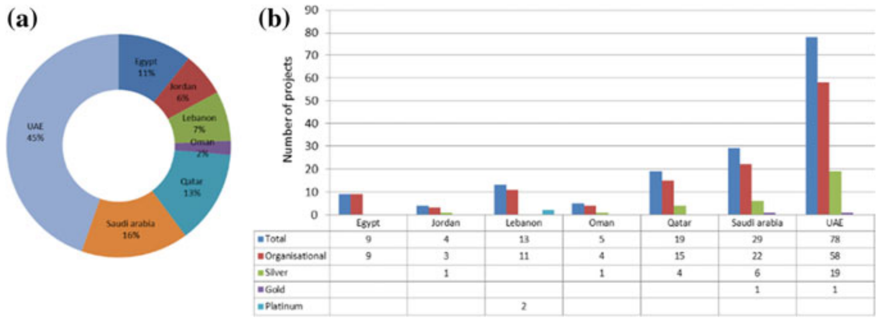


Fig. 4 LEED members' accreditations (**a**) and membership organizations (**b**) [7]

cost-efficient building process. Accordingly, the UAE comes first, then KSA, Qatar, Egypt and then follows the rest of Arab countries.

Similarly, the geographical location and ranking of member organizations (e.g. Platinum, Gold, Silver and organizational memberships status) indicate the availability of systems and services in the local context according to the LEED system's requirements. Interestingly, they are located in main cities: in the UAE (61 in Dubai and 6 in Abu Dhabi), KSA (13 in Riyadh and 9 in Jeddah), Doha (Qatar), Egypt (Cairo), Oman (Muscat) and Jordan (Amman). It is also noteworthy that the highest two Platinum LEED membership organizations are located in the city of Verdun in Lebanon as well as other eight ones in Beirut.

3.3 Know-How

The application of LEED and other GBRSs is considered a recent practice to promote sustainable building design and construction guidelines [12, 13]. Nevertheless, practitioners suffer a lack of 'know-how' to apply the LEED system during the building process which significantly limits its role to documentation and archiving practices and eventually acts against developing its value-contribution. On the contrary, this should pay more concern towards coping with the escalating demands of the building industry of providing user-friendly guidelines, standard criteria of assessment as well as quality-control measures to support the business case of green buildings, which in turn, requires acknowledging the dual-mechanism of operation of GBRSs: rating and certification. Accordingly, Ismaeel [14] has presented a framework to analyse the LEED system and proposed comprehensive criteria to best employ it along with the building process: guidelines, measurement, verification and certification as shown in Fig. 5. Hence, credits can be comprehended in these regards to define the roles and activities of each team member and propose means of optimizing the entire building process and not only individual practices. The study also shows how the system can

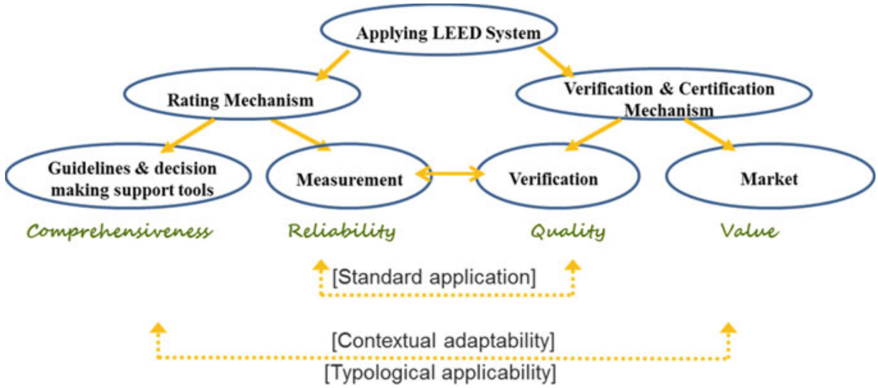


Fig. 5 A deductive approach for the LEED system's operation [14]

be applied to other building types and how it can be better adapted to other local contexts while maintaining standard assessment criteria.

This also requires exploring the best management practices of green-certified buildings as well as employing scientific-based tools and methods. In this regard, LCA comes as a robust method for environmental assessment and recently integrated into a number of GBRSs. Sophisticated models are required to account for buildings' environmental impact along the supply chain. This traces the elementary flows and correlates them to their midpoint and endpoint impact categories. Previous studies showed how both the GBRS approach and the LCA approach could be integrated into a consistent framework to yield reliable results [15]; this can be shown in Fig. 6. This diagnostic study has indicated the variations of score weighting assigned for different midpoint and endpoint impact categories and how this may fluctuate along with different project phases. Greater score weighting is assigned for credits that address the following midpoint impact categories: depletion of non-renewable energy sources and global warming potential, and the following endpoint impact categories: natural resources and human health.

4 Change

The current trend of changes occurring in the MENA region can be traced to a number of aspects: political, economic, legislative, social and environmental. In this regard, countries' status towards promoting the green building industry can be traced, among others, through the number of LEED certified and registered projects, number of LEED accredited professions, the status of their GBCs and existence of national GBRSs. Furthermore, comparative environmental metrics such as the EPI may be used to assess the effect of policy goals in terms of ecosystem vitality and environmental health. Accordingly, the data used to trace and asses the change in

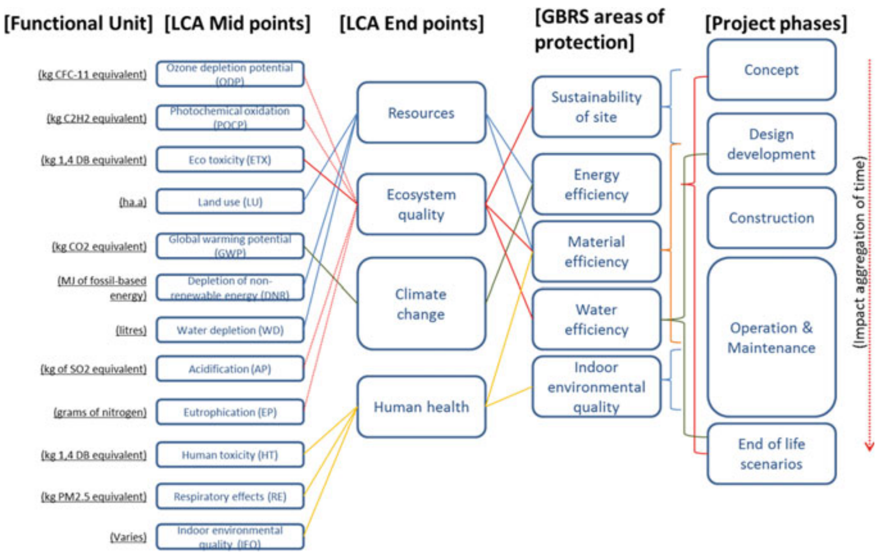


Fig. 6 Investigating midpoint and endpoint impact categories along the project's life cycle [15]

environmental stewardship of MENA countries can be collected from two distinct public directories.

The public project directory of LEED (https://www.usgbc.org/) has been accessed on 9/7/2018 to collect data about certified projects, practitioners and organizations. It is obvious that the number of LEED projects is differing in various Arab countries. These are categorized into two groups for further analysis. The first group includes countries rich in natural resources such as UAE, KSA, Qatar and Oman; while the second group includes countries with limited resources such as Egypt, Jordan and Lebanon. The UAE has the greatest share of 277 certified LEED projects, followed by KSA with 103 projects, Qatar with 20 projects, Egypt with 15 projects, Jordan with 9 projects and Lebanon and Oman with 7 projects for each of the two. These are the main countries shown in Fig. 7 with 1278 total LEED projects (this is almost one-fifth of the total LEED projects in the USA) among which there are 438 LEED-certified projects and 840 projects still under certification, while the others countries have few or none LEED projects [7].

Furthermore, the EPI developed by Yale University and publicly available on the following link (https://epi.envirocenter.yale.edu/) is used as a global matrix to reflect countries status with respect to twenty-four performance indicators categorized under ten categories to discuss ecosystem vitality and environmental health. This method quantifies and ranks countries in these regards to reflect their enactment against the array of environmental stresses. The previous categorization of principal countries can be considered while profiling their EPI rank as shown in Fig. 8. This shows the advancements of some and drawbacks of others, comparatively.

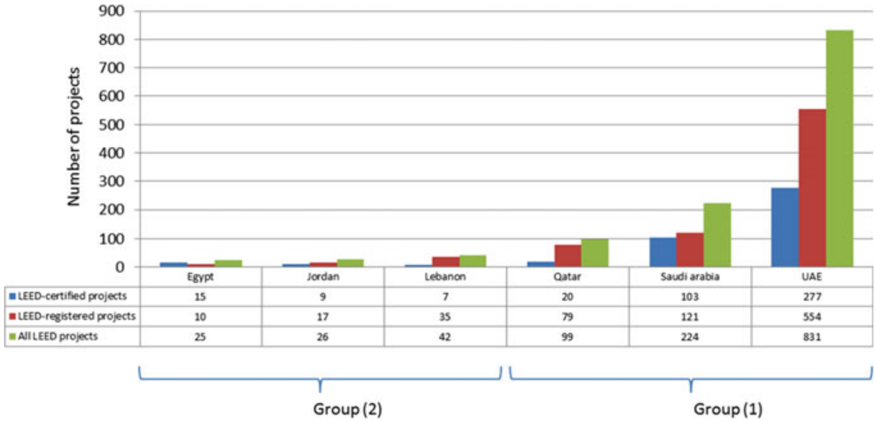


Fig. 7 Comparing the number of LEED projects, certified and registered ones for principal LEED adopting Arab countries [7]

Fig. 8 The EPI profiles of principal LEED-adopting Arab countries

4.1 First Group

This group of countries who adopt LEED certifications includes main hydrocarbon producers and exporters, such as UAE, KSA, Qatar and Oman. They share similar backgrounds of high GDP and GNI per capita. They have similar strategic national targets for energy efficiency by 2030, and they are facing common challenges of resource depletion, rough climate, low cost of energy and energy-intensive construction activities. These are organized in a descending order according to their share of LEED-certified projects in the area discussed as follows [7].

The UAE is taking serious actions towards sustaining its building sector. They are pronounced in the ‘Estidama Program’ and PRS to address the building scale; in the urban scale, the establishment of ‘Masdar City’ became an example of the first zero-carbon city [16]. Similarly, the ‘Green Building Regulations’ and energy labelling schemes issued in Dubai 2010, presented a set of mandatory requirements to achieve a 40% reduction in energy demand of all new governmental and public buildings [17]. According to the EPI, it is ranked the 92nd place in the world which is about the third-best position when it is compared to the listed principal countries. Furthermore, the active initiatives for the UAE among the world’s GBCs demonstrated stability and national positioning that promoted it to act as an ‘Established’ centre. This made the UAE take the lead of the first group and the greatest country in the MENA region-Arab countries to adopt LEED certifications. Noticeably, the Bayti project has contributed towards achieving the LEED certification for Homes with 118 buildings (in 2016 with 103 buildings) and it continued in 2017 with 15 buildings. This has greatly enhanced the UAE’s LEED projects’ profile among peer countries. Almost a half of LEED projects are ‘Certified’ which is the lowest certification level while the third has obtained the Gold level. They are mostly certified under LEED v2008 for Homes followed by LEED NC. Dubai is the main city with LEED-member organizations, followed by Abu Dhabi reaching 61 and 6, respectively. Moreover, there are a total of 1628 LEED practitioners in the UAE; half of which are Green associates and another quarter are LEED AP BD+C.

The kingdom of Saudi Arabia is taking urgent actions to minimize domestic energy consumptions [8]; nevertheless, the national energy standards for new and retrofitted buildings are still in their initial stages [6]. Moreover, the country does not have a registered legal entity among the World GBC nor a national rating system but adopting the LEED system, especially for new public buildings. The ‘King Abdullah Financial District project’ and the ‘King Abdullah Petroleum Studies and Research Center’ project have contributed to achieving the LEED certification with 80 projects, and this has greatly enhanced the KSA’s LEED projects’ profile among peer countries. According to the EPI, it is ranked the 95th place in the world which is the sixth position when it is compared to the listed principal countries. The majority of LEED-certified projects have obtained the ‘Gold’ level under LEED v2008 for Homes followed by LEED NC. Riyadh is the main city with LEED-member organizations, followed by Jeddah reaching 13 and 9, respectively. Moreover, there a total number of 565 LEED practitioners in the KSA, half of which are Green associates and another quarter are LEED AP BD+C.

Qatar is characterized by its high primary energy demands and CO_2 emissions per capita. Hence, the national government has initiated several restructuring projects in the power sector [6]. On the building level, it is pronounced in the national building energy regulation for all new buildings [2], as well as the standards for building insulation; while for the urban level, it is pronounced in the intentions for establishing Qatar’s Energy City. This is in addition to the development of the performance-based whole building rating system, entitled with the Qatar Sustainability Assessment System (GSAS) in 2010 [18]. According to the EPI, it is ranked the 87th place in the world which is the second best position when it is compared to the listed principal countries. This explains the active role of the 'Emerging' GBC in Qatar which has developed organizing structures and initiated several activities to promote the green building industry. The majority of LEED-certified projects have obtained the 'Platinum' level under LEED NC v2.2 followed by LEED v2009. It is noted that all LEED-member organizations are located in Doha. Moreover, there a total number of 492 LEED practitioners in Qatar; half of them are Green associates and another quarter are LEED AP BD+C.

Finally, Oman adopts the LEED system and has no local GBC or a national GBRS. The majority of LEED-certified projects have obtained the 'Silver' level under LEED NC v2009. Muscat is the main city with LEED-member organizations. Moreover, there are a total number of 74 LEED practitioners in Oman; half of them are Green associates and another quarter are LEED AP BD+C.

4.2 Second Group

This group of countries, including Egypt, Jordan and Lebanon, are facing similar challenges of the limited natural resources, and the problem escalates with the increasing number of population, rapid urbanization and economic problems. It is noted that their prevalent climatic conditions provide potentials for employing passive strategies for energy efficiency; nevertheless, the existing building stock shows more dependency on mechanical means [17]. They are organized in a descending order according to their share of LEED-certified projects in the area discussed as follows [7].

Egypt has developed energy efficiency standards, energy labels in addition to developing residential energy efficiency codes in 2003 for HVAC and another for building envelopes with the aim of saving 20% of total energy consumed in buildings [17, 19]. In Egypt, there are two locally developed GBRSs: the GPRS developed by the Housing and Building National Research Centre in 2010 and the TARSHEED developed by Egypt GBC in 2015 [20, 21]. This indicates the dynamic trend being witnessed in the green building industry. According to the EPI, the country is ranked the 104th place worldwide which is the last position when it is compared to the listed principal countries. Nevertheless, it takes the lead of this second group of countries after having established a 'Prospective' GBC with founding members and development plans. The majority of LEED-certified projects have obtained the 'Gold' level under LEED NC v2009 followed by LEED CS. Noticeably, LEED-member organizations are located in main cities; eight organizations are in Cairo. Moreover, there are a total number of 391 LEED practitioners in Egypt; half of them are Green associates and another quarter of them are LEED AP BD+C.

Jordan attempts to raise awareness to adopt the eco-friendly traditional design practices. Moreover, energy efficiency codes are being prepared to enforce the use of thermal insulation in commercial and residential buildings [2, 17]. Also, the Jordan Green Building Guide and Regulations have been released in 2012 provide guidance for efficient high-performance buildings [22]. Moreover, the locally developed GBRS

'SABA' for residential buildings is under development in consideration of the local context and national objectives [23–25]. According to the EPI, the country is ranked the 74th place worldwide which is the first best position when it is compared to the listed principal countries. This indicates the active initiatives for Jordan among the world's GBCs demonstrating stability and national positioning and acting as 'Established' centre since 2010. The majority of LEED-certified projects have obtained the 'Gold' level under LEED NC v2009. Noticeably, LEED-member organizations are all located in Amman. Moreover, there a total number of 231 LEED practitioners in Jordan; half of them are Green associates and another quarter of them are LEED AP BD+C.

Lebanon has developed building thermal insulation codes and standards, energy labels for home appliances, alongside additional assessment tools promoting energy conservation and green buildings with economic incentives provided by the local construction law. Building codes take into consideration the contextual and climatic requirements of different zones in the country [17, 26]. According to the EPI, the country is ranked the 94th place worldwide which is the fifth position when compared to the listed principal countries. Also, the 'Emerging' green building council in Lebanon has developed organizational structures and initiated several activities to promote green building industry. Moreover, the ARZ Building Rating System was launched in 2011 and administered by the Lebanon GBC. The majority of LEED-certified projects are 'Gold' certified under LEED CS followed by LEED NC for v2009. It is noted that LEED-member organizations are located in the main cities; the only two Platinum membership organizations in the city of Verdun and other eight in Beirut. Moreover, there a total number of 265 LEED practitioners in Lebanon; half of them are Green associates and another third are LEED AP BD+C.

5 Conclusion

This section has discussed how the application of the LEED system and other GBRSs in the MENA region present chances and challenges of change towards a green building industry. It is noted that implications of changes towards the diffusion of the LEED system are slowly and steadily taking place in the area.

This, on the one hand, promotes the chances of providing sustainable design guidelines as well as measurement and verification metrics to account for projects' environmental impacts. This is in addition to new open channels of green market communication and exchange in addition to raising practitioners' knowledge and awareness. Furthermore, advanced tools and methods are being promoted to cope with the latest scientific findings.

On the other hand, challenges are seen partially attributed to implementing the LEED system itself and partially to the current local status of MENA countries. This establishes a crucial understanding of the diffusion of the LEED system in developing countries with limited financial resources and characterized by hot arid climate-to

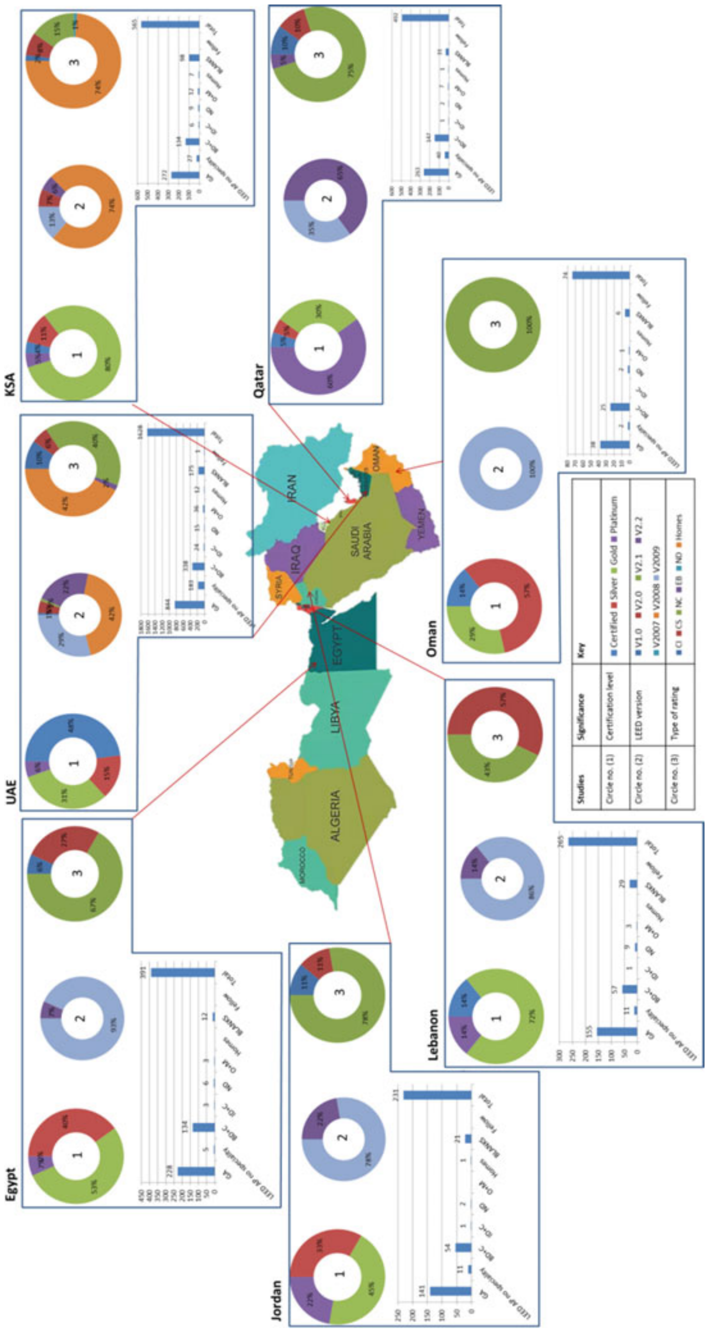


Fig. 9 Principal countries' LEED profile in terms of certification level, version and type of rating [7]

the contrary to the conditions in its country of origin. This traces its applicability and adaptability in this sense to be comparable with the international status.

For the former type of challenges, it has been found similar to international studies in terms of adopting a trajectory approach to market prevalence in main cities. It has been more inviting to private investors for newly constructed office and commercial buildings and less for existing building stock. Meanwhile, the latter type of challenges has returned on the number of LEED projects, accredited professionals and member organizations in one country. It has also returned to the average adoption rates of LEED categories which indicate more adoption of easily achievable and less expensive credits such as those related to the sustainability of the site as well as the efficient use of water. Other main categories such as those related to energy, materials and indoor environmental quality have received less adoption share due to the lack of experienced professionals to carry the required simulation and calculations as well as their high upfront cost and poor governmental and institutional support. This indicates the need to establish a robust legislative base for energy codes and standards; this is in addition to promoting the active role of GBCs and national GBRSs. This should be coupled with promoting the local market and investors' interests. Eventually, profiling principal LEED-adopting Arab countries can be shown in Fig. 9 to provide an evaluation of LEED performance in the MENA region at a glance.

Furthermore, the system lacks providing a 'know-how'; hence, practitioners should be able to compensate for its existing pitfalls during projects' implementation and to establish active research to direct future development of locally developed GBRSs. This would eventually pave the way for third-party building certification as a means of achieving national strategies and adhering to international agreements for the wide benefit, and more specifically following a comprehensive green building process.

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