Highlights:

- A dialectical system framework is proposed to examine green building assessment (GBA)
- The dialectics are elaborated in the dimensions of concept, methodology and value
- Dialectics are found to exist and encounter challenges in all the three dimensions
- 42 GBA systems are identified with 12 compared in depth in high-density city contexts
- The framework provides a new approach to understand the complexity and dynamics of GBA

A dialectical system framework for green building assessment in high-density cities

Wei Pan, Cong Yu*, Jia Du

Department of Civil Engineering, The University of Hong Kong, Pokfulam, Hong Kong, China

Corresponding author email: yucong@connect.hku.hk

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Abstract

Urban areas afford 56% of the world population and the top 600 cities emit 70% of the world greenhouse gases, highlighting enormous challenges and potentials of carbon emission reduction and sustainability in high-density cities. Though vast research has reviewed the green building assessment (GBA) systems in different perspectives, little has explicitly examined the dialectics of GBA, particularly its complexity and dynamics. The assessment of green buildings, however, can be regarded as a complex dynamic system with multifaceted dialectics, particularly in high-density cities. Thus, this paper aims to examine the dialectics of GBA within the context of high-density cities by identifying 42 GBA systems and then comparing 12 widely adopted systems in depth. Dialectics denote the complex and dynamic interdependency among the elements of a system. A dialectical system framework is developed to guide the systematic comparison of the GBA systems in three dimensions: 'concept', 'methodology' and 'value'. The results reveal that dialectics exist and encounter challenges in all three dimensions, including a multi-perspective but inconsistent concept of GBA, well-organised but oversimplified methodology for GBA, and value-laden but insufficient stakeholder engagement in GBA. The developed framework provides a new approach to understanding the complex and dynamic interdependency among the various elements of GBA systems. The findings should raise the awareness of green building developers, planners and designers about the dialectics in GBA and thus inform the associated decision making and design optimisation, making it possible to more effectively achieve green buildings.

Keywords: Green building assessment; high-density city; dialectical system theory; system approach

Abbreviations:

BEAM Plus	Building Environmental Assessment Method Plus
BREEAM	BRE Environmental Assessment Method
CASBEE	Comprehensive Assessment System for Built Environment Efficiency
China GB	Assessment Standard for Green Building
DGNB	German Sustainable Building Council rating system
DST	Dialectical system theory
GBA	Green building assessment
GBI	Green Building Index rating system
Green Star	Green Star rating system
GST	General system theory
IGBC	Indian Green Building Council
LEED	Leadership in Energy and Environmental Design
PBRS	Pearl Building Rating System
POE	Post-occupancy evaluation
STS	Socio-technical system
TOE	Theory of everything

1. Introduction

The Paris Agreement dealing with climate change emphasised the direction of global green development and low-carbon transformation (Horowitz 2016). Building and construction account for 39% of all carbon emissions worldwide (Global Status Report 2017). Building, as one of the key types of consuming carbon emissions, requires green development to tackle the threat of energy shortage and environmental deterioration (Liu et al. 2019). Green buildings, as defined by the World Green Building Council, refer to the buildings that can reduce or eliminate negative influences and provide positive effects on the environment, society and economy in their design, construction and operation. The term "green building" is often used interchangeably with other ones such as sustainable building, sustainable construction, and high-performance building (see e.g. Zuo and Zhao 2014, Li et al. 2017). Green buildings play an essential role in mitigating the negative impact of building and therefore become an important and necessary research topic.

Urban areas afford 56% of the world population in 2019 based on the figures provided by the World Bank (The World Bank 2019). It can be seen that the top 600 cities with the largest population, which are mostly high-density cities, accommodate only 20% of the global population but emit 70% of the greenhouse gas, highlighting enormous challenges and potentials of carbon emission reduction and sustainability in high-density cities. Meanwhile, the percentage of urbanisation has risen rapidly from 36.6% in 1970 to 55.3% in 2018 (UNPD 2019), revealing an urgent need to take measures to reduce carbon emissions in cities. Besides, with the development of emerging green technologies, such as advanced renewable energy and construction materials (Detsi et al. 2020, Dokouzis et al. 2020, Nguyen et al. 2020), there are new opportunities to reduce carbon emissions and become more sustainable. Thus, achieving green buildings in high-density cities is crucial but a promising area.

Green building assessment (GBA) is an effective and widely used method to quantitively assess how "green" the building is (Ali and Al Nsairat 2009). Generally, GBA considers the entire lifecycle of a building, including its planning, design, construction, operation, maintenance, renovation and demolition (Liu et al. 2019). Since the advent of the first GBA system (in 1990, BREEAM), a great number of widely different systems have been developed to assess the sustainability of the buildings. The typical GBA systems include but are not limited to LEED (US) (LEED rating system), BREEAM (UK) (BREEAM - Sustainability Assessment Method), CASBEE (Japan) (CASBEE), Green Star (Australia) (Green Star), BEAM Plus (Hong Kong SAR) (BEAM Plus), Assessment Standard for Green Building (China) (Assessment Standard for Green Building GB/T 50378-2019), Green Mark (Singapore) (Green Mark Certification Scheme), Green Globes (US/Canada) (Green Globes) and Green Building Index (Malaysia) (Green Building Index). These GBA systems were developed to evaluate the performance of green buildings through a series of standardised and pre-designed criteria (Retzlaff 2008). A typical GBA system includes a set of checklists and different point values are allocated to each element, with different weightings for their relative importance in sustainability issues (Papamichael 2000).

By now, numerous studies have conducted the comparison of GBA systems (Awadh 2017; Li et al. 2017; Varma and Palaniappan 2019). Their studies have mainly focused on directly comparing the assessment categories, normalised scores, rating criteria and marking results (Mattoni et al. 2018). To make the GBA comparison smooth, generally, researchers reconstruct target assessment tools based on relevant sustainability theories and/or established assessment frameworks so that these GBA systems can be compared on the same scale (Illankoon et al. 2017, Saldaña-Márquez et al. 2018). Popular ones include pillars of sustainability (adopted by Illankoon et al. (2017), Khoshnava et al. (2018) and Doan et al. (2017), etc.), the category of LEED (adopted by Chandratilake and Dias (2013), etc.), and other assigned categories (Illankoon et al. 2017).

Though vast research has reviewed the GBA systems from different perspectives, little has explicitly examined the dialectics of GBA, particularly its complexity and dynamics. The assessment of green buildings, however, can be regarded as a complex dynamic system with dialectics for the following three reasons.

First, previous studies have found a complex and dynamic relationship between green building certification and occupant attitudes about the service and indoor environment provided by the building. The occupants' satisfaction with the built environment is complex which is determined by both physical parameters and psychological factors. Some studies pointed that residents who know they live in green buildings are generally more tolerant of variations in the thermal comfort in their buildings than those live in non-green buildings (Deuble and de Dear 2012, Gou et al. 2013). Also, green buildings with a comfortable working environment can attract and retain high-quality employees (Heerwagen 2000, Singh et al. 2010), and improve employees' perceived air quality and self-reported productivity (Thatcher and Milner 2016).

Second, dialectical connections were found between the terms of green buildings and building energy saving or energy consumption.

On the one hand, energy consumption or energy savings can be used to evaluate the performance of green buildings. Sometimes green buildings demand more energy than designed, even being indistinguishable from non-green buildings (Geng et al. 2019). The energy consumption discrepancy caused by the as-designed and as-occupied performances of green buildings is complex (Heffernan et al. 2015). Some researchers have attempted to find out the interpretation. For instance, Zhao et al. (2015) found a rebound effect in green buildings. The energy savings produced by applying energy-efficient technologies in green buildings could be less than expected for nontechnical reasons such as public attitudes, occupant behaviour, social and humanistic needs. Liang et al. (2019) observed 117 facility managers in the US in order to examine the performance gap in green buildings and found three reasons for this difference: 1) occupants used more energy than estimated in the energy design, 2) the number of occupants was greater than expected, 3) the energy-efficient technologies had failures. Dwaikat and Ali (2016) conducted a desk study with 17 empirical investigations of green cost premiums and found that more than 90% of green buildings cost no less than their conventional counterparts.

On the other hand, low-energy buildings that feature low energy use intensity (EUI) can be labelled as green buildings, due to the consistency with the green building definition. Optimising the use of energy in buildings is one of the main concerns in green building design (Gan et al. 2020).

Third, a dynamic relationship was found between GBA and project management, such as lifecycle tracking and stakeholder engagement. Kashyap and Parida (2017) emphasised that the effectiveness of the assessment depends on the success of the stakeholder engagement. Wu and Low (2010) reviewed three GBA systems (i.e. LEED, Green Globes and BCA Green Mark) and highlighted that green building is a long operational durational process rather than a simple building and relies on the smooth flow of the project management process. Li et al. (2020) examined the lifecycle costs of non-residential green buildings in Singapore and found that a one-level increase in the Green Mark certificate standard has no significant influence on operation costs. Pan and Ning (2014) reviewed 243 articles related to green buildings and found dialectics exist between the value propositions of various stakeholders and their recognitions of the significance of cooperation in delivering sustainable buildings.

Besides lacking the explicit consideration of the dialectics of GBA, it is not clear whether and how the existing GBA systems thoroughly consider the implications of the characteristics of high-rise high-density cities in relation to green buildings. Given the increasing urbanisation worldwide, high-density cities will be the future trend. Some environmental factors caused by the characteristics of high-density cities, such as urban heat island and light pollution, will affect the assessment of green buildings. This issue has not been adequately considered in previous studies.

In order to address the aforementioned challenges, there is a strong need to propose a dialectical system framework to evaluate the complex and dynamic connections between the elements of a GBA system when used in high-density cities. In addition, many terms have been used to represent the library of toolkits for green building assessment, such as rating or assessment tools, methods, systems, schemes, standards, etc. For consistency, this paper refers to all such terms as 'GBA system'. Following this introductory section, this paper proposes a dialectical system framework for GBA in high-density cities, which considers three dimensions: concept, methodology and value. The paper then examines the challenges faced by GBA using the developed framework, followed by an elaborate examination of the key features of 12 selected GBA systems. Finally, the implications of the findings are discussed, and conclusions are drawn.

2. System theories and dialectical system framework for GBA

System theories provide theoretical support for addressing the dynamic and complex features of GBA. Typical examples of system theories include the general system theory (GST), socio-technical system (STS), theory of everything (TOE) and dialectical system theory (DST).

- GST was proposed by Bertalanffy (1969) and it is a theory for both the evolution and behaviour, which consists of everything ranging from a practical operation to the mathematical theory of selection (Von Bertalanffy 1972). GST can help illustrate GBA in an organic way. However, it cannot expose the interconnections between elements.
- STS aims to address the co-evolution of socio-technical systems, institutions and key stakeholders (Geels 2004). Society is related to the stakeholders' perspectives. Technic refers to sustainable technologies involved in green building assessment. However, a GBA system is more than a stable socio-technical system, as dialectics exist across elements.
- TOE describes an integral vision for business, politics, science and spirituality (Wilber 2001). However, TOE is more likely to set a series of equations explaining all the phenomena that have been or are being observed (Gribbin 2009).
- A dialectical system (DS) has been defined as 'a network/system of essential interdependent viewpoints of consideration'. Dialectical system theory (DST) is 'a theory based on it and links into a DS all the essential viewpoints of consideration of any complex feature' (Mulej et al. 2006). Zenko et al. (2013) stated that DST is a proven next step in GST. DST enables the examination of essential interdependent viewpoints in consideration of complex and dynamic features (Mulej et al. 2006). DST can thoroughly address components, as well as their dialectical interconnections.

Supported by system theories, particularly the DST, some researchers adopted the four-fold framework that consists of ontology, epistemology, methodology and axiology, in examining dialectics of strategic alliances (De Rond and Bouchikhi 2004) and dialectics of sustainable buildings (Pan and Ning 2014; Pan and Ning 2015). Theoretically, ontology means the nature of reality and of what really exists. Epistemology means the relationship between the knower and what is known. The methodology is the strategy and justifications in constructing a specific type of knowledge, as linked to individual techniques. Axiology shows the values that shape or are shaped in the body of knowledge.

Practically, this study adjusted the four folds of the philosophical framework into three folds to guide the examination of the dialectics of GBA systems, namely, concept, methodology, and value. The details of the adjustment are presented below.

First, ontology and epistemology were defined as the perspective of **concept** to show the nature of the GBA system and how we define the GBA system. Because under the topic of GBA systems, based on the above theoretical expression, ontology refers to the GBA system itself, and epistemology is to express how we know what the GBA system is. The concept perspective represents the theoretical foundation of the GBA system. The theoretical foundation can determine many factors such as certification categories and certification methods in the subsequent certification of GBA systems. For example, the concept of sustainability in Green Mark is environmental, social, and economic while that in PBRC is environmental, economic, cultural and social. Compared to Green Mark, PBRC focused more on the cultural factors. The difference in the concept of sustainability would affect the overall performance of the GBA system. The GBA should thus consider the theoretical framework in relation to the concept of sustainability. The dialectics of all the categories of green buildings, such as the categories of environment, society and economy, should also be considered in GBA. In addition, the sustainable effect due to its high-density surroundings should be specified.

Second, **methodology** refers to how the GBA system functions. From the methodology perspective, the GBA should systematically consider the dynamics and dialectics of green building-related components, both individually and collectively. These components comprise both temporal and functional aspects. The temporal aspect means that the components are related to time, such as the procedures of GBA systems. The functional aspect includes the assessment methods (e.g., the criteria, indicators and weighting method), post-occupancy evaluation methods (POE, e.g., lifecycle tracking, periodic checks, building performance monitoring and auditing) and documentation and management of certified buildings. Dialectic and dynamic connections exist in the components themselves and across different components. For example, the selection of indicators should be considered both dialectically and dynamically. Indicators that are massive and useless should not be selected, nor should deficient indicators that cannot reflect the real situation. In addition, the GBA should adapt to local contexts in a specific region. Different regions should have different criteria for GBA. Meanwhile, the selected indicators should cover all the components comprehensively and can reflect the current green/not green situation of the object building. In addition, the GBA should also consider the dialectic and dynamic interconnections between various components, such as the performance gap between the as-designed and as-occupied green buildings.

Third, axiology was defined as the perspective of **value,** which concerned the stakeholders and their networks, and their interfaces with the certification process. Different stakeholders hold various views on the specific process of assessing green building performance [56]. For instance, technicians and architects may give a greater consideration to the technical systems adopted in green buildings. The government and its agencies might focus more on the time flow and function of assessing green buildings to ensure the smooth progress of the assessment. Financers and bankers could be more interested in the cost perspective, and contractors would pay more attention to the actual cost savings related to the materials and energy consumption during the green building construction process.

Guided by this framework, the dialectics of GBA systems were examined using the interconnected dimensions of concept, methodology and value, which are illustrated in Figure 1. By using the proposed dialectical system framework, the gaps in GBA are examined in the following sections with reference to the major GBA systems applied to high-density cities.

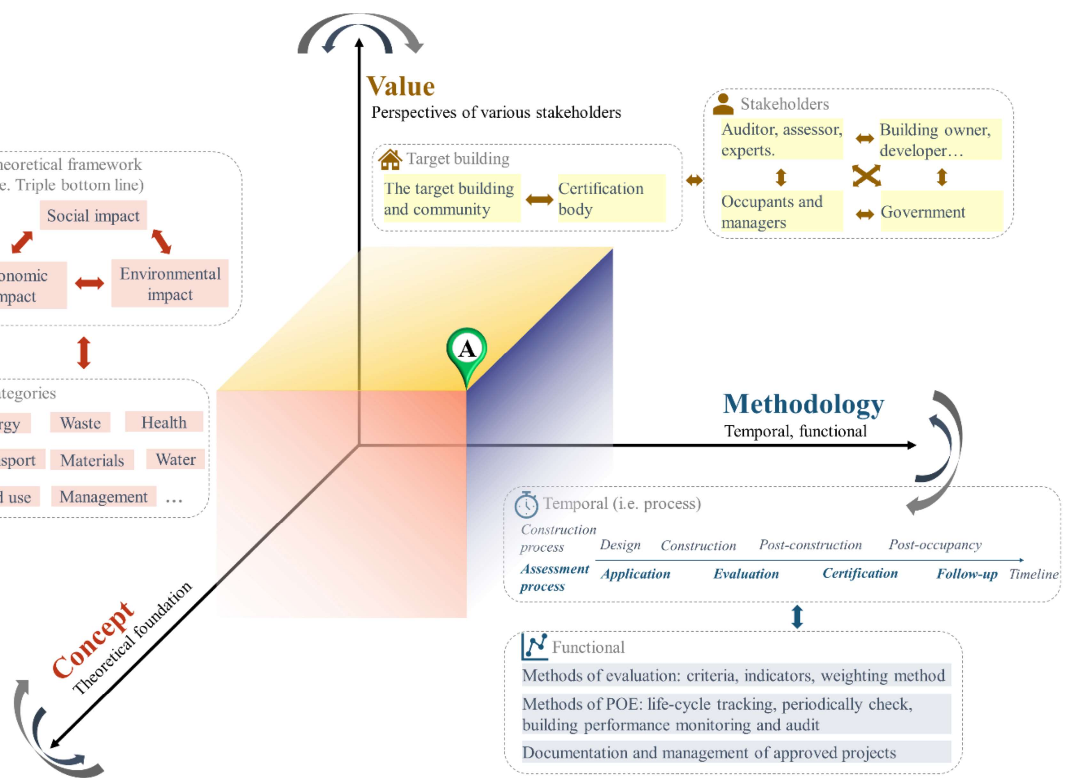


Figure 1 Dialectical system framework of GBA systems

3. Cross comparison of GBA systems

3.1 Selection of GBA systems for comparison

Many international and national GBA systems are available worldwide. As illustrated in Figure 2, 42 GBA systems were identified from the database of the World and Regional Green Building Councils (WGBC 2021) and the literature on green buildings. The most widespread system is LEED, which was developed in the US, with multiple national versions. The other five frequently used systems are BREEAM, CASBEE, Green Star, Green Mark and BEAM Plus. BREEAM is the first GBA system which was developed in the UK in 1990. CASBEE is the widely used GBA system established in Japan. Green Star was developed in Australia and has been customised into national versions in New Zealand and South Africa. Green Mark was launched in Singapore and has been used for some overseas projects. BEAM Plus has mainly been used in Hong Kong to provide an independent assessment of building sustainability.

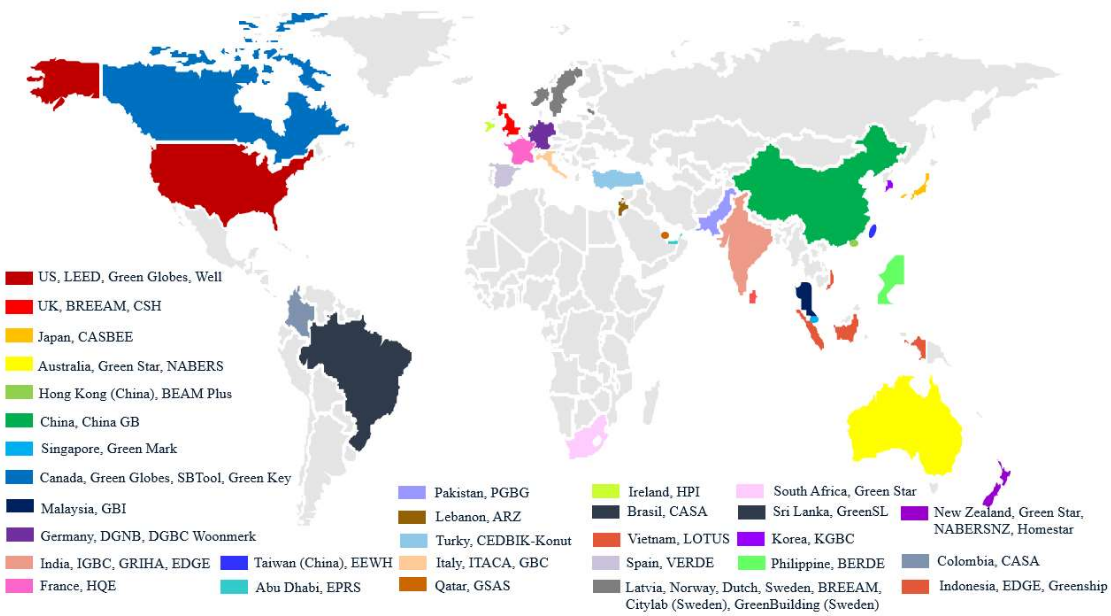


Figure 2 World map of GBA systems

Currently, there is no GBA systems exactly focusing on the context of high-density cities. The selected GBA systems for study in this paper are generally used for their relevant country with complex urban forms but not developed for high-density cities specifically. Given the increasing urbanisation worldwide, high-density cities will be the future trend. Thus, this paper pays particular attention to the GBA systems with good applicability for high-density cities. There is no clear definition of high-density cities in previous studies. Commonly, cities with a population density of 4000 people per square kilometre (pp/km2) or above are referred to as high-density cities. The typical high-density cities or regions include New York 10424 pp/km^2 (NYC 2015), London 5701 pp/km^2 (ONS 2021), Tokyo 6363 pp/km^2 (TMG 2021), inner-city Melbourne 19900 pp/km^2 (ABS 2022), Hong Kong 7126 pp/km^2 (TWB 2020), Shenzhen 6484 pp/km^2 (SMBS 2020), Kuala Lumpur 7188 pp/km^2 (DSMOP 2021), Berlin 4112 pp/km^2 (Statista Accounts 2020), Mumbai 28185 pp/km^2 (CI 2011), Abu Dhabi central residential downtown areas around 30000 pp/km^2 (Elessawy 2021). High-density cities featured by the high-density urban environment have significant phenomena in some respects, such as heat islands, inadequate land supply, light pollution, blazing sunlight and poor natural views.

To best achieve the aim of this study, twelve GBA systems were selected for a comparative analysis within the context of high-density regions or cities. The selection was based on the following criteria:

1) The selected GBA systems are widely used and adopted in high-density cities.
2) The climates of the selected cities or countries should be diverse. Different systems have different application cities or countries; thus, the systems should be selected to cover the different climates of the application cities or countries.
3) Systems developed using the same original GBA system were excluded. For example, some

systems were developed based on popular GBA systems, such as LEED, and have similar aspects and categories that should be excluded.

The selected GBA systems (the first twelve numbers of GBA systems listed in Table 1) are used in a total of 14 regions, including the US, the UK, Japan, Australia, New Zealand, South Africa, Hong Kong SAR, China, Singapore, Canada, Malaysia, Germany, India and Abu Dhabi. It should be noted that all the GBA systems except the GBI meet the above three criteria. Although the GBI was fundamentally derived from the Green Mark and Green Star systems, it has been extensively modified according to the Malaysian tropical weather, environmental context, cultural and social needs. Thus, the inclusion of the GBI did not conflict with the selection criteria.

Table 1 List of selected green building assessment (GBA) systems

No	GBA systems	Country or region	No	GBA systems	Country or region
1*	LEED	US	22	EEWH	Taiwan
2*	BREEAM	UK	23	BERDE	Philippine
3*	CASBEE	Japan	24	BREEAM	Latvia/Norway/ Dutch/Sweden
4*	GREEN STAR	Australia, New Zealand, South Africa	25	CASA	Colombia
5*	BEAM Plus	Hong Kong SAR	26	CityLab	Sweden
6*	CHINA GB	China	27	CEDBIK-Konut	Turkey
7*	GREEN MARK	Singapore	28	DGBC Woonmerk	Germany
8*	GREEN GLOBES	US/Canada	29	LOTUS	Vietnam
9*	GBI	Malaysia	30	Korea Green Building Certification	Korea
10*	DGNB	Germany	31	NABERSNZ	New Zealand
11*	IGBC rating system	India	32	ARZ rating system	Lebanon
12*	PBRS	Abu Dhabi	33	Homestar	New Zealand
13	AQAU-HQE	France	34	GBC Brazil CASA	Brazil
14	SBTOOL	Canada	35	GreenBuilding	Sweden
15	CSH	UK	36	Greenship	Indonesia
16	GRIHA	India	37	EDGE	Indonesia
17	GSAS	Qatar	38	Green Key	Canada
18	ITACA	Italy	39	GreenSL	Sri Lanka
19	WELL	US	40	Pakistan Green Building Guideline BD+C	Pakistan
20	VERDE	Spain	41	Home Performance Index	Ireland

21	NABERS	Australia	42	GBC Home	Italy

Notes: "*" refers to the selected GBA systems for detailed analysis.

Table 2 provides the basic information of the 12 selected GBA systems. By comparing the publish date of the latest version, we can see that most GBA systems had relatively new version except PBRS which adopted the version above ten years ago. A wide range of types were found across GBA systems, covering different types of buildings and the community. Among various categories, particularly, "water", "energy", "materials", "indoor environment", and "site" were the considerable categories since they were the most mentioned by different GBA systems. The GBA systems normally have the rating levels from three levels to seven levels with different level names. Considering the variety of assessment aspects for different building types, this study only focused on new residential buildings.

Table 2 Comparison of selected green building assessment (GBA) systems

No	GBA system	First version	Latest version	Types	Categories for new residential buildings		Rating level
					Type*	Categories	
1	LEED	1998	LEED v4.1	(1) BD+C Building Design and Construction; (2) ID+C Interior Design and Construction; (3) O+M Building Operations and Maintenance. (4) ND. Neighbourhood Development; (5) Homes; (6) Cities and Communities; (7) LEED Recertification; (8) LEED Zero	(1)	Integrative process Location and transportation Sustainable sites Water efficiency Energy and atmosphere Materials and resources Indoor environmental quality Innovation Regional priority	Certified Silver Gold Platinum
2	BREEAM	1990	2016	(1) Communities Master Planning; (2) Infrastructure Civil Engineering & Public Realm; (3) New Construction Homes & Commercial Buildings; (4) In-use Commercial Buildings; (5) Refurbishment & Fit-out Homes & Commercial Buildings	(3)	Management Health and wellbeing Energy Transport Water Materials Waste Land use and ecology Pollution Innovation	Unclassified Pass Good Very good Excellent Outstanding
3	CASBEE	2002	2014	(1) Buildings (New Construction); (2) Buildings (Existing Buildings); (3) Buildings (Renovation); (4) Market Promotion; (5) Commercial Interiors; (6) Temporary Construction; (7) CASBEE for Heat Island; (8) Urban Development; (9) CASBEE for Cities; (10) CASBEE for Detached Housing (New Construction); (11) CASBEE for Dwelling Unit; (12) CASBEE for Health Checklist; (13) CASBEE for Housing Renovation Checklist; (14) CASBEE for Community Health Checklist	(1)	Indoor environment Quality of service Outdoor environment (onsite) Energy Resources and materials Off-site environment	Poor Fairly poor Good Very good Excellent
4	Green Star	2003	v1.2	(1) Green Star-Communities; (2) Green Star-Design & As-Built; (3) Green Star-Interiors; (4) Green Star-Performance	(2)	Management Indoor Environment Quality (IEQ) Energy Transport Water Materials Land use & ecology Emissions	Zero stars One star Two stars Three stars Four stars Five stars Six stars

						Innovation (additional)	
5	BEAM Plus	1996	v2.0	(1) BEAM Plus New Buildings; (2) BEAM Plus Existing Buildings-Comprehensive Scheme; (3) BEAM Plus Existing Buildings-Selective Scheme; (4) BEAM Plus Interiors; (5) BEAM Plus Neighbourhood	(1)	Integrated design and construction management Sustainable site Materials and waste Energy use Water use Health and wellbeing Innovations	Bronze Silver Gold Platinum
6	China GB	2006	2018	GB/T 50378-2019	/	Safety and durability Occupancy convenient Health and comfort Environment liveability Resource-saving Management and innovation (additional)	Base grade One Star Two Stars Three Stars
7	Green Mark	2005	2016	(1) Non-residential Buildings; (2) Super Low Energy Buildings; (3) Residential Buildings: (4) Non-residential New Buildings; (5) Residential New Buildings; (6) Transit Station; (7) Existing Non-residential Buildings; (8) Existing Non-residential Buildings; (9) Existing Buildings; (10) Existing Residential Buildings (Version 1.1); (11) Existing Schools; (12) Healthcare Facilities; (13) Healthier Workplaces; (14) Landed Houses; (15) Infrastructure; (16) District; (17) Restaurants; (18) Supermarket; (19) Existing Data Centres; (20) New Data Centre; (21) Retail; (22) Laboratories	(3)	Climatic responsive design Building energy performance Resource stewardship Smart and healthy building Advanced green efforts	Green Mark Gold Green Mark Gold^{PLUS} Green Mark Platinum
8	Green Globes	2000	2014	(1) New Construction/Significant Renovations; (2) Commercial Interiors; (3) Existing Buildings	(1)	Project management Site Energy Water Materials and resources Emissions Indoor environment	One green globe Two green globes Three green globes Four green globes Five green globes
9	GBI	2009	2019	(1) Non-Residential New construction; (2) Residential New Construction; (3) Non Residential Existing Building; (4) Industrial New Construction; (5) Industrial Existing Building; (6) Non-Residential New Construction: Data Centre; (7) Non-Residential New Construction: Retail; (8) Non-Residential Existing	(2)	Energy efficiency Indoor environmental quality Sustainable site planning & management Materials and resources Water efficiency	Certified Silver Gold Platinum

				Building: Data Centre; (9) Non-Residential Existing Building: Retail; (10) Non-Residential New Construction: Hotel; (11) Non-Residential New Construction: Resort; (12) Non-Residential Existing Building: Hotel; (13) Non-Residential Existing Building: Resort; (14) Township		Innovation	
10	DGNB	2008	2020	(1) Existing Buildings; (2) New Construction; (3) Interiors; (4) Districts	(2)	Environmental quality Economic quality Sociocultural and functional quality Technical quality Process quality Site quality	Bronze (only for existing buildings) Silver Gold Platinum
11	IGBC rating system	2013	2016	(1) New Buildings; (2) Existing Buildings; (3) Homes; (4) Residential Societies; (5) Interiors; (6) Healthcare; (7) Schools; (8) Factory Buildings; (9) Data Centre; (10) Campus; (11) Villages; (12) Townships; (13) Cities; (14) SEZs; (15) Landscapes; (16) Mass Rapid Transit Systems; (17) Existing Mass Rapid Transit System; (18) Affordable Housing	(1)	Sustainable architecture and design Site selection and planning Water conservation Energy efficiency Building materials and resources Indoor environmental quality Innovation and development	Certified Silver Gold Platinum
12	PBRS	2010	2010	(1) Community Rating System; (2) Building Rating System; (3) Villa Rating System	(2)	Integrated development process Natural systems Liveable buildings Liveable indoors Precious water Resourceful energy Stewarding materials Innovating practice (additional)	1 Pearl 2 Pearls 3 Pearls 4 Pearls 5 Pearls

*Notes: this represents the numbering of selected building 'Types' in this study. For example, '(1)' in Row 1 and Column 6 means that this study selected '(1) BD+C Building Design and Construction' in LEED as a study case.

3.2 Results for dialectics of GBA in relation to 'concept'

The dialectics of the GBA system related to this concept were found to exist in three layers. The first layer aimed to analyse the theoretical basis of the GBA system at the strategy level. The second layer of dialectics was observed to be the framework aspects at the breakdown level, which is called the 'category'. The third was the types of buildings covered by the assessment system, which indicates the applicability of the GBA system in high-density cities.

3.2.1 Comparison of theoretical bases for GBA systems

The selected systems were observed to have different sustainability concepts, as displayed in Table 3. In previous research, several frameworks for sustainability were found, including the three pillars theory (environmental, economic, social), four pillars theory (social, human, economic, environmental), five pillars theory (water, energy, materials, ecology, community), scale-density matrix and man-made environment/natural systems integration (Sarté 2010). The majority of the systems (seven systems) in this study were found to be established based on the three aspects of sustainability. PBRC adopted four aspects, and the rest four systems (Green Star, BEAM Plus, China GB, IGBC rating system) utilised five aspects. The concept of sustainability adopted by a system was found to be related to cultural factors and local government policies. For example, the cultural tradition is an important aspect in the definition of green buildings in PBRC because it was developed for implantation in the Middle East.

Dialectics were found within the aspects of sustainability. For instance, taking BREEAM as an example, advanced green technologies are utilised to achieve high energy performance, which belongs to environmental sustainability; however, such technologies are normally with increased up-front cost. Cost-effectiveness was a consideration in achieving sustainability. There exists a trade-off between the environmental and economic factors. Except for the dialectics between the environment and economic aspects, the interdependence between social and environment/economic was also observed. More diverse stakeholder participation in the assessment process would make the process smooth and make the building more environmentally and economically sustainable. For instance, local governments involved in GBA can benefit from fostering sustainable development by developing green building policy and strategies, and public involvement can facilitate the diffusion of green technologies.

Table 3 Definition of green building in selected GBA systems

No.	GBA systems	Definition of green building / Concept of sustainability	Summary
1	LEED	**People, planet** and **profit**	Three pillars theory
2	BREEAM	**Environmental, social and economic sustainability**	Three pillars theory
3	CASBEE	Both to enhance the **quality** of people's lives and to reduce the lifecycle **resource use** and **environmental loads** associated with the built environment, from a single home to a whole city	Three aspects
4	Green Star	1) Reducing the impact of **climate change** 2) Enhancing our **health and quality** of life 3) Restoring and protecting our planet **biodiversity** and **ecosystems** 4) Driving **resilient** outcomes for buildings, fitouts and communities 5) Contributing to **market** transformation and a sustainable **economy**	Five aspects
5	BEAM Plus	1) Improve the **quality** of the indoor environment 2) Minimise **pollution** to the external environment 3) Promote and encourage **energy-efficient** buildings, systems and equipment 4) Reduce the unsustainable consumption of increasingly scarce **resources** 5) Develop more **cost-effective** sustainable building design and processes	Five aspects
6	China GB.	**Land use, energy, water, materials, environment**	Five aspects
7	Green Mark	**Environmental, social, economic**	Three pillars theory
8	Green Globes	**A legacy of convenience**, **cost effectiveness and ease of use**	Three aspects
9	GBI	Increasing **the efficiency of resource use** – energy, water and materials – while reducing a building impact on **human health** and the **environment** during the building lifecycle	Three aspects
10	DGNB	**Ecological, economic** and **sociocultural issues**	Three aspects
11	IGBC rating system	**Employment generation, rural-urban connect, energy security, environmental sustainability and governance**.	Five aspects
12	PBRC	**Environmental, economic, cultural and social**.	Four aspects

3.2.2 Comparison of assessment categories in GBA systems

The concepts for specific categories were inconsistent in the different systems. For example, the heat island effect was a sub-category under the category of sustainable sites in LEED and BEAM Plus. However, in Green Star, the heat island effect was identified as a sub-category parallel to the sustainable sites in the same category: land use and ecology.

The categories of the systems could be divided into three groups based on their proportions, as shown in Figure 3. The proportion of each category was calculated as the sum of the scores of each criterion in each category divided by all the criteria. In Group A, the proportions of the different categories were relatively similar. CASBEE, China GB and Green Mark belonged to this group. Group B showed significant fluctuation between categories, and the category ‘energy’ had the greatest percentage among all the categories. LEED, BEAM Plus, Green Globes, GBI and IGBC rating system were included in this group. It should be noted that the weighting of energy in Green Globes was 40%, which was the highest weighting percentage among all the GBA systems. Group C had several categories with low weights and several with relatively high weights. BREEAM, Green Star, DGNB and PBRC were in this group.

CASBEE	Indoor environment	16.36%
	Quality of service	14.95%
	Outdoor environment (On-site)	15.88%
	Energy	21.03%
	Resources and materials	15.42%
	Off-site environment	16.36%
China GB	Safety and durability	20.00%
	Healthy and comfort	20.00%
	Convenient of occupation	20.00%
	Resouces conservation	20.00%
	Environmental livability	20.00%
Green Mark	Climatic responsive design	25.00%
	Building energy performance	17.86%
	Resource stewardship	25.00%
	Smart and healthy building	17.86%
	Advanced green efforts	14.29%

(a) Group A: similarly weighted

LEED	Integrative process	0.90%
	Location and transportation	14.55%
	Sustainable sites	9.09%
	Water efficiency	10.00%
	Energy and atmosphere	30.00%
	Materials and resources	11.82%
	Indoor environmental quality	14.55%
	Innovation	5.45%
	Regional priority	3.64%
BEAM Plus	Integrated design and construction management	18.00%
	Sustainable sites	15.00%
	Materials and waste	9.00%
	Energy use	29.00%
	Water use	7.00%
	Health and wellbeing	22.00%
Green Globes	Project management	5.00%
	Site	12.00%
	Energy	40.00%
	Water	11.00%
	Materials & resources	13.00%
	Emissions	5.00%
	Indoor environment	15.00%
GBI	Energy efficiency	33.00%
	Indoor environmental quality	22.00%
	Sustainable site planning & management	18.00%
	Material & resources	10.00%
	Water efficiency	10.00%
	Innovation	7.00%
IGBC	Sustainable architecture and design	5.00%
	Site selection and planning	14.00%
	Water conservation	19.00%
	Energy efficiency	30.00%
	Building materials and resources	16.00%
	Indoor environmental quality	9.00%
	Innovation and development	7.00%

(b) Group B: fluctuated with the max ratio of energy category

BREEAM	Management	10.60%
	Health and wellbeing	21.50%
	Energy	20.00%
	Transport	6.41%
	Water	6.73%
	Materials	12.50%
	Waste	5.77%
	Land use and ecology	7.69%
	Pollution	8.80%
GREEN STAR	Management	14.00%
	Indoor environment quality	17.00%
	Energy	22.00%
	Transport	10.00%
	Water	12.00%
	Materials	14.00%
	Land use and ecology	6.00%
	Emissions	5.00%
DGNB	Environmental quality	22.50%
	Economic quality	22.50%
	Sociocultural and functional quality	22.50%
	Technical quality	15.00%
	Process quality	12.50%
	Site quality	5.00%
PBRC	Integrated development process	7.35%
	Natural systems	6.78%
	Livable buildings	20.90%
	Precious water	24.29%
	Resourceful energy	24.86%
	Stewarding materials	15.82%

(c) Group C: modestly fluctuated

Figure 3 Category of each system (Group A: top, Group B: middle, Group C: bottom)

The dialectics were found within the assessment categories. Seven GBA systems have the category of management or process in order to evaluate the sustainability of the whole GBA process. The effectiveness of the management or process could ensure the success of the other categories such as energy, water, transport in achieving sustainability.

The dialectics were also found between assessment categories and theoretical bases. All the categories covered the theoretical bases of the GBA systems. Besides, the categories established by some GBA systems, such as China GB and DGNB, were consistent with their theoretical bases for GBA systems.

3.2.3 Comparison of GBA systems in relation to inclusion of high-density urban environment

Overall, it could be found that all the systems considered the effect of a high-density urban environment to varying degrees, which was present in different categories with different names. The criteria related to heat islands and sustainable sites were found to be the top criteria considered. Specifically, LEED and BEAM Plus considered the reduction of heat islands and light pollution in the category of sustainable sites and the criteria of daylight and quality views in the category of indoor environmental quality. BREEAM considered the reduction of light pollution from the outdoor environments. CASBEE and China GB also had an outdoor environment category, which involved the consideration of high-density districts. The green mark had the urban harmony sub-category, which contained sustainable urbanism, integrated landscapes and waterscapes in response to climate change. Green Globes considered the urban effect in the site category. Green Star considered sustainable sites and heat island effect in the land use and ecology category. IGBC rating system had a site selection and planning category that could address the effects of the urban context. Similar to IGBC rating system, GBI had the category of sustainable site planning and management. PBRS had the category of liveable outdoors with consideration given to the urban context. DGNB had the category of site and environmental quality control. In addition, among the 12 GBA systems, nine had community certification, with China GB, Green Globes and GBI being the exceptions.

3.3 Results for dialectics of GBA in relation to 'methodology'

The dialectical system theory methodology for GBA systems has both temporal and functional aspects. The temporal aspect refers to the timeline of the certification process throughout the lifecycle stages. The functional aspect refers to GBA methods, such as scoring and grading.

3.3.1 Comparison of certification process timelines of GBA systems

Interdependence between certification process and lifecycle stages of the 12 selected systems was evaluated (Figure 4). Overall, the results show the variety and flexibility of the lifecycle process in the GBA. PBRC was found to have the most flexibility, with the ability to assess a project in relation to the design, construction and operation/post-occupancy. BREEAM offered alternatives that make it possible to assess the project either in the planning/pre-design stage or in the design and construction stage. Green Star, China GB and IGBC rating system had optional choices to be assessed in the optional stage. Only three GBA systems (BREEAM, BEAM Plus and DGNB) covered the planning/pre-design stage. Only three GBA systems (CASBEE, GBI and PBRC) included the operation/post-occupancy stage. In addition, CASBEE and BEAM Plus had the most prolonged lifecycle processes, which covered four stages.

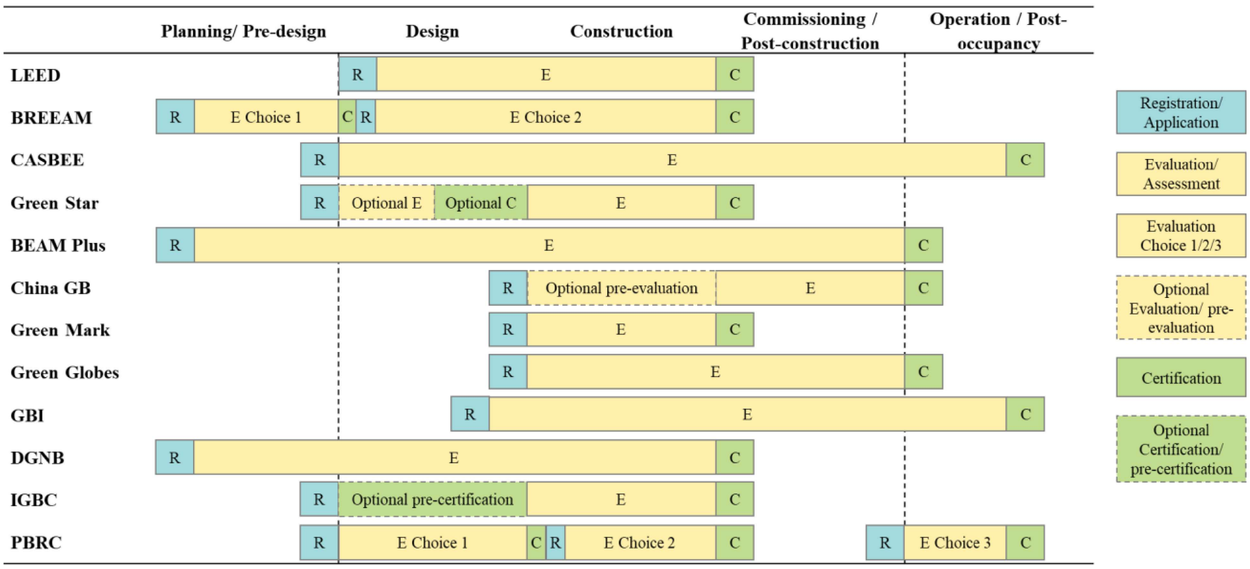


Figure 4 Certification processes of selected systems

Notes: R means registration/application and it can be started at the stage. E refers to evaluation/assessment. Evaluation choice means that the target building can be evaluated for/in the selected stage(s). Optional means that this process can be operated optionally. C means certification.

3.3.2 Comparison of GBA systems functions

The relationships between certification levels and normalised scores of the selected GBA systems are displayed in Figure 5. The GBA systems had a variety of certification levels, ranging from four (Green Mark and DGNB) to seven (Green Star). Different GBA systems had different scores at the same certification level. For instance, a green building that has a 'platinum' certification may only earn a 'certified' grade in another system. CASBEE was excluded in the analysis because of its distinct grading method.

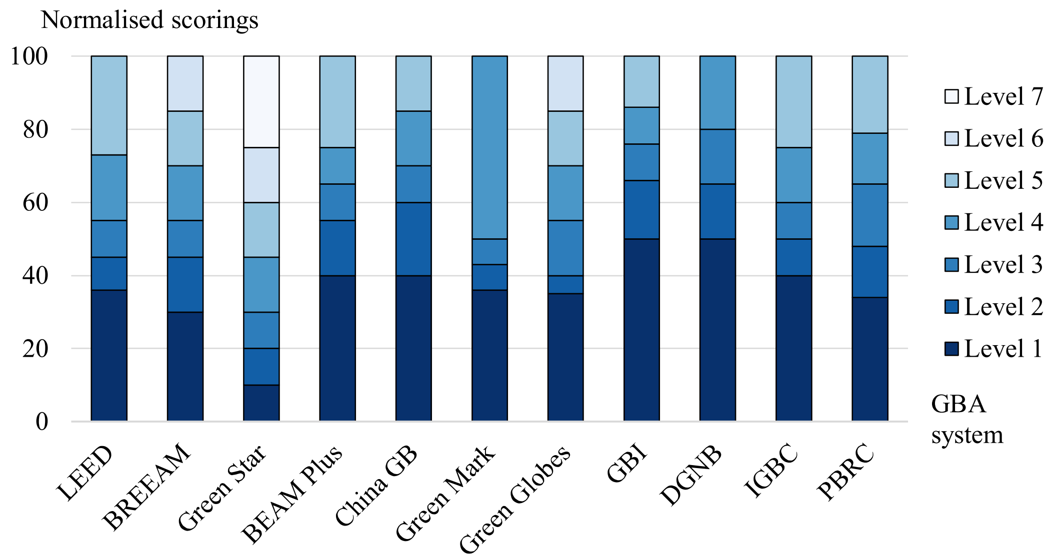


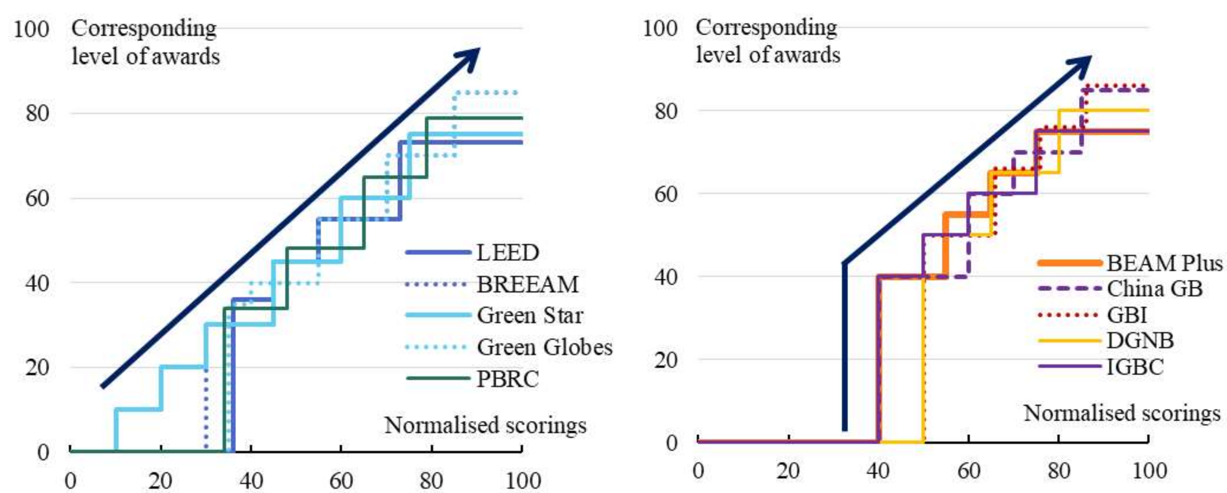
Figure 5 Certification levels and normalised scores of selected GBA systems

Notes: CASBEE is distinct from all other systems in terms of its scoring methods and was excluded.

Interrelationships between scores and certification levels were evaluated. Since different systems have different scores and levels of awards, we set normalised scorings as the X-axis and the corresponding level of awards as the Y-axis to make various systems comparable. This study classified these systems into four types according to the difference in scoring method, lower limit and upper limit, as displayed in Figure 6. The scoring method represents the certification methods. The total score determined the certification level of all the other systems except CASBEE. In CASBEE, environmental quality and environmental load determined the final certification level. The lower limit represents the access threshold. If the lower limit was low, projects with low normalised scorings could earn certifications, which means that projects can easily access the certification. On the contrary, the upper limit represents the required scores to obtain the highest level of certification. If the upper limit is low, a project with relevant good scores can easily obtain the highest certification. Type A was the 'linear' type, which meant that the percentages of the levels were almost uniformly distributed. That is, a group of projects marked with different scores, from low, mid to high scores, under a type A assessment system, should be awarded different levels of certifications. LEED, BREEAM, Green Star, Green Globes and PBRC belonged to this type. Type B was the type with a low limit, where level 1 started at a percentage of more than 40%. BEAM Plus, China GB, GBI, DGNB and IGBC rating systems were included in this type. Green Mark, which belonged to type C, had both low and high limits for awards. CASBEE represented the 'ratio' type, where the certification level was based on the ratio of the environmental quality and environmental load (defined as the built environment efficiency).

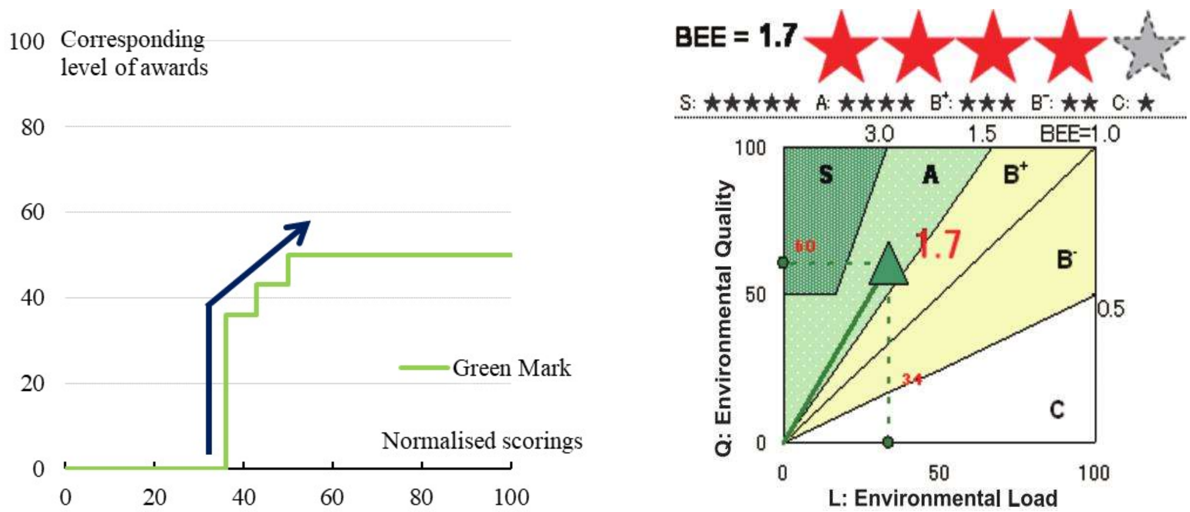
A comparison of these four types showed that the GBA systems from type A were the most accessible systems because awards were achievable even for relatively low scores. When applying GBA systems from type A, it is comparatively easy to obtain a certificate that will guarantee public confidence and facilitate the population of green buildings. However, disadvantages exist because it tolerates several relatively low-performance projects with low-level awards. GBA systems of type B had a relatively high threshold, which can filter out low-performance green buildings. Similarly, green buildings certified using type C GBA systems also had a high threshold, but the corresponding level of awards is relatively low. The weaknesses of type C are obvious: if the building has an unsatisfactory performance, it cannot get a green certificate; on the other hand, if a building shows massive improvement in its performance, it cannot get an appropriate award based on this improvement. In other words, the award level does not differ much between high- and low-performance buildings, which may decrease the motivation of the industry to achieve high-performance green buildings. With type D, two dimensions determined the final awards, the environmental quality and environmental load. In order for a building intending to get higher awards, it has to get a higher score in the former dimension and a lower score in the latter dimension. In summary, the four types of GBA systems had different prolonged impacts on the promotion of green buildings and high-performance buildings. To achieve better awards, the projects will need to choose appropriate GBA systems. It is noticed that a specific project is not necessarily bound to get a higher score or better certification under type A assessment systems than the other three types, nor the certification levels of two type A assessment systems should be comparable. Because GBA systems may differ in the weightings of similar categories, such as environment-related categories. Thus, a project assessed by two GBA systems, even with the same type, is not necessary to be awarded with similar levels of certificates.

Besides, dialectics can be found between the scores and the theoretical bases. CASBEE is a typical example that the score of CASBEE is based on the proportion of the environmental quality and environmental load.



(a) Type A: Linear

(b) Type B: With a low limit



c) Type C: With low and high limits (d) Type D: Ratio (CASBEE)

Figure 6 Four relationships between scores and certification levels

Pre-assessment, an important procedure in GBA systems, was found to have an interrelationship with stakeholder engagement. Pre-assessment is beneficial in the assessment process because it can help stakeholders clarify their roles in the assessment process, the whole process timeframe and extra costs (Mo and Boarin 2018). The selected systems generally showed insufficient pre-assessment. Among the 12 GBA systems, eight systems did not have pre-assessment and the other four GBA systems had different levels of pre-assessment, namely BREEAM, BEAM Plus, Green Mark and IGBC rating system. BREEAM had a full pre-assessment. BEAM Plus had a preliminary technical screening before the assessment. Pre-assessment was optional for Green Mark. IGBC rating system required the submission of preliminary documentation for review comments before the submission of the final documentation.

3.4 Results for dialectics of GBA in relation to 'value'

3.4.1 Comparison of stakeholder engagement in GBA systems

As shown in Table 4, dialectics were found between stakeholders and their involvement in the entire process stage. In general, the wide variety of stakeholders in the process of GBA could facilitate the effective implementation of the projects, reduce conflict, encourage innovation, enhance local decision making and promote equity (Mathur et al. 2008). Based on the results, CASBEE involved the largest variety of stakeholders, while IGBC rating system and PBRC involved the smallest.

Specifically, in the pre-registration process, only BEAM Plus required stakeholders' engagement. In the evaluation/verification process, all the GBA systems involved stakeholders of different organisations or parties, including the rater, assessor and public. In the certification and post-certification processes, one council with public credibility was represented to conduct certification or post-certification generally. Apart from IGBC rating system and PBRC, which did not have post-certification follow-ups, most systems adopted the same council in the certification and post-certification processes. The engagement of other institutions, especially the local government (Quan et al. 2018), would be beneficial in fostering sustainable development. However, among 12 GBA systems, only three (CASBEE, China GB and Green Mark) had local governments involved in the assessment process.

Table 4 Stakeholders involved in the assessment process

No.	GBA systems	Pre-registration / application	Registration / application	Evaluation / verification	Certification	Post-certification
1	LEED	-	Owner / Agent	LEED Green rater, energy rater, homes provider, project administrator	GBCI (Green Business Certification Inc.)	USGBC
2	BREEAM	Owner / Agent, a licensed BREEAM Assessor and AP	BREEAM assessor	BREEAM assessor	BRE Global	BRE Global
3	CASBEE	-	Owner / Person who is responsible for major construction	CASBEE AP	Institute for Building Environment and Energy Conservation (IBEC) and 12 private institutions approved by IBEC	Owner and 24 local governments
4	Green Star	-	Owner / Agent	Green Star project manager, assessor	Green Building Council of Australia (GBCA)	GBCA
5	BEAM Plus	-	Owner / Agent	BEAM assessor, Technical Review Committee (TRC) of BEAM Society Limited (BSL)	HKGBC	HKGBC
6	China GB	-	Applicant	Assessor of qualified institutions assigned by local government and Ministry of Housing and Urban-Rural Development (MoHURD), public	Qualified institutions	Local governments and MoHURD
7	Green Mark	-	Developers, building owners and government agencies	BCA assessment team, building management team	BCA (Building and construction authority)	BCA will conduct a verification which requires updated energy performance data and site inspection and measurement
8	Green Globes	-	Applicant	Verifier, applicant, Green Globes administration	Green Globes Sustainable Interiors Canada (GGSIC)	GGSIC will give a final certification on the post-construction stage, after the preliminary certification; verifier, applicant
9	GBI	-	Applicant	GBI certifier, applicant / GBI facilitator, Green building index Sdn Bhd (GSB)	GBI Accreditation Panel (GBIAP)	Applicant, GBI certifier, GBIAP will conduct a verification upon the completion of the project
10	DGNB	-	Contractor / Client, DGNB auditor	DGNB auditor, DGNB technical committee, DGNB partner	DGNB	DGNB

11	IGBC rating system	-	Applicant	Project team, IGBC assessor	IGBC	-
12	PBRC	-	Applicant	Pearl qualified professional, Pearl assessor, Design team	Abu Dhabi Urban Planning Council (UPC)	-

Note: AP is short for accredited professionals.

3.4.2 Comparison of public involvement in GBA systems

Public involvement is believed to be the effective supervision for the certification of the GBA. It can also help promote the green concept to the public. Generally, the public was found to be involved during the process of post-certification. As Table 5 shows, public involvement was available in 10 of the 12 GBA systems, except IGBC rating system and PBRS. The common practice when involving the public in GBA was to announce basic project information on public websites during post-certification. Such public involvement in the selected GBA systems was insufficient. Uploading basic information online during post-certification is somewhat weak and may not effectively supervise the certification of the target green building or spread the green concept to the public. More effective and attractive public involvement is suggested, including the disclosure of written materials such as brochures or online information during certification and spoken communication such as charettes and public lectures during post-certification (Retzlaff 2008).

Table 5 Public involvement in green building assessment (GBA) systems

<table>
<tr><th>GBA systems</th><th>Public involvement</th><th>Certification process</th></tr>
<tr><td>LEED</td><td>1) A certification challenge may be initiated by GBCI or by any third party within 18 months of a project certification.
2) USGBC public LEED project directory.</td><td>During certification and post-certification</td></tr>
<tr><td>BREEAM</td><td>BRE Global lists certified buildings and assets on Green Book Live.</td><td>During post-certification</td></tr>
<tr><td>CASBEE</td><td>Applying Sustainable Building Reporting System (SBRS) to large buildings, the government will publish the evaluation reports on the website.</td><td>During post-certification</td></tr>
<tr><td>BEAM Plus</td><td>Brief project information is displayed on the HKGBC website for public information.</td><td>During post-certification</td></tr>
<tr><td>China GB</td><td>1) Before certification, the evaluation results are publicised and announced to the public.
2) After certification, the project is available online via the Chinese Green Building Evaluation Label.</td><td>During certification and post-certification</td></tr>
<tr><td>Green Star</td><td rowspan="5">Basic project information is available online via their official websites.</td><td rowspan="5">During post-certification</td></tr>
<tr><td>Green Mark</td></tr>
<tr><td>Green Globes</td></tr>
<tr><td>GBI</td></tr>
<tr><td>DGNB</td></tr>
</table>

IGBC rating system	Not mentioned.	N/A
PBRS		

3.5 Reflections on the dialectics of GBA systems

With the proposed dialectical system framework, dialectics were found to be complex and intertwined within and across the dimensions of the concept, methodology, and value.

Regarding the dialectics within dimensions, four notable findings were observed. First, a trade-off relationship was found between environmental, economic, and social factors. To achieve sustainability, we should consider all the factors holistic rather than being in isolation. Second, the category of process or management with well-organised and effective processes could ensure the other categories such as energy, water, and transport in achieving sustainability. Third, the relationship between the certification process and the lifecycle process in the GBA was found to have variety and flexibility. Forth, the four scoring types of GBA systems had different prolonged impacts on promoting green buildings and high-performance buildings.

In relation to the dialectics across dimensions, three noteworthy findings were observed. First, dialectics can be found between scores and theoretical bases. Second, more diverse stakeholder participation in the assessment process would make the process smooth and make the building more environmentally and economically sustainable. Third, the well-prepared pre-assessment process could help stakeholders clarify their roles in the assessment process, the whole process timeframe and extra costs.

4. Discussion

4.1 Overall methodological discussion

The proposed dialectical system framework of GBA highlights the interdependence between the system elements in a dialectical way from the perspectives of ‘concept’, ‘methodology’ and ‘value’. This new framework considers the intrinsic connections among the different aspects of the GBA systems and is thus distinct from the prior direct comparison of GBA systems reported in the literature such as category and indicator comparison (Varma and Palaniappan 2019), energy and water category comparison (Awadh 2017), and general observation of the structure of GBA systems (Gowri 2004)). Although large variations exist between the 12 selected GBA systems, their comparison suggests a consensus that the dialectics of GBA are multidimensional and interweaved, which can be clearly elaborated using the proposed three-dimensional framework. The analysis reveals that dialectics are involved in all three dimensions, including a multi-perspective but inconsistent concept, well-organised but oversimplified methodology, and value-laden but insufficient stakeholder engagement.

This dialectical system framework can be applied to review other assessment systems for the following considerations. Theoretically, dialectical system thinking can help interpret different types of assessment systems, including but not limited to green building assessment systems. The dialectical system framework proposed in this study consists of three perspectives, namely, concept, methodology, and value. Generally, assessment systems should be established on a solid theoretical basis (concept), with certain evaluation procedures, criteria and scoring methods (methodology), and involve various stakeholders and lead to certain impacts on the community (value). The basic components of green building assessment systems are consistent with those of other assessment systems targeting different objects such as green roads and sustainable hydropower. Practically, although this dialectical system framework has not yet been adopted to examine assessment systems, it has been adopted in previous studies to examine sustainable buildings (Pan and Ning 2014) and zero-carbon buildings (Pan and Pan 2018).

The novelty of this review article is to introduce dialectical thinking into the field of GBA and highlight the interrelationship with each aspect related to GBA. Particularly, the dialectical system framework has been developed and applied to review 12 widely adopted GBA systems in high-density cities in depth. This article is significant as it addresses both the practical need for improving GBA and the scientific knowledge gap in assessing green buildings with dialectical thinking. This article expands the body of knowledge about GBA by addressing the dynamic and sophisticated features of GBA using the dialectical system theory. It provides a new approach to understanding the dynamic interdependence of the various aspects of GBA systems. It highlights the interconnected dimensions of the concept of, methodology for, and value of GBA.

4.2 'Concept of GBA': multi-perspective, but inconsistent

The dialectics of GBA in relation to 'concept' exist in three layers, namely the theoretical bases at the strategy level, the category at the breakdown level, and the types of assessed buildings that consider high-density urban environments.

At the strategy level, differences were found in the theoretical bases of the selected GBA systems. As reported in previous reviews, behavioural and cultural factors played important roles in green building development (Cole et al. 2010, Deuble and de Dear 2012). The concept of sustainability differs across different countries or regions, which demands different supporting policies and practical measures. In other words, an international system cannot be directly adopted in different countries with the same framework of sustainability. For example, PBRC was developed for the Middle East, where the cultural context that cultivates the local people's comprehension of sustainability should be carefully considered.

Similarly, at the breakdown level, the categories of the systems should not only cover the aspects of sustainability, but also adapt to local contexts. Our findings are in line with previous studies that GBA systems differ in the environmental concerns and the assessment approaches (He et al. 2018). For instance, LEED is an energy oriented GBA system while China GB is a performance balanced GBA system. Some studies have compared different GBA systems in a normalised manner (Mattoni et al. 2018). However, the re-categorisation of different GBA systems to the given normalised categories is subjective, and there is a chance that the results of such a comparison will be inaccurate. Some studies developed a global GBA system for existing buildings considering the regional variations with fuzzy logic to overcome the climate effect of the systems adopted in different places (Mahmoud et al. 2019). This kind of system may be not suitable for some regions because regional difference is not only related to the environmental factors such as climate effect but also the social factors such as social structure and religion.

An examination of the types of assessed buildings suggests that every GBA system more or less considers the effect of high-density urban environments, but not in a systematic way. The same aspect sometimes belongs to different categories, but such inconsistency has rarely been pointed out in previous studies.

Overall, the dialectics of GBA in relation to the concept are multi-perspective, but inconsistent.

4.3 'Methodology for GBA': well-organised, but oversimplified

The dialectics of GBA in relation to the methodology are reflected in the temporal and functional aspects in a well-organised manner. It can be seen that different countries choose different methods (referred to as "systems" in this paper) for GBA. There are two main reasons. One is about the various concepts of sustainability targeted by different countries. As discussed in Section 3.2.1, the concept of sustainability is the theoretical base for GBA and is generally set based on the local contexts (e.g., local government policies, cultural traditions and social values) by local authorities. For instance, PBRC was developed for implementation in the Middle East and the cultural tradition is an important aspect in the definition of green buildings. The other is about the various natural factors of the target countries, e.g., climatic and geographic factors. These natural factors should be considered in the setting of the category and sub-category, and their weightings of GBA systems to satisfy the requirements of the target country. For example, as shown in Section 3.2.2, PBRC, developed in the Middle East with a dry climate, has a high weighting for the category of precious water.

However, the existing methods for measuring the performances of buildings have methodological limitations.

First, all the criteria of the GBA systems are subjectively scored. The existing scoring methods also fail to consider the dialectical interconnections between the aspects covered in the GBA systems. Some other studies have also pointed out this shortcoming and attempted to eliminate the effect using well-defined quantitative indicators for all aspects of sustainability (Chandratilake and Dias 2015). BIM (Building Information Modelling), a technology and process for 3D modelling and information management throughout the life cycle of buildings, has been extensively researched in recent years in helping evaluate the criteria of GBA systems (Lu et al. 2017, Ansah et al. 2019). Furthermore, for a given system the scores are not necessarily related to the results from simulations (e.g., energy simulation and cost simulation). In particular, some systems do not provide simulation results or the scientific foundation of the scores, which makes the scores less reliable. Moreover, optimising the performance on sustainability may not earn better scores in some GBA systems, which will lower the stakeholders' motivation to improve the 'actual green aspect' of the buildings.

Second, all of the GBA systems consider the construction stage, but none cover the holistic lifecycle assessment of green buildings. Giving attention to multiple stages is important because the activities in the earlier stage can affect the later stages of the lifecycle (Ochoa and Capeluto 2008).

Overall, the dialectics of GBA in relation to the methodology are well-organised, but oversimplified when considering the dialectics across the criteria, assessment/optimisation of 'actual' green buildings and lifecycle assessment.

4.4 'Value in GBA': value-laden, but with insufficient stakeholder engagement

The results suggest that the dialectics of GBA in relation to value exist in the engagement of different stakeholders in different lifecycle stages and certification processes. All 12 GBA systems involve different stakeholders. However, the selected systems often judge the performance of a building based on the attitudes of assessors and engineers and overlook the attitudes of contractors, building owners and the government. Only three systems (i.e., CASBEE, China GB, Green Mark) have local governments involved in the assessment process. Moreover, the public involvement enabled by the GBA systems is simple and insufficient, and the common practice to involve the public is to announce the basic project information on a public website. In addition, whether the stakeholders could take further practical actions to improve the performance in relation to the cost, materials and energy is still vague (Rickaby et al. 2020). It is thus necessary to rethink the roles of all the stakeholders in GBA systems and raise their awareness of sustainable development or green buildings systematically. The observed insufficient stakeholder engagement in the field of green building is in accordance with the finding of previous research by Pan and Ning (2014). Some articles have even pointed out that the main challenges for the improvement of green buildings are no longer technological or economic, but social and psychological (Hoffman and Henn 2008, Kato et al. 2009). In a nutshell, the dialectics of the GBA system in relation to value are value-laden, but with insufficient stakeholder engagement.

5. Conclusions

This study has examined the body of knowledge for green building assessment (GBA) within the context of high-density cities through adopting a dialectical system framework. The novelty of this study is to introduce dialectical thinking into the field of GBA and highlight the interrelationship with each aspect related to GBA. The complex and dynamic interdependence between the elements of GBA systems was framed based on three dimensions, i.e., concept, methodology and value, based on the dialectical system theory. In this study, 12 of the 42 identified GBA systems adopted in high-density cities were carefully selected for an in-depth examination and cross comparison. The study concludes that dialectics exist and are interwoven throughout all the three dimensions. The main findings and conclusions are as follows:

- **Multi-perspective but inconsistent concept of GBA**: First, the concept of sustainability largely relies on local contexts (e.g., local government policies, cultural traditions and social values). Second, the effect of the high-density environment is mentioned in all 12 GBA systems to various extents but not in a systematic way since the same aspect sometimes belongs to different categories. Thus, the direct application of GBA systems should be avoided and it is necessary to consider the climate and cultural characteristics of the target countries or regions.
- **Well-organised but oversimplified methodology of GBA**: First, the majority of the GBA systems fail to cover the entire lifecycle of a green building, and it is highly recommended to involve more stages in GBA in the future. Second, all the GBA systems subjectively examine the criteria and fail to consider the dialectics across the criteria. Thus, quantitative indicators are recommended to replace criteria-based scores in GBA systems. In addition, scores cannot fully represent the actual green performance of the building and may fail to handle occasions

when the optimised performance on sustainability is better than the maximum score of the criteria. More reliable assessment methods are needed to motivate stakeholders to make greater sustainable efforts.

- **Value-laden but with insufficient stakeholder engagement**: Though all the GBA systems involve different kinds of stakeholders, stakeholder engagement is still insufficient, especially in the aspects of local government participation and public exposure. Besides, the selected systems generally judge the performance of a building based on the attitudes of assessors and engineers and overlook the attitudes of contractors, building owners and the government. More participation by various stakeholders in GBA would not only shorten the GBA time, but also make the assessment result more reliable, which is therefore highly recommended.

There are two contributions of this study. First, the developed dialectical system framework for GBA highlights the interconnected dimensions of the concept of, methodology for, and value of GBA. This framework expands the body of knowledge about GBA by addressing the dynamic and sophisticated features of GBA using the dialectical system theory. The framework also provides a new approach to understanding the dynamic interdependence of the various aspects of GBA systems. The other contribution is the use of the developed framework for a systematic review of the widely adopted GBA systems. The review results illustrate the existence of the GBA systems' interaction across the aspects and points out the characteristics of the selected GBA systems to provide suggestions for future assessment improvement. These findings should raise the awareness of green building developers, planners and designers about the dialectics in GBA and thus inform the associated decision making and design optimisation, making it possible to more effectively achieve green buildings.

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