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A Comparative Analysis of Green Building Rating Systems in China and the United States

Abstract

Several studies have compared green building rating systems (GBRSs) in China and the United States, Nonetheless, few studies included in-depth analysis on specific rating tools with project specific data validating green building technologies and actual performance. This study conducted a comprehensive data-driven comparison of the GBRSs of China and the United States. The goal was to understand the current status and further improve China's GBRS and promote green building technologies. The study first conducted thorough comparisons of GBRSs in China and the U.S. by selecting a series of distinct rating tools. Then, it analyzed each tool's development objectives, contents, and rating score settings. The comparison concludes the future development needs for China's GBRS. In addition to standard comparison, green building technologies applied in certified projects were also summarized. The results demonstrated that GBRSs in both China and the U.S. reflect well the technical paths to achieve green building sustainable development. By analyzing certified projects, it was also found that the incremental costs of green building technologies were controllable. Finally, based on the comparison and case analysis, the study provide a set of policy recommendations to further improve China's green building stanards.

Keywords

green building rating systems
sustainable development concept
green buildings assessment standards

LEED

green building technologies

incremental cost

1. Introduction

After the Industrial Revolution, and especially since the 1970s, climate change, environmental deterioration, as well as resource shortages, have become more severe. Moreover, humans shifted emphasis to environmental issues and search for appropriate ways to improve the situation. In 1987, *Our Common Future* (*the Brundtland Report*) proposed the definition of the Sustainable development concept (SDC) for the first time (WCED, 1987). In 1992, *Agenda 21* was released. It is a comprehensive plan of action to be implemented globally, nationally, and locally by organizations of the United Nations system, governments, and major groups in all areas where humans have a significant impact on the environment (UNCED, 1992). In accordance with *The Future, We Want* (UNCSD, 2012) and *The 2030 Agenda for Sustainable Development* (United Nations, 2015), sustainable cities and the human community are critical issues in sustainable development. In *Our Common Future,* sustainable development is characterized as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WECD, 1987). The environment, society, and economy are three crucial aspects of sustainability. In other terms, they are the triple bottom line of the Sustainable Development Concept (Bernardi et al., 2017).

The construction industry plays a crucial role in satisfying societal needs and enhancing the quality of life (Tam et al., 2004), and contributing to a country's economic growth (Kucukvar et al., 2013). On the other hand, building block production accounts for approximately 40% of total energy consumption (WBCSD, 2008), 30% of greenhouse gas (GHG) emissions (UNEP SBCI, 2009), and 17% of freshwater consumption, and it produces between 45% and 65% of disposed waste in landfills (Yudelson, 2008). Consequently, controlling environmental impacts on the building sector has got to be a significant issue (Li et al., 2017).

Green building is part of the larger concept of “sustainable building” (Montoya, 2010). Moreover, a concise definition of a green building is provided by ASTM Standard E2114–08 as “a building that provides the specified building performance requirements while minimizing disturbance to and improving the functioning of local, regional, as well as global ecosystems both during and after its construction and specified service life” (ASTM, 2008). Several terms and meanings are associated with what it means for a building to be green, but a green building is typically defined as one that has earned one or more certifications via a GBRS (Walsh, 2012). A GBRS is a tool for evaluating whether a particular building is green or not, and a corresponding rank is given in accordance with the detailed assessment requirements. It is a valuable tool for determining whether or not a building is environmentally friendly(Wu et al., 2015). And various green rating systems have been established globally to evaluate the sustainability of construction projects (Doan et al., 2017).

It is estimated that there are approximately 600 green rating systems globally (Vierra, 2011). Numerous GBRSs arose from 2000 to 2010, including BREAM (Building Research Establishment Environmental Assessment Method), LEED (Leadership in Energy and Environmental Design, United States), CASBEE (Comprehensive Assessment System for Built Environment Efficiency, Japan), DGNB (Deutsche Gesellschaft für Nachhaltiges Bauen, Germany), and ASGB (Assessment Standard of Green Buildings, China) (Zhang et al., 2019).

Since the 21st century, China has experienced a significant shift in its conception of social development, which has synchronicity with the SDC (Qiu, 2005). The concept of green building arises from this development and has developed rapidly in the past 10 years (Ye et al., 2012). Since 2012, the Chinese government has incorporated the "construction of ecological civilization" into the "five-sphere integrated plan" for sustainable development, and green development has become the guiding principle for social development. This transition has impacted the development of the construction industry, and green building has received increased attention. And the Chinese government has made several compulsory and incentivizing policies for the purpose of promoting green building (Ye et al., 2014). In 2013, the Ministry of Housing and Urban-Rural Development (MOHURD) and the National Development and Reform Commission (NDRC) of China formulated the Action Plan on Green Buildings, bringing 20% of new construction up to the standard of green building. And green building has become the predominant trend for future buildings in China (Zhang et al., 2016). With the continued development of green development concepts and the emphasis on "people-oriented" concepts in 2018, the connotation and denotation of green buildings are expanded and enriched in the future. By the end of June 2022, the new green building area accounted for more than 90 percent of new buildings, and the new green building area in China increased from 4 million square meters in 2012 to 2 billion square meters in 2021 (CCTV network, 2022).

China has numerous green building rating standards published by various organizations (Ye et al., 2014). In this research, the Chinese GBRS refers to a series of national standards that target a green building or green district assessment. And the Chinese GBRS contained 10 national standards by the end of 2020. They all have been issued by MOHURD (Table 1).

Table. 1. Constitution of Chinese GBRS （by 2020）

Standard number	Standard	Year
GB/T 50378	Assessment Standard for Green Building	2006
		2014
		2019
GB/T 50878	Evaluation Standard for Green Industrial Building	2013
GB/T 50908	Assessment Standard for Green Office Building	2013
GB/T 51100	Assessment Standard for Green Store Building	2015
GB/T 51141	Assessment Standard for Green Retrofitting of Existing Building	2015
GB/T 51153	Assessment Standard for Green Hospital Building	2015
GB/T 51148	Assessment Standard for Green Museum and Exhibition Building	2016
GB/T 51165	Assessment Standard for Green Hotel Building	2016
GB/T 51255	Assessment Standard for Green Eco-district	2017
GB/T 51356	Assessment Standard for Green Campus	2019

The Chinese GBRS defines a green building as “saving the resources (save energy, save land, save water, save material), protecting the environment and reducing the pollution, providing individuals with healthy, functional, and efficient space, while existing harmoniously with nature during the whole life cycle of the building." (ASGB 2014). Prior to ASGB 2019, the Chinese GBRS targeted "four saving and one environmental." By a project's points, the system contained design and operation ratings and rated green buildings on a scale from one to three stars (distinct rating tools have distinct point requirements on the same level). By the end of 2017, 10,927 projects had been certified by the Chinese GBRS (Beijing Daily, 2018). These projects are accredited by organizations in numerous U.S. provinces. Some organizations publish brief information regarding the certified projects on the Web, but none publish the scores or technologies applied to the projects. As of June 2021, MOHURD took over the certification of green buildings.

The U.S. GBRS is recognized as Leadership in Energy and Environmental Design (LEED). It is a voluntary standard developed by the U.S. Green Building Council (USGBC). USGBC created LEED to measure and define green buildings and provide a roadmap for developing sustainable buildings. In 1998, a pilot version was initially introduced(LEED 1.0). From 2000 to 2020, USGBC launched five versions of LEED (Table 2). From v1.0 to v4.1, LEED has developed numerous rating systems for structures, neighbourhoods, and cities (USGBC, 2021). It is considered the most widely adopted rating scheme, on the basis of the number of countries, with more than 100,000 participating projects (LEED, 2019), over 43,063 registered projects, and 10,735 certified projects, reaching 103 countries and territories in 2021 (Wang, 2011). Before credits can be calculated, LEED requires certain prerequisites, and the total score and threshold for each level are fixed. For instance, in accordance with the total points of the building calculated through the scorecard, new construction can be classified into four groups: Certified (40–49 points), Silver (50–59 points), Gold (60–79 points), and Platinum (80–110 points). Green Business Certification Inc. provides a concise overview and scorecard of certified projects on the Web.

Table. 2. Constitution of LEED by 2020

Version	Tool	Year	Revision

v 1.0	New Construction		2000	——
v 2.0	New Construction & Major Renovations		2001	V 2.0
			2003	V 2.1
			2005	V 2.2
	Commercial Interiors		2004	——
	Existing Buildings		2004	——
	Core & Shell		2006	——
v 2009	New Construction & Major Renovations		2008	——
	Core & Shell		2008	——
	Commercial Interiors		2008	——
	Existing Buildings		2008	——
	Homes	Homes	2008	——
		Homes Multifamily Mid-Rise	2010	——
v 4.0	Neighbourhood Development		2013	——
	Interior Design and Construction		2013	——
	Operation and Maintenance		2013	——
	Building Design and Construction		2014	——
	Homes Design and Construction		2014	——
v 4.1	Interior Design and Construction		2019	——
	Operation and Maintenance		2019	——
	Residential BD+C		2019	——
	Cities and Communities		2019	——
	Building Design and Construction		2020	——

This study compared Chinese GBRS and LEED for three reasons. In the first place, they are both derived from sustainable development ideas, and the Chinese GBRS has incorporated many valuable components associated with foreign systems, including LEED (Geng et al., 2012). The shared concept makes them contextually comparable. Secondly, they both have experienced updates, and the time of updates is close, making them comparable in the development stage. Thirdly, they come from distinct types of countries (ASGB comes from a developing country, and LEED comes from a developed one), whereas both have plenty of certified projects that make them representative in the region.

The structure of this paper is:

1. Conduct a literature review to identify research gaps.

2. Make a fundamental analysis of the two GBRSs and select the research objects, which are specific rating tools. Identify the predominant research methods and their using scope.

3. Compare the selected rating tools based primarily on their textual content and

analyze the rating framework， the main topics, the important issues, the certification level threshold, and related developing trends of the two GBRSs. Comparative analysis of the technologies utilized in real certified projects.

4. Discuss the developing ideas, the orientations for projects, as well as the way of guiding technology of the two GBRSs and propose their similarities and distinctions.

5. Render some suggestions for the development of Chinese GBRS and related technologies.

The original contributions of this research are:

1. Proposed a comparative analysis method aiming to conduct a comprehensive quantitative analysis of the content of rating tools in ASGB and LEED as well as demonstrate the similarities and distinctions between the two GBRSs.

2. By analyzing the correlation between GBRSs and actual certification projects, some valuable suggestions are formed for revising the Chinese GBRS and formulating relevant policies.

3. By analyzing the weak points of green building technology orientation in China and proposing some suggestions for optimizing development, this paper examines the application of green building technologies.

2. Literature review

The academic literature is abundant on GBRSs and their comparisons. This research generally falls into three categories.

The first category focuses on a general review of GBRSs. Using comparative analysis, a systematic literature review on green building assessment methods is conducted. And it investigates the primary contributing authors and countries, the number of relative and high-frequency assessment methods, the current status of comparison topics, etc. Additionally, it proposes a comparison of four levels of assessment methods (1) general comparison, (2) category comparison, (3) criterion comparison, and (4) indicator comparison (Li et al., 2017). Except for that, Shan conducted a systematic review of GBRS papers to identify the prevailing GBRSs adopted by the current sustainable construction industry and proposed directions for future GBRS research. Furthermore, he noticed the most critical evaluation criterion from 15 prevailing GBRSs and four major themes within the existing GBRS research (Shan et al., 2018). A recent study demonstrated the extensive research efforts conducted by various countries on the GBRS. It provided a summary of the hierarchy tree/structural framework considered by Building Sustainability Assessment Systems (BSAS) and identified six significant steps involved in developing BSAS using multi-criteria decision-making methods (Lazar et al., 2020). In one study, *A Review of Data Collection and Analysis Requirements for Certified Green Buildings*, major operation, and maintenance-related building certification schemes were surveyed for the purpose of revealing performance gaps in certified buildings (Afroz et al., 2020).

Besides, the second category focuses on analyzing and comparing certain aspects of GBRSs. For instance, a comparative analysis was made of five international GBRSs containing BREEAM, LEED, BEAM, GM, and ASGB on-site planning and design. It primarily compared the relative importance of site planning and design-related items in selected GBRSs regions (Huo et al., 2017). Similar research centered on five GBRS waste management requirements and predominantly explored the effectiveness of GBRSs as applied to construction waste management (Wu et al., 2015). A comprehensive comparison of LEED and the three-star-system is made by employing logistic models and finding their character in the application (Zou, 2018). C. Zhang et al. conducted a comprehensive review of the renewable energy assessment methods utilized in green building/neighborhood rating systems. Zhang et al. By testing several assessment methods in a building, they found both relative and absolute methods are employed to evaluate renewable energy in GBRSs and Green Neighborhood Rating Systems (GNRSs), along with some other conclusions (Zhang et al., 2019). Sartori made a comparison between Life Cycle Assessment (LCA) and GBRS assessment methodologies whereas analyzing the LCA parameters within the GBRS. Through comparison, he proposed a schematic framework to perform an environmental impact assessment (EIA) throughout the design life cycle (Sartori et al., 2020). Another study provided a multifaceted analysis of the incorporation of biophilic strategies into green building rating tools (GBRTs)—LEED and Green Mark—and found policy and climate comprises to be the critical influencing factors, with high impacts for Green Mark (GM) and LEED for Building Design and Construction (LEED BD+C). Policy and geography were found to be essential factors for LEED for Neighborhood Development (LEED ND) (Jiang et al., 2020).

The third category of GBRS literature compares multiple GBRSs utilizing distinct dimensions or methods. For the purpose of analyzing the changes and trends in the three sustainability pillars of GBRT and reinforcing the previous GBRTs, Wen selected 10 global GBRTs consisting of LEED and ASGB to make a comparison. The results illustrate that at GBRTs have evolved and are moving toward the balance of three sustainability pillars (Wen et al. 2020). Investigation into the creation of green rating systems (including BREEAM, LEED, CASBEE, and Green Star NZ) seeks to discover how interest and research in them have developed while identifying the similarities, differences, strengths, and weaknesses among green rating systems. It also examines whether the projects are comprehensively evaluated in terms of sustainability (Doan et al., 2017). Another study proposed a comparative analysis of the scoring method of terminal indicators (SMTIs) between two GBRTs: the Evaluation Standard for Green Building (ESGB) and the Ecology, Energy Saving, Waste Reduction, and Health (EEWH) system. It was discovered that the Formula Scoring Method (FSM) and Direct Scoring Method (DSM) are respectively associated with the highest and lowest maturity levels. And the quantitative evaluation systems (QESs) of the two GBRTs primarily depend on only one SMTI with the same utilization rate, resulting in a poor SMTI balance in both QESs and a higher QES maturity of EEWH than ESGB (Zhang et al., 2017). The sustainability performance of five GBRT samples was analyzed and compared to a dependable methodology that takes into account the multi-attribute characteristics of green building criteria (GBC). The results showed that the performance of the GBRT samples was almost similar, on the basis of the three pillars of sustainability wherein the weightage obtained for environmental, social, and economy for each GBRT was almost similar (Liang et al., 2021).

It is necessary to emphasize that some research has already compared the Chinese and U.S. GBRSs. J. Chen compared the Chinese "Evaluation Standard for Green Building" (GB T 50378-2006) with LEED 2009 and LEED v2.2 whereas pointing out their shortcomings and identifying distinctions. Compared with the previous version, this paper found that reducing GHG emissions has made essential changes to energy, transportation, and water in LEED 2009. Neither LEED 2009 nor ESGB has conducted its economic analysis. (Chen et al., 2011). B. Wen found that LEED and ASGB, as well as many other GBRTs, have the same trend in their relationship with the three sustainability pillars; for instance, both have a high-weight category that presents a steady downward trend. In the past three decades, there has been a consistent decline in the weight of the environmental category, an apparent increase in the weight of the social category, and a slight increase in the weight of the economic category, according to the results of his study (Wen et al., 2020). He examined the potential influence of Green Star (GS) in Australia on the design of a project, in comparison to LEED and ASGB, and found that LEED predominantly focuses on energy efficiency. In the meantime, GS and ASGB holistically consider energy and indoor environment quality (He et al., 2018).

We found that none of these papers considered comparability (including with the same application objects and same period) before comparing GBRSs of China and the United States, and few conducted deep comparisons between specific rating tools and versions. We also found none adopted plenty of actual certified projects to verify some of the discoveries and make a comparison of technologies applications with incremental cost data to give further suggestions for green buildings. This study sought to mitigate the gaps in comparisons of the GBRSs of China and the U.S. and offer a new vision for analysis of the development of the GBRSs and technologies applied to guide their development.

3. Basic analysis

3.1 System constitution

The system constitution is one of the fundamental characteristics of a GBRS. A rational classification and comprehensive subsystem is the feature of a scientific GBRS. This study employs the most recent versions of the two GBRSs to analyze the system architecture. In accordance with *Management measures for green building signs* (MOHURD, 2021), the newest version of the Chinese GBRS is as demonstrated in Fig. 1; other rating tools demonstrated in Table 1 are not used anymore. The latest version of LEED is LEED v4.1 (Fig. 2).

Fig. 1. The constitution of the latest Chinese GBRS and LEED v4.1

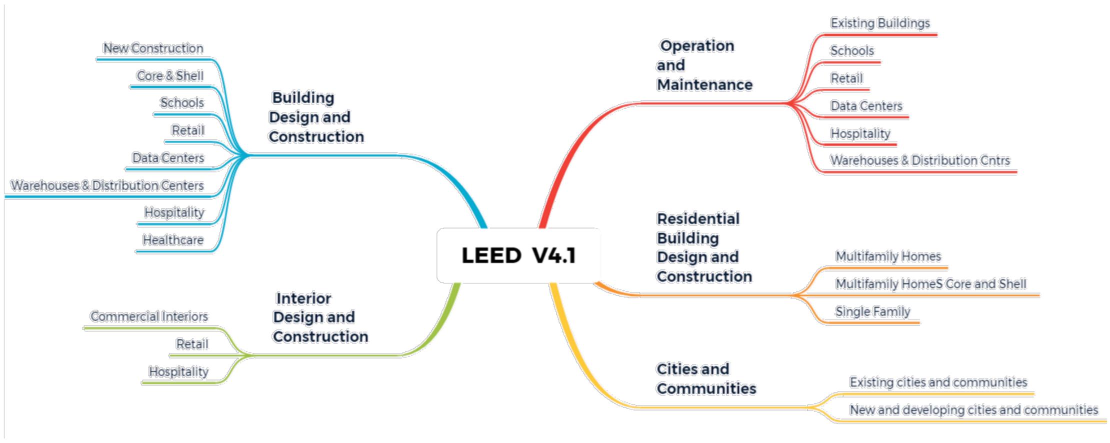

Fig. 2. The constitution of LEED v4.1

Building types

The Chinese GBRS could be applied to all types of civil buildings, including residential, office, retail, campus, hospital, industrial, and urban areas, with all civil buildings using the same rating tool: ASGB 2019.

As the latest version, LEED v4.1 could represent the complete system of LEED. LEED v4.1 includes five rating tools covering residential buildings, including single homes, commercial and public buildings (six certain types have separate checklists), communities, as well as cities.

Building life stage

Chinese GBRS considers the design, construction, and operation & maintenance stage. ASGB 2019 rates civil buildings at the Pre-rating (for design) and Rating (for operation) tools. Evaluation Standard for Green Industrial Building2013 rates industrial buildings at the design and operation stage. There is a unique standard for green retrofitting of the existing building.

LEED v4.1 separates BD+C(building design and construction) from O&M(operation and maintenance) as distinct rating tools. LEED BD+C is applicable for a significant renovation, and LEED O&M is appropriate for minor renovation.

Building construction type

LEED v4.1 has separate tools to rate a building's shell and interior separately. They are LEED BD+C: Core & Shell and LEED ID+C (Interior Design and Construction). In contrast, the Chinese GBRS consistently evaluates a single structure as an integral system.

Considering the latest version, the Chinese GBRS and LEED are both comprehensive rating tools that can be applied to all commercial and public buildings and cities, and that consider their entire life cycle. LEED is applicable for parts of the building space, whilst the Chinese GBRS rates a single building as a whole.

3.2 Selection of the analysis objects

Both the Chinese GBRS and LEED have a variety of rating instruments. This research focuses on some specific rating tools to make the comparison more efficient. The analysis rating tools chosen consider three aspects: the first is widely employed to reflect the universality, the second one is suitable for the same building types, and the third covers the whole life cycle and the whole volume of buildings. As introduced above, ASGB is the most widely used rating system in the Chinese GBRS; it applies to all types of civil buildings and includes a rating for the entire life cycle. LEED contains numerous tools for definite types of buildings. Since the fundamental information of all the registered projects (except some confidential ones) is public on USGBC.org, this study determined the top four widely adopted rating tools in LEED by the number of certified projects. They are LEED Homes, LEED NC(new construction), LEED CI(commercial interiors), and LEED EB(existing buildings). Considering the chosen principle, this research centered on all the versions of ASGB and LEED v2.0 to LEED v4.1 (LEED v1.0 is a pilot version) and chose specific rating tools from LEED Homes, LEED NC(new construction), LEED CI(Commercial interiors), and LEED EB. All the analysis rating tools and their abbreviation are shown in Fig. 3.

When comparing rating tools, preference is given to those for the same building type, same life cycle stage, and same year of publication.

Chinese used distinct rating tools to rate distinct buildings. Nonetheless, in ASGB 2019, the rating system has no classification of building function, and all structures utilize the same system which inevitably diminishes the relevance of buildings' functions. LEED has gradually developed a system that contains divergent tools for certain kinds of buildings. The rating system in LEED v4.1 is more comprehensive and considerate, making it more adaptable than ASGB 2019.

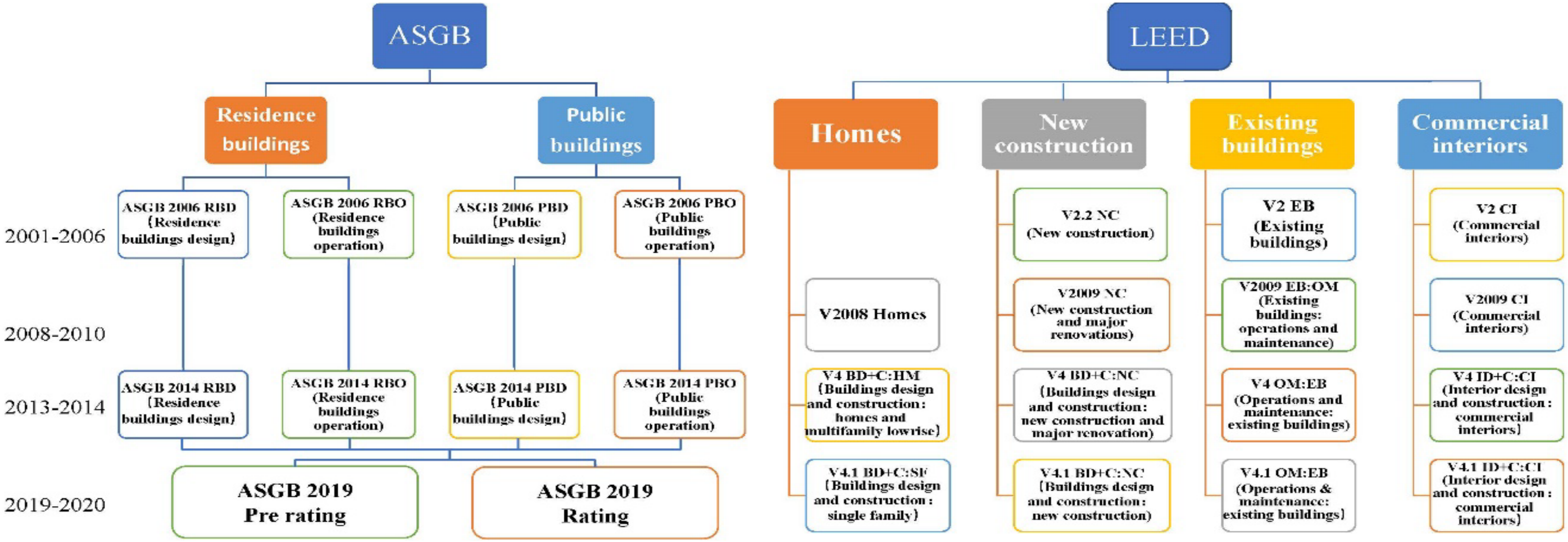

Fig. 3. Analysis of objects from Chinese GBRS and LEED

4. Methodology

Although both GBRSs are on the basis of sustainable development concepts, ASGB and LEED have distinct frameworks and rating methods, In accordance with a similar study, the comparison research must first select a suitable dimension for analyzing rating systems. Considering the triple bottom line of the SDC, this research defined the three dimensions as (1) atmosphere protection as well as environmental sustainability, (2) humanity's well-being and social sustainability, and (3) resource-saving and economic sustainability, to involve the necessary keywords (Fig. 4).

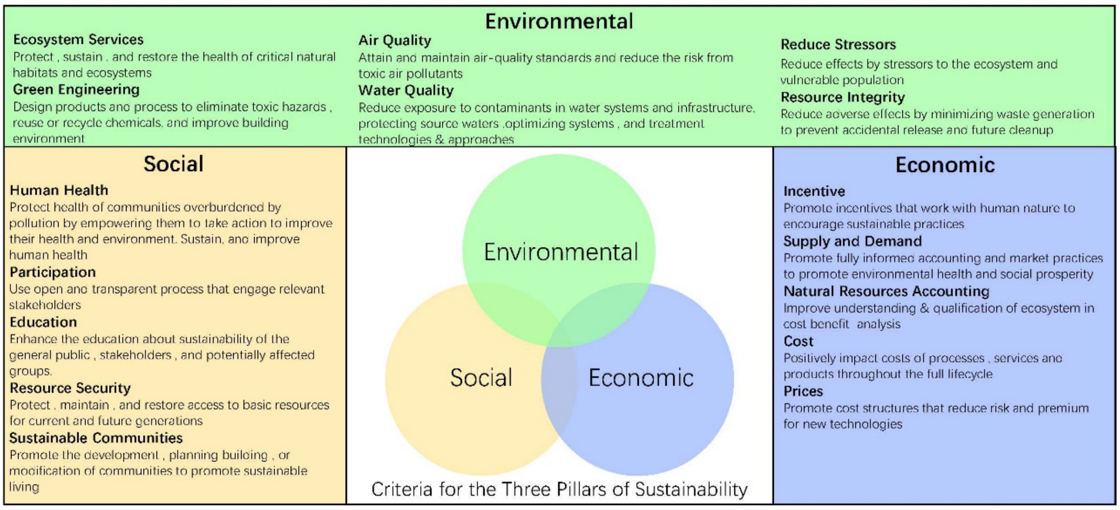

Fig. 4. SDC criteria for comparing GBRS

As the primary methodologies, this study employed content analysis, quantity analysis, and a comparative approach to examine the framework of ASGB and LEED content and their evolution in updates, as well as to compare them.

Content analysis: Krippendorff defined *content analysis* as “a research technique for making replicable and valid inferences from texts (or other meaningful matter) to the contexts of their use” (Krippendorff, 2012). Researchers can quantify and analyze the meanings and relationships of text data by identifying and counting the occurrences of particular words or concepts in a corpus of texts. Similar studies have been conducted by Z. Wu (Wu et al., 2015) and X. Huo (Huo et al., 2017) in several GBRTs. Content analysis is an appropriate tool for analyzing and comparing distinct GBRSs.

On the condition that conducting content analysis, this research uses text containing both the intent and items of the rating tools. The intent text is more important due to the fact that it always reflects the original target of the items. In ASGB, the intent text is in the description of items, and LEED lists intent in the main text.

Essential taxonomies are an effective method of content analysis. Comparing Green Mark and LEED, Jiang identified four influential factors: climate, policy, hydrology, and geography (Jiang et al., 2020). Furthermore, Shan classified various GBRSs into structure and project types (Shan et al., 2018). This research will employ this methodology when discussing the GBRSs' orientation and analyzing their essential topics.

Quantity analysis: This research makes analyses predominantly depend on quantity analysis. The system frame and the analysis of the main topics are made by quantifying the dimension to which the content belongs and the credit items with value and weights to explore the critical point of the GBRSs. The vital issue analysis is made on word frequency, which is a specific quantity analysis. The certification level comparison relies on score calculation and uses the multi-segment line to demonstrate the general trend between distinct objects. The technology analysis made on statistics.

The comparative approach: The comparative approach is a research method that can facilitate the sharing of knowledge and provide insight into future practices (Shen et al., 2011). Geng used this approach to compare China's green building standards with those of other countries to indicate the benefits and challenges to be met (Geng et al., 2012). In this research, the comparison approach was used on the basis of the result of quantity analysis.

5 Comparison results

5.1 The rating tool frame

The *rating tool frame* refers to the relationship between the prerequisites and the credit items. For the purpose of analyzing the system frame and comparing them, first, using the content analysis method, all items are analyzed and categorized into one dimension, with each receiving one point. Some of the items contribute to more than one dimension, accordingly, their one-point award will be divided on average into two or three dimensions. Second, the total points of the three dimensions are added up separately by the prerequisite and the credit items. Third, the points are standardized into a percentage by the total number of items. The distinct percentages are calculated in Eq. (1~6):

$$P_{en}=\Sigma AP_{en}/\Sigma T,\quad P_S=\Sigma AP_S/\Sigma T,\ P_{ec}=\Sigma AP_{ec}/\Sigma T$$

$$C_{en}=\Sigma AC_{en}/\Sigma T,\quad C_S=\Sigma AC_S/\Sigma T,\ C_{ec}=\Sigma AC_{ec}/\Sigma T \qquad (1\sim6)$$

where:

P_{en}: percentage of all prerequisites in the environmental dimension (%)

P_s: percentage of all prerequisites in the social dimension (%)

P_{ec}: percentage of prerequisites in the economic dimension (%)

C_{en}: percentage of all credit items in the environmental dimension (%)

C_s: percentage of all credit items in the social dimension (%)

C_{ec}: percentage of all credit items in the economic dimension (%)

ΣAP_{en}: total points the prerequisites got in the environmental dimension

ΣAP_S: total points the prerequisites got in the social dimension

ΣAP_{ec}: total points the prerequisites got in the economic dimension

ΣAC_{en}: total points the credit items got in the environmental dimension

ΣAC_S: total points the credit items got in the social dimension

ΣAC_{ec}: total points the credit items got in the economic dimension

ΣT: total number of items (contains prerequisites and credit items)

An illustration of this analysis method is the item "*construction activity pollution prevention*" in LEED v4.1 BD+C: NC(buildings design and construction: new construction) was classified into the environmental dimension and got 1 point as a prerequisite in this dimension. In comparison, the item “heat island reduction” got 0.5 points in the environmental dimension and 0.5 in the social dimension as a credit item. In this manner, their chapter “sustainable sites” got 1 in P (prerequisite) and 3.5 in C (credit items) in the environmental dimension, 0 in P and 2.5 in C in the social dimension, as well as 0 in the economic dimension. Subsequently, the researchers calculated the percentage of every score by the total points (57 for the rating tool) and got 1.75% in P and 6.14% in C in the environmental dimension, and 4.39% in C in the social dimension. The environmental dimension score was then separately summed by P and C, which represent the triangle's coordinates (Fig. 5).

In Fig. 5, the orange triangles represent the percentage of the credit items, and the blue triangles represent the prerequisite percentage.

In ASGB, all the credit items triangle contains the prerequisite triangle, and the two triangles of the same rating tool are frequently similar, which signifies that credit items mostly have more requirements in the same dimension than the prerequisite does. The triangles of the same version are similar. In ASGB 2014, the prerequisite triangle is smaller than that in ASGB 2006 and ASGB 2019, while the credit items are comparable in size, which means the required prerequisite in ASGB 2014 is comparatively lower than that in other versions. ASGB 2019 has more triangles for prerequisites than previous editions due to the fact that it has more prerequisite requirements.

In LEED, the credit items mostly have more requirements in the same dimension in comparison to the prerequisite except for LEED v4.1 OM: EB (Operations and maintenance: existing buildings). The triangles of the same tool are similar. From LEED v2009 to LEED v4, the prerequisite triangle becomes a little bigger, whereas the credit items triangle gets a little smaller, which means the prerequisite requirement becomes increasingly prevalent. The credit items are getting fewer, which makes them closer. LEED v4.1 OM: EB is unique due to the fact that it changes some credit items like *Energy performance* and Indoor environmental quality performance into prerequisites with minimum score requirements(Fig. 6).

Generally speaking, ASGB and LEED all have rational frames. The most recent versions of ASGB and LEED have gradually loosened prerequisite requirements compared to earlier editions. ASGB has a similar frame for tools with identical versions, and the same rating tools in LEED have identical frames for all versions. And the prerequisite triangle in ASGB is always more significant than in LEED, which means ASGB has a higher prerequisite requirement than LEED.

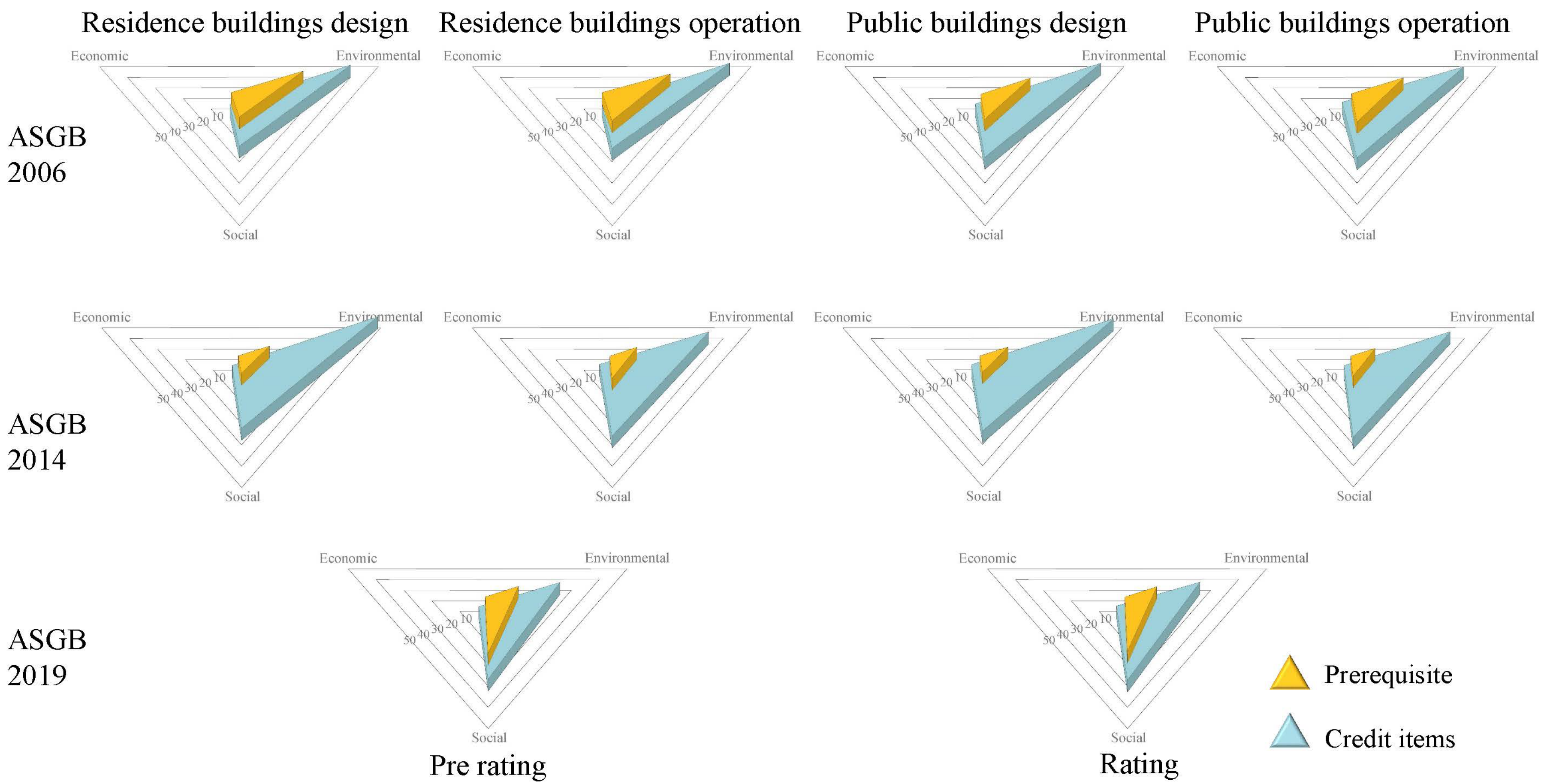

Fig. 5. The rating tool frame analysis of ASGB

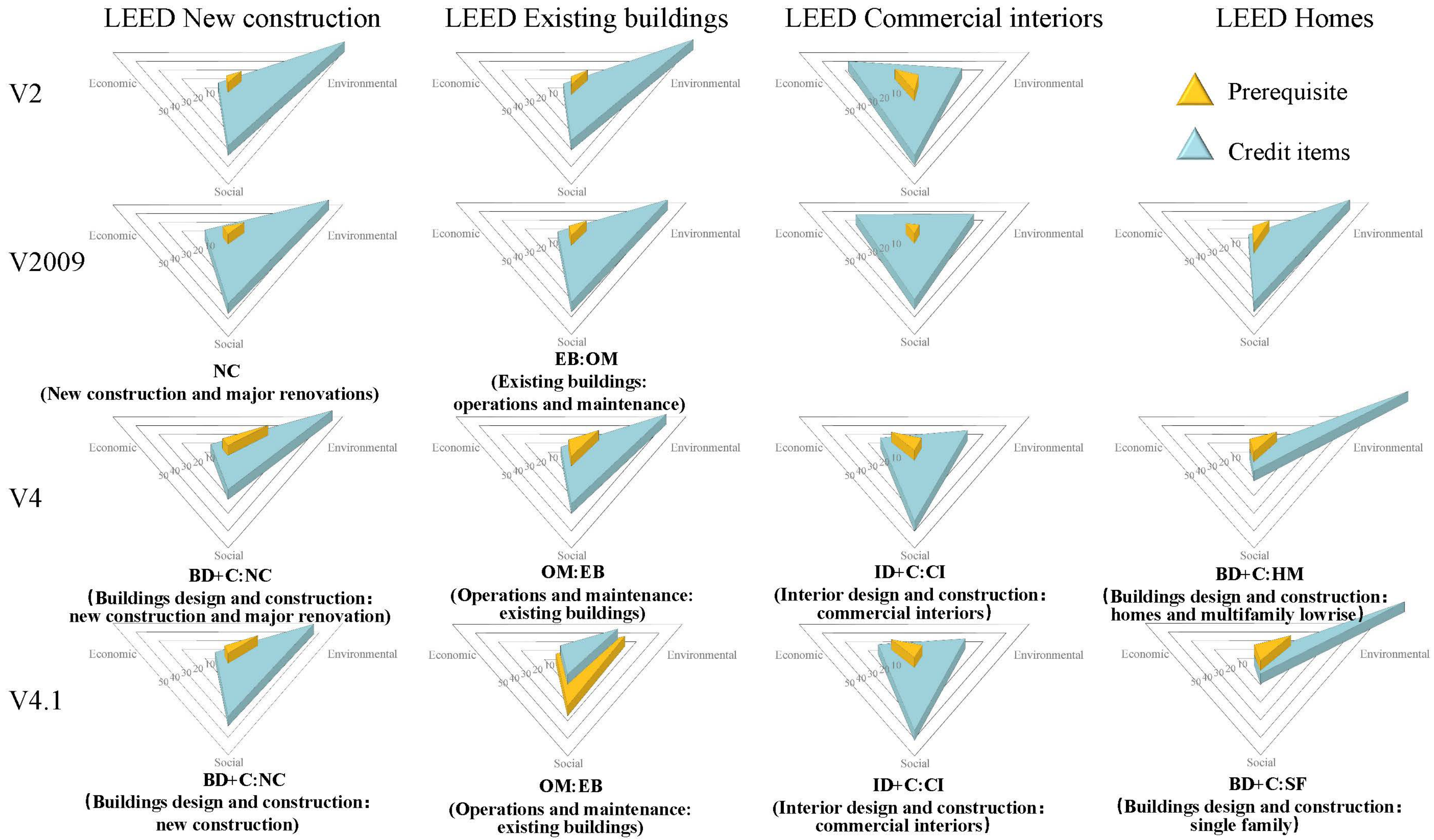

Fig. 6. The rating tool frame analysis of LEED

5.2 The main topics and change trend

The main topics refer to one of the three dimensions of the SDC that the content of the rating tools pays great attention to.

First, the data from the first step of the rating tool frame analysis is employed, and the total points of all the items in every chapter are added up in the three dimensions. The points are then converted to a percentage based on the number of items. The distinct percentages are calculated in Eq. (7~9)

$$X_{en}= P_{en}+ C_{en},\ X_S= P_S+ C_S,\ X_{ec}= P_S+ C_S \qquad (7\sim9)$$

where:

X_{en}: percentage of all items in one chapter in the environmental dimension (%)

X_s: percentage of all items in one chapter in the social dimension (%)

X_{ec}: percentage of all items in one chapter in the economic dimension (%)

An example of this procedure is when LEED v4.1 BD+C: NC got 1.75% in P (prerequisite) and 6.14% in C (credit items) in the environmental dimension. The numbers were added together, and we got 7.89% as the coordinate of the environmental dimension for the "Sustainable sites" triangle. The appendix tables indicate the percentage of every chapter in the central dimension. Fig. 7 indicates the results of the distribution in ASGB.

On the condition that comparing divergent rating tools, it is clear that the same kind of tools has the same primary topic distribution in the same version. Fig. 7 indicates that in ASCB 2006, rating tools for the same building type have a similar distribution, and for the same stages have distinct distributions. In ASGB 2014, the situation is the opposite. The distributions of rating tools for the same stage are comparable, whereas rating tools for the same building types differ. Pre-rating and Rating tools of ASGB 2019 have similar main topics. Examining specific content in depth, we discovered that the same content tends to contribute primarily to one dimension. Fig. 8 demonstrates that *Energy, Water*, and *Material Saving and Utilization* chapters in ASGB 2006 PBO(Public building operation) and ASGB 2014 PBO the and *Resources*

Saving chapter in ASGB 2019 Rating all distribute to the environmental dimension. The rating tools with the same name in LEED have almost the same contributions to the main topics. For example, LEED OM contributes predominantly to the social dimension and secondly to the environmental dimension. In contrast, LEED CI all contribute predominantly to the social dimension and secondly to the economic dimension. On the condition of analyzing the specific chapters, the researchers noticed that the predominant topics of some chapters have more comprehensive coverage with revisions, including the *Energy and Atmosphere* chapter, and some have become more focused, including the *Material and Resources* chapter. *The Indoor Environmental Quality* chapter changes its leading dimension from environmental in LEED v4 BD+C: HM (buildings design and construction: homes and multifamily lowrise)to social in LEED v4.1 BD+C: SF(buildings design and construction: single family). The changing trends analysis part only concerns the credit items, which determine whether a project could be certified and thus represent the most important topics. Moreover, their quantification is straightforward. This part employs the same analysis method as the first part on the credit items, and the weight of the items in ASGB 2014 is multiplied by the points from the content analysis. By generating the trend lines from the percentage numbers, this research discovers the noticeable trend through updating over time and exhibits them. In ASGB, the environmental dimension trend line declines and the social dimension trend line rises, while the economic dimension trend line rises slightly. In LEED, the trend line of the environmental dimension rises at first and then declines, and the trend line of the social dimension declines at first and rises again, whereas the trend line of the economic dimension varies little (Fig. 9).

Broadly speaking, ASGB focuses more on environmental and social issues than economic ones, and the publication's distribution has remained largely unchanged over time. LEED has more individualized coverage with distinct rating tools, and the coverage on the three dimensions is more balanced with the updates. On the condition of comparing the rating tools for the same building types of the two GBRSs, we discovered that the ASGB and tools for rating the design of public buildings cover a similar subject matter, which are environmental and social dimensions. Nonetheless, the situation of rating tools for residential buildings is distinct. And the operation rating tools of ASGB and LEED OM have more similarities, not only in the main topics but also in the distribution of the chapters. For instance, the rating tools for indoor environment quality are almost centered on social issues, and the energy chapter is primarily on the environmental dimension.

The changing trend of ASGB's primary topics is evident. The social dimension changes positions with the environmental dimension and becomes the most critical dimension. The changing trend of the main topics in LEED demonstrates a return trend. The percentage of the environmental dimension experiences rises, and the percentage of the social dimension experiences declines. Nonetheless, in LEED v4.1, the percentage nearly returns to its initial level.

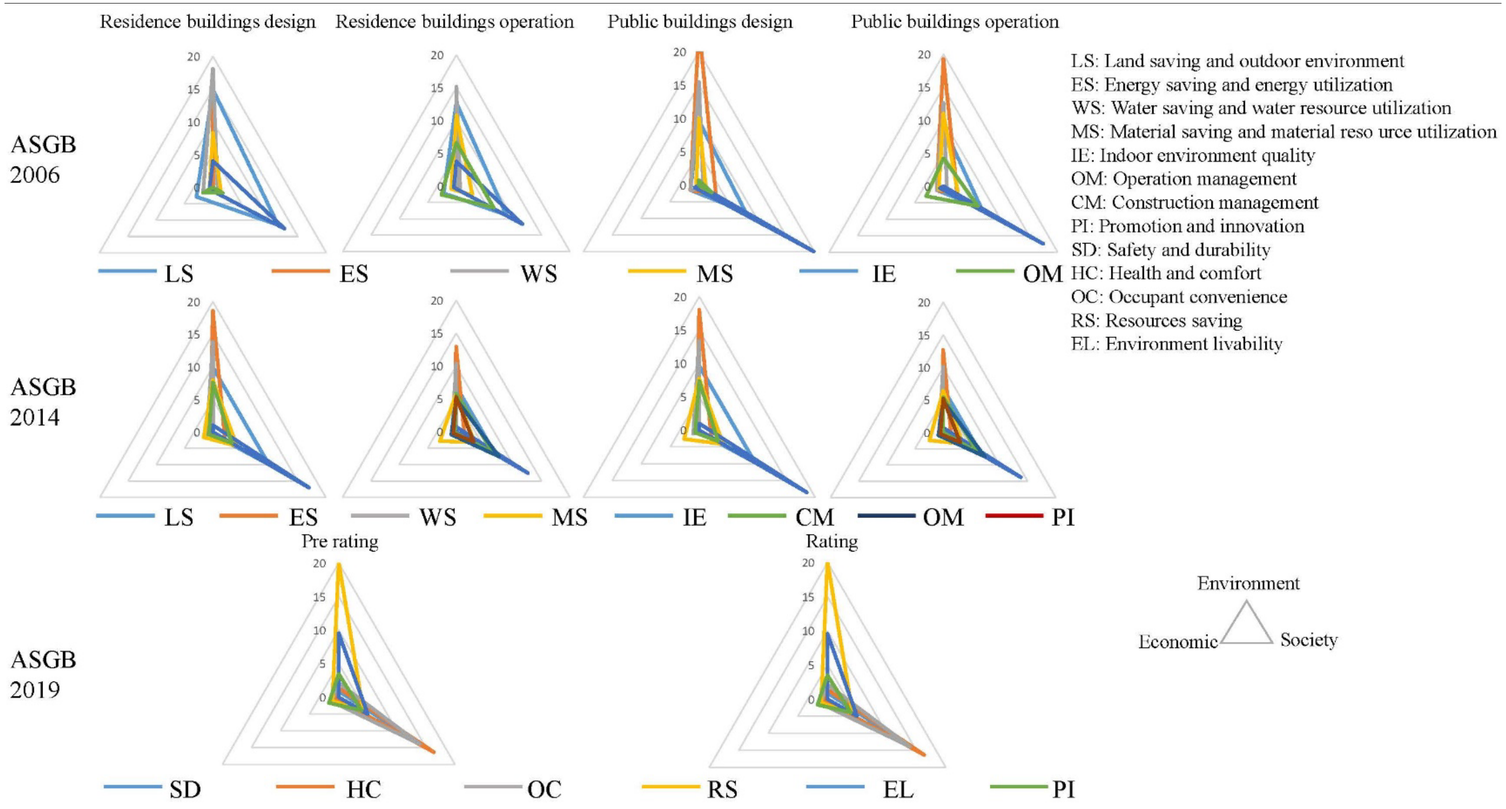

Fig. 7. The sustainability coverage of all the items in ASGB

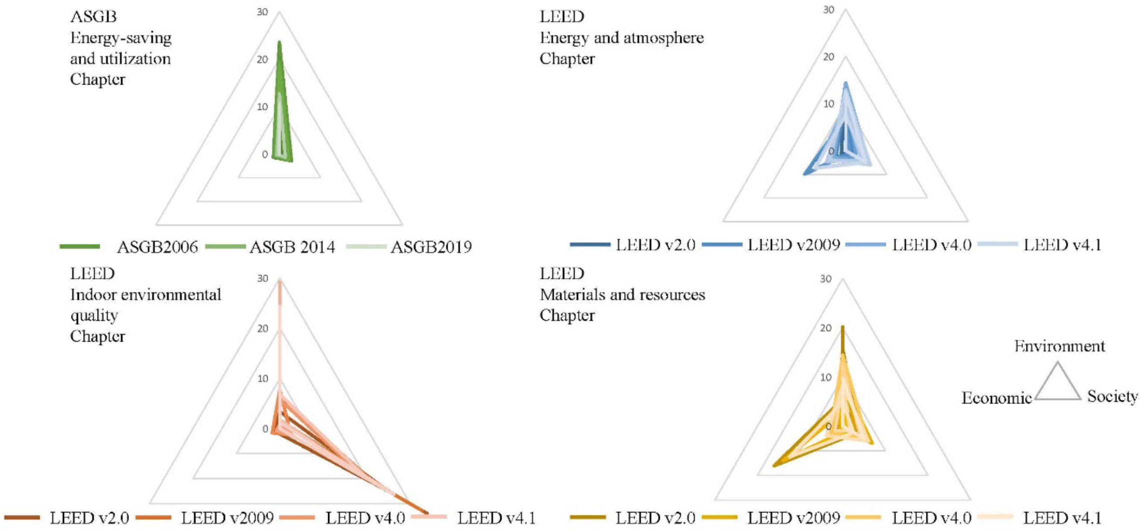

Fig. 8. The sustainability coverage of specific chapters in ASGB and LEED

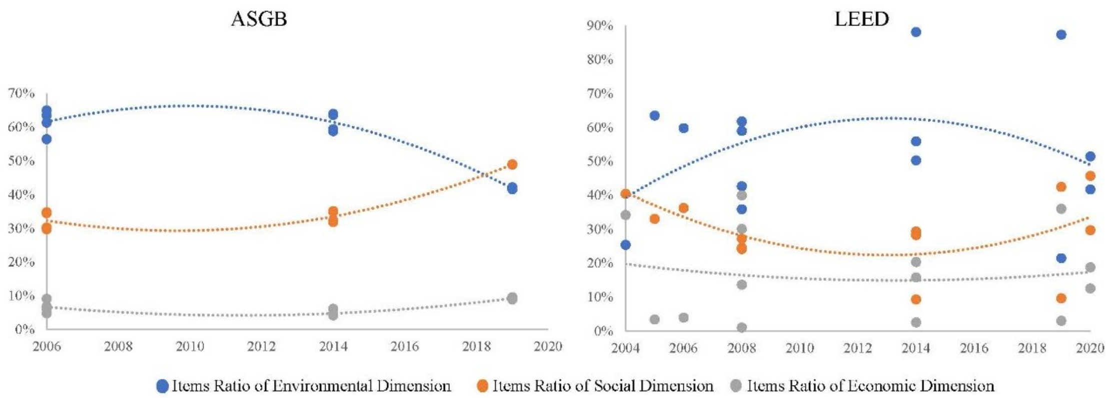

Fig. 9. Change of main topics in ASGB and LEED over time

As the two GBRSs have been updated, there is a clear trend indicating that content related to the social dimension has increased. In contrast, content in relation to the environmental dimension has diminished, and the economic dimension generally has garnered attention. Furthermore, the new version of ASGB considers economic issues to some extent, predominantly the cost and operating expenses of the building system, and yet the proportion still needs to be stronger. The market sensitivity of LEED is double that of ASGB, and its emphasis on economic issues is twofold.

This situation is, so to speak, related to the evolution of the SDC. From the *Twenty-First Century Agenda* to the *2030 Agenda*, the SDC has to optimize its core theme (Fig. 10). As attention on human issues like high-quality education and healthy life increases, environmental-related issues receive less attention. That does not mean environmental issues are no longer necessary to address. It simply represents a more balanced relationship between humans and the environment. As technology tools, GBRSs reflect this change and will offer feedback to support the development of the idea.

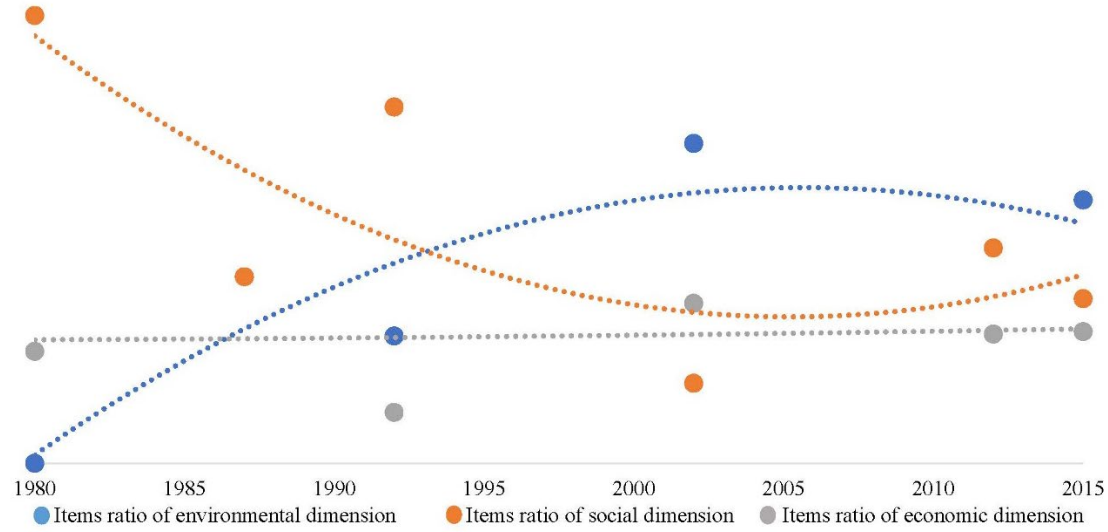

Fig. 10. The changing trend of the SDC

5.3 The important issue

This research analyzed the word frequency of all the analysis objects; that is, all the text in ASGB and some of the text in LEED that contained the intent, requirement, and performance of the items. The result of the counter indicates their 15 most pressing priorities (Fig. 11).

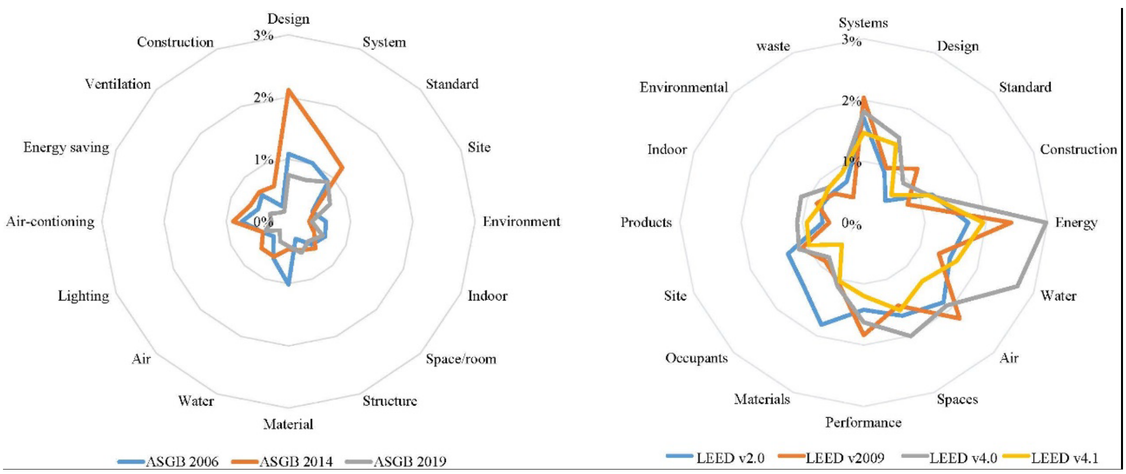

Fig. 11. The top 15 high-frequency words in ASGB and LEED

ASGB 2014 embodies a significant change from ASGB 2006, and it placed more emphasis on design issues. ASGB 2014 attempted to alter this phenomenon by revising numerous items. Moreover, ASGB 2019 changed the framework of the system and provided a more balanced one that contained ideas like safe, healthy, and convenient, resources, as well as a living environment.

The various versions of LEED have relatively concentrated subject matter. Most of the LEED versions focus on energy, systems, and air.

In general, 62.5% of the top 15 frequent words of all the selected rating tools in ASGB and LEED are the same. ASGB 2006 and LEED v2.0 address nearly identical issues, and some issues have similar word frequency. That is a clue for the close relationship between the two GBRSs and their comparability of them. Considering their system frame and sustainability, they are similar in content at the same stage in time. In the latest versions, ASGB followed new ideas, which makes the tool quite distinct from the earlier versions, while LEED has some changes that are not striking.

The critical issues reflect the GBRSs' actual orientation. This study classified the top 15 issues into four categories, based primarily on their characteristics and potential functions in green building construction (Table. 3.).

Table.3. Distinct types of the important issues

Design and construction path	Building components	Elements in built environment	Technology
Design	Environment	Occupants○	Air-conditioning※
System	Site	Energy○	Energy conservation※
Standard	Spaces○	Water	Ventilation※
Construction	Indoor	Air○	Lighting※
	Room※	Materials	
	Structure※	Products○	
	Performance○	Waste○	

- ※represent issues only for ASGB and○ represent issues only for LEED, issues without symbol are for both ASGB and LEED.

Considering all the versions, the top 15 issues of ASGB lie in four categories, while the top 15 issues in LEED predominantly fall into the first three categories.

When examining each version in detail, it has been obvious that ASGB 2006 focuses primarily on the construction path, as design, standards, system, and materials are frequent concerns. ASGB 2014 also focuses on design, systems, and standards, and continually uses technological issues, namely, air-conditioning. ASGB 2019 balanced the issues more evenly, and the construction issues gained more focus than other categories. The primary focus of LEED v2.0, LEED v2009, and LEED v4.1 are on the first three categories. LEED v4 focuses predominantly on element issues.

LEED NC and LEED EB is applicable to the different construct stage. So we compare them with ASGB and got more issues. The different issues from their top 15 issues further show the different paths. ASGB design rating tools has more technical issues such as sound insulation, heating than LEED NC. LEED EB proposes more issues on construction path like policy, management and baseline. ASGB wish to achieve the goal of green building through the technical measures in design stage and LEED EB uses complex measures containing policy, standard and management to ensure the green operation of buildings.

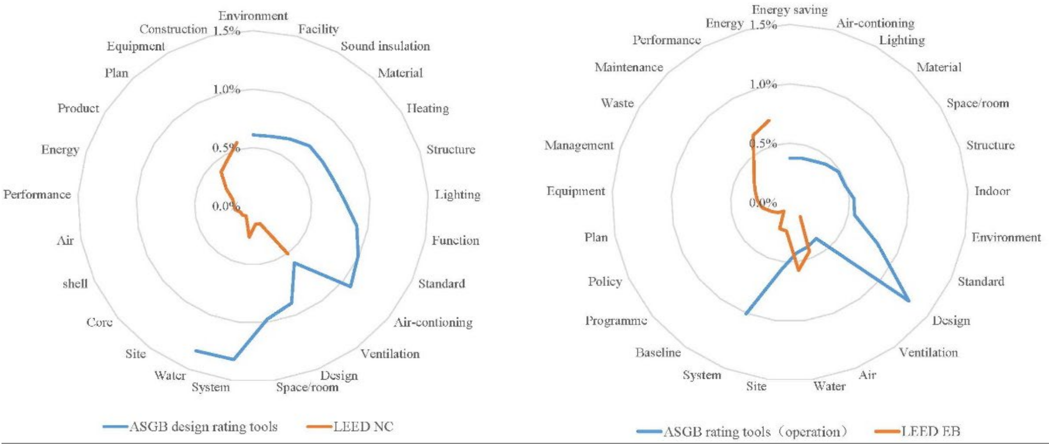

Fig. 12. The top 15 high-frequency words from different rating tools in ASGB and LEED

5.4 The certification level threshold

The certification threshold refers to the lowest credit requirement of every certification level. This study computes the percentage of the threshold credit in the total score, distributes the percentage across distinct chapters if required by the system, and analyzes the percentage to determine the threshold level of the rating systems' tools.

The lowest certification grade in ASGB 2006 and ASGB 2014 is termed the *one-star level,* and it requires a minimum number of credits in each chapter. In ASGB 2019, the lowest certification grade is named the *basic level,* which requires all the prerequisites. The threshold of ASGB 2006 is higher for public buildings than for residential buildings and lower for the Design rating tool than the Operation rating tool. In ASGB 2014, the situation became balanced. This situation implies frame optimization. In ASGB 2019, the threshold of Rating is lower than that of Pre-rating due to the non-rating items in Pre-rating.

The lowest LEED certification grade is the certified level, which does not require threshold credits in a single chapter and only requires a specific total credit total. The full credits of the rating tools in LEED v2.0 are distinct, so the credits of the certified level are not the same, and yet the percentage of threshold in the total credit is almost the same. From LEED v2009, the total score and certified threshold are almost the same except for LEED v2009 Homes (33.09%) and LEED v4.1 OM: EB(40%), and the threshold percentage is mostly 36.36%.

The percentage of each version's certification level threshold in each rating tool is represented by a dot, with the year issued on the graph. The trend lines are generated from every bunch of dots represented in the same rating stage.

The certification level threshold change of ASGB indicates an apparent rising trend (Fig.13). And the trend line keeps rising from ASGB 2006 to ASGB 2019. ASGB 2014 lifted the one-star level certification threshold by a significant extent (9%) while keeping uniformity on other levels. ASGB 2019 increased the certification requirements for all levels by introducing the *primary level*. In ASGB 2019, the one-star level had nearly the same score ratio(56.07%) as the two-star level in ASGB 2014(56.20%). When considering the detailed item requirements of the GBRSs, we noticed that it is even more difficult for projects to obtain a certification with ASGB 2019 due to the fact that some requirement of similar items in ASGB 2019 is higher than that of ASGB 2014. As mentioned in the rating tool frame part, ASGB 2019 has an additional prerequisite.

The trend in LEED certification thresholds is smooth. And we found only a tiny rising trend between LEED v4 and LEED v4.1. Since the LEED version 2009, the LEED threshold and total score have remained constant.

The certification level criterion reflects the level of technical difficulty required to obtain it. For both GBRSs, the threshold for obtaining the same certification is rising. With each update, certification for the same level has become more complex due to social and technological advancements.

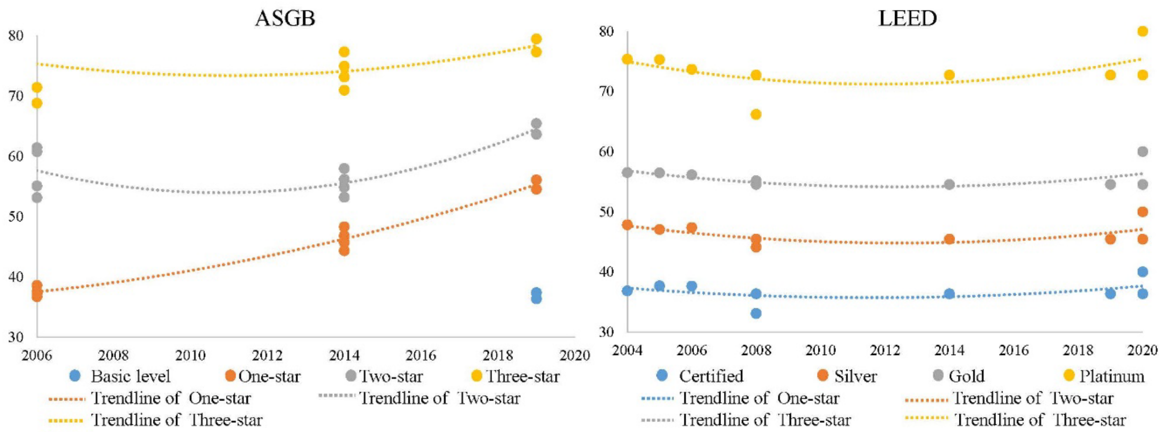

Fig. 13. Certification scores ratio in distinct versions of ASGB and LEED

With the average scores of the four levels of all the projects certified by LEED NC, LEED CI, and LEED EB (LEED Homes doesn’t demonstrate the scorecard online)in the United States by April 2020, this study determined the percentage increase over the certificate threshold and determined the changing trend line of the projects’ increment ratio through the versions. The projects received lower and lower scores for the same rating level in LEED NC and LEED CI, whereas in LEED EB, the average scores rose slightly from LEED v2.0 to LEED v4.0 and declined from LEED v4.0 to LEED v4.1 (Fig.14).

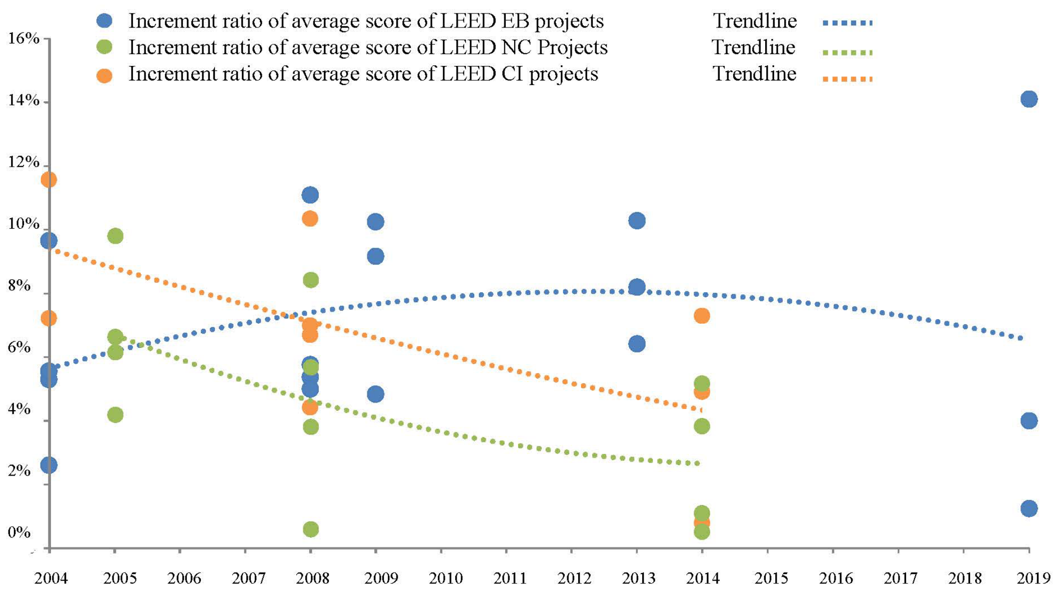

Fig. 14. LEED project scores changing trends

5.5 The technology applied

This study also sought to identify the leading technologies that were applied in the certified projects of the two GBRSs and compare them.

This study employs Jiangsu province projects as representative examples of China's technology usage for three reasons. First, although China has a wide territory and diverse climate zones, which causes disparities in the selection of technologies in distinct regions when considering the rating tool ASGB, The technology guide is specific in some way, especially in the field of energy and resources application (ASGB 2014). This circumstance prompted the implementation of mature and applicable technologies. Second, Jiangsu was at the forefront of developing green buildings in China during these years. By the end of 2020, Jiangsu had accumulated a green building area of 800 million square meters and had completed 5,416 green building identified projects, accounting for more than 20% of the sum of green buildings for the whole country. The types of green building projects in Jiangsu were comprehensive, including residential buildings, public buildings, and industrial buildings; with public buildings covering office buildings, schools, hospitals, commercial buildings, and other types (Jiangsu HURDD et al. 2022). Consequently, Jiangsu projects broadly represent a variety of building types. Last, but not least, the certification process has started using an online system in Jiangsu, making data more available.

On the basis of the details from 188 certified projects in Jiangsu in 2020, the study identified the ratio of the technologies used. There are 158 residential projects and 30 public projects in this selection of projects, and all are two-star level green buildings certified by ASGB 2014.

This study examines the costs of technologies and supports them with incremental cost survey data from green buildings in Jiangsu (Fig. 15.) .And the incremental cost comes from other technologies or equipment that green buildings use in comparison to buildings that meet the current standards. In Jiangsu, some green building technologies are widely employed and not considered incremental cost (Table 3.), and some renewable energy utilization technologies are obligated by the policies, despite the fact that the incremental cost is high. For instance, *Measures of Jiangsu province for the administration of building energy conservation*(Jiangsu provincial Gov,2009) require residents below 12 floors to employ solar thermal and public buildings invested by the government utilizing one form of renewable energy.

Jiangsu *province's green building development regulations*(Jiangsu provincial PCSC,2021) require new buildings with a land area of more than 20,000 square meters to construct a rainwater collection and utilization system and require large public buildings to adopt one kind of renewable energy source, and new residential buildings, hotels, hospitals using solar thermal systems were added.

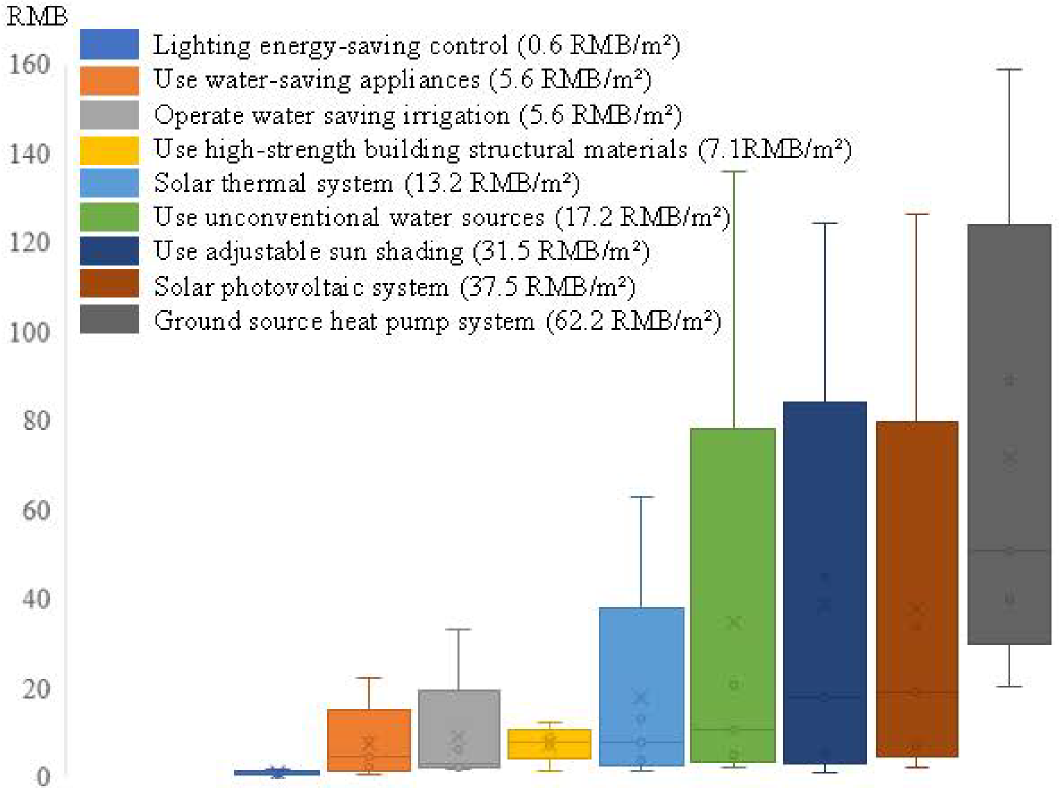

Fig. 15. The survey data of incremental cost for green technologies

Considering the total economic benefit of green buildings, we divide the technologies whose average incremental cost per unit area is under ten RMB as low-cost technologies, and exceeds ten RMB as medium-cost or high-cost technologies.

The top 15 technologies applied in both types are shown in Fig. 16.Within the top tier of the two types of buildings, twelve technologies repeatedly emerged. The top five high-frequency applied technologies are: (1) using water-saving appliances, (2) optimizing natural lighting, (3) using ready-mixed mortar, (4) using premixed concrete, and (5) optimizing indoor natural ventilation.

We find all five technologies are no-cost or low-cost technologies. In general, technologies mandated by codes or policies have a high utilization rate, although some are expensive. The third discovery is that public buildings are utilizing fewer high-priced technologies, indicating that they may become more price-sensitive. Since public buildings are always smaller than private buildings, the cost per square foot of technology may be high.

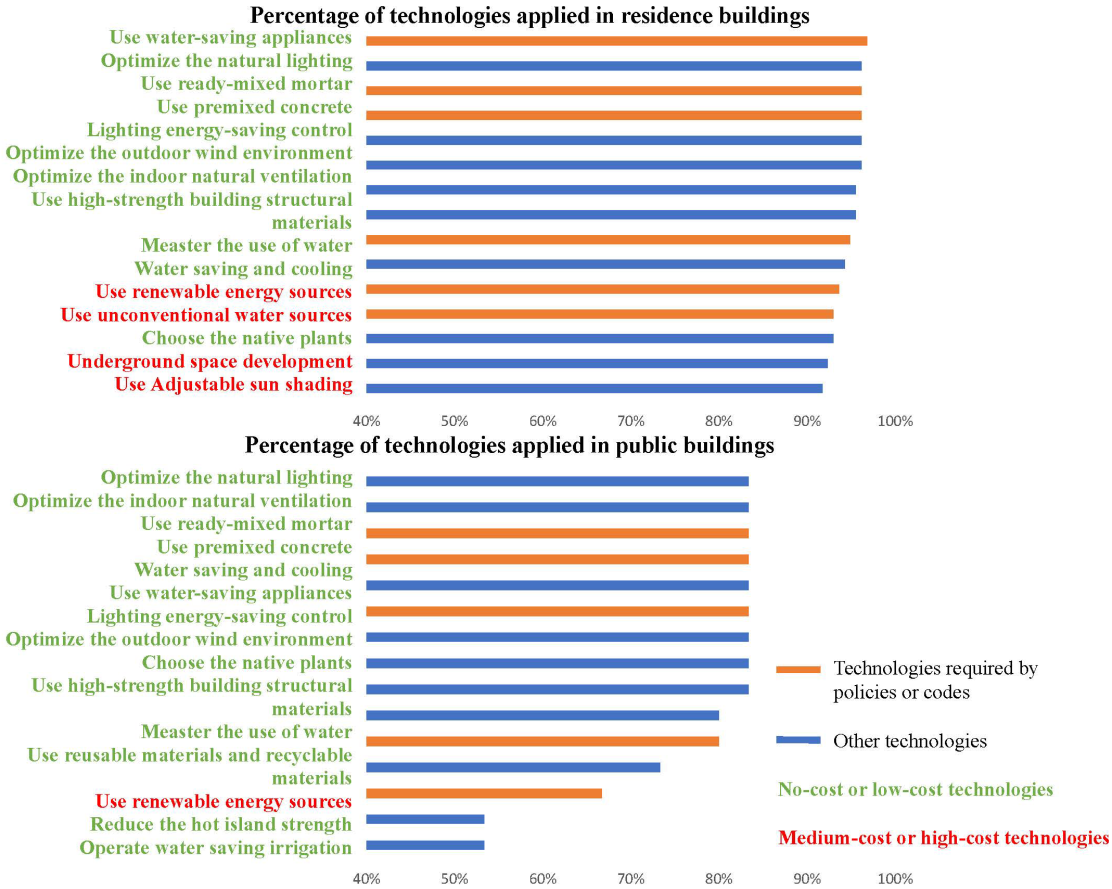

Fig. 16. Technologies applied in projects certified by ASGB 2014

Building energy-saving rate, renewable energy utilization rate, non-traditional water sources utilization rate, and reusable materials and recyclable materials utilization rate are the indices of green buildings on the certificate identification in China. This research takes two popular technologies: solar hot water utilization rate and non-traditional water sources utilization rate, for further research. The utilization rate represents the proportion of projects using the technology, and the supply rate represents the proportion of energy resources provided by the technology as a proportion of the demand for use. To contribute to the analysis, we classified the 188 certified projects into small categories: residential buildings are classified by area of structure into four categories as demonstrated in Fig. 17.-18. Public buildings are categorized by function, so 13 kindergartens are listed separately from other types of buildings with small numbers

The study found that 97.46% of residential buildings, all the kindergartens, and 64.7of 1% of other public buildings use solar hot water equipment to offer domestic hot water, with the average supply rate being 52.38% for residential, 73.63% for kindergartens, and 59.85% for other public buildings. The larger the residential scale, the lower the average utilization rate within the residential buildings. It also found that 94.30% of residential buildings, 15.38% of kindergartens, and 82.35% of other public buildings adopt nontraditional water sources, with an average supply ratio of 2.73% for residential buildings and 9.90% for other public buildings. The apparent phenomenon within residential structures is that the larger the residential scale, the lower the average occupancy rate.

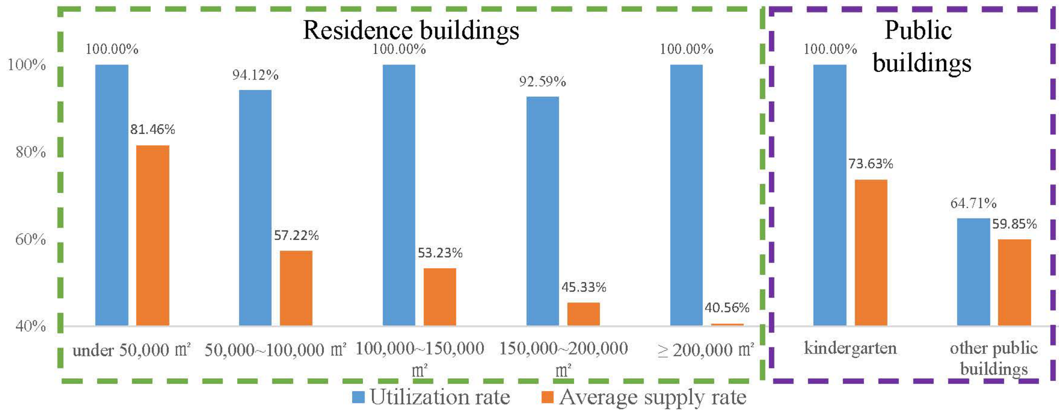

Fig. 17. Solar hot water equipment use in projects certified by ASGB 2014

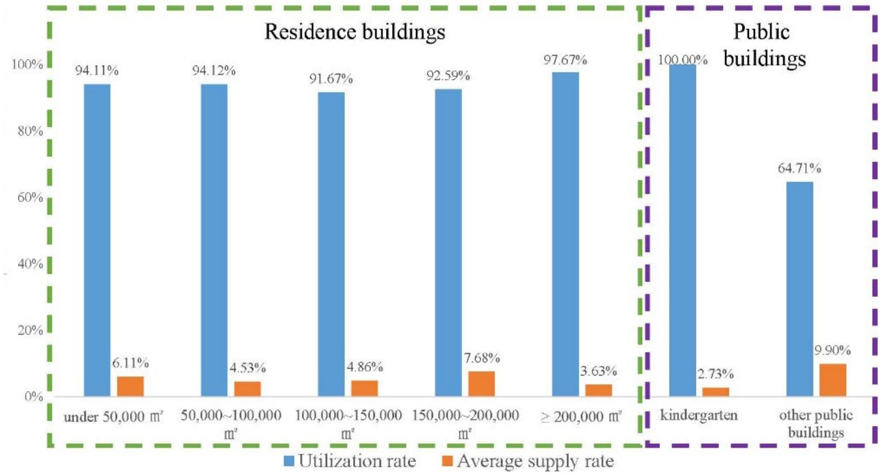

Fig. 18. Nontraditional water sources use in projects certified by ASGB 2014

This study downloaded from USGBC.org the scorecards of 10,820 U.S. projects certified by LEED v2009, of which 4,034 LEED NC projects (certified and silver certification projects), 3,280 LEED CI projects and 3506 LEED EB projects were included. By classifying these projects by their certification level and calculating their average scores from scorecards, this study determined the score distribution for each chapter. Subsequently, the researchers spent time on statistics of items that reflect a specific technology applied (Fig. 19).

On the whole, except for innovation and design process, the most accessible way to get points is to design a sustainable site (Fig. 24). The second is indoor environment quality in LEED NC, water efficiency in LEED CI, and regional priority in LEED EB. That signifies technologies in these fields are simple to use for green buildings. When investigating the specific technologies in-depth, this paper chose projects certified by LEED v2009 NC (new construction and major renovations) as the target due to the fact that those buildings are similar to those in projects certified by ASGB. By stating the specific points on the scorecards and calculating the average ratio of every item, we identified the top 15 technologies employed in the projects certified. The most prevalent technologies are virtually identical, with only the top 10 technologies changing their ranking. The technologies applied frequently are primarily passive measures, including materials choice and design tactics. Half of the top 10 technologies involve the use of materials.

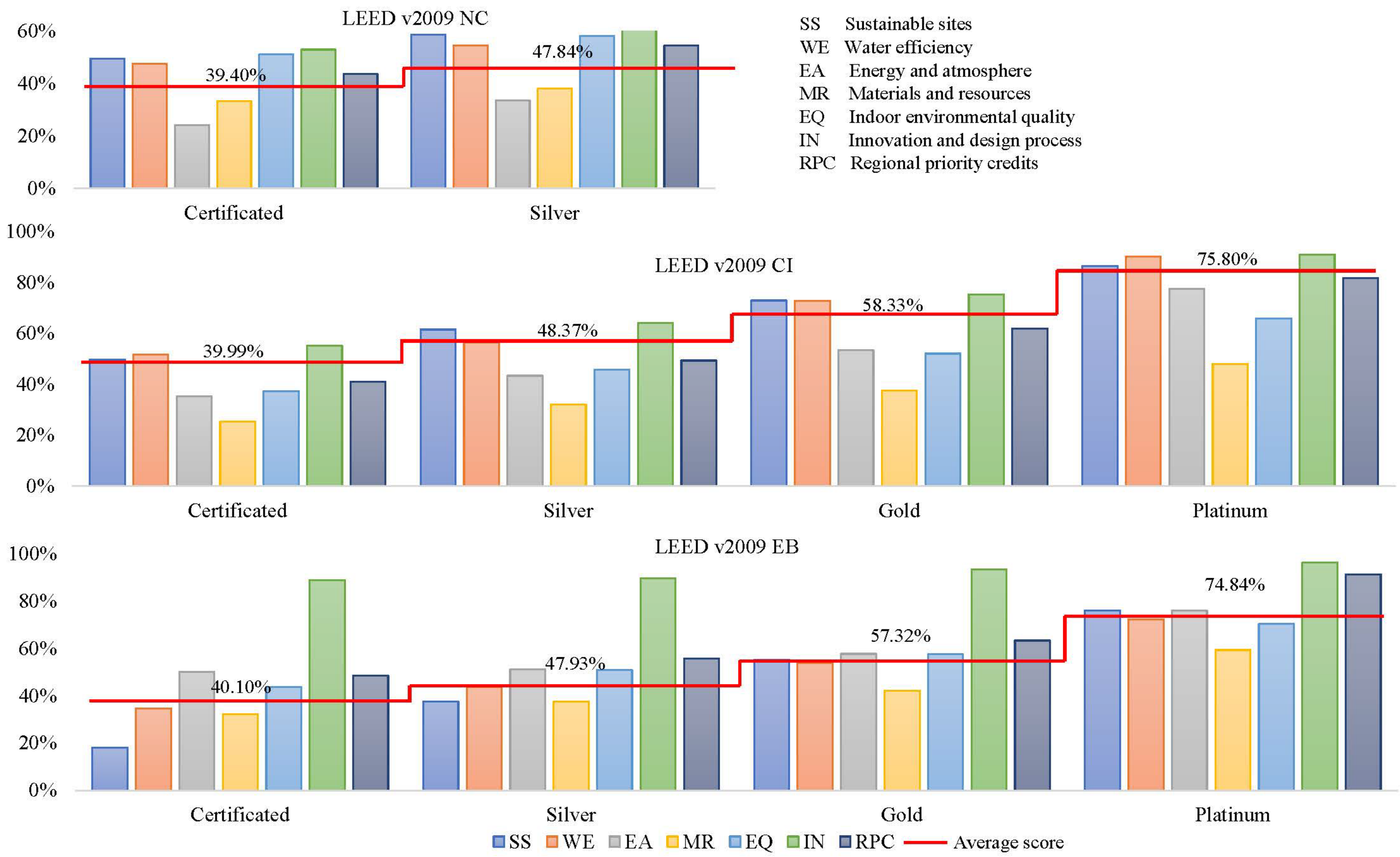

Fig. 19. Types of technologies applied in LEED projects

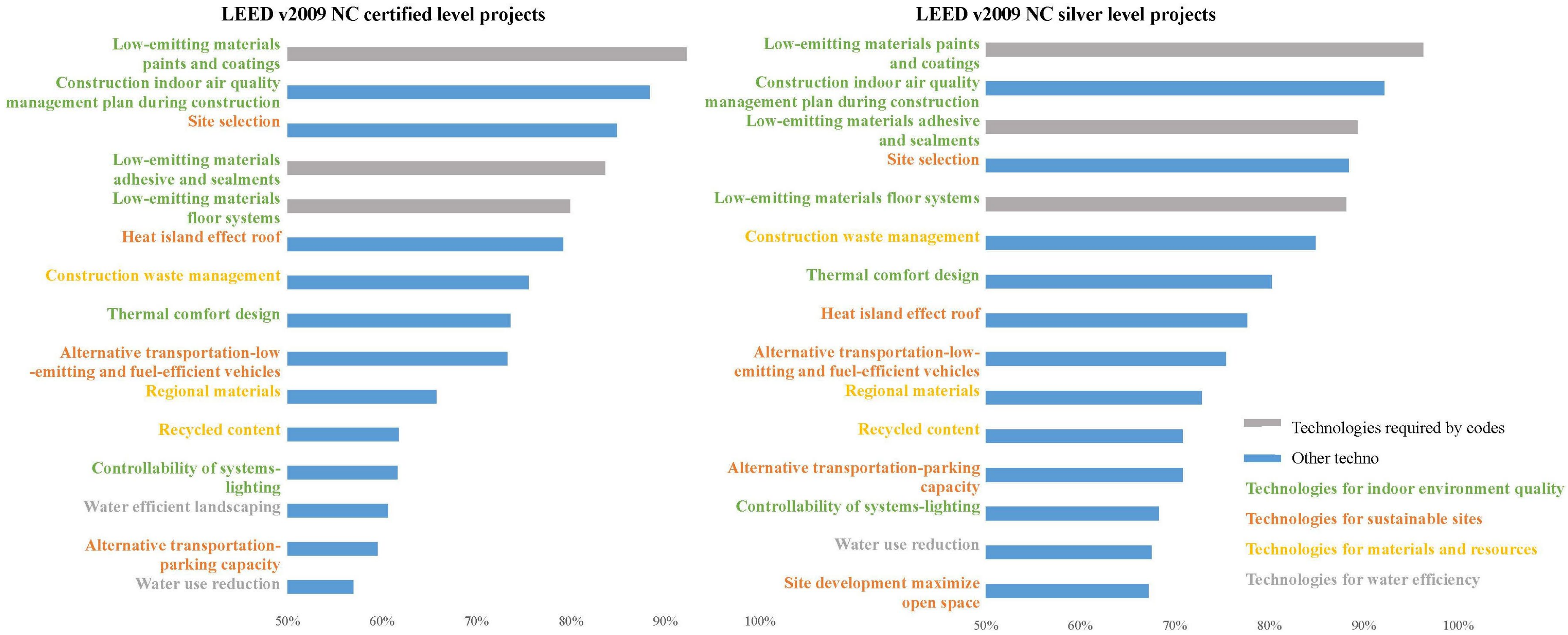

Fig.20. Top 15 technologies applied in LEED NC v2009

In Jiangsu, the technologies utilized for residential and public construction projects are comparable. Passive measures are prevalent in green buildings due to their low costs and positive effect in creating a comfortable environment. Green buildings typically use low-cost technologies to meet the requirements of the ASGB, whereas the high-priced technologies mandated by policies or codes have a high adoption rate despite their expense. Public buildings seem more sensitive to the cost of technologies due to the fact that they are generally smaller in square meters than residential buildings and thus may have more unit costs.

In the United States, green buildings score higher in chapters on sustainable sites, water efficiency, and indoor environment quality, indicating that technologies in these fields are applied effectively. When analyzing the specific technologies applied in LEED v2009 NC, the top 15 technologies predominantly belong to the indoor environment quality and sustainable site chapter. This consistency suggests that easy-to-score items and the techniques they require are frequently the most popular. Furthermore, when we check the requirement in the text of the rating tool, it is evident that all frequently employed technologies are either inexpensive or mandated by the code.

6. Discussion

6.1 The similar developing ideas

Since the birth of ASGB, its evolution has been synchronized with the SDC. ASGB 2006 focused on energy, land, water, and materials, as well as environment-benign and pollution-reducing. And the content of ASGB 2014 became more balanced, stressing the indoor environment and the function of "design" more heavily. ASGB 2019 changed the definition of green building and the technology system. The social dimension increases noticeably as the number of items pertaining to human safety and health increases. This procedure is similar to the development of SDC from *21 Century Agenda*.

In LEED, the development of the SDC did not cause significant changes. Although we found a trend of waning and waxing, the changing direction of the three dimensions is relatively flat.

When we looked deeply into the similar change trend and the distinct change situation, we noticed that the execution mode of the GBRSs may play an important role. ASGB is a Chinese government-issued national standard primarily administered by government institutions. It is undoubtedly influenced deeply by governmental policy guides. LEED is a commercial standard that is primarily driven by the market. It is not sensitive to policy changes unless they are related to market benefit.

6.2 The distinct orientations for green buildings

ASGB tends to use comprehensive rating tools to evaluate distinct types of buildings, whereas LEED tends to use a variety of rating tools. ASGB focuses more on design and construction issues, while LEED focuses more on elements inbuilt buildings that should be saved, reused, or optimized. This difference reflects the two countries' distinctive approaches to green building development. China cares about how to “produce” a green building, while the U.S. cares about what a green building contains. There is no “right” way for green buildings and GBRS; distinct perspectives result from unique histories. ASGB is a technical system relatively independent of the traditional building construction system, and yet it was supported by the government soon after it began operating and became a standard requirement for new constructions. Accordingly, it needs a convenient operation process to deal with large amounts of certification. This is the reason why the system has been simplified. ASGB has taken “passive priority, active optimization” as the primary technical principle, so it mentioned design and system requirements and cited more other standards in the new versions to meld with the building construction system. LEED established itself as a commercial certification from the very beginning. By emphasizing the important elements in the content with a specific index or concrete requirements, LEED aims to enhance building performance in order to increase commercial value, consequently, it keeps focusing on performance keywords and relative technical measures.

6.3 The suitable way of guiding technology development

ASGB increases indexing and technology application requirements with each update. LEED did not change the certification threshold but improved the item requirement, so the actual certification scores still indicate a downward trend. Green buildings in China tend to choose low-cost technologies while following the policies and codes. Some of the mandated technologies could be more effective in practice. LEED projects employ more low-cost technologies than ASGB, and these applications helped the projects get effective scores to pass certification. In this way, LEED once again embodies its market-leading characteristics, achieving greater benefits at a nominal cost. The GBRS always reflects the trend of green building technology development. Every update will surely revise the items in accordance with both the new code and the new technological direction. In this way the GBRSs lead technology progress in projects. If this procedure is smooth and suitable to the degree of technological progress and its application, it is referred to as a "standard lead" effect. Nevertheless, if portions of the procedure are performed too quickly or too slowly, the procedure may not be effective, it may not only present a barrier to the new version's popularization, but also make the GBRS inefficient.

Suppose policies and regulations stipulate the use of high-cost technologies; the economic benefits of green building will decline. If some costly technologies have limited benefits, the building's overall benefits will be further diminished. These conclusions are made on the analysis of Jiangsu green buildings and have some representativeness as well as reference significance for China.

From LEED, we learn that easily used technologies are always the frequently used ones. Only when technology is both efficient for sustainability and also useful in getting points for green buildings will it be used frequently.

Some aspects could be improved in this research. The first one is that the green building samples in Jiangsu are small in quantity. Consequently, some of the discoveries from them may be restricted and only reflect part of the situation. The second one is that the incremental analysis of technologies is not related to technical efficiency due to the fact that data is lacking, so the suggestion for developing technologies does not include a dimension considering efficiency. We hope these limitations can be refined in a future study.

7. Conclusions and recommendations

From the comparison of the GBRSs, we notice some obvious characteristics of ASGB and make some recommendations.

7.1 Strengths of ASGB

The content becomes balanced in the distribution of the three dimensions in the SDC through updating. The framework system shifted from the environmental structure controlled by "conservation and environmental protection" to content related directly to human experience and "safe, healthy, convenient and livable" features.

The text in ASGB contains the basic conditions, implementation path, elements, and technology of green buildings, and it is clear that ASGB concentrates on the comprehensive performance of the building instead of the equipment and technology application. In comparison with the previous version, ASGB 2019 further enhanced its scientific nature, and its content is innovative and comprehensive.

7.2 Recommendations for Chinese GBRS

The Chinese GBRS needs to expand its framework and develop new tools applicable to a variety of building types, including high energy-consuming buildings including data centers, hospitals, shopping malls, and hotels, and also considering distinct regions in China.

More attention must be paid to the data of the ASGB 2019-certified projects. Moreover, the universality and specificity of the current items can be evaluated by analyzing data on the technologies used and the average scores, and the revised job will be more targeted. In order to do this, it is preferable to construct an online information system. that shares some primary data. Data available for users of the online system will contribute to diversification research of green buildings and GBRS.

It is also important to optimize the technology system in ASGB. For the purpose of guiding the healthy development of green buildings, the items about technologies should be more scientific and rational, especially when addressing the technologies of prerequisite. It is better to adjust measures to local conditions and still provide technological options.

Last but not least, it is necessary for revision to increase the proportion of economic items in the ASGB; this will be advantageous for leading technology development and effective for the widespread use of the rating tool.

7.3 Recommendations for green buildings technologies in China

When selecting technologies for a green building, cost and efficiency are crucial considerations. Their relationship is recognized as "techno-economic", which is the key to the sustainable and healthy development of green buildings when achieving a good state. There are numerous low-cost and adequate technical measures for green buildings, some of which are passive measures, due to the fact that they can realize the performance of the buildings without any additional equipment.

Selecting and employing these technologies embody one of the essences of "green": "reducing resource input and increasing output efficiency". Design based on performance is the most rational way to implement passive technology. Green buildings should maintain design as the leading technology orientation and strengthen the integration of construction, operation issues as well as related technologies.

Green building and technology have a complementary relationship. It is necessary to improve the performance of green buildings to contribute to their development through the application of mature technology and to explore more efficient practical technology through technological innovation in green building practice.

Appendix

Table A1. Percentage of the main topics in ASGB

Chapter	Rating Tools	Environmental (%) E	Social (%) S	Economic (%) E	Rating ool	Environmental (%) (	Social (%) (	Economic (%) (	Rating ool(	Environmental (%) (	Social (%) (	Economic (%) (	Rating ool(	Environmental (%) (	Social (%) (	Economic (%) (
LLand saving and outdoor environment	**ASGB 2006 (Residence Bbuilding design**	13.05	11.7	2.27	**ASGB 2006 Residence building operation**	9.86	8.84	1.71	**ASGB 2006 (Public building Ddesign**	9.57	8.51	1.06	**ASGB 2006 Public building operation**	7.89	7.02	0.88
EEnergy saving and energy utilization		20.27	1.35	0		15.31	1.02	0		25.53	3.19	1.06		21.05	2.63	0.88
WWater saving and water resource utilization		16.22	0	2.7		14.29	0	0		12.77	0	2.13		10.53	0	1.75
MMaterial saving and material resource utilization		10.35	2.24	0.92		14.61	2.37	1.39		12.4	1.77	0.72		14.32	2.04	1.19
IIndoor environment quality		3.59	11.7	0.92		3.73	9.86	0.69		0	18.09	1.06		0	14.91	0.88
OOperation management		0	2.7	0		7.14	8.16	1.02		1.06	3.19	0		2.63	7.89	3.51
Land saving and outdoor environment	**ASGB 2014 Residence**	12.19	7.08	0.4	**ASGB 2014 Residence**	6.91	6.91	0.25	**ASGB 2014 Public building**	9.62	9.62	0.35	**ASGB 2014 Public building**	7.89	3.71	0
Energy saving and energy utilization		20.57	1.57	0.34		12.96	1.48	0.37		18.04	2.07	0.52		18.38	2.16	0

Water saving and water resource utilization	**buildin g esignD**	15.73	0	1.12	**buildin g operati on**	10.37	0	0.74	**D design**	13.4	0	1.03	**opera-tion**	12.5	0	0
Material saving and material resource utilization		6.62	4.24	1.08		5.8	3.2	2.86		7.72	4.12	2.6		12.5	0.44	0.46
Indoor environment quality		1.01	13.99	0		0.74	12.59	0		1.03	18.55	0		0.8	12.59	0
Construction management		–	–	–		5.8	6.54	0.25		–	–	–		6.43	2.5	0
Operation management		–	–	–		4.94	7.53	0.87		–	–	–		2.23	6.43	0.27
Promotion and innovation		7.79	4.98	1.27		5.3	3.08	0.5		7.38	3.26	0.7		6.54	3.87	0.3
S Safety and durability	**ASGB 2019 Pre-rating**	0.69	12.43	0.62	**ASGB 2019 Rating**	0.64	11.63	0.58								
Health and comfort		0.55	12.64	0.55		0.51	11.83	0.51								
Occupant convenience		1.03	8.59	0		1.82	9.79	1.25								
Resources saving		23.71	3.38	0.37		22.19	3.17	0.35								
Environment livability		11.06	2.68	0		10.35	2.51	0								
Promotion and innovation		5.11	9.23	7.36		6.07	9.92	6.89								

Table A2. Percentage of the main topics in LEED

Chapter	**Rating Tools**	**Ratin g Tools**	**Envir onme ntal (%)**	**Social (%) S**	**Economic (%) E**	**Ratin g ool**	**Envir onme ntal (%) (**	**Social (%) (**	**Economic (%) (**	**Ratin g ool(**	**Envir onme ntal (%) (**	**Social (%) (**	**Econom ic (%) (**	**Ratin g ool(**	**Envir onme ntal (%) (**	**Social (%) (**
SSustainable Sites	**Nv2.2 New construction**	17.39	2.9	0	**Ev2.2 Existing buildings**	14.04	3.93	0	**v2.0 Commercial interiors**	7.14	1.79	0				
WWater Efficiency		7.25	0	0		7.86	0	0		0	0	3.57				
EEnergy and Atmosphere		23.19	1.45	0		13.48	4.49	1.12		7.15	0.89	9.82				
MMaterials and Resources		13.77	3.62	1.45		20.23	0	0		5.64	3	18.15				
IIndoor Environmental Quality		0	21.74	0		3.37	24.72	1.12		0	33.93	0				
IInnovation & Design Process		1.91	3.36	1.97		1.48	2.61	1.53		2.36	4.21	2.36				
LLocation and Linkage	**Nv2009 New construction and major renovation**	–	–	–	**Ev2009 Existing buildings: operation and maintenance**	–	–	–	**v2008 Homes**	8.72	5.13	0	**v2009 Commercial interiors**	–	–	–
Sustainable Sites		20.04	2.88	0.52		19.72	4.13	0		14.62	2.31	0		7.27	1.82	0
Water Efficiency		6.25	0	6.25		12.84	0	0		12.82	0	0		0	0	3.64
Energy and Atmosphere		9.62	1.83	2.61		18.35	2.75	11.01		10.77	8.72	0		7.27	0.91	10
Materials and Resources		10.94	3.13	0		4.59	3.21	0.46		9.49	0.77	0		3.02	1.24	13.93
Indoor Environmental Quality		0	26.57	0		3.21	10.55	0		0.77	18.72	0		0	32.73	0
Innovation & Design Process		2.58	4.14	2.66		1.21	2.13	2.17		1.79	2.82	1.03		3	4.91	3

RRegional Priority		3.13	3.13	0		1.83	1.83	0		0	0	0		7.27	0	0
AAwareness and Education		–	–	–		–	–	–		0	1.54	0				
IIntegrative Process	**Nv4 Building design and construction: new construction and major renovation**	0.57	0.57	0.59	**Ev4 Operation and maintenance: existing buildings**	–	–	–	**v4 Building design and construction: Homes and multifamily lowrise**	0.5	0.5	0.52	**v4 Interior design and construction: commercial interiors**	0	1.22	1.22
Location and Linkage		9.48	4.31	0		1.92	0	0		6.44	4.92	0		6.1	3.66	0
Sustainable Sites		9.48	2.59	0		8.65	4.81	0		4.55	0.76	0		–	–	–
Water Efficiency		10.34	1.72	1.72		11.54	0	0		9.09	0	0		0	0	4.88
Energy and Atmosphere		11.19	2.57	3.48		14.43	5.77	2.88		28.79	0	0		9.76	4.88	7.32
Materials and Resources		12.07	4.31	2.58		6.73	3.84	2.88		28.79	0	0		4.85	2.49	12.17
Indoor Environmental Quality		7.74	2.57	1.76		5.77	19.23	0		7.2	0.38	0		1.22	25.61	0
Innovation & Design Process		0.57	2.29	0.59		0.63	2.56	0.65		1.25	1.25	2.05		0.8	3.27	0.8
Regional Priority		3.45	3.45	0		3.85	3.85	0		1.52	1.52	0		4.88	4.88	0
IIntegrative Process	**Nv4.1 Building design and construction: new construction**	0.58	0.58	0.6	**Ov4.1 Operation and maintenance: existing buildings**	–	–	–	**v4.1 Building design and construction: single family**	0.59	0.59	0.61	**v4.1 Interior design and construction: commercial interio**	0	1.25	1.25
Location and Linkage		8.47	4.96	0.6		14	0	0		5.36	3.57	0		6.25	3.75	0
Sustainable Sites		7.89	4.39	0		2.5	1.5	0		5.36	0.89	0		–	–	–
Water Efficiency		11.4	0.88	0		7.5	7.5	0		13.39	0	0		0	0	5
Energy and Atmosphere		9.05	3.79	4.7		11.89	11.39	11.72		35.71	0	0		7.5	5	7.5
Materials and Resources		8.76	1.74	1.79		4.5	4	0.5		9.38	1.34	0		4.98	2.55	12.48

Indoor Environmental Quality		1.75	17.55	0		1	21	0		14.29	0	0	**rs**	1.25	26.25	0
Innovation & Design Process		0.58	2.33	0.6		0.33	0.33	0.34		1.47	1.47	2.41		0.83	3.35	0.83
Regional Priority		3.51	3.51	0		–	–	–		1.79	1.79	0		5	5	0

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