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Article

A Comparative Study on Architectural Design-Related Requirements of Green Building Rating Systems for New Buildings

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Abstract: Design teams' work is greatly influenced by green building rating systems (GBRSs). Early GBRSs that had an energy- or resource-based hierarchy and prioritized mechanical components and active technologies were unable to adequately support the architectural design (AD). Due to the recent rise in awareness of the importance of AD in the creation of GBs, many GBRSs may now improve requirements pertaining to AD. However, it has not been examined in earlier studies. As a result, this study uses a comparative approach, content analysis, and significance evaluation to examine the effectiveness of six GBRSs as applied to AD in terms of significance, inclusiveness, comprehensiveness, and certainty. Six GBRSs include Leadership in Energy and Environmental Design (LEED), Assessment Standard for Green Building (ASGB), Green Mark (GM), WELL Building Standard (WELL), Assessment Standard for Healthy Building (ASHB), and Living Building Challenge (LBC). A heuristic theoretical evaluation framework (TEF) is developed with the goal of providing guidelines and references for the improvement of GBRSs and the strategic idea of AD. There are four key findings. Firstly, LBC assigns the highest and certain weight to AD, followed by LEED and ASGB, then ASHB, and finally GM and WELL. Secondly, green and regeneration GBRSs emphasize resource, environment, and physiological health, while wellbeing GBRSs emphasize physiological and psychological health. Thirdly, GM, ASGB, WELL, and ASHB are the most inclusive and comprehensive in process, resource, and environment, physiological health, and sociological and psychological health, respectively. Fourthly, LBC performs best in setting mandatory requirements in included aspects.

Keywords: architectural design; green building rating system; theoretical evaluation framework; health; regenerative design

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1. Background

Industrialization and urbanization promoted the initiation of the environmental campaign. Building construction, a crucial component of human developmental activities, began pursuing mainstream green in the environmental campaign. Three milestones were tied to green building rating systems (GBRSs) in the early green building (GB) movement. The first milestone occurred in 1990. The GB movement had its start with the announcement of the first international GBRS, known as the Building Research Establishment Environment Assessment Method. Since that time, numerous developed countries and cities have progressively announced GBRSs, including the local Green Building Tool in Canada, the national High-Quality Environmental standard in France, the international Leadership in Energy and Environmental Design (LEED) in the United States, etc. However, at that time, the GB movement was mostly promoted in Europe and North America. The US Green Building Council (GBC) facilitated the World GBC's formal foundation in 2002, which was the second milestone—the creation of the global GB platform. It spurred the propagation of GBRSs throughout the world, especially in Asia, Africa, and Australia. The national Assessment Standard for Green Building (ASGB) in China, the international Green Star in Australia, the national Comprehensive Assessment System for Built Environment Efficiency in Japan, and the national Green Mark (GM) in Singapore are representative GBRSs. The third milestone was that An Inconvenient Truth won the 2007 Nobel Peace Prize. The majority of governments started to acknowledge the role that humans play in climate change and the value of GBRSs in addressing the environmental impact of building construction. Since then, the GB movement has entered into an era of high-speed development that has drawn in a large number of projects. Take LEED as an example, a comparison of data before and after 2006 reveals a sharp rise in the monthly registered projects from 60 to 700, and the monthly certified projects from 11 to 63 [1]. The GBRSs are a crucial element of the GB movement, serving as a standardized expression of the evolution of GB concepts and a roadmap for future directions of both market and academia.

2. Introduction

To achieve GBRS certification, all stakeholders must dutifully complete their own work throughout the design, construction, operation, and maintenance processes. Architects, as the guardian of the built environment from ancient times to the present, are one of the most concerned entities or parties amongst the numerous building stakeholders. It has always been a major concern how the architectural design (AD) complied with GBRSs. In fact, architects and "green" have been at odds from the early GB movement [2–5]. GB's initial focus, influenced by modern technology, is to achieve the goal of energy and resource conservation through technological and mechanical knowledge mainly possessed by engineers [6]. Almost all GBRSs in this context featured an energy- or resource-based hierarchy with mechanical components and active technologies, allowing their performance can be quantified. However, it was clearly distinct from AD attributes in terms of content and thinking. GBRSs did not adequately represent the effort or contribution of architects, i.e., AD. This is why it is challenging for architects at that time to accept and adapt to GBRSs.

More studies have recently demonstrated the significance of some AD strategies or ideas, either directly or indirectly. Research results of Elaouzy and El Fadar [7] revealed that most proper passive design strategies had been proven to effectively reduce the energy consumption and carbon footprint of buildings. From the concept of "ecological building" developed in architecture, a new concept called "regenerative design" was developed. This concept was proposed to break through the constraints of the mechanistic worldview and the conventional GB paradigm, shifting the focus to the intricate and positively evolutionary interrelationship between humans and ecosystems [8–11]. As more studies revealed the importance of building occupants in GB use, the concept "wellbeing" or "healthy building" also began to emerge. Mamalougka [12] demonstrated that user awareness and behavior directly influenced the actual performance of buildings. According to Scofield [13], human behavior could cause energy consumption to increase, making green buildings less green. The phrase "design for human" is more in line with architects' pursuits, which include offering occupants a comfortable built environment that meet the residential, commercial, educational, and recreational demands while also fostering the growth of the economy and culture. These two concepts have launched their own evaluation systems that are referred to as emerging GBRSs. Along with this tendency, many conventional GBRSs have gradually considered AD in their version evolution. Based on the review of the literature published in the last ten years [14–21], it was found that some studies critically examined the evaluation contents or methodological approaches of various GBRSs from the perspectives related to AD, including urban planning, site planning and design, local feature, regional context, passive design, biophilic design, human behavior, and wellbeing. However, no systematic research on GBRS evaluation accurately targeting AD has been conducted, and few studies have chosen emerging GBRSs as an evaluation object.

2.1. Research Aims

This study selects six representative GBRSs from the conventional "green" concept and the emerging "wellbeing" and "regeneration" concepts as comparison samples, and critically scrutinizes their effectiveness as applied to AD by a comparative analysis, so as to:

- Explore the key differences and similarities between the architectural design-related (ADR) weight and credit systems of LEED, ASGB, GM, WELL, ASHB, and LBC, thus deepening the understanding of the ADR evaluation content of the prevailing GBRSs and generating references for the quality improvement of six selected GBRSs.
- Propose a framework that has the potential of shedding new light on architects' strategic ideas during the early GB design process, eventually supporting the green building development.

2.2. Research Objectives

- Clarify the areas that need attention in the upcoming credit identification and weight calculation by reviewing of the GBRSs' general information.
- Count the quantity and points of all credits and ADR credits to investigate the significance of the ADR evaluation content at the category and standard levels; further analyze significance with certainty and explain the negative effects on AD caused by the characteristic of the scoring items.
- Compare six GBRSs to provide suggestions when generating radar charts and bar charts during credit identification and weight calculation.
- Establish a heuristic theoretical evaluation framework (TEF) that is accurate to variables; use six GBRSs to carry out the variable-to-credit correspondence.
- Analyze the attributes and meanings of each variable from the perspective of an architect; categorize variables to support the comprehensive analysis that follows.
- Define the key sections of ADR evaluation in GBRSs; investigate the focus of GBRSs on these sections; determine if there are any similarities between GBRSs that pertain to the same concept.
- Examine the inclusion degree of each GBRS in all sections; discuss whether this inclusion is comprehensive and whether every included aspect has mandatory requirements; analyze each GBRS's merits and demerits and make recommendations; rank six GBRSs depending on the indicator system's inclusiveness, comprehensiveness, and certainty to determine the best performer.

2.3. Potential Contributions

- Provide GBRS authorities and other green building decision-makers with more in-depth inputs on credit level than indicator level, and eventually encourage future GBRSs worldwide to be more architect- and design-friendly.
- Lay a theoretical foundation for future academic studies on sustainable AD and building environmental evaluation methods.
- Provide feasible comparison methods for other scholars to analyze GBRSs.

2.4. Research Framework

The structure of the paper is as follows. The methodology is described in Section 3 and includes the definition of ADR credits, criteria for GBRS selection, attributes and applications of comparative analysis, and calculation methods for significance evaluation. Section 4 first describes the major differences between the general information of the six GBRSs shown in Table 1. It provides a foundation for later systematic examinations and comparative analyses. Then, this section recognizes ADR credits, examines their mandatory requirement, credit distribution, and significance based on Appendix A, and gives suggestions during the preliminary comparison. In Section 5, recognized credits are recategorized to develop TEF and, as a fundamental exploration, the emphasis and inclusion degree of ADR credit systems are compared. Section 6.1 analyzes the possibility of ADR credits being replaced by calculating the minimum ADR ratio based on the identified scoring and grading methods as well as the obtained ratios from Section 4. Section 6.2 is an in-depth comparative discussion of the inclusiveness analysis from Section 5.2. In order to clarify the aspects that variables have, the attributes and meanings of variables are first analyzed from the perspective of AD. This analysis serves as a foundation for discussing the comprehensiveness and certainty of the ADR credit system. In this discussion, the deficiencies of six selected GBRSs may provide guidelines for their improvement as applied to AD. Finally, Section 7 summarizes the key findings and limitations.

Table 1. General information of six selected GBRSs. (Source: by the author).

	LEED V4.1	ASGB 2019	GM 2021	WELL V2	ASHB 2016	LBC V4.0
Category	Integrative Process (IP), Location and Transportation (LT), Sustainable Site (SS), Water Efficiency (WE), Energy and Atmosphere (EA), Materials and Resources (MR), Indoor Environmental Quality (EQ), Innovation (IN), Regional Priorities (RP)	Safety and Durability (SD), Health and Comfort (HC), Occupant Convenience (OC), Resources Saving (RS), Environment Livability (EL), Promotion and Innovation (PI)	Energy Efficiency (EE), Sustainability Sections (SS): Intelligence (IT), Health and Well-being (HW), Whole life Carbon (CN), Maintainability (MT) Resilience (RE)	Air, Water, Nourishment, Light, Movement, Thermal comfort, Sound, Materials, Mind, Community, Innovation	Air, Water, Comfort, Exercise, Humanity, Service, Promotion and Innovation	Place, Water, Energy, Health and Happiness (HH), Materials, Equity, Beauty.
Mandatory requirements	Prerequisites	Prerequisites Minimum points per category: 30%	Prerequisites Maximum points per category: 15	Prerequisites Minimum points per category: 1 for Silver, 2 for Gold, 3 for Platinum Maximum points per category: 12	Prerequisites	Core credits
Weighting factor	×	×	×	×	√	×
Bonus item	√	√	√	√	√	×
Total point/ Maximum possible point/ Number of credits	104 points (scoring items) + 6 points (bonus items)	40 points (prerequisites) + 60 points (scoring items) + 10 points (bonus items)	75 points (scoring items) + 8 points (bonus items)	100 points (scoring items) + 28 points (bonus items)	100 points (scoring items) + 10 points (bonus items)	51 items (core credits) + 34 items (advanced credits)

Table 1. *Cont.*

	LEED V4.1	ASGB 2019	GM 2021	WELL V2	ASHB 2016	LBC V4.0
Ranking grade	Certified (40 points) Silver (50 points) Gold (60 points) Platinum (80 points)	Basic (40 points for prerequisites) One-star (60 points) Two-star (70 points) Three-star (85 points)	GoldPLUS (EE > 50%, 30 points for SS) Platinum (EE > 55%, 40 points for SS) SLE (EE > 60%, Zero Energy)	Bronze (40 points) Silver (50 points) Gold (60 points) Platinum (80 points)	One-star (50 points) Two-star (60 points) Three-star (80 points)	Core (core credits) Petal (core credits, advanced credits of Water, Energy, and Materials) Living (all credits)

3. Methods

3.1. Architectural Design-Related (ADR) Credits

The AD in this study refers to the design work performed by architects throughout the early design stage (Figure 1). At this stage, the design that has not yet been fully integrated with technical details is simple to change and does not incur excessive costs. The architect's AD has a profound impact on the selection of principal technical solutions, the work of technical specialist consultants in various sub-disciplines in the later design stage, and the overall performance of the building.

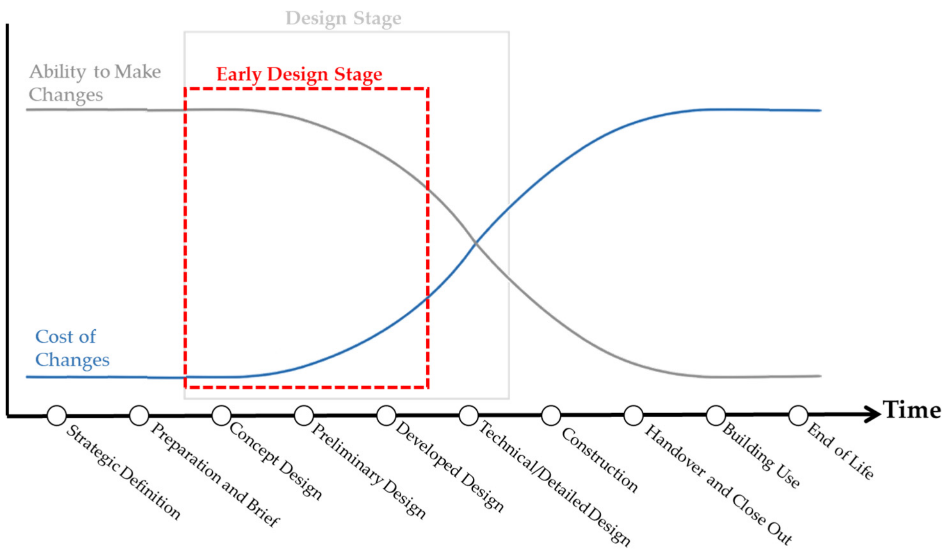

Figure 1. Cost versus design changes during a green building design process [22].

The GBRS follows a hierarchical structure, with a singular theme and a group of categories at the top, and subsequent levels of sub-categories and indicators beneath them. The theme is sometimes termed as "scope", "goal", or "coverage", and it can be considered as a broad area to achieve green, wellbeing, or regeneration. Categories, which have several indicators, can also be referred to as "criteria" or "issues". Categories are parameters used to assess the contribution of projects to the achievement of required objectives [23]. Each indicator has detailed requirements, known as terminal evaluation requirements, which are abbreviated as "credits" in this study. An AD credit is one that directly evaluates AD. A technical credit is one that evaluates the technical details of later design stages. There are also pre-design credits, construction credits, and management credits belonging to other stages of the GB design process. To comprehensively and systematically review ADR requirements in GBRSs, the study cannot only identify AD credits. Much of the AD-related (ADR) content is hidden behind other credits, due to the nature of GBRSs as an evaluation tool based on performance and terminal output after the technical design. Take WELL as an example, the technical credit "impact noise reduction" requires acoustic engineers to take technical measures to meet performance requirements. Requirements specify the location of the floor–ceiling assembly, which potentially inform architects to consider the acoustic impact of upper and lower spaces when organizing the space.

3.2. GBRS Selection

Many GBRSs for new buildings have been announced since the 1990s. The study employs three procedures—collection, screening, and selection—to choose representative GBRSs. The first step is to gather about 40 GBRSs based on literature reviews, which are then screened into 13 GBRSs while considering reliability, accessibility, timeliness, and comparability. Taking into account the concept, popularity, market, context, updated year, and other factors, six GBRSs are ultimately chosen (Table 2).

Table 2. Selected GBRSs of this study. (Source: by the author).

GBRS and Version	Type of GBRS	Effective Year of Version	Last Updated Year of Revision	References
Leadership in Energy and Environmental Design (LEED) V4.1	International GBRS Conventional "green" concept/theme	2013	2021	[24,25]
Assessment Standard for Green Building (ASGB) 2019	National GBRS Conventional "green" concept/theme	2019	2019	[26]
Green Mark (GM) 2021	Local GBRS Conventional "green" concept/theme	2021	2021	[27]
WELL Building Standard (WELL) V2	International GBRS Emerging "wellbeing" concept/theme	2020	2022	[28]
Assessment Standard for Healthy Building (ASHB) 2016	National GBRS Emerging "wellbeing" concept/theme	2017	2017	[29]
Living Building Challenge (LBC) V4.0	International GBRS Emerging "regenerative design" concept/theme	2019	2019	[30]

The Leadership in Energy and Environmental Design (LEED) has taken the lead in the GB market since its release by USGBC in 1998. With more than 160 countries and territories included, it has the widest spread area and the most certification projects worldwide. As it is an international tool, its credits are probably established with a great degree of flexibility for designers to appropriately address important design considerations. In other words, it may evaluate ADR credits differently than GBRSs that are customized and employed in local contexts. The latest version, LEED V4.1, was introduced in 2013 and has been modified many times up to 2021. "LEED V4.1 BD+C for New Construction" and "LEED V4.1 Residential for New Construction" are both selected. Singapore expects to achieve the goal of having at least 80% of its buildings be green by 2030. The green industry in Singapore is showing robust growth. The Green Mark (GM), which is based on a high-density and tropical climatic context, may differ from other GBRSs that sacrifice place-specific characteristics in order to be applicable to a large market. China is a developing country with the world's largest construction market. The Assessment Standard for Green Building (ASGB), developed by the Ministry of Housing and Urban-Rural Development (MOHURD), is the most popular GBRS in China. Its evaluation is based on a national context that sits in between the international context of LEED and the local context of GM; as a result, it could have both peculiarities and commonality.

The WELL Building Standard (WELL) and Assessment Standard for Healthy Building (ASHB) are derived from the emerging "wellbeing" concept. WELL is the first GBRS to address wellbeing into the built environment, while ASHB is the second to compete with

WELL in the Chinese construction market. WELL was released in 2014 and updated into the latest version in 2020. ASHB has not been updated since its promulgation in 2017.

The Living Building Challenge (LBC) was launched in 2006 and underwent six revisions before 2022. It is firstly a philosophy, secondly an advocacy tool, and thirdly a certification that sets out a simple and easy-to-use approach for evaluating any conceivable project of any scale, anywhere in the world. The reason it refers to itself as the living building rather than the GB is that its focus is on the human understanding of and relationship with life, in which a just society, rich culture, and restored ecology are all important. Its pursuit goes beyond the "green", reconciles the "sustainability" with "wellbeing", and calls itself "a visionary path to a regenerative future". Influenced by the concept "regeneration", it may have different views on AD. It features a hierarchical structure, specific indicators, and quantitative requirements, just as the previous five GBRSs.

3.3. Comparative Approach and Content Analysis

The comparative approach is a common method in GBRS evaluation. This method was used in almost all of the relevant studies cited in the previous section. It is a fundamental way to examine the complex patterns of differences and similarities among a range of cases [31,32], which goes beyond qualitative and quantitative strategies [33]. Research outcomes from Shen et al. [34] illustrated how the comparative basis contributed to knowledge sharing and effective communication between different research objects, guided future policy making, and improved future practices. Content analysis is another important method. It is defined as a social science research method for making "replicable and valid inferences from texts to the contexts of their use" [35]. It is employed to analyze emerging themes from the qualitative data collected from semi-structured interviews or documentation reviews [36,37]. It has two different uses: "semantic and structural analysis", where the relationship and meaning of qualitative data can be quantified and analyzed through counting and determining certain texts and concepts involved [15,38]. It has been a typical and common method for qualitative data analysis in environmental research [15,39–41]. Consequently, the comparative approach and content analysis are appropriate for this study in order to identify and compare the content of each GBRS's documentation, classify and summarize recognized credits, and explore meanings.

3.4. Significance Evaluation

Significance evaluations in this study are based on the relative significance index (RSI). Its calculation follows a bottom-up cumulative manner in all GBRSs but uses different equations because different evaluation objects have different attributes and mathematical models. For the LBC's credits and the remaining five GBRSs' prerequisites, the evaluation relies on the number of fit items rather than points. The RSI is calculated by Equation (1).

$$\text{RSI} = N_{ADR} / N_T \quad (1)$$

where N_{ADR} means the number of ADR credits in the corresponding category or GBRS; N_T means the total number of all credits in the corresponding category or GBRS.

For the scoring items of LEED, ASGB, GM, and WELL, weighting factors are not taken into account when accumulating the total points of both GBRS and category levels, so the RSI is calculated by Equation (2).

$$\text{RSI} = \sum P_i / P_T \quad (2)$$

where P_i means the maximum designated point of the ADR credit i in the corresponding category or GBRS; P_T means the total point or maximum possible point of the corresponding category or GBRS.

For the scoring items of the ASHB, specific weighting factors are set for each general category. Then, the total point of the GBRS level is the sum of the weighted point of general categories and the added point of an innovation category. Its RSI is calculated by Equation (3). The RSI for the category level is still calculated by the above Equation (2).

$$\text{RSI} = \sum(P_i * W_j + P_{Bi})/P_T \quad (3)$$

where P_i means the maximum designated point of the ADR credit i in the category j; W_j means the weighting factor of the corresponding weighted category j; P_{Bi} means the maximum designated point of the ADR bonus credit i in the innovation category; P_T means the total point or maximum possible point of the corresponding GBRS.

4. Overview and ADR Credit Identification of Six GBRSs

Table 1 summarizes the most important general information for six GBRS. As can be seen from this table, five main aspects deserve attention to facilitate and promote subsequent credit analyses. First of all, there are various categorizations of current GBRSs. It is different from the previous situation, where almost all categories were composed of energy, materials, water, indoor environmental quality, and innovation. This is a positive trend, indicating that current GBRSs are gradually moving away from the resource-based leading ideology that arose in the early GB movement as a result of the energy crisis, and toward considering more fields to improve building quality. However, such a diversified situation will also present users with difficulties in choosing. Moreover, the diversity of categorizations does not necessarily mean that the evaluation content is also diverse. Therefore, credit identification and self-categorization are required to ensure that comparison results are clear. Secondly, GM and WELL require that the point total for each category should not exceed the specific points, which indicates that the actual points for these categories might exceed the limit. Therefore, it is essential to replace all points with the maximum possible point and the cumulative total point in the credit identification of these two GBRSs. Thirdly, ASGB and WELL require the minimum point for each category. If their categories have high ADR ratios for scoring items, it is likely that some ADR credits will become mandatory. This needs to be further discussed. Fourthly, ASHB is the only GBRS to set different weighting factors for non-residential buildings (NRB) and residential buildings (RB). Therefore, it is necessary to strictly distinguish NRB and RB not only in the indicator system but also in the weight system in the identification and calculation processes. Fifthly, ASGB allocates 40 points to its prerequisites. This is a phenomenon not found in other GBRSs now or in the past. In essence, this setting is meaningless because the definition of "prerequisite" itself is that all specified requirements must be met. In other words, 40 points must be obtained, and there is no case of obtaining 0 to 39 points. It should be noted that the points corresponding to each ranking grade in ASGB include 40 points, so 40 points should be deducted when analyzing scoring items in relevant discussions.

Appendix A shows the breakdown of ADR credits, non-ADR credits, and ADR ratios. The ADR ratio shown in bar charts equals the value of ADR credits divided by the value of all credits shown in the corresponding radar charts, except for the scoring items of GM and WELL, whose denominator used for the calculation is the maximum possible points instead of all points.

It can be seen from the graph for prerequisites or core credits that GM only sets prerequisites for energy, and LEED does not set prerequisites for the Integrative Process (IP) or Location and Transportation (LT). Strictly speaking, they should set prerequisites in each general category, just like the other four GBRSs, to ensure that the final building performance covers all aspects. Among categories where prerequisites are set, some are completely independent of AD, such as LEED's Sustainable Site (SS), LBC's Energy, etc. There are two main reasons for this situation. One is that the field corresponding to such a category is indeed irrelevant to AD, and the other is that the GBRS itself does not consider the importance of AD in such a category. If it is the latter, the corresponding GBRS needs to remedy these defects, which requires further credit analyses.

As can be seen from all radar charts, the distribution of prerequisites or points presents two main shapes: the full and the sharp. The maximum possible points specified by GM and WELL for general categories are limited to the same point, so their evaluations in all aspects are equally important. Their difference lies in the importance they attach to non-general categories. WELL pays about twice as much attention to innovation as the maximum possible point in general categories, while GM pays about half as much attention to innovation as the maximum possible point of general categories. All prerequisites and all points of LEED, all prerequisites of WELL, all prerequisites of ASHB, and all points of LBC show sharper shapes, that is, are lacking in balance. The shapes of all prerequisites and all points of ASGB, all points of ASHB, and all prerequisites of LBC are slightly sharp on a full basis. In other words, their evaluations not only consider the balance in all aspects but also emphasize individual aspects, which is worth learning from other GBRSs.

The amount of ADR contents cannot be determined solely by the value of ADR credits in radar charts, because this value is heavily influenced by the value of all credits. Therefore, it is necessary to conduct comparative analyses based on their ratios, i.e., ADR ratios shown in bar graphs. The ADR ratio is theoretically between 0% and 100%. The ratio of the Health and Wellbeing (HW) in GM is as high as 120% because the existence of cumulative total points allows ADR points to exceed the prescribed maximum possible point. The ratio comparison between NRB and RB is only done in the LEED's prerequisites and scoring items, as well as the ASHB's scoring items. The ratio difference between NRB and RB in most categories is very small. Only a few categories of LEED have large differences, because RB has more than twice as many prerequisites unrelated to AD as NRB, and RB's "daytime and quality views" are three points less than NRB's. In addition, although the cumulative total points of GM are divided into NRB and RB, the final ADR ratios are not different between NRB and RB. The reason is that all identified ADR credits are applicable to both NRB and RB. In summary, there is little difference between NRB and RB in the evaluation of current prevailing GBRSs for new buildings.

For the ratio comparison among various categories, it can be seen from the bar charts that ASGB's ratios for the general categories except Environment Livability (EL) are relatively similar, ranging from 30% to 50%. At the other extreme, the ratios of GM and ASHB in general categories are at an extreme state. Some categories have very high ratios, while the remaining categories have very low ratios. The extreme case of GM is particularly significant. Both situations have advantages and disadvantages. The former indicates that architects can make contributions in every category, but the architect's work may be integrated with the work in other fields in one category. This situation faces the risk that the responsibility of architects cannot be well differentiated. The latter shows that the work of architects is concentrated in several categories, which helps architects identify ADR evaluation contents, thus facilitating their use of GBRSs. However, it is not conducive to integration with other non-AD evaluation contents. Last but not least, ASGB and WELL set minimum point requirements, so the high ratios of their scoring items, including ASGB's EL (95%) and WELL's Movement (100%), need to be recorded to facilitate subsequent discussions.

5. Theoretical Evaluation Framework (TEF) Establishment and Corresponding Status in GBRSs

During the credit identification process, the differences and similarities among ADR credits from six GBRSs are studied using a comparative approach and content analysis. The TEF, which is depicted on the left side of Appendix B, is created by recategorizing all recognized ADR credits into 88 variables, 15 categories, and 5 sections. In order to make the framework as complete as possible, RB versions of LEED and ASHB with more credits are chosen as the basis for this study. On the right side of Appendix B, the allocation of prerequisites and points in GBRSs corresponds to TEF's variables one-by-one. In TEF, the number of individual variables (30) is nearly twice that of universal variables (16), indicating that the peculiarity of the ADR credit systems of six GBRSs is far greater than their commonality. ASGB has the most individual variables (8), followed by ASHB (7), LBC (6), WELL (4), GM (3), and LEED (2). The ratios calculated in the last row of each section are shown in Figures 2–4.

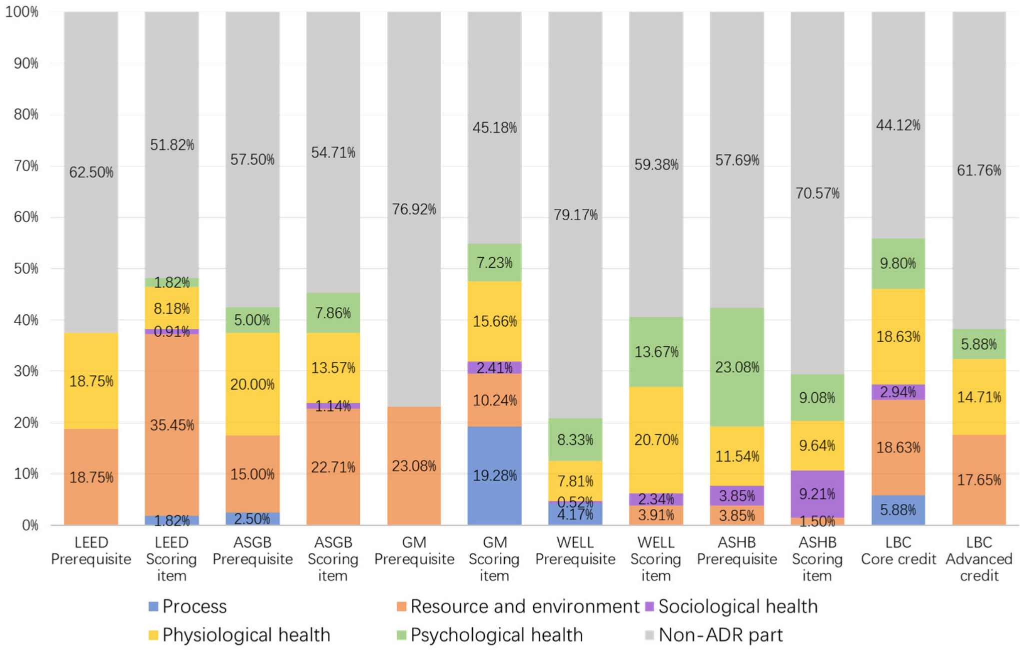

Figure 2. RSI comparison of TEF's five sections in prerequisites and scoring items of six GBRSs. (Source: by the author).

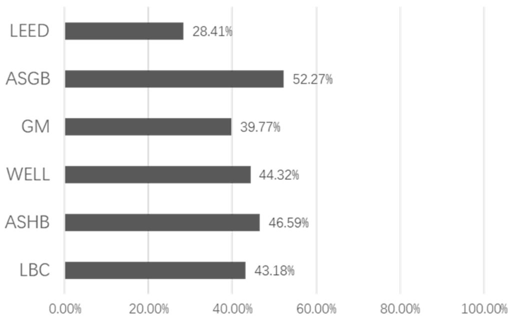

Figure 3. Inclusion degree of six GBRSs. (Source: by the author).

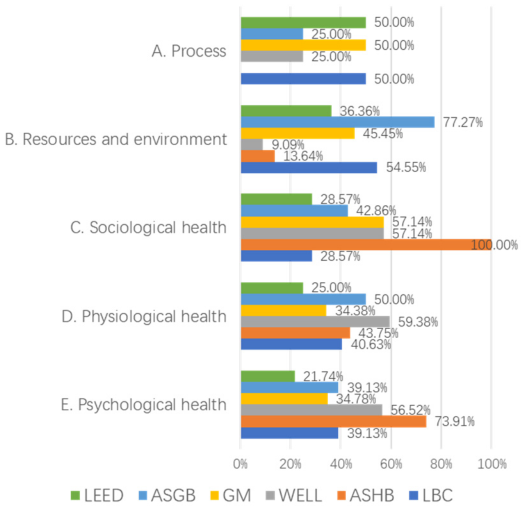

Figure 4. Breakdown of inclusion degree in five sections. (Source: by the author).

5.1. Focus of ADR Credit Systems

As shown in Figure 2, LEED, ASGB, and LBC all focus on “resource and environment” and “physiological health”. The difference between them is that LEED inclines toward the former, LBC inclines slightly toward the former, and ASGB inclines toward the latter. The reason why ASGB is judged to be biased toward “physiological health” is that the RSI advantage of prerequisites is more certain than that of scoring items. In GM, ADR prerequisites draw all the attention to “resource and environment”. Its scoring items focus most on “process”, followed by “physiological health”, and then “resource and environment”. Therefore, GM has three foci, two of which are the same as the aforesaid three GBRSs. Both WELL and ASHB place a strong emphasis on “physiological health” and “psychological health”, but WELL inclines toward the former while ASHB inclines toward the latter.

5.2. Inclusion Degree of ADR Credit Systems

Figure 3 shows that ASGB has the highest inclusion degree, while at the other extreme, LEED has the lowest one. Figure 4 shows the breakdown of inclusion degree in each section. From the perspective of “process”, LEED, GM, and LBC include half of the variables, while ASHB neglects all variables. From the perspective of “resource and environment”, the inclusion degree of ASGB is the highest, followed by LBC, GM, and LEED. The inclusion degree of WELL and ASHB is undoubtedly the lowest, given that this section is environment-oriented rather than human-oriented. From the perspective of “sociological health”, ASHB fulfills all variables. From the perspective of “physiological health”, WELL fulfills more than half the variables, followed by ASGB, ASHB, LBC, GM, and finally LEED. From the perspective of “psychological health”, ASHB covers the most variables, followed by WELL. ASGB, LBC, and GM have similar inclusion degrees. LEED’s inclusion degree is still the lowest.

6. Discussion

6.1. Certainty and Replaceability of ADR Credits

LBC is structured from a qualitative perspective under the influence of the nature of integrative thinking. To emphasize a systematic thinking of the synergy between various elements in a holistic living system, all credits are mandatory. The remaining five GBRSs, in contrast, construct hierarchal evaluation systems from a quantitative perspective under the influence of the nature of technical and mechanical thinking. The core of a quantitative evaluation system is a mathematical model. It synthesizes or scales all evaluation values of credits into a dimensionless evaluation result that reflects holistic performance. These five GBRSs’ mathematical models adopt a weighted sum approach. They directly add each category’s point to get the total points of evaluated projects, from which a ranking grade is determined. The weighted sum model has a simple structure and obvious evaluation results, making it simple to understand and popular in marketing. However, this model may have a significant compensation phenomenon. This phenomenon specifically refers to the fact that the credit with higher points compensates for the credit with lower points, resulting in the total point concealing the evaluation’s weakness. To sum up, the weighted sum model is not conducive to a uniform enhancement in the holistic building performance. It also enables the substitution of non-ADR credits for ADR credits. In order to control the holistic building performance, GBRSs using this mathematical model typically set additional minimum point requirements for each category and extract important credits as prerequisites. Prerequisites are certain and irrevocable, in contrast to optional and replaceable scoring items. In other words, the ADR ratios for prerequisites in Figure A7 are definitive, whereas the ADR ratios for scoring items may be lower due to the nature of the compensation. It is therefore worth exploring the possibility of ADR scoring items being replaced and calculating the minimum ADR ratios of five GBRSs.

Every GBRS has a number of ranking grades and corresponding baselines. To facilitate the discussion with ADR ratios, these baselines are converted into ratios based on the total or maximum possible point of GBRSs. As previously mentioned, the conversion does not include the ASGB ranking grade "Basic" and its 40 points. In Figure 5, calculated minimum ADR ratios are displayed. The possibility that ADR scoring items would be compensated for and replaced increases as the size of the red square decreases. The baseline columns of LEED's "Certified", as well as all non-highest-ranking grades of the remaining GBRSs, do not overlap their corresponding ADR columns. It indicates that ADR scoring items among them are at high risk of being completely replaced. For the highest-ranking grades, LEED has the highest minimum ADR ratio (32.73% for NRB, 29.09% for RB), followed by ASGB (15.29%), WELL (7.03%), GM (4.21%), and ASHB (0.38% for NRB, 2.16% for RB). In addition to the ranking grade's baselines, the minimum point requirement for each category may affect the result of the final minimum ADR ratios. In ASGB, each general category must receive at least 30% of its points, and EL has a high ADR ratio of 95%, implying that 25% of the EL's points will certainly be obtained. The 25% in EL is equivalent to 3.57% in ASGB. WELL also stipulates the minimum point for each category and has a high ratio, 100%, in the category "Movement". The same algorithm as ASGB can be used to calculate its minimum ADR ratios. The minimum point requirement for each category, together with the high ADR ratio at the category level, can reduce the risk of replacements marginally. Eventually, the final minimum ADR ratios of various ranking grades are displayed in Table 3.

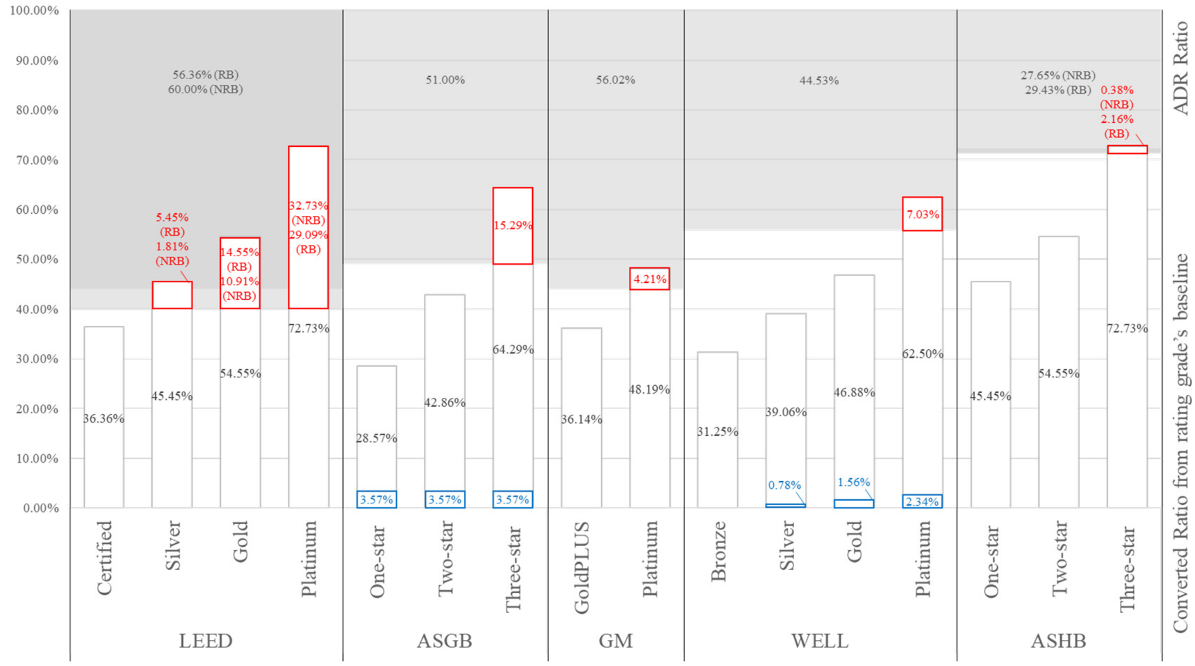

Figure 5. Calculation of minimum ADR ratios by ranking grade's baselines and minimum point requirements for each category. (Source: by the author). Baseline column: the bottom-up white column that shows the ratio converted from a ranking grade's baseline; ADR column: the top-down gray column that shows the ADR ratio of scoring items in Figure A7; Minimum ADR ratio: the red square where the baseline column and ADR column overlap, and the blue square which shows the ratio calculated from both the minimum point requirement for each category and ADR ratio of category.

According to both certainty and significance, LBC performs best, which can be attributed to its distinctive mechanism brought about by its advocacy of design integrity. LEED NRB performs well among the GBRSs with scoring items, with all of its ratios being the highest. However, it has the disadvantage that ADR scoring items in the lowest ranking grade are at risk of being completely replaced. The ratios of LEED RB are all lower than LEED NRB's, and two of them are lower than ASGB's. Even if the majority of ASGB's ratios are lower than LEED's ratios, ASGB has an advantage over other GBRSs in that it prevents the possibility of complete replacement at any ranking grade. Although ASHB has the lowest minimum ADR ratios, its prerequisite's ratio is twice as high as that of GM and WELL. Hence, ASHB lags behind LEED and ASGB. While WELL's ratios for scoring items are 0.78–2.82% higher than those of GM, GM's ratio for prerequisites is 2.25% higher than WELL's. GM's performance is nearly equivalent to WELL's. In short, from highest to lowest, the relevance order of these GBRSs to AD at the actual evaluation is: LBC, LEED and ASGB, ASHB, and GM and WELL.

Table 3. ADR ratios and minimum ADR ratios in GBRSs. (Source: by the author).

		LEED NRB	LEED RB	ASGB	GM	WELL	ASHB NRB	ASHB RB	LBC
ADR ratio of prerequisite/ core credit		45.45%	37.50%	42.50%	23.08%	20.83%	42.31%	42.31%	55.88%
ADR ratio of scoring item/ advanced credit		60.00%	56.36%	51.00%	56.02%	44.53%	27.65%	29.43%	-
Minimum ADR ratios of scoring item/ advanced credit	Lowest ranking grade ↓ Highest ranking grade	0%	0%	-	-	0%	-	-	-
		5.45%	1.81%	3.57%	-	0.78%	0%	0%	-
		14.55%	10.91%	3.57%	0%	1.56%	0%	0%	30.43%
		32.73%	29.09%	15.29%	4.21%	7.03%	2.16%	0.38%	38.24%

6.2. Discussion on TEF's Five Sections

6.2.1. Process

The "process" includes all phases other than the design phase that affect AD and are affected by AD. "Pre-design preparation" and "maintenance" are two recognized phases, as shown in Appendix B. They encourage architects to play an active role with other designers earlier in the process of creating both beautiful and green environments, as well as optimize the life-cycle performance of assets in AD with the goal of safe and resource-efficient maintenance. Architects are given the opportunity to take on the role of leaders rather than just form-givers in a broader team collaboration. Compared to evaluations for LEED, ASGB, WELL, and LBC, which concentrate on just one phase, GM's evaluation of both phases is more comprehensive. GM has no prerequisites, whereas ASGB, WELL, and LBC require all evaluations to be mandatory. The evaluation of this section is ignored by ASHB.

6.2.2. Resource and Environment

Resources includes "energy", "materials", "land", and "water". The "ecology" is combined with the "water" because the ADR requirements for the "water" are related to the landscape design targeted at the "ecology", such as drought-tolerant plant selection, waterscape design for stormwater treatment, and so on. As the core part of conventional GBRSs, there is little doubt that this section is environment-oriented. The following discussion focuses on four environment-oriented GBRSs.

The "energy" variables are classified as technical type (No. 5, 6, 10, 11) and design type (No. 7–9). In design variables, the "natural ventilation design" evaluated by GM is one of many passive design means mentioned in ASGB's "energy saving design". GM requires that common areas be naturally ventilated, which can also be found in ASGB's "zoning temperature setting". In short, ASGB's evaluation scope for design includes that of GM. This inclusion could be attributed to the different in contexts between Singapore and China. Singapore is located in the tropics and near the equator, where an evaluation scope can be refined to the natural ventilation, while China has so many climatic zones that its evaluation scope must be broadened to allow architects to design flexibly according to the climate. ASGB and GM consider both technology and design. GM has prerequisites for both types, while ASGB only sets prerequisites for the design type. LEED and LBC pay their attention to technical variables, with LBC designating all credits as scoring items. Technical variables are affected by the special shape and façade outcome of buildings, and affect the beauty of the building as well as the site. They present design challenges for architects to understand a sufficient amount of knowledge in order to achieve effective collaboration with other professionals in the creation of a green and beautiful environment. However, in fact, the project might meet requirements without considering designs and aesthetics because technology itself serves as the evaluation object for these technical variables. In this case, the architect's role is at a great disadvantage. In order to escape this disadvantageous situation, setting design variables is necessary for LEED and LBC to reflect the architect's contributions to reduce the load for active technologies through the priority utilization of passive design strategies such as the layout of the building groups, building shapes, orientation, form and dimension, opening position, and typology.

In "materials", all environment-oriented GBRSs include the variables "building and material reuse" and "collection of recyclable item or waste". ASGB and LBC have the individual credits "local material" and "avoidance of decorative member" respectively to ensure that architects respect local materials and strive to beautify the appearance of buildings without wasting materials. Except for GM, all GBRSs set prerequisites wherever possible. Zhang et al. [42] said that rapid economic and population growth, as well as a change in consumption patterns in high-density Singapore, led to a continued increase in waste production in recent years. Singapore will have a much higher volume of recycled waste than other countries and regions, which is a valuable resource. Hence, GM should raise the evaluation of recyclables from scoring items to prerequisites.

There are two ways to achieve "land" savings, one is to establish a close supply–demand relationship between the infrastructures of a project and its neighborhood, and the other is to design for an efficient use of the land and space within projects. For the former, the common AD thinking first targets the uptake of existing surrounding infrastructures as much as possible (No. 17), and then builds infrastructures for the project itself that cannot be provided by the neighborhood (No. 18). However, ASGB is the only GBRS evaluating this design as a whole, while the remaining GBRSs evaluate this design process separately. Such a split situation has a high probability of leading to a one-sided evaluation, as shown in Appendix B, where LEED and LBC consider only one variable, which is not conducive to the building of harmonious communities and cannot result in a truly efficient land use. GM does not consider both variables because, as Sim et al. [43] said, Singapore has a comprehensively coordinated land transport policy integrating land use, transportation planning, and demand management measures. For the latter, ASGB considers all variables, followed by LBC, and then GM. LEED, as an international GBRS, is bound to evaluate projects in Asian cities, especially in China, where there is the largest green market and many high-density cities. It is essential for LEED to add an evaluation of efficient project land use, thus promoting local architects to explore more design strategies of stacked structures and vertical spaces. Judging from the certainty, only LBC makes all of its evaluations mandatory.

In the category "water and ecology", "ecology protection and restoration" is popularized in four GBRSs and set as the prerequisite by LBC. LEED and LBC pay attention to waterscape-design-related variables (No. 25, 26), while GM pays attention to landscape-design-related variables (No. 23, 24). Water can contribute to the environment through its physical and even aesthetic qualities, as well as express symbolic meanings that other natural elements cannot [44]. Therefore, evaluations should combine the waterscape design with the landscape design. ASGB considers the certainty of both waterscape design and landscape design but omits the certainty of "ecology protection and restoration".

Overall, ASGB has the most comprehensive set of variables, followed by GM, LBC, and LEED. LBC mandatory requirements cover the most included aspects, followed by LEED, ASGB, and finally GM. ASGB obviously gives a higher degree of certainty to design-related variables such as passive design, waterscape design, and landscape design. Additionally, GM's mandatory requirements exclusively favor the "energy" category.

6.2.3. Sociological Health

The AD for "sociological health" mainly refers to the environment construction of buildings, infrastructures, or spaces where people visit, stay, gather, and interact. The greater the variety of environments, the more choices people have. ASHB covers all variables. The remaining GBRSs have a clear tendency. For example, GM and WELL emphasize public spaces; LEED emphasizes outdoor public spaces; and ASGB and LBC respectively emphasize recreational spaced and social spaces. These five GBRSs should cover more types of spaces or infrastructures to encourage architects to design different social environments, ultimately giving occupants more choices. For the certainty, LBC's requirements are all mandatory, although it considers fewer aspects. WELL and ASHB set prerequisites only for recreational spaces. All the variables included in the three conventional GBRSs are scoring items.

6.2.4. Physiological Health

"Transportation and movement" is often considered in conjunction with "land" in AD to create an efficient and pedestrian-friendly project, thereby supporting a human-powered lifestyle and reducing the use of fossil fuel-based vehicles. Its variables can be further summarized into the following aspects:

- Controlling the walking distance between project entrances and the public transit or pedestrian-friendly street (No. 37, 38).
- Adjusting the number of bicycle parking spaces and fossil fuel-based vehicle parking spaces (No. 35, 36).
- Ensuring pedestrian safety on and around the site via vehicle–pedestrian separated design and safe interface design between buildings and pedestrian walkways (No. 34, 41).
- Designing staircases and signage that are aesthetically pleasing and user-friendly purposes (No. 39, 40).
- Designing for particular persons or situations (No. 42, 43).

The first two belong to green transportation outside sites, and the latter three belong to healthy movement inside sites or buildings. In terms of comprehensiveness, ASGB involves all aspects. GM, WELL, ASHB, and LBC take four aspects into account. The first aspect is not considered by GM because of the successful local land transport policy. LEED only considers the first two aspects, assessing the off-site transport while ignoring onsite movement. When it comes to certainty, ASGB, WELL, and LBC all impose four aspects, while ASHB only has one: "barrier-free and universal design".

The category "wind and thermal comfort" has the most variables. They are divided into three types: specific design variables (No. 44–46, 49, 51–53, 56, 57), general design variables (No. 48, 54), and performance variables (No. 47, 50, 54, 55). The specific design variable, as its name implies, mandates which passive design strategy a project must adopt to meet the criteria, whereas the general design variable has a wider evaluation scope, encompassing all passive design strategies with the intent of meeting criteria. The performance variable allows evaluation objects to meet the performance value in whatever way they choose. Such a way can be either passive or mechanically active. The performance evaluation of GBRSs mostly relies on simulation results that provide scientific support for the optimization of architects' passive design. As mentioned in the study [6], it is only by going back and forth between design and simulation that great designs can be produced. Both design variables and performance variables are indispensable for AD. There are four evaluation objects for these variables: outdoor wind comfort, outdoor thermal comfort, indoor wind comfort, and indoor thermal comfort. For performance variables, ASGB evaluates all objects. GM and WELL ignore one outdoor object. LEED, ASHB, and LBC ignore all outdoor objects. Outdoor comfort not only affects indoor comfort but also improves human willingness to walk and the quality of outdoor public spaces. It is decisive in creating a high quality of "sociological health" outdoors, "transportation and movement" on the site, and "wind and thermal comfort" indoors, illustrating the importance of an outdoor comfort standardization. Therefore, all GBRSs except ASGB need to strengthen the performance evaluation of outdoor comfort. For design variables, ASGB and WELL cover all objects. LEED, GM, and LBC do not include indoor thermal comfort. ASHB only takes outdoor wind comfort into consideration. Theoretically, there should be four general design variables, but the status quo is that all GBRSs lack the general design variable for outdoor wind comfort and indoor thermal comfort, and only WELL considers the general design variable for outdoor thermal comfort. The building environmental evaluation method should place a high priority on the general design variable because it has such a broad evaluation scope, reflects the work of architects, and provides architects with design flexibility that specific design variables cannot. In summary, practically every GBRS perform poorly in this category for the comprehensiveness. LBC is the only one of the six GBRSs that has mandatory requirements for all included aspects. Mandatory requirements of LEED, ASGB, WELL, and ASHB have a particular tendency.

The category "human basic necessities" includes designs that support human daily life and various routine activities. Most of its variables are evaluated by two GBRSs using the wellbeing concept. LBC and GM consider two variables, illustrating that they start to push the evaluation boundary to a wellbeing direction. This category is especially important during an emergency such as the epidemic. "Urban agriculture", in particular, is increasingly recognized as an important sustainable pathway that not only enhances food production and urban food resilience but also improves sociological health through gardening and farming, and restores the ecology through integration with landscape designs [45]. Hence, it is recommended that LEED and ASGB learn from human-oriented GBRSs to break through the green boundary. In addition, all GBRSs have no mandatory requirements.

To sum up, all GBRSs perform poorly in terms of comprehensiveness and certainty in "physiological health". WELL's comprehensiveness is the highest, followed by ASHB, ASGB, then GM and LBC, and finally LEED. LEED and ASGB neglect the evaluation of "human basic necessities". Their mandatory requirements are not set for all included aspects, except for LBC's assessment of "wind and thermal comfort".

6.2.5. Psychological Health

"Psychological health" can also be called "mental health". According to the research [46,47], various types of nature experiences such as sound, daylight, and views were associated with psychological health. Art has long been a healing strategy to enhance mental health in a therapeutic field where the terms "art therapy" and "cultural intervention" were coined [48]. This section is most closely related to architectural aesthetics. There is a new type of design variable called an aesthetic design variable.

"Sound" is a branch of building physics. Its evaluation is ignored by LBC. ASHB has the most design variables, which even include the aesthetic design variable (No. 74). Among the rest of the GBRSs, the evaluation mainly focuses on indoor performance variables (No. 69–71). As discussed in "energy" and "wind and thermal comfort", design variables, especially general design variables, are more conducive to supporting AD. GM and WELL, which evaluate indoor general design (No. 68, 72), outperform ASGB, which evaluates outdoor performance. For certainty, ASGB and ASHB mandate performance variables, while WELL mandates general design variables.

In addition to heat and sound, light is the third branch of building physical environments. Utilizing daylight to its fullest can help cut back on artificial lighting use and energy usage. The difference between the "daylight" and the "wind and thermal comfort" is that its performance requirements of "daylight" are primarily achieved by a passive design. This means that the work of architects is necessary in this category. Five variables are targeted in turn at outdoor performance, outdoor specific design, indoor specific design, indoor general design, and indoor performance. ASGB is the most comprehensive, followed by ASHB, WELL, LBC, GM, and eventually LEED. LBC's mandatory requirements cover all included aspects. ASGB, WELL, and ASHB mandatory requirements have a tendency.

With the rise of wellbeing and biophilic trends, daylight and nature are valued together as stimuli from the natural world that resonate with human perceptions, which can be briefly called the "nature experience". Indeed, architecture has used them as matters when constructing spaces and buildings to shape various feelings before the mainstream green. There are many representative cases, including the Church of Light by Tadao Ando, Philip Johnson's Crystal Cathedral in California, Fallingwater by Frank Lloyd Wright, etc. ASGB neglects this category. LEED considers the "view to outside or greenery". GM, WELL, and ASHB consider the variables related to environmental features and natural elements (No. 80–83). LBC is the only GBRS whose evaluation scope breaks through environmental features and natural elements to a higher level on spatial perception and nature's pattern (No. 84, 85). Three emerging GBRSs set prerequisites for this category, but none of them covers all included aspects. LBC is a trendsetter in this area, directing other GBRSs to push the evaluation boundary of the tangible entity into the realm of perceptible invisibility, and its mandatory requirements cover the widest range.

AD is a creative work during which the imagination, as the main source in the act of creation, does not have any limits. Hence, ADR evaluation is not limited to the above categories. The "other architectural design strategy" includes the evaluation closely related to the design and artistic ability of architects, such as AD styles, aesthetic emotions, the level of privacy, etc. Both WELL and ASHB recognize that comfortable spaces need to be designed not only for the physical environment and natural experience but also for colors, textures, forms, furniture arrangement, visual privacy, and others that accommodate user preferences and the intended uses of the space (No. 86, 87). ASGB, WELL, and LBC are conscious of other vital aesthetic elements in addition to natural elements, including subtle weather variations, local culture, the spirit or sense of a place, and the arts (No. 88). Emerging GBRSs provides the certainty for evaluation, but only one variable is set as a prerequisite.

This category is remarkably similar to the previous one. WELL and ASHB are the most comprehensive, followed by ASGB, GM and LBC, and finally LEED. Their mandatory requirements do not cover all included aspects, except for LBC's "daylight". ASGB neglects "nature experience". LEED and GM neglect "other architectural design strategy".

6.2.6. Summary

From the above discussion and Section 5.2, it can be found that GM and ASHB have the highest degree of inclusiveness and comprehensiveness in "process" and "sociological health", respectively, while other GBRSs are lacking in comprehensiveness no matter how many variables they contain. In "resource and environment", ASGB contains the most variables and covers all aspects. In the second-tier GBRSs, GM fulfills fewer variables than LBC, but it is more comprehensive than LBC. In the category of "physiological health", WELL achieves the highest level of inclusiveness and comprehensiveness, followed by ASGB and ASHB, and then LBC and GM. In "psychological health", ASHB and WELL are part of the first-tier GBRS, which is the most inclusive and comprehensive. ASGB, LBC, and GM are the second-tier GBRSs. In these three sections, LEED is ranked last. In addition, taking into account whether included aspects have mandatory requirements, LBC performs significantly better than other five GBRSs.

7. Conclusions

Architectural design (AD) plays an important role in building construction. It is worth exploring whether prevailing green building rating systems (GBRSs) can effectively embody and support AD. This paper scrutinizes the effectiveness of six GBRSs as applied to AD and establishes a theoretical evaluation framework (TEF) including 5 sections, 15 categories, and 88 variables. The main conclusions that can be drawn from the study are:

- In terms of the significance and certainty of the GBRS's weight system, LBC gives the highest and certain weight to AD, followed by LEED and ASGB, then ASHB, and finally GM and WELL. (See Table 3 for details.)
- The GBRSs from "green" and "regeneration" concepts focus more on "resource and environment" and "physiological health", with GM additionally emphasizing "pro-

cess". The GBRSs from a "wellbeing" concept focus more on "physiological health" and "psychological health". (See Figure 2 for details.)

- In terms of the inclusiveness and comprehensiveness of the GBRS's credit system, GM, ASGB, and WELL perform best in "process", "resource and environment", and "physiological health", respectively. ASHB performs best in both "sociological health" and "psychological health". At the other extreme, LEED is the least inclusive and comprehensive in "resource and environment", "physiological health", and "psychological health", and not comprehensive in "process" and "sociological health". (See Sections 5.2 and 6.2 for details.)
- LBC performs significantly better than the other five GBRSs when taking into account whether the included aspects have any mandatory requirements. (See Section 6.2 for details.)

This study may deepen architects' understandings of the ADR weight and credit systems of prevailing GBRSs, provide guidelines for the quality improvement of six selected GBRSs, and provide useful references for architects' design strategic ideas related to GB and the policy making on other GBRSs related to AD. Moreover, the methodology of this study can be applied to scrutinize GBRSs from other perspectives. This systematic and comparative study lays a theoretical foundation for further research on sustainable AD and relevant building environmental evaluation methods in academia. Although this study selects six representative GBRSs from the concepts of green, wellbeing, and regeneration, there are diverse GBRSs and even other emerging concepts worldwide. Therefore, future studies should scrutinize other GBRSs and explore more ADR credits, which would improve the TEF, especially for architect-friendly variables, thus promoting more effective AD in the early stages of the GB design process.

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Appendix A. ADR Credits, Non-ADR Credits, and ADR Ratios in Six Selected GBRSs

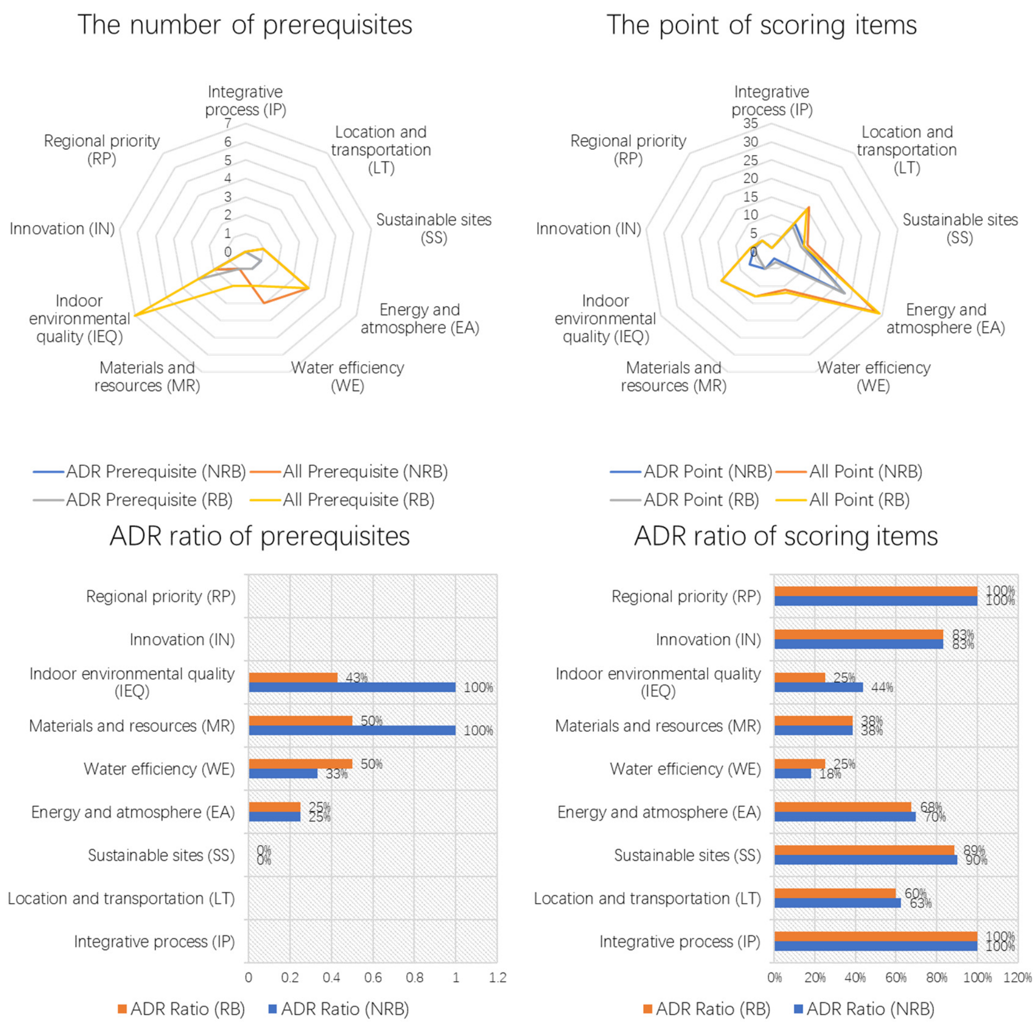

Figure A1. Breakdown of the number of prerequisites, the point of scoring items, and ADR ratios in diverse categories of LEED. (Source: by the author).

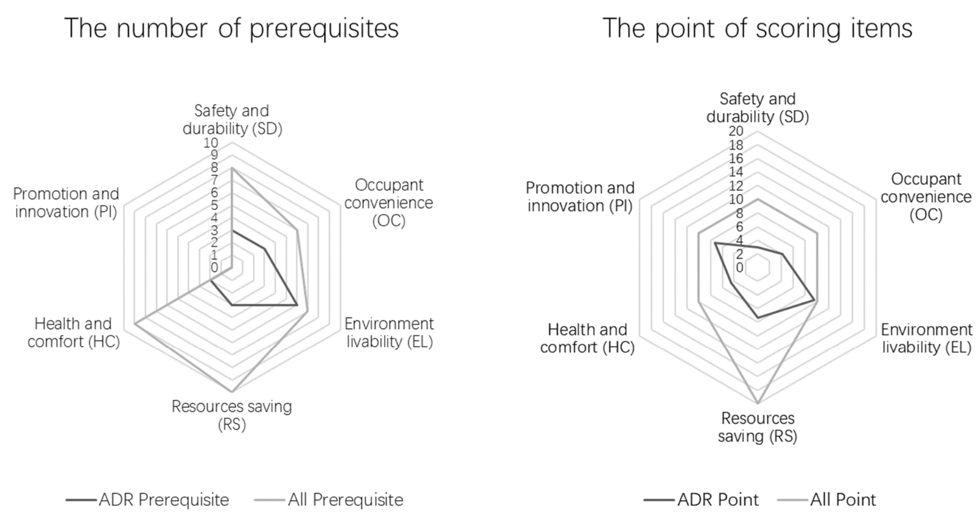

Figure A2. *Cont*.

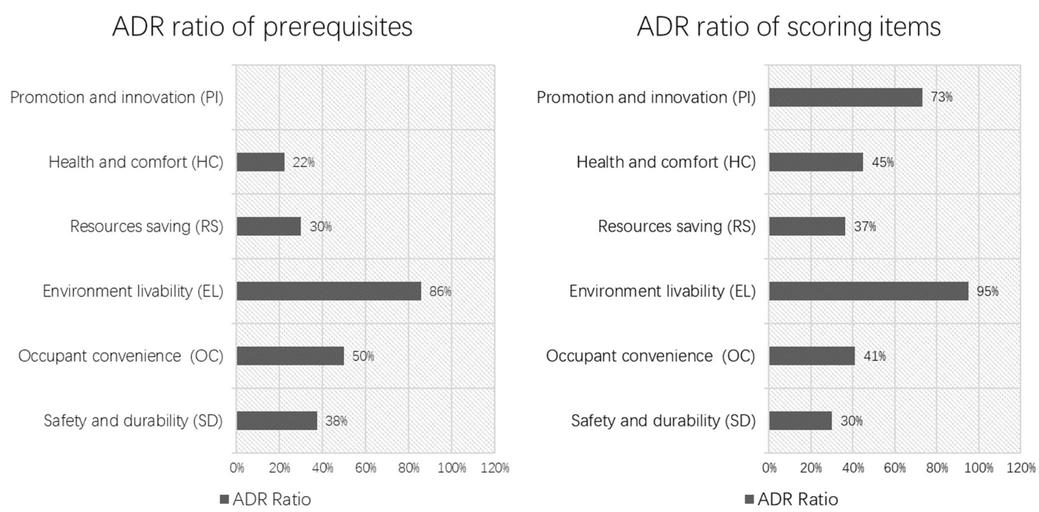

Figure A2. Breakdown of the number of prerequisites, the point of scoring items, and ADR ratios in diverse categories of ASGB. (Source: by the author).

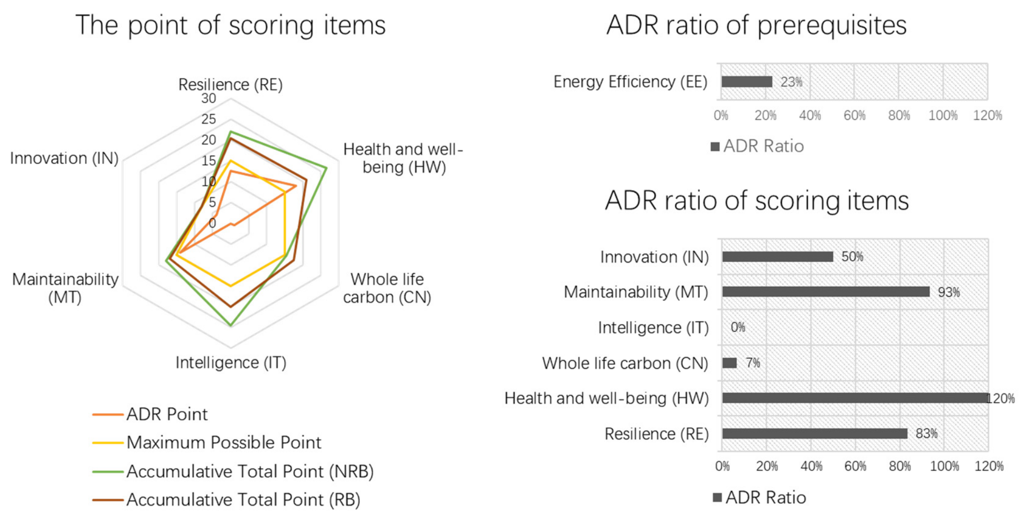

Figure A3. Breakdown of the number of prerequisites, the point of scoring items, and ADR ratios in diverse categories of GM. (Source: by the author).

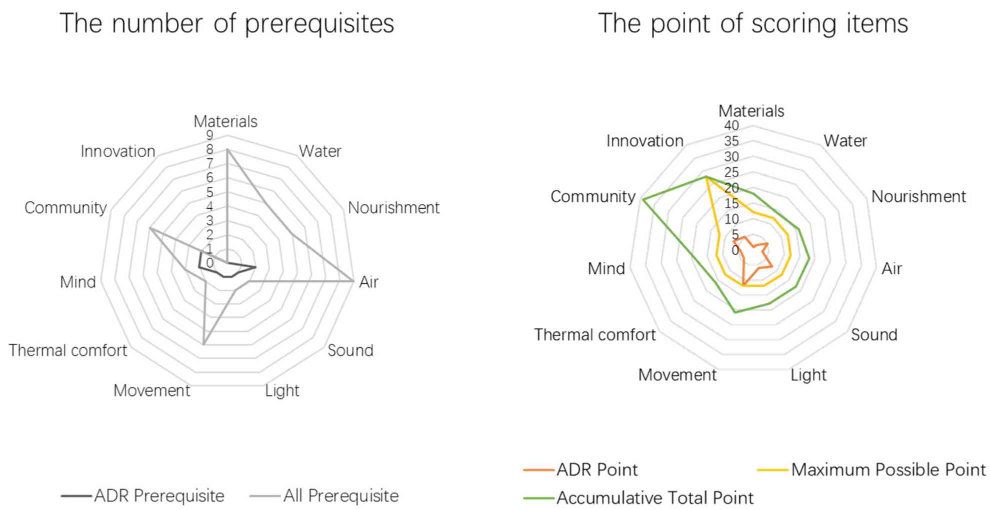

Figure A4. *Cont.*

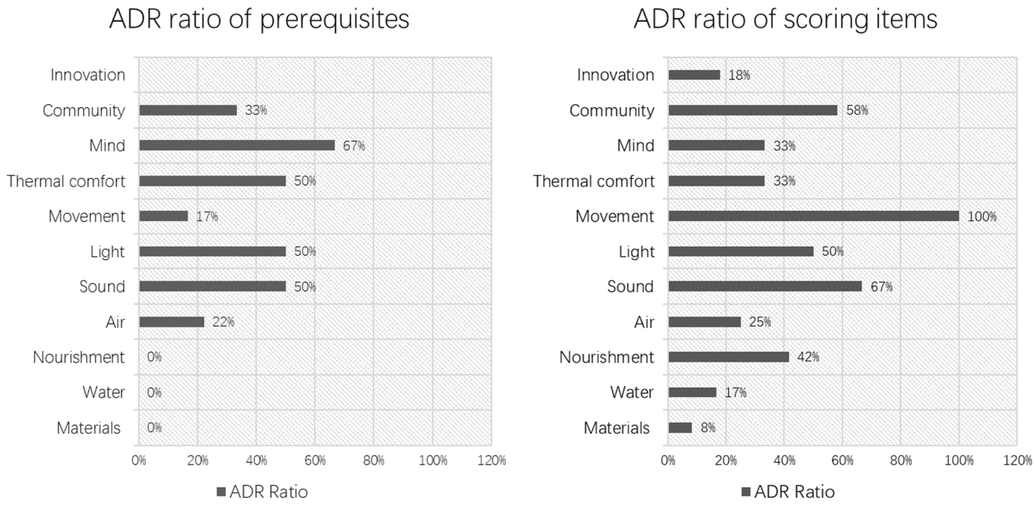

Figure A4. Breakdown of the number of prerequisites, the point of scoring items, and ADR ratios in diverse categories of WELL. (Source: by the author).

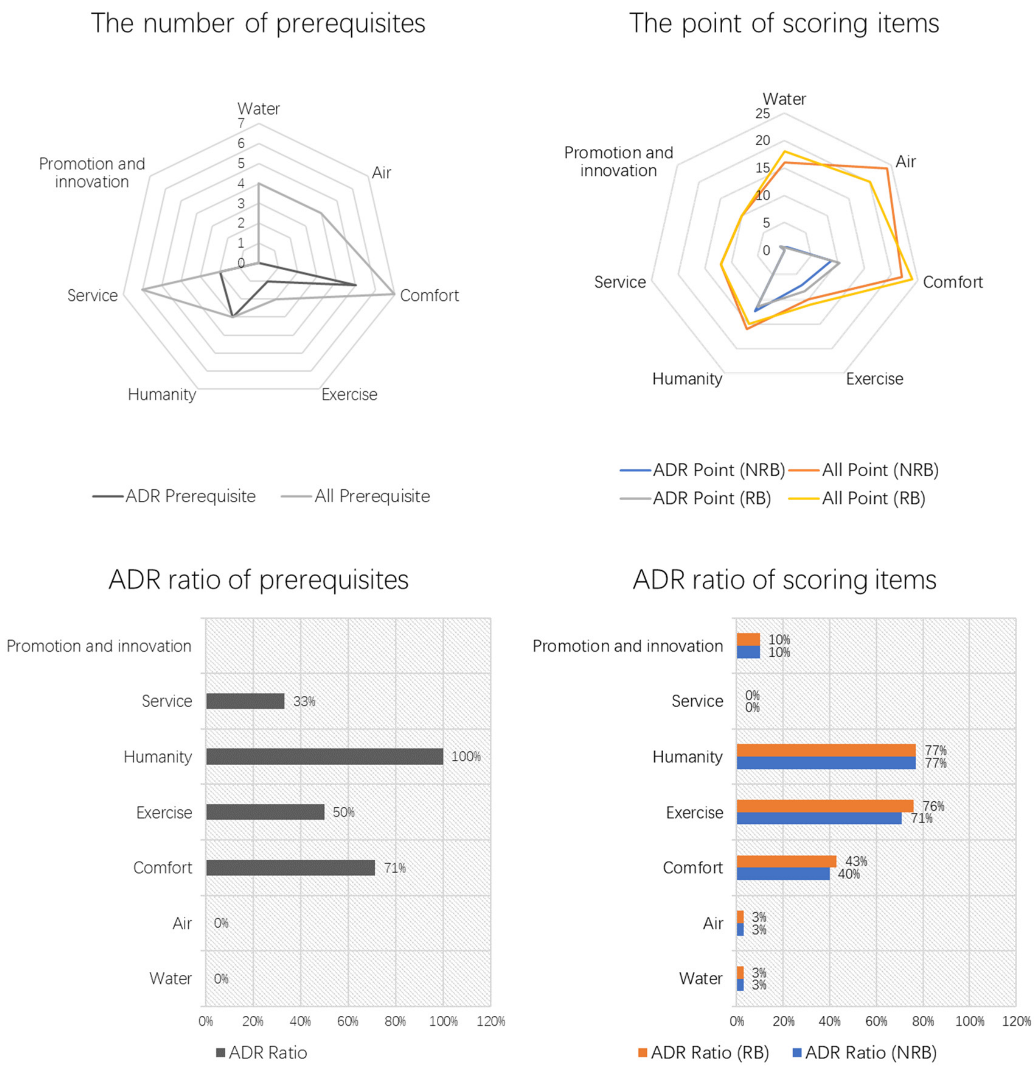

Figure A5. Breakdown of the number of prerequisites, the point of scoring items, and ADR ratios in diverse categories of ASHB. (Source: by the author).

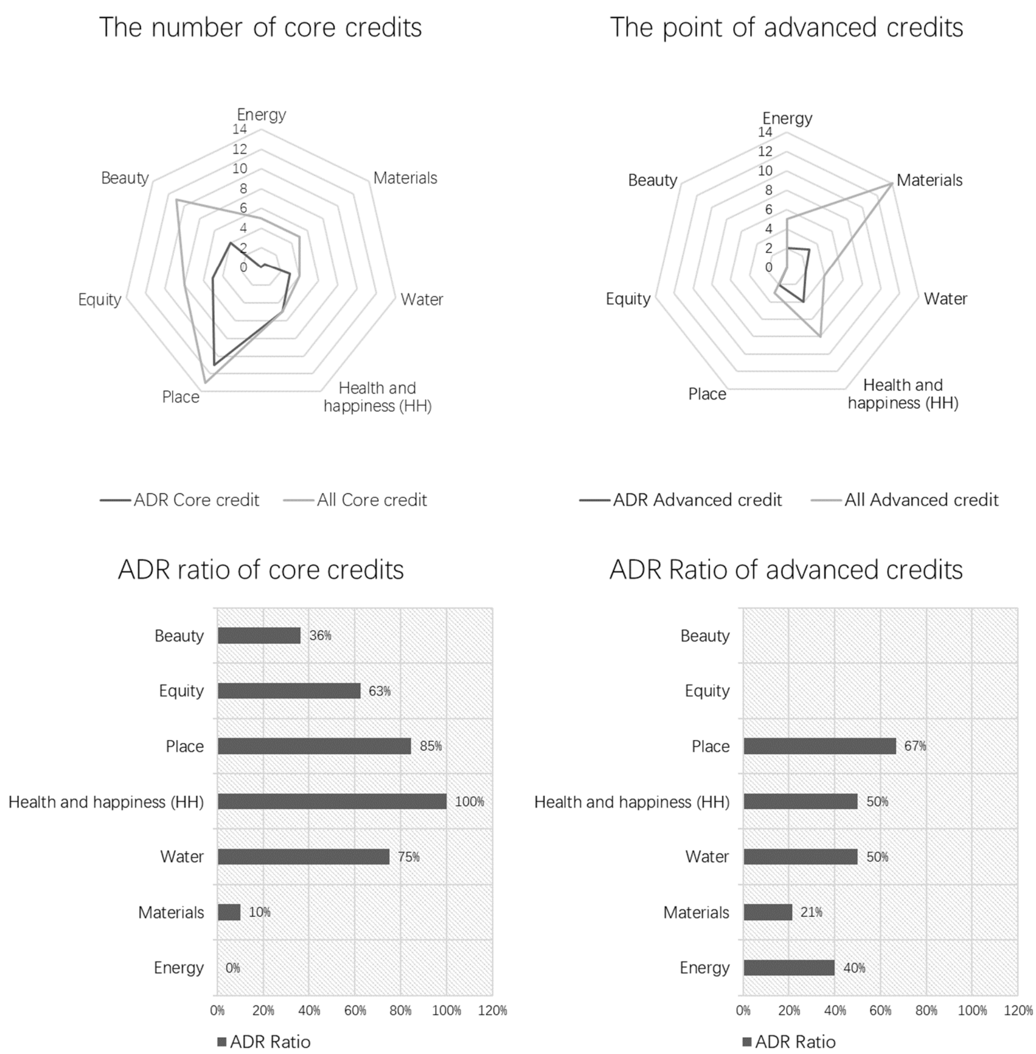

Figure A6. Breakdown of the number of core credits and advanced credits, and ADR ratio in diverse categories of LBC. (Source: by the author).

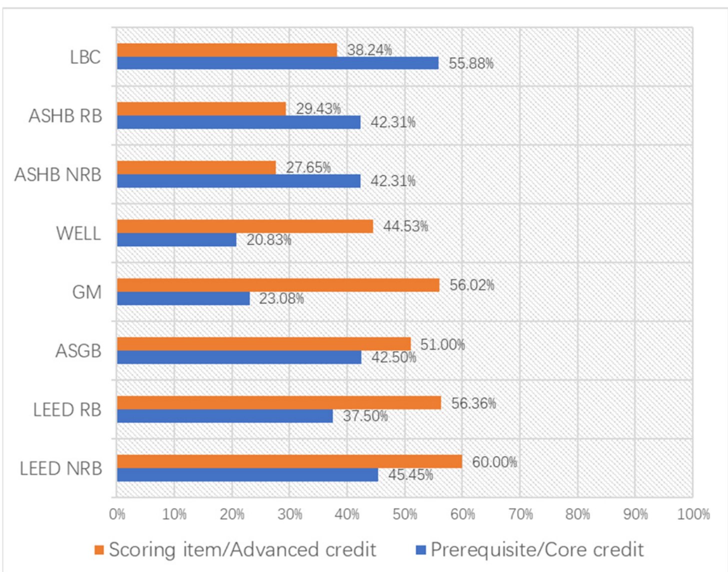

Figure A7. ADR ratios in different GBRSs. (Source: by the author).

Appendix B

Table A1. Theoretical Evaluation Framework and Corresponding Status in Six Selected GBRSs (Source: by the Author).

Theoretical Evaluation Framework					LEED			ASGB			GM			WELL			ASHB			LBC		
Section	Category	No	Variable	Universal/ Individual Variable	Status	Prerequisite	Scoring Item	Status	Prerequisite	Scoring Item	Status	Prerequisite	Scoring Item	Status	Prerequisite	Scoring Item	Status	Prerequisite	Scoring Item	Status	Core Credits	Advanced Credits
A. Process	1. Pre-design preparation	1	Integrative design process	U (3 themes)	√	–	1	–	–	–	–	–	–	√	2	–	–	–	–	√	1	–
		2	Context assessment	–	√	–	1	–	–	–	√		2	–	–	–	–	–	–	√	2	–
	2. Maintenance	3	Integrated design and maintainability of external facilities	I (ASGB)	–	–	–	√	1	–	–	–	–	–	–	–	–	–	–	–	–	–
		4	Design for maintainability	I (GM)	–	–	–	–	–	–	√	–	14	–	–	–	–	–	–	–	–	–
Subtotal					50.00%	0.00%	1.82%	25.00%	2.50%	0.00%	50.00%	0.00%	19.28%	25.00%	4.17%	0.00%	0.00%	0.00%	0.00%	50.00%	5.88%	0.00%
B. Resources and environment	3. Energy	5	Energy performance	I (LEED)	√	1	18	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
		6	Envelope thermal performance	–	–	–	–	√	–	1.5	√	1	–	–	–	–	–	–	–	–	–	–
		7	Energy saving design	I (ASGB)	–	–	–	√	1	–	–	–	–	–	–	–	–	–	–	–	–	–
		8	Natural ventilation design and performance	I (GM)	–	–	–	–	–	–	√	1	–	–	–	–	–	–	–	–	–	–
		9	Zoning temperature setting	I (ASGB)	–	–	–	√	1	–	–	–	–	–	–	–	–	–	–	–	–	–
		10	Renewable energy	–	√	–	5	√	–	1	√	1	–	–	–	–	–	–	–	√	–	1
		11	Energy resilience	I (LBC)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	√	–	1
	4. Materials	12	Building and material reuse	–	√	–	5	√	–	0.8	√	–	1	–	–	–	–	–	–	√	–	1
		13	Local material	I (LBC)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	√	–	1
		14	Avoidance of decorative member	I (ASGB)	–	–	–	√	1	–	–	–	–	–	–	–	–	–	–	–	–	–
		15	Collection of recyclable item or waste	U (3 themes)	√	1	–	√	1	–	√	–	1	–	–	–	√	1	–	√	0.5	1
		16	Collection of food waste	–	–	–	–	√		–	√	–	0.5	–	–	–	–	–	–	√		–
	5. Land	17	Surrounding diverse use	–	√	–	2	√	–	1.5	–	–	–	√	–	4	√	–	0.45	–	–	–
		18	Non-building infrastructure accessible to public	–	–	–	–	√	–		–	–	–	–	–	–	–	–	–	√	1.5	–
		19	Land use, density and scale	–	–	–	–	√	–	2	–	–	–	–	–	–	–	–	–	√	2	–
		20	Underground space and parking garage	–	–	–	–	√	–	2	–	–	–	–	–	–	–	–	–	√		–
		21	Space resilience	–	–	–	–	√	–	0.7	√	–	1	√	–	1	–	–	–	–	–	–
	6. Water and ecology	22	Ecology protection and restoration	–	√	–	3	√	–	1	√	–	2	–	–	–	–	–	–	√	3.5	–
		23	Green ratio	–	–	–	–	√	–	2.1	√	–	1	–	–	–	–	–	–	–	–	–
		24	Green space allocation, planting, and wild area	–	–	–	–	√	1	–	√	–	2	–	–	–	√	–	1.2	–	–	–
		25	Rainwater management	–	√	–	3	√	1	3.3	–	–	–	–	–	–	–	–	–	√	1	–
		26	Water use reduction	–	√	1	3	–	–	–	–	–	–	–	–	–	–	–	–	√	1	1
Subtotal				–	36.36%	18.75%	35.45%	77.27%	15.00%	22.71%	45.45%	23.08%	10.24%	9.09%	0.00%	3.91%	13.64%	3.85%	1.50%	54.55%	18.63%	17.65%
C. Sociological health	7. Public space	27	Indoor social space	U (3 themes)	–	–	–	–	–	–	√	–		√	–	1	√	–	1.2	√	1.5	–
		28	Outdoor social space	U (3 themes)	√	–	1	–	–	–	√	–	2	√	–		√	–	1.35	√		–
		29	Outdoor recreational space	–	√	–		√	–	0.3	√	–		√	0.25	1	√	1	2.86	–	–	–
		30	Indoor recreational space	–	–	–	–	√	–	0.3	√	–		√		1	√		1.1	–	–	–
	8. Public infrastructure	31	Outdoor fitness trail	–	–	–	–	√	–	0.2	–	–	–	–	–	–	√	–	1.1	–	–	–
		32	Cultural and recreation center in residentials	I (ASHB)	–	–	–	–	–	–	–	–	–	–	–	–	√	–	1.2	–	–	–
		33	Service facilities for fitness personnel	I (ASHB)	–	–	–	–	–	–	–	–	–	–	–	–	√	–	1.32	–	–	–
Subtotal				–	28.57%	0.00%	0.91%	42.86%	0.00%	1.14%	57.14%	0.00%	2.41%	57.14%	0.52%	2.34%	100.00%	3.85%	9.21%	28.57%	2.94%	0.00%

Table A1. *Cont.*

Theoretical Evaluation Framework					LEED			ASGB			GM			WELL			ASHB			LBC		
Section	Category	No	Variable	Universal/ Individual Variable	Status	Prerequisite	Scoring Item	Status	Prerequisite	Scoring Item	Status	Prerequisite	Scoring Item	Status	Prerequisite	Scoring Item	Status	Prerequisite	Scoring Item	Status	Core Credits	Advanced Credits
D. Physiological health	9. Transportation and movement	34	Safe access in and around site	–	–	–	–	√	–	0.8	√	–	0.5	–	–	–	–	–	–	√		–
		35	Parking footprint reduction	–	√	–	1	–	–	–	–	–	–	–	–	–	–	–	–	√	3	–
		36	Bicycle facilities	U (6 GBRSs)	√	–	1	√	1	–	√	–	0.5	√		3	√	–	0.55	√		–
		37	Access to public transit	U (3 themes)	√	–	3	√	1	0.8	–	–	–	√		2	√	–	0.55	√		–
		38	Access to pedestrian-friendly street	–	–	–	–	–	–	–	–	–	–	√	0.75	2	–	–	–	√		–
		39	Staircase	–	–	–	–	√	–	0.2	√	–	1	√		2	√	–	0.88	–	–	–
		40	Signage for safety and convenient use	–	–	–	–	√	2	–	–	–	–	√		1	–	–	–	–	–	–
		41	Avoidance of falling object	I (ASGB)	–	–	–	√	–	1.5	–	–	–	–	–	–	–	–	–	–	–	–
		42	Passage space for emergency	–	–	–	–	√	1	–	–	–	–	–	–	–	√	–	0.3	–	–	–
		43	Barrier-free and universal design	U (3 themes)	–	–	–	√	1	0.8	√	–	2	√	–	2	√	1	1.8	√	1	–
		44	Protect adjacent property from noxious emissions	I (LBC)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	√	0.5	–
		45	Tobacco smoke control	U (6 GBRSs)	√	1	–	√	–	0.9	√	–	1	√	1	–	√	1	–	√	1	–
		46	Non-toxic and harmless planting	I (ASHB)	–	–	–	–	–	–	–	–	–	–	–	–	√	1	–	–	–	–
	10. Wind and thermal comfort	47	Outdoor wind comfort performance		–	–	–	√	–	1	–	–	–	√	–	2.5	–	–	–	–	–	–
		48	Outdoor heat management strategies	I (WELL)	–	–	–	–	–	–	–	–	–	√	–		–	–	–	–	–	–
		49	Heat island reduction	–	√	–	2	√	–	1	√	–	1	–	–	–	–	–	–	√	1	–
		50	Outdoor thermal comfort performance	–	–	–	–	√	1	–	√	–	2	–	–	–	–	–	–	–	–	–
		51	Avoidance of pollutant	U (3 themes)	–	–	–	√	1	–	–	–	–	√	–	1	√	–	0.6	√	1	–
		52	Combustion venting	I (LEED)	√	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
		53	Circulation strategies for respiratory particle exposure reduction	I (WELL)	–	–	–	–	–	–	–	–	–	√	–	1	–	–	–	–	–	–
		54	Indoor wind comfort performance and natural ventilation design	U (3 themes)	√	1	1	√	–	0.8	√	–	3	√	1	2	–	–	–	√	2	2
		55	Indoor thermal comfort performance	–	√	–	1	√	–	0.8	√	–		√	1	–	√	–	1.68	–	–	–
		56	Adjustable shading facilities for thermal comfort	I (ASGB)	–	–	–	√	–	0.9	–	–	–	–	–	–	–	–	–	–	–	–
		57	Windows with multiple opening modes for thermal comfort	I (WELL)	–	–	–	–	–	–	–	–	–	√	–	1	–	–	–	–	–	–
	11. Human basic necessities	58	Urban agriculture	–	–	–	–	–	–	–	–	–	–	√	–	2	√	–	1	√	–	1
		59	Drinking water access	–	–	–	–	–	–	–	√	–	1	√	–	1	√	–	0.54	–	–	–
		60	Food and water resilience	I (LBC)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	√	–	2
		61	Bathroom	–	–	–	–	–	–	–	–	–	–	√	–	1	√	–	0.48	–	–	–
		62	Kitchen of residentials	I (ASHB)	–	–	–	–	–	–	–	–	–	–	–	–	√	–	0.72	–	–	–
		63	Maternal and child care	–	–	–	–	–	–	–	–	–	–	√	–	2	√	–	1.5	–	–	–
		64	Nap space	I (WELL)	–	–	–	–	–	–	–	–	–	√	–	1	–	–	–	–	–	–
		65	Environment and amenities for outsourced worker	I (GM)	–	–	–	–	–	–	√	–	1	–	–	–	–	–	–	–	–	–
Subtotal				–	25.00%	18.75%	8.18%	50.00%	20.00%	13.57%	34.38%	0.00%	15.66%	59.38%	7.81%	20.70%	43.75%	11.54%	9.64%	40.63%	18.63%	14.71%

Table A1. *Cont.*

Theoretical Evaluation Framework					LEED			ASGB			GM			WELL			ASHB			LBC		
Section	Category	No	Variable	Universal/ Individual Variable	Status	Prerequisite	Scoring Item	Status	Prerequisite	Scoring Item	Status	Prerequisite	Scoring Item	Status	Prerequisite	Scoring Item	Status	Prerequisite	Scoring Item	Status	Core Credits	Advanced Credits
E. Psychological health	12. Sound	66	Ambient noise reduction	–	–	–	–	√	–	1	–	–	–	–	–	–	√	1	0.96	–	–	–
		67	Limit noise source from close traffic	I (ASHB)	–	–	–	–	–	–	–	–	–	–	–	–	√	–	0.72	–	–	–
		68	Sound zoning design	–	–	–	–	–	–	–	√	–	0.5	√	1	–	–	–	–	–	–	–
		69	Indoor background noise level	–	√	–	1	√	0.5	0.8	√	–	2	√	–	3	√	1	1.2	–	–	–
		70	Sound barrier and impact insulation	–	√	–		√	0.5	–	√	–		√	–	3	√	1	0.48	–	–	–
		71	Reverberation time performance	–	√	–		–	–	–	√	–		√	–	2	√	–	0.72	–	–	–
		72	Reverberation time design		–	–	–	–	–	–	–	–	–	√	–		√	–	0.48	–	–	–
		73	System and position of service equipment	I (ASHB)	–	–	–	–	–	–	–	–	–	–	–	–	√	–	0.48	–	–	–
		74	Soundscape design combined with architectural and landscape design	I (ASHB)	–	–	–	–	–	–	–	–	–	–	–	–	√	–	0.48	–	–	–
	13. Daylight	75	Sunlight on building	I (ASGB)	–	–	–	√	0.5	–	–	–	–	–	–	–	–	–	–	–	–	–
		76	Protect adjacent property from light pollution or sunlight block	U (3 themes)	–	–	–	√	0.5	0.5	–	–	–	–	–	–	√	1	–	√	1	–
		77	Integrated or controllable shading for glare prevention	–	–	–	–	√	–	0.3	–	–	–	√	–	2	√	–	0.72	–	–	–
		78	Interior plan layout and façade design for daylight	U (6 GBRSs)	–	–	–	√	–	0.9	√	–	1	√	–	2	√	1	1.2	√	0.5	0.5
		79	Daylight simulation and glare control	–	√	–	1	√	–		–	–	–	√	1	2	√			–	–	–
		80	View to outside or greenery	U (3 themes)	√	–		–	–	–	√	–	0.5	–	–	–	√	0.5	–	√	0.5	0.5
	14. Nature experience	81	Nature access indoors	–	–	–	–	–	–	–	–	–	–	√	–	1	√	–	0.3	√	–	1
		82	Nature access outdoors	U (3 themes)	–	–	–	–	–	–	√	–	1	√	–	1.5	–	–	–	√	–	
		83	Incorporating nature through environmental features and natural elements	U (3 themes)	–	–	–	–	–	–	√	–	1	√	1	–	√	–	1.2	√	1	–
		84	Incorporating nature through light and space	I (LBC)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	√		–
		85	Incorporating nature's patterns and evolved human-nature relationships	I (LBC)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	√	1	–
	15. Other architectural design strategy	86	Restorative space	–	–	–	–	–	–	–	–	–	–	√	–	1	√	–	1.05	–	–	–
		87	Public-private space zoning	I (ASHB)	–	–	–	–	–	–	–	–	–	√	–		√	0.5	–	–	–	–
		88	Design with weather, culture, and place	U (3 themes)	–	–	–	√	–	2	–	–	–	√	1	–	–	–	–	√	1	–
Subtotal					21.74%	0.00%	1.82%	39.13%	5.00%	7.86%	34.78%	0.00%	7.23%	56.52%	8.33%	13.67%	73.91%	23.08%	9.08%	39.13%	9.80%	5.88%
Total					28.41%	37.50%	48.18%	52.27%	42.50%	45.29%	39.77%	23.08%	54.82%	44.32%	20.83%	40.63%	46.59%	42.31%	29.43%	43.18%	55.88%	38.24%

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