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Sustainability Performance of Green Building Rating Systems (GBRSs) in an Integration Model

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Abstract: In most countries, more than one green building rating system (GBRS) is available on the market. Because of their different approaches, it is difficult to confirm which system can respond to sustainability requirements better. A building considered to be "green" by one Green Building Council (GBC) may fail to satisfy the requirements set by another council. The aim of this study is to evaluate the sustainability performance of GBRSs and establish an integrated model of multi-certification for optimal sustainability. A direct content analysis method was utilized to evaluate GBRSs' qualitative performance using the ISO sustainable building standards. In this study, seven purposively selected multi-certified buildings were evaluated, and an integrated model was proposed as a better mechanism for the multi-certification process. The proposed integrated model contributes to the achievement of sustainability indicators. The model was implemented on case study buildings, and the proposed combination shows better sustainability performance than existing practice. The developed model helps practitioners in their selection of GBRSs in the multi-certification process. In addition, the performance evaluation of GBRSs will support the future update of GBRSs. The qualitative performance evaluation was performed considering mandatory requirements and prerequisite and credit requirements of selected rating systems, making the work a stronger approach than previous studies.

Keywords: green building rating systems; sustainable building; ISO sustainability indicators; multi-certification; integration model

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1. Introduction

Sustainable building principles, a major part of sustainable construction, are mainly applied using green building rating systems (GBRSs). Acceptance of the systems has been increasing since their emergence [1–3]. Nowadays, several rating systems, from those in the local context to fully flexible international systems, such as the Sustainable Building Tool (SBTool) [4,5], are available on the market. However, the heterogeneity [6] of the GBRS approach and the contradictory results of the system performance [7,8] along with the benefits for users [9–11] have been believed to affect the wide acceptance of the approach, especially in developing nations.

One of the key challenges in the system is the difficulty in balancing the conflicting requirements among the main dimensions (i.e., environmental, social, and economic) [12]. Because of this challenge, the managers of building design and construction need more support to achieve the complete sustainability [13]. Doan, et al. [14] evaluated Leadership in Energy and Environmental Design (LEED), Building Research Establishment Environmental Assessment Method (BREEAM), Comprehensive Assessment System for Built Environment Efficiency (CASBEE), and Green Star New Zealand (Green Star NZ) according to the environmental, social, economic, and institutional "sustainability pillars" and concluded that they fail to balance and fulfill all requirements. Moreover, a building classified as green or sustainable by one rating system may not satisfy the requirements set by another rating system [15,16]. For these reasons, owners apply for more than one green building certification [17,18]. However, multiple certifications implemented so far lack clear objectives on sustainability, making the process less efficient. The availability of many rating systems in one country [19,20] and lack of a simple and user-friendly international checklist to evaluate the sustainability of heterogeneous indicators [21] in GBRSs make the selection of a rating system a complex task. Although some of the GBRSs are widely accepted and are promoting sustainability worldwide, because they are developed based on the country of origin's situation they have limitations on balancing the developed and developing nations' priority areas [22,23]. It is a difficult task to decide on which rating system to adopt and which one can respond to local sustainability priorities.

Most of the previous studies mainly focus on evaluating the rating system performance based on the weighting assigned to each category or criterion. This evaluation method has limitations because of the uncertainty [24] and subjectivity [25] of the weighting assignment. Moreover, the weighting of each category depends on the local priority area of assessment, yet some systems are adopted in many countries. These conditions motivated researchers to conduct qualitative performance evaluation using content analysis [26–28], which is more reliable than any other of unit of analysis method [29]. The content analysis was carried out based on the International Standards Organization (ISO) sustainable building indicators, the available international benchmark. The standard was also used by Liang et al. [30] to evaluate GBRSs' performance on the "institutional" pillar. Multi-certified projects were analyzed to identify their contribution toward sustainability.

The case study evaluation result shows the impact of subjective selection of GBRSs on sustainability. For example, the LEED system and HQE have no assessment for a life cycle cost indicator. A dual-certified building from these systems lacks one of the essential economic aspect indicators. Because of inconsistency on the evaluated building performance, this study developed an integrated model that helps to achieve optimal sustainability that is from the perspective of balancing the three main pillars, incorporating seven core areas of protection (CAPs) and their indicators listed under the ISO sustainable building standards [31]. The developed model was validated using case studies of multi-certified buildings. This study mainly emphasizes sustainability performance rather than only the popularity of the GBRSs during the selection process. The objectives of the study are as follows:

a. Evaluate GBRS sustainability performance using the ISO sustainable building indicators;
b. Discuss the performance of selected multi-certified buildings based on the ISO indicators;
c. Develop an integration model that helps practitioners in the selection of multiple GBRSs for a single project.

The previous studies conducted on multi-certified projects only show the differences in approach and the impact of rating system selection on level of certification. This is the first study on an integration model for selection of multiple rating systems on a single project. The model helps to balance qualitative indicators of the three main pillars and to achieve more sustainability indicators.

This paper is organized into six Sections. Section 2 focuses on GBRSs used in the study, previous studies in the area, and the sustainability principles in the ISO standard. Section 3 clarifies the method and procedure used in this study. Section 4 evaluates the GBRSs using the ISO standard. The results and discussion presented in Section 5 focus on evaluating the variation of parameters among the different rating systems, identifying the limitations of multi-certified buildings, and the application of the integrated model on selected cases. Finally, we draw conclusions on the study output in Section 6.

2. Materials and Methods

2.1. Selecting Rating Systems for the Study

To identify and select well-known rating systems, a review of the literature was carried out, and information on the websites of the World Green Building Council (WGBC) and the GBCs of different countries was collected. There is previous research on comparing the rating systems for certain countries or areas [32]. Selecting different rating systems influences the strategies to calibrate the design principles and construction methods, such as roof systems [33]. Because of the availability of many GBRSs globally, the researchers used purposive sampling to select rating systems. The following rating systems were selected for the following reasons. BREEAM is a leading method in building certification [34], and LEED is a widely accepted rating system [35] reaching 167 countries and territories. DGNB awarded certification in around 30 countries [36]; HQE certified projects in five continents [37], and both are popular systems in Europe [6]. The country of origin-focused rating systems, CASBEE [4,38,39] and ITACA (Istituto per l'innovazione e Trasparenza degli Appalti e la Compatibilita Ambientale) [40,41], are also well-known. Nowadays, CASBEE is expanding outside the country by certifying buildings in China [39].

Among the selected systems, ITACA has been included in the study sample because it is well-known from the SBTool-adopted methods. SBTool is an international standard managed by the International Initiative for Sustainable Built Environment [42], which has a different approach to most popular systems for evaluation and certification. To include one rating system from developing countries, a popular green star system family [3,43] that has been gaining acceptance in African countries and adopted in more than five countries [44], the Green Star South Africa (Green Star SA) was included in this study.

2.2. Sustainability: The Top Goal for Green Buildings

Previous studies have illustrated the difficulty in defining sustainable building when comparing variations in scoring and certification levels for the sample buildings. Suzer [15] compared the compliance and correlation between 20 dual-certified (LEED and BREEM) buildings and concluded that the LEED score and award level tended to be higher than that of BREEAM. Asdrubali, Baldinelli, Bianchi, and Sambuco [14] conducted a study to compare residential buildings certified by LEED and ITACA in Italy using five common parameters. The study showed that the ITACA evaluation score was higher than the LEED evaluation score. Cruz, et al. [45] developed a roadmap to ensure "sustainable sustainability" that helps to balance the main pillars. Other studies aimed to respond to common industry challenges by studying mechanisms to achieve more points [46], developing a new rating system for a specific country using various GBRSs and local situations [23,47,48], and some other studies developed rating systems based on stakeholder interest [49].

Sustainability should be the top goal based on the concept of the theory, science, and style of buildings [50]. It also has to contain the insights of life cycle assessment [51]. Although many studies have been conducted, they did not establish necessary mechanisms for achieving more sustainability indicators from existing GBRSs. By contrast, the activity of multi-certification is gaining greater acceptance in the industry [52,53]. However, no specific criteria are established for the selection of rating systems during the multi-certification process, and the contribution of multi-certificates is not clear yet.

The ISO 21929-1 set 14 major and 12 minor indicators. For the purpose of analysis, the 26 indicators in this study are adapted from ISO 21929-1 [31] and grouped into 19 based on their direct influence area (aspect) and the approach of GBRS use for evaluation. However, outdoor conditions, emission to air (troposphere), and heat island effect directly affect more than one aspect as specified in the standard, and they are grouped together, including nuisance on neighborhood (which has a direct effect on only one aspect), as "outdoor environment", as shown in Table 1. Use of renewable resources and that of non-renewable resources have similar aims in green building assessment; therefore, they are merged and renamed as "resources".

Table 1. Sustainable building indicators adapted from ISO 21929-1 [31].

Code	Indicators Group		Indicators	Aim
1	Emission to air	A.	Global warming potential	Reduce greenhouse gas (GHG) emissions
		B.	Ozone depletion potential	Minimize/avoid stratospheric ozone layer depilating materials
2	Resources **	A.	Renewable and non-renewable resource consumption **	Reduce non-renewable and use renewable/recycled material
		B.	Renewable and non-renewable energy consumption **	Enhance renewable energy and energy saving
3	Freshwater consumption	-	Freshwater consumption	Reduce freshwater consumption
4	Waste generation		Waste generation	Reduce waste production during construction and enhance reusing, recovering, and recycling
5	Change of land use		Change of land use	Avoid use of greenfield, reuse brownfield, and infill sites.
6	Access to services	A.	Public modes of transportation	Enhance quality and proximity of public transport
		B.	Personal modes of transportation	Provide sidewalks, pedestrian footways, bicycle paths
		C.	Green and open areas	Provide publicly accessible green and open areas
		D.	User-relevant basic services	Presence of basic services in the building site
7	Accessibility	A.	Accessibility of building site (curtilage)	Make all relevant parts of the building site (or curtilage) barrier-free
		B.	Accessibility of building	Accessibility of a building by all users (different classes)
8	Indoor conditions and air quality	A.	Indoor thermal conditions	Provide good indoor thermal conditions
		B.	Indoor visual conditions	Provide good indoor visual conditions
		C.	Indoor acoustic conditions	Provide good indoor acoustic conditions
		D.	Indoor air quality	Provide indoor air suitable for human health and comfort
9	Adaptability	A.	Change of use or user needs	Adaptability in terms of changed user requirements, use/purpose
		B.	Adaptability for climate change	Adaptability during unexpected projected climate change
10	Life cycle costs (LCC)		Lifecycle costs	Lifecycle cost of building
11	Maintainability		Maintainability	Quality of maintenance plan that considers LCC, user comfort, and building functionality
12	Safety	A.	Structural stability	Stability against loading
		B.	Fire safety	Resistance of building to fire loadings and provisions for early warning and means of escape, considering different fire scenarios.
		C.	Safety in use	Usability of the building while limiting the potential risk of tripping, falling, and other types of accidents.

Table 1. *Cont.*

Code	Indicators Group		Indicators	Aim
13	Serviceability		Serviceability	Ability of a building to fulfil the user requirements from the functionality point of view.
14	Esthetic quality		Esthetic quality	Consideration of cultural value and stakeholders' requirements
15	Emission to land/water **	A.	Emission to water *	Reduce PO_4 equivalent chemical emission
		B.	Emission to land/water *	Reduce SO_2 equivalent chemical emission
16	Value stability		Value stability *	Future value of building stability or growth
17	Outdoor environment **	A.	Emission to air (troposphere) *	Minimize/avoid tropospheric ozone (O_3) formation materials
		B.	Nuisance on neighborhood *	Minimize nuisance and other effects on neighborhood and local environment.
		C.	Outdoor conditions *	Enhance good outdoor environment
		D.	Heat island effect *	Reduce heat island in the area
18	Site ecology **	A.	Protection of rare species and natural features *	Protect rare species and valuable individual natural features on-site (within the curtilage)
		B.	Ecological quality of site *	Avoid construction in areas valuable in biodiversity
		C.	Effect on surface drainage *	Reduce paved and non-permeable area
19	Participation		Participation *	Enhance users' and other stakeholders' participation

* Additional indicators of ISO. ** Name given or renamed for analysis purposes.

3. Research Approach

3.1. Sampling and Analysis Method

In this study, we propose a three-phase approach as shown in Figure 1 to achieve the aim of the study. The first phase is to select and evaluate GBRS candidates. The LEED, BREEAM, CASBEE, DGNB, HQE, Green Star SA, and ITACA protocols were the selected rating systems. Of the various manuals available in GBRSs, we selected the manual for new construction of office buildings, because office building types are leading in certification [34,36,54]. Various approaches of content analysis were used by researchers to evaluate sustainability performance [55–57]; therefore, direct content analysis [29,58–60] is adopted in this study as shown in Figure 2.

To identify the multi-certification gap, ISO indicators were used for evaluation. Since no specific database exists that helps identify multi-certified buildings, in this study available information collected by using beneficial keywords on literature and generic search platforms as well as GBC websites was used to select multi-certified buildings. Seven samples were selected using the following criteria: combination of certifications to represent GBRSs in this study, office building type, one sample from each combination, and availability of essential information for analysis [17,18,34,36,37,54,61,62]. There was no multi-certified combination identified from CASBEE, ITACA, and Green Star SA, and so they are not included in the analysis.

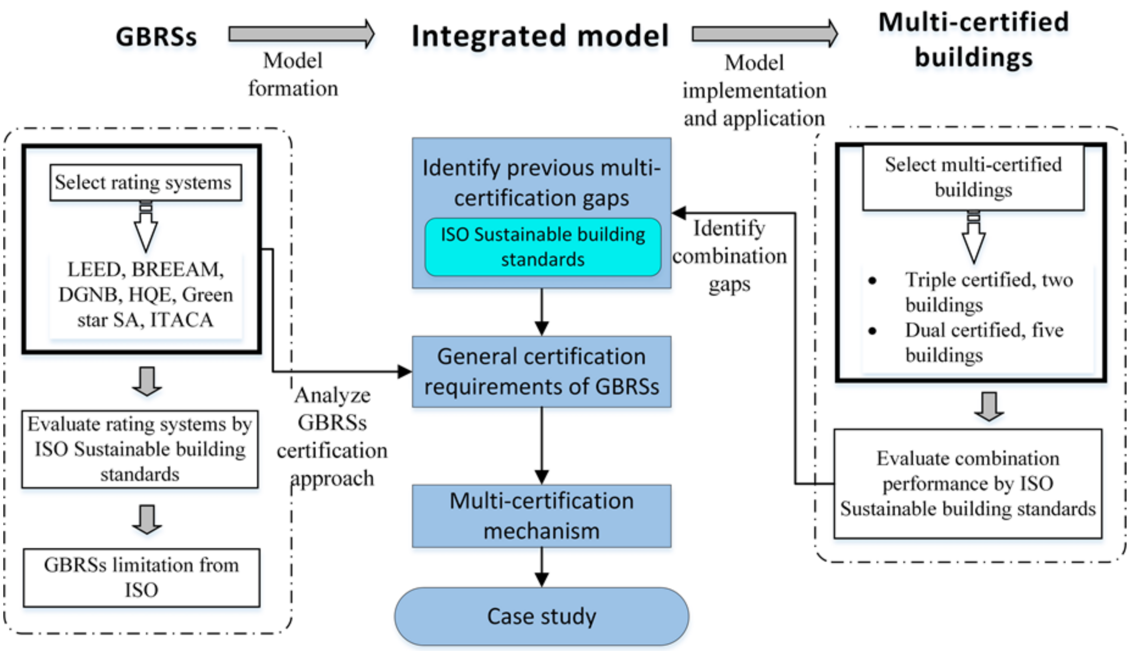

Figure 1. Research approach.

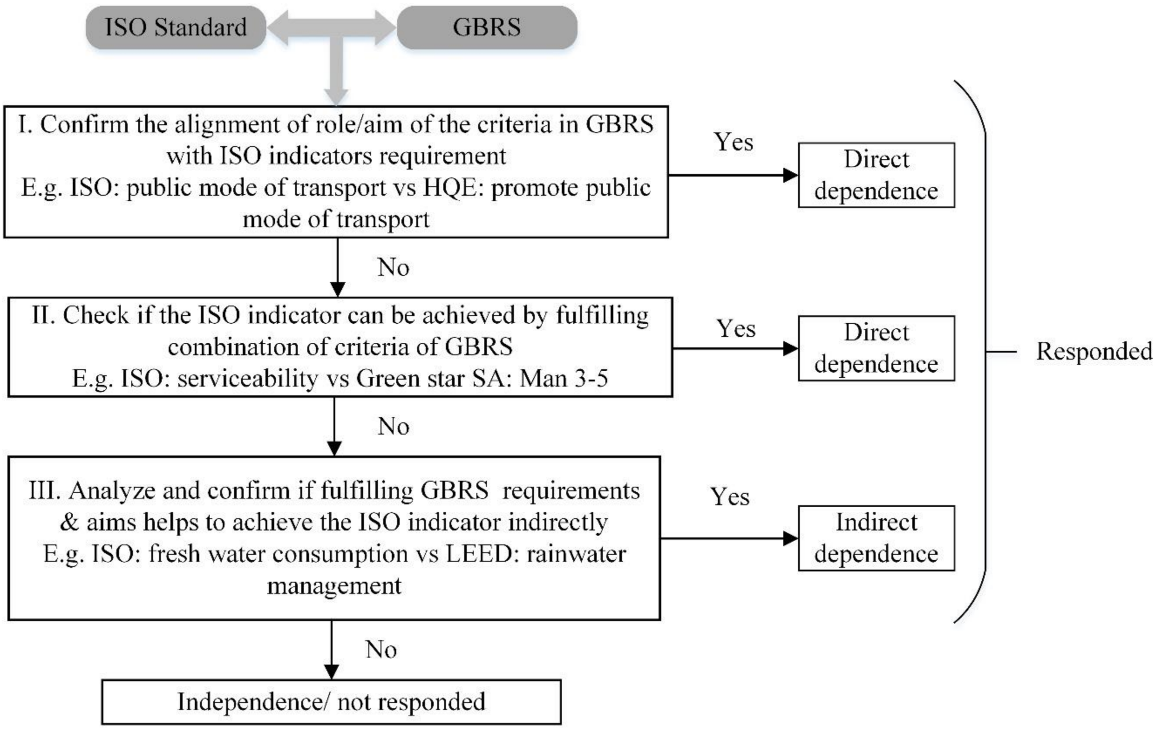

Figure 2. Proposed evaluation system based on direct content analysis.

3.2. Development of Integrated Model

Desk study conducted on the existing practices of multi-certification indicates that there is no scientific model or approach that helps to select GBRSs for multi-certification. Moreover, the evaluation result of dual- and triple-certified buildings is inconsistent. A new integrated model that helps to achieve both ISO sustainable building indicators and developer interest was developed in this study as shown in Figure 3.

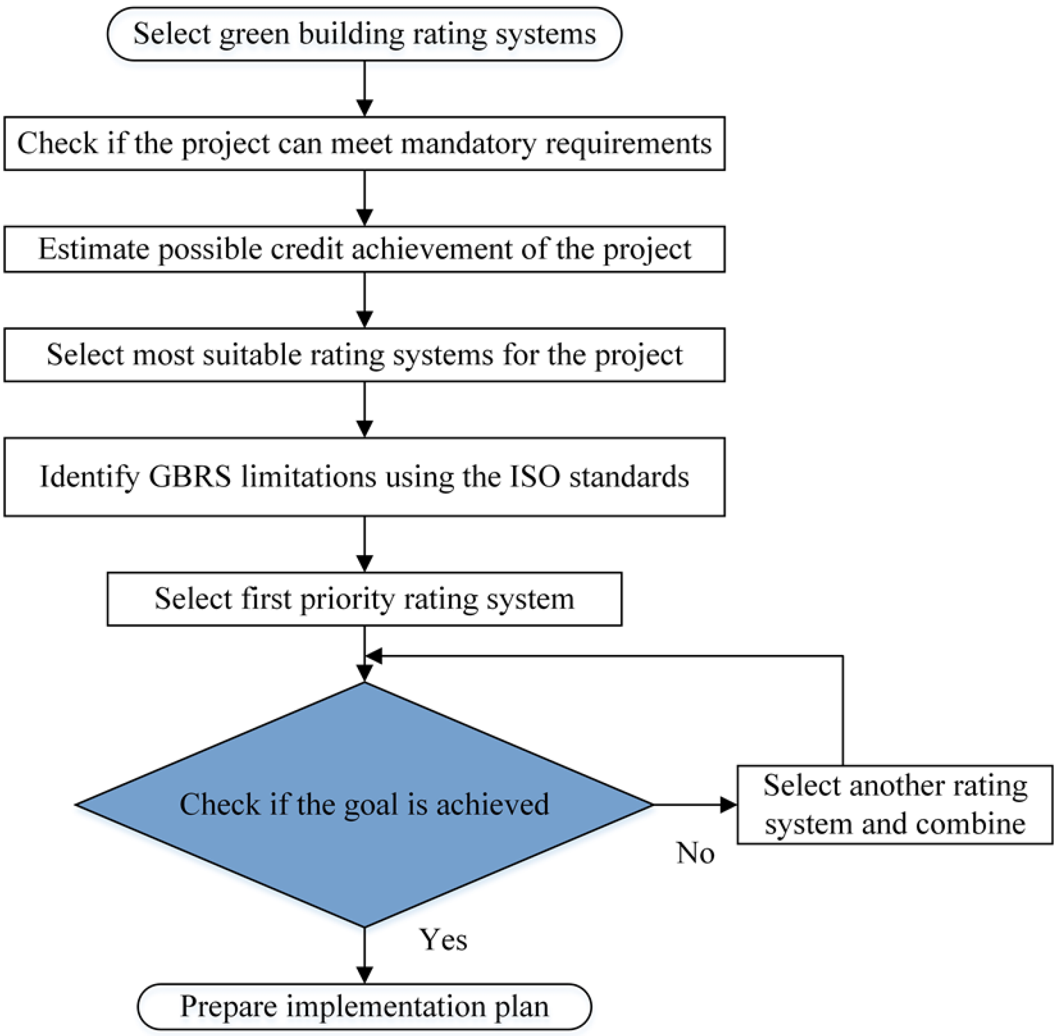

Figure 3. Green building rating system integration model.

The first step in implementation of the model is selection of preferable rating systems for the project. This can be done based on the interest of the project owner or suggestion from experts. Rating systems such as LEED and DGNB have mandatory/minimum requirements that must be fulfilled by all projects. Therefore, the next step is checking whether the project can meet minimum requirements set by selected GBRSs. Because receiving higher certification increases the market value of a building, initial estimation of the certification level is conducted for the candidate rating systems. The rating systems that are deemed suitable for the project are then listed and evaluated for their ability to meet the ISO sustainable building indicators. The first candidate GBRS is selected depending on the interest of practitioners. If the first rating system cannot fully meet the ISO indicators, an integration procedure should be implemented until the combination fulfills the set requirements or achieves the ISO sustainable building benchmark indicators. Finally, the expert prepares an implementation plan, which considers aspects including the scope of the selected rating system, conflicting requirements, similar parameters, and the most dominant category or credit from similar parameters.

4. Evaluation of Green Building Rating Systems Using ISO Standard

Although ISO by itself has some limitations, it is the available international benchmark that balances the three main pillars sufficiently [30]. The ISO [31] indicators are suggestions for the development of a sustainable building rating system. Some credits and criteria in the rating systems can respond to the ISO indicator individually, whereas others must come together to respond to the indicators. For example, the serviceability of a building requires the engagement of owners or users during the design period, setting criteria of evaluation, and subsequent evaluation of user satisfaction after occupancy in terms of space design and other specified requirements.

Although the scope of assessment relative to the ISO requirements may vary between the rating systems, this study completed the evaluation using direct content analysis, as shown in Figure 2. The evaluation of analysis is summarized as shown in Table 2.

Table 2. Evaluation of green building rating systems using the ISO standard.

Code	ISO Core Areas	LEED	BREEAM	HQE	CASBEE	DGNB	Green Star SA	ITACA
1A	Global warming potential	V	V	V	V	V	V	V
1B	Ozone depletion potential	V	V	V	V	V	V	
2A	Renewable and non-renewable raw materials consumption by type **	V	V		V	V	V	V
2B	Renewable and non-renewable energy consumption **	V	V	V	V	V	V	V
3	Freshwater consumption	V	V	V	V	V	V	V
4	Waste generation by type	V	V	V	V	V	V	V
5	Change of land use	V	V		V	V	V	V
6A	Public modes of transportation	V	V	V	V	V	V	V
6B	Personal modes of transportation	V	V	V	V	V	V	V
6C	Green and open areas	V	-	-	V	V	-	V
6D	User-relevant basic services	V	V	-	-	V	V	V
7A	Accessibility of the building site (curtilage)	-	-	V	-	V	-	-
7B	Accessibility of the building	-	V	-	V	V	-	-
8A	Indoor thermal conditions	V	V	V	V	V	V	V
8B	Indoor visual conditions	V	V	V	V	V	V	V
8C	Indoor acoustic conditions	V	V	V	V	V	V	V
8D	Indoor air quality	V	V	V	V	V	V	V
9A	Change of use or user needs		V	V	V	V	-	-
9B	Adaptability for climate change	-	V	-	-	V	-	-
10	Life cycle costs	-	V	-	-	V	-	-
11	Maintainability	-	V	V	V	V	-	V
12A	Structural stability	-	V	-	V	V	-	-
12B	Fire safety	-	-	-	-	V	-	-
12C	Safety in use	-	-	-	-	V	-	-
13	Serviceability	-	V	V	V	V	V	-
14	Esthetic quality	-	-	-	V	V	-	-
15A	Emission to water *	V	V	V	V	V	V	V
5B	Emission to land/water *	V	V	V	V	V	V	-
16	Value stability *	-	V			V		-
17A	Emission to air (troposphere)	V	V	V	V	V	V	-
17B	Nuisance on neighborhood *	-	V	V	V	V	V	-
17C	Outdoor conditions *	-	-	V	-	V	-	-
17D	Heat island effect *	V	-	V	V	-	-	V
18A	Protection of rare species *	V	V	V	V	V	V	-
18B	Ecological quality of site *	V	V	-	V	V	V	-
18C	Effect on surface drainage *	V	V	V	V	V	V	V
19	Participation *	V	V	V	-	V	-	-

* Additional indicators. ** Indicator renamed for analysis. V: GBRS system fulfilled the ISO indicator requirements.

5. Results and Discussion

5.1. Comparison of Evaluated Rating Systems

This study selected and evaluated seven GBRSs by using the ISO sustainable building requirements. Among the 14 major and 12 additional indicators of the ISO standard, safety in use and fire safety are covered only by the DGNB system. The effect of fire on the sustainability of a building and that of the chemicals used for firefighting on the environment [63] is enormous, and some less developed nations have limitations in implementing fire safety and safety in use issues. Most widely acceptable GBRSs should consider the global situation.

Most of the environmental aspect-related indicators in the ISO standard are considered by all seven rating systems included in the evaluation, whereas the economic aspect-related ISO indicators are considered less, as shown in Figure 4; this also poses a limitation in most GBRSs in responding to and balancing sustainability goals. The comparison of GBRS performance is summarized according to the three aspects as described in the following sections.

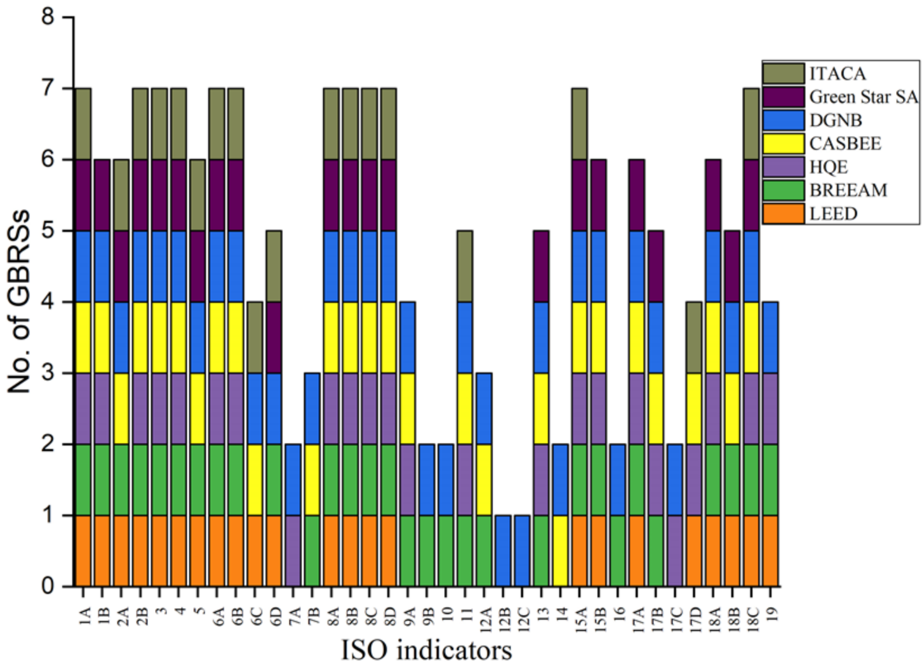

Figure 4. ISO indicators consideration in seven GBRSs.

5.1.1. Environmental Aspects

Emission to air, which is measured using the global warming potential and ozone depletion potential, were assessed in the GBRSs by analyzing the effects of energy consumption, transportation, construction materials, and the refrigerant selection. Consumption of non-renewable energy, public and personal modes of transport, and maintainability of buildings are also related to emission to air. Therefore, some credits/issues, such as those for energy, transportation, and materials, can be used to fulfill more than one ISO requirement. Although all of the rating systems focused on energy consumption, transportation systems, and material usage as strategies to respond to global warming impact, CASBEE only evaluated bicycle usage as transportation and used other categories such as "Consideration of global warming" and "Air pollution" to assess global warming potential. LEED's depth of assessment and its evaluation parameters are more detailed, compared with those of the other systems, for accounting for global warming.

The only rating system that does not consider ozone-depleting materials or refrigerant requirements is ITACA, while LEED and BREEAM set strict criteria. The LEED rating system requires that candidate buildings should eliminate CFC-based refrigerants in heating, ventilating, air-conditioning, and refrigeration (HVAC&R). In BREEAM, European standard and ISO minimum requirements must be satisfied to obtain the credits under "Impact of refrigerants". Table 3 summarizes the environmental aspect-related ISO indicators with the corresponding credits/criteria of the seven GBRSs.

Table 3. ISO indicators and corresponding GBRS criteria in environmental aspect.

Indicator	LEED	BREEAM	HQE	CASBEE	DGNB	GSSA	ITACA
1A	LT5–8 EA(P)2/(P)3/2–5, MR1–4, WE3	Man03, Ene01/02a/04–08, Tra01–05, Mat01	1.1.3/1.1.4/2.2/2.3/3.2/3.3/4.1/4.2/4.3.1	LR1.1–1.4, LR3.1	ENV1.1/1., TEC3.1, PRO2.1/2.2/2.5	Ene(all) Tra2–5, Mat5/6/9/11, Emi2/3	A1.6/3.4, B1.2/1.5/3.2/3.3/4.9/6.2, C1.2, E3.5
1B	EA(P)4/6 MR1/2/4	Pol01	4.3.3/4.3.4	LR2.3	ENV1.2	Emi1/4	-
2A	MR1/3/5	Mat03–06, Wst02	-	LR2.2	ENV1.1/1.3, TEC1.6	Mat2–6/8–10	B4.6/4.7/4.10, E6.1
2B	EA(P)2/(P)3/2–5	Ene (all)	3.3.1/4.1/4.2/7.2.1	LR1.1–1.4	TEC1.3/1.4	Ene0/2/3/5	B1.2/1.5/3.2/3.3, C1.2, E3.5
3	WE (all), SS4	Wat (all)	3.3.2/5.1–5.3/7.2.2	LR2.1	ENV2.2	Wat(all)	B5.1/5.2
4	MR(P)1/P2/1–3	Mat06, Wst01/03a/04	2.1/3.1/6.1/6.2	LR3.2.3	TEC1.6/PRO2.1	Man7, Mat1/3/9	B4.6/4.7/4.10, C3.2
5	LT2/3/7 SS(P)1/1/2	LE01	-	Q3.1	ENV2.3	Eco1-3	A1.5
15A	SS(P)1/4, LT7	Pol03, Mat01	3.2.3/5.3	LR3.2.3	ENV1.1/2.2	Emi5/6	C4.1/4.3
15B	SS4	Pol02/03, Mat01	3.2.3/4.3.2/5.3	LR3.2.1/3.2.3	ENV1.1/2.2	Emi5/6	-
18A	SS1	Man03, LE02/04/05	1.1.6/3.2.5	Q3.1	ENV2.4	Eco4	-
18B	LT2	LE02	-	Q3.2	PRO2.1	Eco0	-
18C	LT7, SS4	Pol03	1.1.5/5.3	LR3.2.3	ENV2.2	Emi6, Tra1	C4.1/4.3

Note: "/" (slash) and "," (comma) are used only for separation purposes, and they represent "and". "–": all consecutive credits; (all): all credits in the category; "/": credit in the same category. GSSA: Green Star SA; LEED category with (P): prerequisites; without (P): credit.

BREEAM, LEED, HQE, Green Star SA, and ITACA consider both the operational waste management systems and waste minimization and management during construction activities. The DGNB system mainly focuses on waste during construction activities and evaluates liquid waste management during the operation phase. The ISO standard mentions waste generation generally, and so all rating systems address this core area, regardless of the scope of assessment.

LEED, BREEAM, DGNB, CASBEE, and Green Star SA are found to be the strongest rating systems that respond to all ISO indicators in the environmental aspect, and HQE is the weakest. However, the method of assessment and the depth of criteria/requirement set vary from one GBRS to another.

5.1.2. Social Aspects

Studies show consideration of social aspects in green building development help to improve work comfort and productivity [64]. In Middle Eastern countries, the cultural issue is one of the essential parameters [23]. Only one indicator, "esthetic quality", is available in the ISO to measure the cultural issue directly. The evaluation (Table 2) shows that, except CASBEE and DGNB, all of the remaining rating systems do not consider integration of cultural values in new building construction. The focus area of all of the evaluated rating systems is indoor conditions and air quality. The ISO also has a number of direct indicators for indoor air quality assessment. Unique among the rating systems, Green Star SA includes "Formaldehyde minimization" and "Mold prevention" as a part of the "Indoor environmental quality" assessment, whereas HQE assesses measures to "limit electromagnetic exposure".

The green and open areas requirement in GBRSs and the accessibility of the building site (curtilage) in ISO standards have a similar target. Green Star SA and BREEAM do not include private space in the assessment of office buildings. LEED, CASBEE, and ITACA consider private or outdoor areas in their assessment, but they do not include accessibility requirements. In the LEED system, physical accessibility and level differences are considered; however, the rating system does not include specific evaluations for universal accessibility or accessibility restriction based on prosperity and wealth differences [31], which is one of the main targets of the ISO standard.

DGNB is the only rating system that fulfills all social aspect indicators of the ISO standard and Green Star SA shows the weakest performance. Preceding the environmental aspect, most rating systems criteria fall under social aspects, as shown in Table 4.

Table 4. ISO indicators and corresponding GBRSs criteria in social aspect.

Indicator	LEED	BREEAM	HQE	CASBEE	DGNB	GSSA	ITACA
6A	LT5	Tra01	1.1.3	LR3.2.3	SITE1.3	Tra4	A1.6
6B	LT6	Hea06, Tra03a	1.1.2/1.1.4	LR3.2.3	SITE1.3	Tra3	A3.4
6C	SS3	-	-	Q2.1.2	SOC1.6	-	A3.3
6D	LT4	Tra02	-	-	SITE1.4	Tra5	A1.8
7A	-	-	1.2	-	SOC1.7/2.1	-	-
7B	-	Hea06	-	Q2.1.1	SOC2.1	-	-
8A	IEQ5	Hea04	8.1–8.4	Q1.2	SOC1.1	IEQ9	-
8B	IEQ6–8	Hea01	10.1/10.2	Q1.3	SOC1.4	IEQ4/5/7/8, Ene4	-
8C	IEQ9	Hea05	9.1	Q1.1	SOC1.3	IEQ12	-
8D	EIQ(P)1/(P)2/1–4	Hea02	11.1, 12.1/12.2,13.1/13.2	Q1.4/LR2.3	ENV1.2, SOC1.2/1.5	Man4, IEQ1/3/11/13–17, Emi3	-
12A	-	Hea07	-	Q2.2.1/2.2.4	SITE1.1	-	-
12B	-	-	-	-	Mand	-	-
12C	-	-	-	-	SITE1.7	-	-
14	-	-	-	Q3.2	PRO1.6	-	-
17B	-	Man03, Pol04/05	1.3, 3.2.1/3.2.2	LR3.3	PRO2.1	Man6	-
19	IP	Man01/02	Mand	-	PRO1.6/2.1	-	-

Mand: mandatory requirement for certification.

The BREEAM, DGNB, and CASBEE systems evaluate the resistance of structures to natural hazards. However, the CASBEE system focuses on earthquake hazards. Because the BREEAM and DGNB assessments consider most natural hazards that may occur, these systems are strong in the structural stability indicator of the safety criteria.

5.1.3. Economic Aspects

From the evaluated systems, the only rating system that responds to all economic aspects is BREEAM. However, to increase the acceptance of GBRSs in developing countries, it is essential to indicate economic benefits of the system [65,66], although studies show that energy efficiency and water efficiency can save up to 40% of life cycle cost [67], because high cost is one of the major barriers in green building [68]. Table 5 shows weakness of some rating systems, such as LEED, in this aspect.

In the ISO standard, life cycle cost is used as one of the major indicators for this pillar. Only BREEAM and DGNB consider this major indicator in their assessment strategies. In BREEAM, the “Life cycle cost and service life planning” and “Project brief and design” criteria are included, while the DGNB incorporates life cycle cost credits and additional assessment areas such as “influence on the district”, and “ease of cleaning” The value stability indicator of the ISO is one of the additional but essential indicators to respond to economic sustainability of green buildings. DGNB’s assessment areas for the building’s "influence on the district" and "commercial viability" criteria are most suitable to fulfill this indicator.

Table 5. ISO indicators and corresponding GBRS criteria in economic aspect.

Indicator	LEED	BREEAM	HQE	CASBEE	DGNB	GSSA	ITACA
9A	-	Wst06	2.1	Q2.3	ECO2.1	-	-
9B	-	Wst05	-	-	SITE1.1	-	-
10	-	Man01/02	-	-	ECO1.1, TEC1.5	-	-
11	-	Man04/05	7.1	Q2.1.3	TEC1.5, PRO2.2	-	E6.5
13	-	Man05	-	Q2.1.1	PRO2.4, ECO 2.1	Man3–5	-
16	-	Man02	-	-	ECO2.2, SITE1.2	-	-

5.1.4. Indicators with Direct Effect on More Than One Aspect

Some of the ISO indicators directly impact more than one aspect as indicated in the ISO standard. Except "Nuisance on neighborhood", which has a direct influence only on the social aspect, all indicators in a group named "outdoor environment" in this study have a direct effect on two aspects. HQE is the strongest system that considers all indicators in this group. The emission to air (troposphere) indicator is considered by all GBRSs except ITACA. Table 6 summarizes the three indicators with a direct effect on more than one aspect and their corresponding rating system criteria.

Table 6. ISO indicators and corresponding GBRS criteria in dual aspects.

Indicator	LEED	BREEAM	HQE	CASBEE	DGNB	GSSA	ITACA
17A	IEQ2, MR1	Pol02	3.2.4	LR2.1	ENV1.1/1.2	Emi9	-
17C	-	-	1.2.2/1.2.3	-	TEC1.7, SITE1.2	-	-
17D	LT7, SS5	-	1.1.5/1.2.1	LR3.2.2	-	-	C6.8

The analysis also shows that the qualitative depth of assessment varies across rating systems. Cases from multi-certified buildings are selected and evaluated to identify the benefits of existing multi-certification practice for sustainability, as shown in Table 7.

Table 7. Multi-certified buildings evaluation summary.

Case No.	Project Name and Location	Certification (Year)	Combination Deficiency to ISO	Remark
1	Challenger (Versailles, France)	BREEAM, Outstanding (2014) HQE, Exceptional (2014) LEED, Platinum (2014)	12B: Fire safety 12C: Safety in use 14: Esthetic quality	The ISO indicators not satisfied
2	Tour First (Paris, France)	HQE, Very Good (2011) LEED, Gold (2009)	7B: Accessibility of building 9B: Adaptability for climate change 10: Life cycle cost 12: Safety 14: Esthetic quality 16: Value stability	The ISO indicators not satisfied
3	BNP Paribas (Luxembourg)	HQE, Exceptional (2016) BREEAM, Excellent (2017) DGNB, Good (2018)	-	The ISO indicators satisfied

Table 7. *Cont.*

Case No.	Project Name and Location	Certification (Year)	Combination Deficiency to ISO	Remark
4	Enovos (Luxembourg)	BREEAM, Very Good (2016) HQE, Exceptional (2016)	12B: Fire safety 12C: Safety in use 14: Esthetic quality	The ISO indicators not satisfied
5	Administrative building of Max Frank (Leiblfing, Germany)	LEED, Gold (2015) DGNB, Gold (2015)	-	The ISO indicators satisfied
6	Eiffel Palace office building (Budapest, Hungary)	BREEAM, Very good (2009) LEED, Gold (2009)	7A: Accessibility of building site 12B: Fire safety 12C: Safety in use 14: Esthetic quality 17C: Outdoor conditions	The ISO indicators not satisfied
7	Company House III (Aarhus, Denmark)	BREEAM, Very Good (2012) DGNB, Gold (2012)	17D: Heat island effect	The ISO indicators not satisfied

5.2. Evaluation of Multi-Certified Buildings

Seven cases from multi-certified buildings are considered for the evaluation, as shown in Table 7. The evaluation was conducted considering the sustainability limitations of the certification combination and individual GBRSs' limitations identified in Table 2.

The Challenger building in France received the top-level certification from three popular GBRSs. The rating systems selected by experts are preferable for having many common criteria, minimizing conflicting requirements. However, from the perspective of the ISO sustainable building, they have limitations that come from a weak combination of rating systems. The BNP Paribas building in Luxembourg also received triple certification from three popular rating systems but with a different combination. Although the building achieved a low rating in the DGNB system, owing to the low performance in "site evaluation" (60.1%), "process quality" (62.7%), and "technical quality" (63.1%) [36], the combination selection of HQE, BREEAM, and DGNB is beneficial for sustainability evaluation.

All but one of the dual-certified buildings have their own limitations in sustainability indicators. Although the aim of the study is not about the performance of the building itself, this study identified variation in most buildings' certifications, which is due to the designers' preference of one rating system or the low performance of buildings in some GBRS criteria [15]. From the five combinations, the HQE and LEED combination (case 2) is the weakest combination.

The study finds that it is not the number of rating systems that makes the building fulfill the sustainability indicators (case 1 and case 4 have a similar combination deficiency) but the choice of the rating systems. The developed integrated model (Figure 3) is implemented on the case study buildings as described in the following section.

5.3. Application of Integrated Model

Multi-certification should consider many aspects that ensure that a building is acceptable for everyone. However, criteria conflict, and participation of various stakeholders [69] and accredited professionals in a project causes difficulties and challenges for integration. Therefore, while using the model shown in Figure 3, it is essential to identify possible conflicting requirements in the rating systems.

To implement and demonstrate the efficacy of the proposed model, this study selected two of the cases from combinations that fail to fulfill the ISO indicators and completed the integration process based on the model shown in Figure 3. To clarify the model process, case 1, the Challenger building in France, and case 2, the Max Frank building in Germany, shown in Table 7, were selected. The selection and integration process is shown in Figure 5.

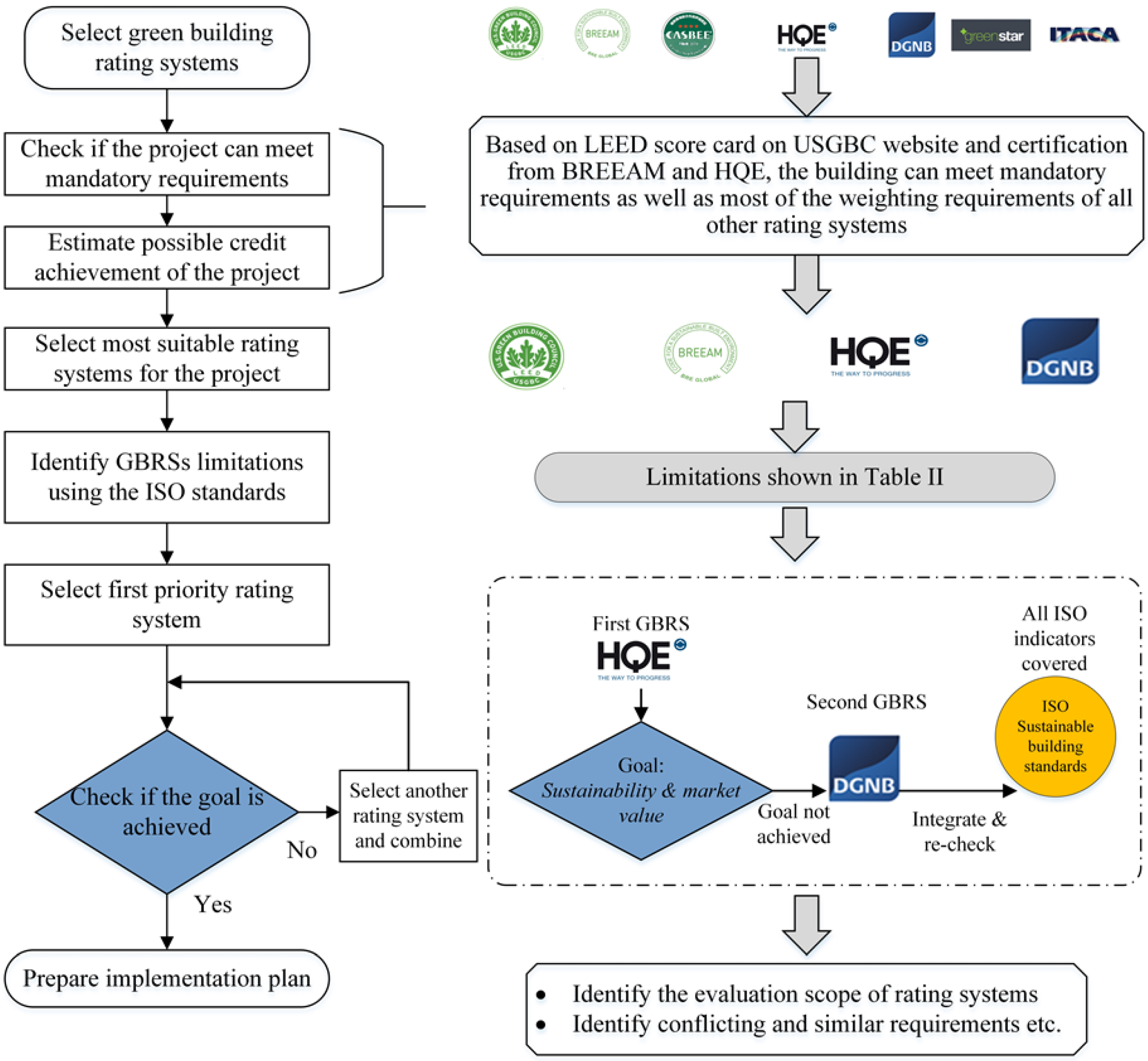

Figure 5. Case 1: Integration process for multi-certification.

For case 1, the model first selected the candidate rating systems for the project. In this study, all seven rating systems were selected for evaluation. Although the detailed evaluation of the building is not acquired from GBCs, this study utilized the LEED scorecard [54], and the level of achievement in the three rating systems indicates that the building can meet mandatory requirements of all candidate GBRSs; in addition, the building may be able to achieve a high score in other rating systems. Because of the preferences of the French green building market, we selected LEED, BREEAM, DGNB, and HQE for integration for this case. ITACA, CASBEE, and Green Star SA have no certification in France. To start the integration process, we first selected HQE as the first priority, because it is a local rating system and widely accepted in the country. For analysis purposes, the goal for the project is to achieve sustainability and to increase the (market) property value [70]. According to this goal, we chose to begin integration using DGNB to increase the sustainability assessment coverage. The two rating systems help evaluate all sustainable building indicators of the ISO. Because the interest was triple certification, the next integration was selected to increase the global influence of the building. Although both BREEAM and LEED are globally recognized rating systems, BREEAM is preferable in this scenario, because it is a more common system that is related to LEED in France [34,54]. As shown in Figure 5, the proposed model provides the suggestion that the combination of BREEAM, HQE, and DGNB are suitable and beneficial for this building, because these systems can assess more ISO indicators.

This study also utilized the proposed model for other cases. The second example selected for model application was the Tour First in France (case 2). Case 2 was preferred to other dual-certified buildings, because this case shows more deficiencies of combination from all cases. By applying the proposed model, we found that integrating either LEED or HQE with the DGNB systems can result in better coverage of the ISO sustainability indicators. A similar procedure was implemented on cases 4, 5 and 7, and the model shows better performance.

The seven buildings selected by this study received multiple certifications from well-known rating systems. The performance of the applied rating systems combination is not consistent, as shown in Table 7. We used the developed model and found that it is possible to create a better combination that considers both sustainability and popularity or market value during multi-certification. The model developed in this study can be used to achieve building sustainability, and it also can provide support to regional or any applicable standards for achieving complete sustainability.

6. Conclusions

The selection of GBRSs nowadays is dependent on the popularity of rating systems. This situation may lead to the industry missing the sustainability goals. This study was conducted to influence practitioners to pay more attention to sustainability performance than popularity of GBRSs during selection.

The first main contribution of this study is to build a model that helps to achieve more sustainability indicators. Seven multi-certified buildings were selected as case studies and evaluated using the ISO standard. The multi-certification practices have gaps in considering more sustainability. The developed integrated model was applied on case study buildings to validate its application. The results indicate that the proposed model can consider different scenarios of certification and assessment of more sustainability areas.

Another main contribution of this study is to demonstrate sustainability performance of existing GBRSs samples. This study evaluated the qualitative performances of the seven well-known GBRSs according to the ISO sustainable building criteria, which have relatively balanced indicators in the environmental, social, and economic aspects. The evaluation was conducted considering the mandatory requirements, prerequisites, and criteria that the rating systems use for certification. The evaluation results indicated that DGNB is the strongest in covering most of the ISO indicators. The BREEAM system is the only rating system that covers all economic aspect indicators of the ISO, which are the least considered by most of the rating systems. LEED and ITACA pay more attention to the environmental aspects, while the LEED depth of assessment in this aspect is stronger than the rest. CASBEE emphasizes the local scenario; HQE is the only rating system that evaluates all outdoor environment-related ISO indicators. The performance evaluation conducted in this study will help developers in their GBRSs selection and GBCs for their future updates of the systems.

The integrated model is the first scientific approach to integration of different GBRSs for multi-certified projects. The model was developed considering the heterogeneous approach of different GBRSs. The model is beneficial to considering the vast scope of sustainable construction and its core area of protection. The developed model can be utilized by accredited professionals, owners, or builders for decision-making on selecting a suitable combination from the available systems.

This model was developed based on the international sustainable building standard benchmark indicators. In practice, the sustainable building indicators may vary depending on project location, economic status of the nation, and other factors. For more practical utilization, the model proposed by this study can be extended in future research using international, regional, or national standards on selected new construction projects to elaborate more on the process and real challenges during the implementation of the model on multi-certification.

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